7-1984

Fighting Hunger with Research

Judy F. Winn

INTSORMIL

Fighting Hunger with Research

A Five-Year Technical Research Report of the Grain Sorghum/Pearl Millet Collaborative Research Support Program

Edited by Judy F. Winn

INTSORMIL

Fighting Hunger with Research

A Five-Year Technical Research Report
of the
Grain Sorghum/Pearl Millet
Collaborative Research Support Program

Edited by Judy F. Winn

Report Coordinator:
George L. Teetes
Professor of Entomology
Texas A&M University

For additional information contact the INTSORMIL Management Entity at:

INTSORMIL
241 Keim Hall
East Campus
University of Nebraska
Lincoln, Nebraska 68583

Telephone (402) 472-6032 Telex 488-340 UNN COMM LCN

A Research Development Program of the Agency for International Development, Participating Land-Grant Universities, Host Country Research Agencies and Private Donors.

INTSORMIL INSTITUTIONS

University of Arizona
Florida A&M University
Kansas State University
University of Kentucky
Mississippi State University
University of Nebraska
Purdue University
Texas A&M University

Edited and designed by Judy F. Winn, Bryan, Texas.

TABLE OF CONTENTS

ACRONYMS

EEP	External Evaluation Panel
TC	Technical Committee
CRSP	Collaborative Research Support Project
PI	Principal Investigator
PES	Program Evaluation Statement
INTSORMIL	International Sorghum and Millet
SADCC	Southern African Development Coordination Conference
ICRISAT	International Crops Research Institute for the Semi Arid Tropics
IRRI	International Rice Research Institute
CIMMYT	International Maize and Wheat Improvement Center
CIAT	International Center for Tropical Agriculture
ME	Management Entity
MOU	Memorandum of Understanding
LDC	Less Developed Country
IARC	International Agricultural Research Center

FOREWORD

The Sorghum/Millet Collaborative Research Program, INTSORMIL, combines the resources and research talent of host country research institutions, eight land grant universities, and the Agency for International Development. Its objective is to improve world-wide sorghum and millet production and utilization. This 5-year report shows that the international sorghum-millet research program is one in which researchers from the U.S. and host countries can effectively collaborate. The INTSORMIL External Evaluation Panel and other reviewers have and will continue to recommend program strengthening changes. Adjustments in research program content and scientist involvement will result as plans are made for future research.

Sorghum and millet are basic food grains for millions of people. Most of them are located in the poorer nations of the world where economic, labor, soil and water resources are limited. The research is challenging because sorghum and millet production and utilization in the less developed countries are impeded by problems such as heat and drought stress, insects, diseases, and storage difficulties. INTSORMIL strives to overcome these problems through a collaborative program of research, technical assistance, training and institution building. The impacts of INTSORMIL research in the host countries are multiplied through workshops, newsletters, information exchanges, scientist exchanges, and an international exchange of sorghum and millet germplasm.

INTSORMIL's research program helps to realize the goals of the Agency for International Development and the Board for International Food and Agricultural Development; that is, to alleviate world hunger. INTSORMIL's research results are applicable to all farms in the world where sorghum and millet are grown.

The INTSORMIL team is a large one. We appreciate the grant support from the Agency for International Development. And the cooperation of the International Agricultural Research Centers, particularly ICRISAT, CIAT, CIMMYT and IRRI, and the USAID Missions has been vital to the success of our collaborative research.

Institutions in the host countries have been able to improve sorghum and millet varieties and production techniques, food quality, farming systems, agricultural policy, and scientist training. These results are only the beginning of INTSORMIL's effort to fight hunger with research.

Glen J. Vollmar
Program Director

SOCIOECONOMICS

APPENDICES

ACRONYMS

EEP	External Evaluation Panel
TC	Technical Committee
CRSP	Collaborative Research Support Project
PI	Principal Investigator
PES	Program Evaluation Statement
INTSORMIL	International Sorghum and Millet
SADCC	Southern African Development Coordination Conference
ICRISAT	International Crops Research Institute for the Semi Arid Tropics
IRRI	International Rice Research Institute
CIMMYT	International Maize and Wheat Improvement Center
CIAT	International Center for Tropical Agriculture
ME	Management Entity
MOU	Memorandum of Understanding
LDC	Less Developed Country
IARC	International Agricultural Research Center

FOREWORD

The Sorghum/Millet Collaborative Research Program, INTSORMIL, combines the resources and research talent of host country research institutions, eight land grant universities, and the Agency for International Development. Its objective is to improve world-wide sorghum and millet production and utilization. This 5-year report shows that the international sorghum-millet research program is one in which researchers from the U.S. and host countries can effectively collaborate. The INTSORMIL External Evaluation Panel and other reviewers have and will continue to recommend program strengthening changes. Adjustments in research program content and scientist involvement will result as plans are made for future research.

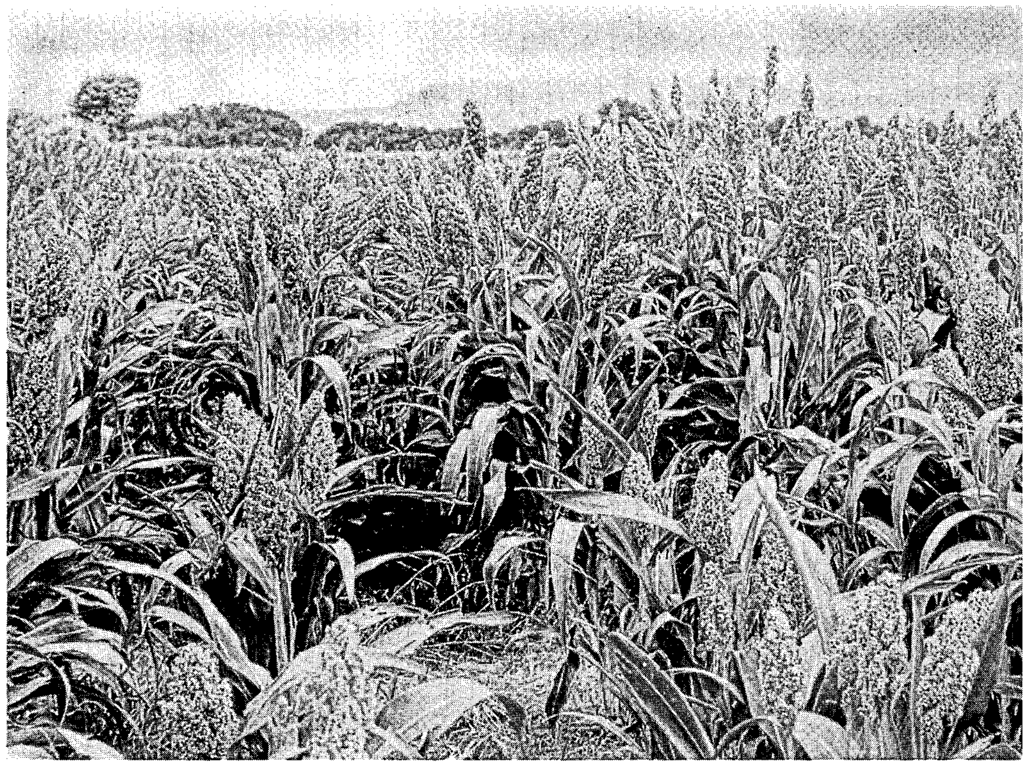
Sorghum and millet are basic food grains for millions of people. Most of them are located in the poorer nations of the world where economic, labor, soil and water resources are limited. The research is challenging because sorghum and millet production and utilization in the less developed countries are impeded by problems such as heat and drought stress, insects, diseases, and storage difficulties. INTSORMIL strives to overcome these problems through a collaborative program of research, technical assistance, training and institution building. The impacts of INTSORMIL research in the host countries are multiplied through workshops, newsletters, information exchanges, scientist exchanges, and an international exchange of sorghum and millet germplasm.

INTSORMIL's research program helps to realize the goals of the Agency for International Development and the Board for International Food and Agricultural Development; that is, to alleviate world hunger. INTSORMIL's research results are applicable to all farms in the world where sorghum and millet are grown.

The INTSORMIL team is a large one. We appreciate the grant support from the Agency for International Development. And the cooperation of the International Agricultural Research Centers, particularly ICRISAT, CIAT, CIMMYT and IRRI, and the USAID Missions has been vital to the success of our collaborative research.

Institutions in the host countries have been able to improve sorghum and millet varieties and production techniques, food quality, farming systems, agricultural policy, and scientist training. These results are only the beginning of INTSORMIL's effort to fight hunger with research.

Glen J. Vollmar
Program Director



PROGRAM BACKGROUND

Scientists from American universities have been involed in international agricultural research for many years. The establishment of various international agricultural research centers has furthered this work, while calling attention to the many problems of agricultural production in the poorer countries of the world.

Birth of The CRSP Concept

Wishing to expand this effort to improve worldwide agricultural production, the U.S. Congress, in December 1975, approved an amendment to the Foreign Assistance Act of 1961. Included in the amendment was Title XII, "Famine Prevention and Freedom from Hunger." A main objective of the new title was to provide the means by which the U.S. universities could make their expertise in science and technology more available to low income countries, and thus help them solve food and nutrition problems.

One component of the Title XII program is "support for long-term collaborative university research, in developing countries themselves, to the maximum extent possible, on food production, distribution, storage, marketing and consumption." Collaborative Research Support Programs (CRSPs) are one of the avenues of achieving this objective.

Funding for the CRSPs was to be provided by the U.S. Agency for International Development (USAID). A Board of International Food and Agricultural Development (BIFAD) was established to implement the Act. A Joint Research Committee (JRC) was appointed by BIFAD to help plan the CRSP programs and determine what areas they should cover.

By 1977, two research areas had been chosen to become the first two CRSPs. These areas were small ruminants and sorghum/millet production. Other CRSPs have been added since.

It is understandable that sorghum and millet were chosen as the subject of one of the first CRSPs. Much of the sorghum and millet in the world are produced and consumed in the poorest countries, areas which are arid and semi-arid, tropical and sub-tropical (Table 1). In these areas yields are relatively low. Thus, sorghum and millet are typically subsistance crops important to the survival of many low income peoples. Worsening drought conditions in many areas of the world make sorghum and millet the "last resort" of crop production for some countries.

There were good reasons for combining research on the two crops into one CRSP. Although sorghum and millet are genetically different, they are grown in many of the same areas and require fairly similar production practices. Thus, a scientist can and often does work effectively with both crops.

Most of the millet for grain is produced in the Sahelian region of Africa, the Indian sub-continent, and the People's Republic of China. Grain sorghum is grown in most of these same regions, in addition to North, Central and South America. With the exception of China, AID has or has had missions in many of these areas. Establishing a sorghum/millet CRSP in these areas fit very well into AID's goal of relieving hunger in the world. Thus, the International Sorghum and Millet program — INTSORMIL — was born.

History of INTSORMIL

The initial development of INTSORMIL was carried out by scientists at the University of Missouri under contract to USAID. As a result of their planning, twelve universities were recommended for participation in the program and the University of Nebraska was selected as the Management Entity (ME). Scientists from around the world who are authorities in grain sorghum and pearl millet production in lesser developed countries (LDCs) met to determine research priorities to be addressed by INTSORMIL. Fifteen research areas were established, and 44 research proposals were accepted from an original 75 submitted from 19 universities. These proposals met criteria of economic, technical and administrative feasibility, and also provided for the training of collaborators in host countries.

The sorghum/millet CRSP was officially established July 1, 1979, with an expiration date of June 30, 1984. The grant was later extended to June 30, 1985. At the time INTSORMIL was begun, there were ongoing sorghum/millet projects, funded in part by AID, at four of the participating universities. These four projects were: millet breeding (Kansas State); sorghum stress physiology/breeding (University of Nebraska); sorghum breeding for quality and nutrition (Purdue); and sorghum breeding for insect and disease resistance (Texas A&M). These projects were folded into INTSORMIL, and the fact that they were already underway had considerable impact on the ultimate make-up of the INTSORMIL program. In fact, it was decided that INTSORMIL would focus on collaborative research among universities and host countries, rather than pairing each university with one host country to work on a single research objective.

The Evaluation Process

The first External Evaluation Panel (EEP) review was conducted in Lubbock, Texas in September 1980, nine months after INTSORMIL began. The panel consisted of Dr. Hugh Doggett, Dr. Brhane Gebrekidan, Dr. Bruce Maunder, and Dr. Bobby Renfro. Two other foreign members were unable to attend. The panel reported favorably on the program as it was then functioning. Their report states that "never before have the research capabilities and the concern for the peoples of the developing world held by staff and scientists of the U.S. agricultural universities been so effectively organized into a cooperative activity bringing professional and technical knowledge to bear on the problems of ordinary sorghum and millet growers living in the LDCs." Panel members emphasized the importance of conducting a substantial portion of the research in the LDCs. They also suggested that research be aimed at several production problems which do not occur in the U.S., and especially encouraged projects relating to human nutrition.

The second EEP review was conducted in Kansas City, Missouri in February 1982. The panelists were Drs. Doggett, Gebrekidan, Maunder and Renfro, as well as Dr. Ricardo Brèssani and Dr. Ralph Cummings, Jr., who substituted for Dr. Uma Lele. In addition, senior ICRISAT staff members, the INTSORMIL Board of Directors, the project leaders, and representatives of AID and BIFAD were in attendance.

The project leaders presented reports and there was opportunity for panelists to ask questions. The Panel's report states: "We are most favorably impressed by the progress made since the earlier review 16 months ago. We are delighted by the speed and imaginative ways in which the overseas linkages have been created. We appreciate the way in which the suggestions made in our last report have been examined and acted upon. An excellent beginning has been made."

The Panel found a majority of the projects to be relevant and good. Four projects were given unfavorable assessments.

AID conducted an INTSORMIL "managerial review" January 4-20, 1984. The team consisted of Dr. Elvin F. Frolik, chairman, Dr. Keith Byergo, Dr. Harve J. Carlson and Dr. Fred Johnson. Dr. Robert I. Jackson, AID Program Manager for the sorghum/millet CRSP, accompanied the team.

The team attended the INTSORMIL Principal Investigators' Conference in Scottsdale, Arizona and held conferences with participants from universities in Arizona, Kentucky and Indiana. Later the team held conferences at Mississippi State University, Kansas State University, Texas A&M University and the University of Nebraska. The team stated that much relevant research was underway and that beneficial collaboration had been established in 14 host countries. It noted also that information on INTSORMIL was available in a brochure entitled "INTSORMIL — CRSP Sorghum and Millet — 1983 Progress Report Executive Summary."

The team reported favorably on the potential for participating in the degree program of Southern African Development Coordination Conference (SADCC), and on the close working relationships with four International Agricultural Research Centers (IARCs): ICRISAT, IRRI, CIMMYT and CIAT.

In their report the team made recommendations having to do mostly with the management of the CRSP, which it described as loosely structured. Specific recommendations included close involvement of the EEP and AID Missions, continued scheduled reporting, and the development of a global plan.

Purpose and Structure of INTSORMIL

The primary purpose of INTSORMIL is to develop technology to increase and improve sorghum/millet production and quality, and to collaborate with researchers in LDCs to apply that technology. The program also provides vital assistance in training scientists in LDCs, who often must work in isolated conditions and with very limited funding, equipment and labor. Periodic visits by U.S. scientists to provide on-site counselling, and their assistance to LDCs in personnel training and institution building, make the difference between program success and failure.

Internal Management

The Board of Regents of the University of Nebraska is, technically, the Management Entity of the INTSORMIL program. The INTSORMIL Program Director reports through the Executive Dean for International Programs to the Vice Chancellor for the Institute of Agriculture and Natural Resources. The business and financial aspects of the program are directed by the Vice Chancellor for Business and Finance, with the day-to-day operations handled by the Fiscal Manager of Grants and Contracts. The AID funds are granted to the University of Nebraska, and funds for projects are sub-granted to participating universities. The INTSORMIL staff at Nebraska includes a Program Director, Associate Program Director, an administrative technician and a secretary.

The Administrative Council was established to provide general policy guidance for carrying out the sorghum/millet CRSP. The Council is made up of one representative appointed by each participating institution, one representative from USDA/ARS, and one representative from ICRISAT.

The Board of Directors consists of representatives from five institutions, who serve 4-year terms. As lead institution, the University of Nebraska has a continuing membership. The Board considers input from the ME and the Technical Committee in setting overall operational policy for the CRSP and budget allocation. The Board elects a chairman annually, and the Program Director serves as Board secretary.

The Technical Committee (TC) consists of seven members, one from each institution with an active project(s). Principal Investigators are nominated for membership on the TC by the institutions. A ballot vote is held with all PIs voting. On the basis of the vote, nominations are made by the TC to the Board, which makes the final selections. An effort is made to keep the TC balanced with regard to discipline representation. The term of office is 3 years. Officers of the TC consist of the chairman, vice chairman and secretary. The TC acts on most technical and operational matters, and forwards its recommendations to the Board of Directors and the Program Director.

Country Coordinators are selected by the TC and are responsible for coordinating research in their respective countries. They work closely with the PIs, the TC and the Program Director. The Country Coordinators facilitate collaboration between the host country and U.S. scientists, and contribute to intra eco-zonal collaboration.

Discipline Coordinators are recognized by their peers and their respective scientific organizations to be leaders in their fields of research. The Discipline Coordinators are approved by the TC on the basis of consensus by the scientists in a specific discipline. Discipline Coordinators provide information for budget review and evaluation. There are six disciplines within INTSORMIL: agronomy and physiology; plant breeding; pathology; entomology; food quality and utilization; and socio-economics. In addition, there are special research projects in *Striga* and germplasm.

Principal Investigators (PIs) are the professional research staff members listed on the INTSORMIL projects. They have the technical responsibility for designing, conducting and reporting on research projects. They establish and maintain linkages with researchers in the host countries, at the IARCs and with other insitutions. They play a key role in supervising the research of host country graduate students in the INTSORMIL program.

The External Evaluation Panel (EEP) consists of eight members, nominated by PIs, the TC and institutional representatives. The Board of Directors recommends EEP members to AID/W and BIFAD, which make final approval. The EEP has a chairman and a vice chairman. Representatives from international institutions and countries other than the U.S. are included on the EEP. The EEP is charged with overall evaluation of the sorghum/millet CRSP program, which includes research collaboration domestically and with host countries.

Research Activities

The ME has executed subgrants and research subcontracts with the following U.S. universities:

University of Arizona-Tucson	Mississippi State University
Florida A&M University*	University of Nebraska-Lincoln
Kansas State University	Purdue University
University of Kentucky	Texas A&M University

(*Became inactive with research work as of June 30, 1982.)

INTSORMIL agreements finalized during 1979-84 are shown in Table 2, and on-site host country collaborative projects are shown in Table 3.

Collaborative research activities have increased since INTSORMIL was begun, and now include work in many countries. Since ICRISAT is the IARC charged with conducting sorghum and millet research, INTSORMIL has maintained a close working relationship with this group. The collaboration was formalized in a Memorandum of Understanding signed in June 1983.

First Priority Programs

Programs in this category involve long-term assignments of INTSORMIL personnel and substantial financial outlays. In most cases, more than one discipline is involved and the work has a regional, ecological zone impact. These programs involve host country research institutions, and the participation of USAID/Missions. There are four such programs.

In 1981, work began in **Honduras** on defining sorghum farming systems, delineating sorghum nutrition, releasing improved varieties, developing photoperiod-sensitive maicillo crillo and non-sensitive varieties and hybrids, agronomic experimenting, and determining major disease and insect pests and control techniques. INTSORMIL institutions involved include Mississippi State University, University of Kentucky and Texas A&M University. They work with the Honduran Ministry of Natural Resources, the Honduran National Institute of History and Anthropology, and USAID/Honduras. The budget consists of $120,000 from INTSORMIL, $30,000 from USAID/Honduras, and $50,000 from the government of Honduras in the form of land, facilities and personnel.

In **Northern South America**, Mississippi State, Purdue, Nebraska and Texas A&M are working with CIAT and EMBRAPA in Brazil to determine if sorghum can be grown effectively on highly acid soils, to develop varieties resistant to aluminum and iron toxicity, and to determine the causes of toxicity. This research program began in 1982 and has been allocated $120,000 from INTSORMIL and $40,000 in facilities and equipment from the International Center for Tropical Agriculture (CIAT).

Objectives of research in **Sudan** include evaluating farming systems in Kordofan, analyzing research and extension in sorghum/millet producing areas, plant breeding to develop sorghum and millet varieties adaped to Sudan, studying **Striga** under field conditions, studying human nutrition, and developing effective processing techniques for sorghum and millet. The work, begun in 1980, is being carried out by Kentucky, Purdue, Texas A&M, Mississippi State, Nebraska and Kansas State, in conjunction with the Agricultural Research Corporation, University of Khartoum. Western Sudan Agricultural Research Project (WSARP) and USAID/Sudan. The current budget is $150,000 from INTSORMIL, with Sudanese contributions averaging $25,000 per year in equivalent services.

In 1982, research in **Botswana** began to focus on establishing an effective sorghum agronomy research program, developing suitable cropping systems, testing and releasing the best available germplasm, and training Botswanan staff. Kansas State, Nebraska and Texas A&M collaborate in this program with SADCC, the Department of Agricultural Research of the Ministry of Agriculture, and USAID/Botswana. The budget is made up of $90,000 from INTSORMIL, $40,000 in housing and services from USAID/Botswana, and an estimated $60,000 in housing, facilities, labor and services from the government of Botswana.

High Priority Programs

Programs in this category may or may not have an INTSORMIL scientist on-site. Their objectives are slightly less broad than those in the first priority category, and substantial support from host countries is expected. There are four programs in this category.

Work begun in the **Dominican Republic** in 1983 focuses on determining the best sorghum cropping systems for this country. Nebraska and Texas A&M are working with the Dominican Republic Ministry of Agriculture and USAID/Dominican Republic. Through 1983 the budget was less than $20,000 per year. But from mid-1984 on, projections call for $50,000 per year from INTSORMIL, about $25,000 from the Ministry, and about $30,000 from the USAID/Mission.

Research in **Mali** is a joint effort of INTSORMIL, TROPSOILS and IER, the Institute of Rural Economy of Mali. Other agencies involved are the Agronomic Research Institute, USAID/MALI and ICRISAT, along with Texas A&M and Nebraska. INTSORMIL collaborates on sorghum and millet breeding for drought tolerance and grain quality. The TROPSOILS component involves land preparation and fertilization. Both programs complement the work of the USAID-ICRISAT research team in Mali. This program was begun in 1981. Its budget includes $30,000 from INTSORMIL, $30,000 from TROPSOILS, $15,000 from the government of Mali, and $20,000 from USAID/ICRISAT.

In **Niger**, Purdue, Texas A&M, Arizona and Mississippi State are collaborating with INRAN (National Agricultural Research Service) and with contract teams from USAID/Purdue and the ICRISAT Sahelian center. The objective of the INTSORMIL institutions is to work with these teams to create a balanced and comprehensive program of sorghum and millet research. Specific research areas include plant breeding, utilization, and biological control of insect pests. This program began in 1983 and is funded with $35,000 from INTSORMIL.

Middle Income Countries

Three programs have been established in middle income countries. Each takes advantage of collaboration with a well-organized agricultural research system in the host country. Each program has had a regional impact with minimal outlay of INTSORMIL funds and personnel time.

A multi-disciplinary program begun in **Brazil** in 1983 is promoting the exchange of scientists and information to address a wide variety of topics related to sorghum improvement and utilization. Purdue, Texas A&M, Mississippi State and Nebraska currently are participating. The budget consists of $15,000 from INTSORMIL.

Work in **Mexico** is involving all the INTSORMIL disciplines in a large-scale collaborative program with the National Agricultural Research Agency, the Autonomous University of Mexico City, the Graduate University of Agriculture (Chapingo), and the International Maize and Wheat Improvement Center (CIMMYT). Although the program covers many areas, two of particular importance are the exchange of staff and germplasm. The work was begun in 1979 and receives $30,000 annually from INTSORMIL, plus $15,000 for an annual workshop at CIMMYT.

In 1981, INTSORMIL began research in the **Philippines** to determine if sorghum could be used as a dry-season crop in paddy rice cropping systems. This includes research in agronomy, production economics and marketing. INTSORMIL contributes $25,000 for direct collaboration, plus $25,000 for special economic studies. An estimated $35,000 in land, facilities, equipment and personnel is contributed by Philippine agencies and the International Rice Research Institute. Nebraska and Texas A&M are the INTSORMIL institutions participating.

Lower Priority Programs/Individual Projects

In **Egypt**, a collaborative program of sorghum research is being explored in areas such as plant breeding, utilization, plant physiology, entomology and agronomy. Nebraska, Purdue and Texas A&M are working with the Egyptian Major Cereals Improvement Project.

In **India**, millet-based farming systems in West Rajasthan were studied by Kansas State, the University of Udaipur, and the American Institute of Indian Studies. This project was terminated in 1983 because institution collaboration was not established.

Purdue and Texas A&M participate in a project in **Burkina Faso (Upper Volta)** whose purpose is to study the economics of sorghum production and marketing, the impact of pricing and other policies, and various aspects of food utilization. Host country agencies involved are the Ministry of Agriculture, the ICRISAT Regional Center, and SAFGRAD.

Special Activities

Striga research is being carried out by Kansas State, Mississippi State, Texas A&M, Purdue and North Carolina State. This research involves field and laboratory work and training aimed at applying more useful approaches to *Striga* control. Emphasis is on work with *Striga hermonthica* in Africa. Host country agencies include the Sudan ARC and the University of Khartoum, ICRISAT in India and ICRISAT and IDRC in Upper Volta. INTSORMIL has contributed $40,000 per year in 1982 and 1983, and $45,000 in 1984.

Germplasm research is aimed at determining if INTSORMIL can help establish an effective germplasm program for sorghum (and possibly pearl millet) in the Western Hemisphere. All INTSORMIL institutions except Kentucky and Florida A&M are participating, along with ICRISAT and major research groups in Honduras, Brazil, Mexico and the Dominican Republic.

Workshops

From 1979 through 1984 INTSORMIL has conducted workshops both on its own initiative and in collaboration with other agencies, particularly ICRISAT. INTSORMIL recognizes that workshops are an effective method of networking research knowledge throughout the world. Estimates of total expenditures by INTSORMIL are difficult to make because part of the costs of attending many workshops was drawn from project funds or funds from sources other than INTSORMIL. Workshops held to-date are as follows:

- March 30-April 3, 1981: *Sorghum Disease Short Course for Latin America;* at CIMMYT, El Batan, Mexico; funded by INTSORMIL ($6,000), INIA, ICRISAT and CIMMYT; 75 participants; mimeographed proceedings distributed.
- October 28-31, 1981: *International Sorghum Grain Quality Symposium*; at ICRISAT, Hyderabad, India; funded by INTSORMIL, ICRISAT and ICAR; 100 participants; proceedings published as a book.
- November 2-7, 1981: *Sorghum in the 80's*; at ICRISAT; funded by INTSORMIL ($80,000 for this workshop and the International Food Quality Symposium), ICRISAT and ICAR; 250 participants; printed proceedings published as a two-volume book.
- April 13-17, 1982: *Sorghum Grain Quality Workshop for Latin America*; at CIMMYT; funded by INTSORMIL ($11,000), INIA and ICRISAT; 100 participants; mimeographed proceedings (largely in Spanish) distributed.
- November 15-19, 1982: *Symposium on Agrometeorology of Sorghum and Millet*; at ICRISAT; jointly funded by INTSORMIL ($20,000), ICRISAT, FAO and World Meteorology Organization; 150 participants; proceedings in press.
- April 10-16, 1983: *Sorghum Plant Breeding Workshop for Latin America*; at CIMMYT; funded by INTSORMIL ($20,000), INIA and ICRISAT; 150 participants; proceedings (largely in Spanish) being prepared for distribution.
- August 8-26, 1983: *Striga Short Course*; at North Carolina State University and USDA/ARS Methods Research Laboratory, Whiteville, North Carolina; funded by INTSORMIL ($32,000); 25 students plus some 20 speakers.
- November 5, 1983: *Hybrid Sorghum Seed Workshop for Sudan*; at Wad Medani, Sudan; in cooperation with ARC (Sudan) and ICRISAT; funded by INTSORMIL ($25,000); 40 participants; reports distributed.
- November 27-December 2, 1983: *Sorghum Root and Stalk Rot Symposium;* at Bellagio, Italy;

funded by INTSORMIL ($20,000), ICRISAT and Rockefeller Foundation; 25 participants; published as a book.

- March 26-28, 1984: *Sorghum Production and Utilization in the Dominican Republic*; funded by INTSORMIL ($8,600); 80 participants; proceedings to be published in Spanish.
- June 14-16, 1984: *Sorghum Production and Utilization in the Philippines*; in the Philippines; funded by INTSORMIL ($12,000), PCARRD and IRRI; 90 participants.

Student Training

In INTSORMIL's extensive student training program there were 96 international students from 27 countries funded for INTSORMIL research, in addition to 181 U.S. students. All students were advised by INTSORMIL PIs. The breakdown of international students by country is shown below.

Miscellaneous Information

Summary

INTSORMIL was never viewed as a program in which the U.S. universities would exclusively give assistance and the host countries would receive it. Rather, it is a collaborative arrangement in which all parties contribute and benefit.

Obviously, research in the U.S. is usually much more advanced than in the LDCs. However, U.S scientists can benefit greatly through the INTSORMIL program by exchanging germplasm, testing materials and methods under a wide variety of environmental conditions, observing pest problems before their possible occurance in the U.S., conducting research on economic, cultural and nutritional problems which may have implications for the U.S., and, in general, broadening their understanding of research needs and approaches.

The benefits to host countries are obvious. In addition to the production improvements that can be achieved through the research, host countries benefit through staff training and counsel by the 80 or so INTSORMIL scientists who travel abroad (see Appendix XII). Advanced training to the Masters Degree and Ph.D. levels is provided as candidates are available and as funds permit (see Appendix X). INTSORMIL also has provided funds so that host country scientists can travel to scientific meetings.

The impact of the INTSORMIL program is being felt in many parts of the world. Its research efforts are reaching far and wide to fight world hunger.

Table 1. 1982 Hectarage, Yield, and Production of Sorghum and Millet in Selected Countries, Grouped by Continents or Sub-continents.[a]

	Sorghum			Millet		
Continent and Country	Area harvested (1000 HA)	Yield KG/HA	Production (1000 MT)	Area harvested (1000 HA)	Yield KG/HA	Production (1000 MT)
World	47,760	1447	69,111	42,841	681	29,166
Africa	15,412	696	10,734	16,358	631	10,315
Angola	—	—	—	80	625	50
Botswana	120	125	15	5	400	2
Burundi	110	864	95	37	811	30
Cameroon	—[c]	—	—	455	893	406
Egypt	—	—	—	174	3647[b]	633[b]
Ethiopia	1000	1300	1300	230	870	200
Kenya	210	1048	220	82	1585	130
Lesotho	48	542	26	—	—	—
Malawi	130	1114	145	—	—	—
Mali	—	—	—	1454	655	952
Mozambique	250	620	155	20	250	5
Niger	1131	315	357	3066	423	1295
Nigeria	6000	633	3800	5100	647	3300
Senegal	—	—	—	850	765	650
Somalia	470	500	235	—	—	—
Sudan	3000	700	2100	800	288	230
Swaziland	2	1000	2	—	—	—
Tanzania	350	629	220	220	682	150
Upper Volta	1100	636	700	900	467	420
Zambia	80	500	40	70	857	60
Zimbabwe	208	630	131	390	687	190
N & C America	7613	3534	26,902	—	—	—
Costa Rica	22	2045	45	—	—	—
Dominican Republic	12	4167	50	—	—	—
El Salvador	114	1202	137	—	—	—
Honduras	56	804	45	—	—	—
Mexico	1340	3699	4956	—	—	—
Nicaragua	90	1122	101	—	—	—
USA	5766	3705	21,364	—	—	—
South America	3123	2966	9261	—	—	—
Argentina	2510	3187	8000	132	1168	154
Brazil	116	1834	212	—	—	—
Colombia	198	2611	517	—	—	—
Peru	20	2325	47	—	—	—
Venezuela	210	1605	337	—	—	—
Asia	20,669	978	20,215	23,476	708	16,626
China	2804	2857	8011	4003	1625	6504
India	16,000	675	10,800	18,000	500	9000
Pakistan	399	576	230	560	473	265
Yemen AR	670	870	583	39	1558	60
USSR	132	758	100	2821	709	2000

[a]Extracted from the 1982 FAO Production Yearbook, Volume 36, FAO Statistics Series Number 47, United Nations, Rome, 1983.
[b]One or possibly both of these figures appear to be in error.
[c] — Means that production figures are not listed in the FAO Production Yearbook.

Table 2. INTSORMIL Agreements — Finalized or Pending as of July 17, 1984.

Date agreement executed	Collaborating institutions/countries	Type of agreement
Aug. 12, 1983	EMBRAPA (Brazil)	Memorandum of Understanding
Aug. 11, 1983	Government of Botswana and USAID/Botswana	Memorandum of Understanding
Feb. 11, 1981	CIAT/ICRISAT/INTSORMIL	Memorandum of Intention
Nov. 22, 1981	CIAT	Memorandum of Agreement
Aug. 15, 1983	IICA	Memorandum of Understanding
June 30, 1983	Dominican Republic	Memorandum of Understanding
Oct. 16, 1980	EMCIP (Egypt)	Memorandum of Understanding
Aug. 1981	Natural Resources-Honduras	Memorandum of Understanding Additional Provisions (1982)
Nov. 15, 1982	IHAH (Honduras)	Memorandum of Understanding
April 15, 1983	INIA (Mexico)	Memorandum of Understanding
Mar. 27, 1984	Mali/TROPSOILS/INTSORMIL	Memorandum of Understanding Additional Provisions Pending
April 8, 1983	INRAN USAID/Niger	Memorandum of Understanding
Mar. 19, 1981	PCARRD (Philippines)	Memorandum of Understanding Additional Provisions
Mar. 19, 1981	IRRI (Philippines)	Memorandum of Understanding
Nov. 23, 1980	ARC (Sudan) WSARP (Sudan)	Memorandum of Understanding Additional Provisions (1984)
Feb. 21, 1984	Universidad Autonoma MetropolitanaMexico	Memorandum of Understanding
Nov. 23, 1980	University of Khartoum-Sudan	Memorandum of Understanding
Sept. 25, 1982	TARO (Tanzania)	Memorandum of Understanding
1984	Upper Volta	Memorandum of Understanding
June 23, 1983	ICRISAT	Memorandum of Understanding

Table 3. **INTSORMIL Collaborative Host Country Projects.**

Project	Location & title	Project leader
KY 2	Sudan, Honduras, Mexico Sociocultural Constraints in the Production and Consumption of GS/PM in Less Developed Countries	Dr. Milt Coughenour
KS 1-1	Sudan Expansion of the Pearl Millet Breeding Program at Fort Hays Branch Agricultural Experiment Station and Organization and Development of a Pearl Millet Breeding Program at Kansas State University	Dr. Tareke Berhe
KS 7	Botswana Water use efficiency, inter-cropping with legumes, tillage, tillage practices, fertilization, seeding rates, depth of planting, row and in-row spacings, weed and pest control, seed selection, seeding dates, crop rotation of sorghum/millet and associated mixed crops in Botswana	Dr. L.V. Withee
MSU 11	Cali, Columbia Adaptation of Sorghum to Highly Acid Tropical Soils	Dr. Lynn Gourley
PR 9	Niger Country Coordinated Research	Dr. John Axtell
NE 21	Sorghum production in the Philippines	Dr. Jerry Maranville
NE 22	Dominican Republic Improved Sorghum Production/Utilization	Dr. Ralph Neild
TX 31	Sorghum Improvement in Honduras	Dr. Dan Meckenstock
TX 32	Sorghum Improvement in Tanzania (Project terminated-political problems)	Dr. John Mann
Sudan*	A comprehensive sorghum/millet production and utilization collaborative research program with the Sudanese Agricultural Research Corporation and the University of Khartoum	Dr. Allen Kirleis
Mali*	A joint collaborative research project with TROPSOILS and the IER/Mali. The project involves breeding and fertility research for sorghum/millet.	Dr. Art Onken
Mexico*	This project involves research collaboration with Mexican reserachers in INIA and Mexican universities on a wide range of sorghum production and utilization problems.	Dr. Fred Miller
Brazil*	The research involves acid soils and sorghum disease collaborative research.	Dr. R. Frederiksen

*Budgets for these projects are held by the Management Entity.

Table 4. International Students for INTSORMIL Research.

Country	Bachelor	Masters	Ph.D.	Post Doc.	Total
Upper Volta			2		2
Mali		1	1		2
Tanzania	1	3	2		6
Kenya		1			1
Thailand			1	1	2
Colombia		3	3		6
Botswana		1	1		2
Sudan		3	4		7
Senegal		1			1
Nicaragua		1	1		2
Honduras		1			1
Philippines		3	13	2	18
Nigeria		1	7	1	9
India		1	8	3	12
Pakistan			1		1
Ethiopia			2		2
Benin			1	1	2
Mexico		3	5		8
El Salvador		2	2		4
Brazil			1		1
Dominican Republic			1		1
Taiwan		1			1
Hong Kong		1			1
Peru			1		1
Venezuela			1		1
Germany			1		1
Ghana				1	1
Total	1	27	59	9	96

Various cultural practices for improving sorghum/millet production are being tested around the world.

AGRONOMY / PHYSIOLOGY

One of the major constraints to sorghum and millet production in LDCs is the adverse growing environment created by low rainfall and high temperature coupled with soil fertility problems. These crops are usually grown in marginal agricultural areas because of their drought tolerance. Thus, achieving stable yields under stressful environmental conditions is a major concern of this CRSP.

Research in Agronomy/Physiology can be categorized as follows: (a) stress physiology; (b) stand establishment; (c) agroclimatology; and (d) cropping systems. Reserach projects in these areas overlap each other and the breeding program. Heat, water and nutrient stress research is emphasized in order to identify resistant genotypes. In addition, physiologists are collaborating with plant breeders to screen genotypes for drought and nutrient resistance. Stand establishment is a major problem in the LDCs; therefore, agronomists are characterizing seeds on the basis of high seedling vigor and good stand establishment under adverse seedbed conditions. Variabilities in weather play a significant role in crop management practices (planting, fertilization, cultivation, rotation, intercropping, etc.). Agroclimatologists are applying modeling and statistical concepts in the development of technological packages. Because of the management and cultural constraints in many regions, using the correct cropping and intercropping sequences can significantly enhance agricultural production. Thus, it is important to have agronomists stationed in the LDCs.

Agronomy/Physiology has made major strides in developing a research program in millet and sorghum production in LDCs. There have been 72 professional publications as a result of Agronomy/Physiology projects. These publications indicate a considerable research effort and suggest significant advancement in knowledge. There have been 58 graduate students and six post doctoral students trained at U.S. universities. These students have completed degrees, and many have returned to their countries to take responsible positions there or in international institutes. As important as the training is the contact or linkage these former students provide for collaborative research. Collaborative research is not accomplished between one country and another but between individual scientists. Because of the training aspect of the INTSORMIL program, and the need to understand plant physiology to overcome production constraints in the LDCs, a strong research program is required at each of the member institutions in the U.S.

Executive Summary

It was first demonstrated in one of the projects that the line source sprinkler irrigation gradient is an effective method of screening many genotypes for response to continuously increasing drought stress. This method is being used by plant breeders in Nebraska, Arizona, Texas, ICRISAT and Mali. The responses to drought stress of a number of experimental sorghum and millet lines was investigated by use of sprinkler irrigation gradients. Drought-tolerant germplasm has been identified.

Nutrient stress and nutrient use efficiency are linked with water availability and water use efficiency. Therefore, the research concepts are similar. Laboratory and field tests have been developed to assess genotypic tolerance and susceptibility to mineral nutrition deficits.

A method of determining the deep rooting potential of various sorghums was developed by growing them hydroponically in plastic tubes. Deep rooting was promoted by withholding nutrients from the tubes. It was shown that the potential for deep rooting correlates positively with the yield stability of lines grown on the irrigation gradient. When hydroponically tested genotypes were field grown, those with deeper roots in the tubes also produced deeper roots when drought stressed.

Another study suggests that average afternoon canopy and air temperatures, as observed in a non-stressed environment with an infrared thermometer, could be used effectively to screen millet genotypes for their grain yield and yield stability in a stressed environment.

Plant development models have been established for sorghum and pearl millet. These models have been used to evaluate growing seasons in an intercropping sequence. Therefore, probability estimates can be made from climatological records as to the relative success of growing these crops.

It has been found that both seed size and seed density greatly affect pearl millet field establishment, and that this effect frequently carries through to final grain yield. In order to put this knowledge to use as rapidly as possible in LDCs, various management practices for seed production were studied. These are presently being tested in Sudan.

The use of cowpeas and groundnuts as nitrogen sources for cereal crops is being investigated in Botswana. Results show greater growth of maize seedlings in a field previously planted to cowpeas than in a field previously planted to sorghum or fallowed. Research also indicates that sorghum yields are higher when grown after a legume than when sorghum is grown continuously.

Intercropping research in two locations for 2 years indicates that the efficiency of sorghum and pearl millet is marginally increased when these two crops are grown together. This is a common system in Tanzania, and further on-site work will better demonstrate advantages of the system and allow more detailed work on components of the system. Intercropping sorghum and soybeans has produced a clear advantage to both crops over narrow, alternating strips, both under irrigation and dryland conditions.

Several linkages have been made between INTSORMIL investigators and LDC scientists. An INTSORMIL agronomist is located in El Obeid, Sudan and two others are positioned in Botswana. An agronomist from the University of Nebraska (Dr. Maranville) has recently completed a sabbatical leave in the Philippines.

Identify and Evaluate Physiological and Development Processes Adversely Affected by Environmental Stresses

E.T. Kanemasu and M.B. Kirkham

Kansas State University

Environmental stress is the major factor limiting sorghum and millet production in semi-arid areas of the world. This project seeks to develop techniques for selecting germplasm tolerant to adverse environments.

In developing new cultural practices or techniques (e.g., residue management, tillage and crop rotation), we are concerned with environmental stresses they may impose on plants. Such stresses may include light distribution, canopy temperature and humidity, soil temperature and soil moisture. Microclimate of the crop affects development, morphology, canopy net photosynthesis, transpiration, and insect and disease infestation. The effects of environmental stress on yield will be quantified so that we can study the overall effects of new cultural practices.

This project also is supporting Striga research by studying the role of ethylene in the germination of Striga and the amount of ethylene given off by seeds and roots.

Research Accomplishments

Soil water gradient study

A field study during the 1981 growing season was conducted at Manhattan, Kansas to determine the genotype difference in grain sorghum and pearl millet. Four sorghum hybrids (RS 626, RS 671, G 623-GBR, and A 28+) and four millet genotypes (Senegal bulk, Serere 3A, H 2150X1137, and HMP 550) were studied by measuring the soil moisture, leaf and air temperatures, stomatal resistance and xylem-water potential.

The grain yield of sorghum was about 38 percent greater than that of millet, whereas the total dry matter yield was only 3 percent greater. Among the sorghum hybrids, A 28+ showed the lowest yield while yields of the other three hybrids were roughly similar. Among the millets, H 2150X1137 had the highest grain yield.

The seed weight and head weight of pearl millet were lower than those of sorghum, but the number of heads was greater for millet.

Under well-watered conditions, millet's average cumulative water use (60.4 cum) was higher than sorghum's (56.8 cum). The water use efficiency (WUE) of total dry matter compared to the grain water use efficiency was about 3.8 times higher for millet and 2.5 times higher for sorghum (Table 1). The grain WUE of sorghum was more than twice that of millet. With sorghum the major quantity of water used was from 15

Table 1. Cumulative Water Use and Water Use Efficiency (WUE) of Sorghum and Millet Genotypes (1981).

Treatments	Cumulative water use (cm)	WUE (kg/ha/cm) Grain	Total dry matter
Sorghum			
G 623 GBR			
76-cm row	54.9	145 a	356 a
38-cm row	59.2	129 b	370 a
RS 671	58.4	133 b	332 b
RS 626	57.8	133 b	311 b
A 28+	53.8	113 c	242 c
Millet			
H 2150 X 1137	60.8	93 a	286 b
HMP 550	60.1	85 a	257 b
Serere 3A	58.4	68 b	377 a
Senegal Bulk	62.4	62 b	260 b

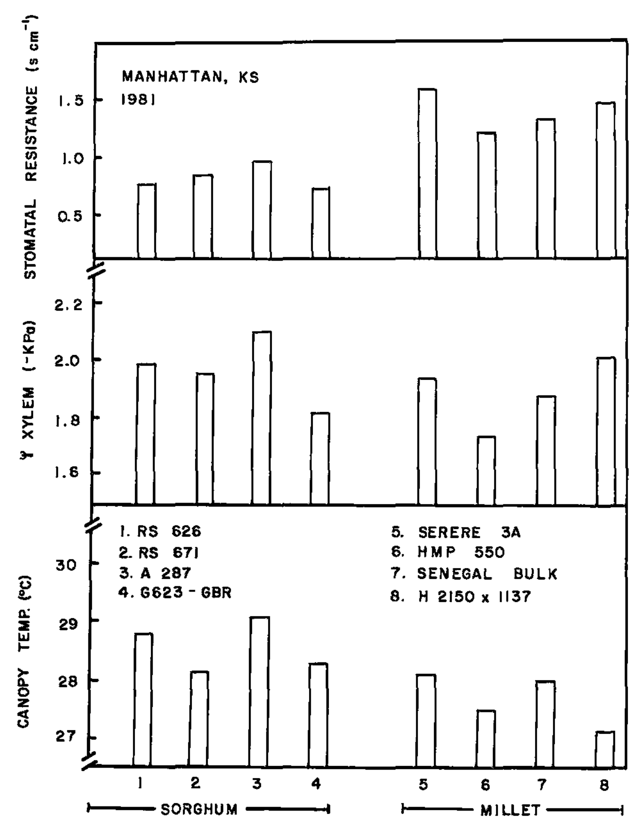


Figure. 1. Mean afternoon (1300-1500 CDT) canopy temperature, xylem water potential and stomatal resistance of sorghum and millet varieties.

cm to 120 cm of soil depth, whereas millet genotypes extracted water beyond 300 cm soil depth. Xylem water potential and stomatal resistance of sorghum were lower than those of pearl millet, but millet was slightly cooler than sorghum (Fig. 1). The vapor pressure deficit (VPD) and canopy temperature minus air temperature (Tc-Ta) correlated well for both sorghum and millet (Fig. 2).

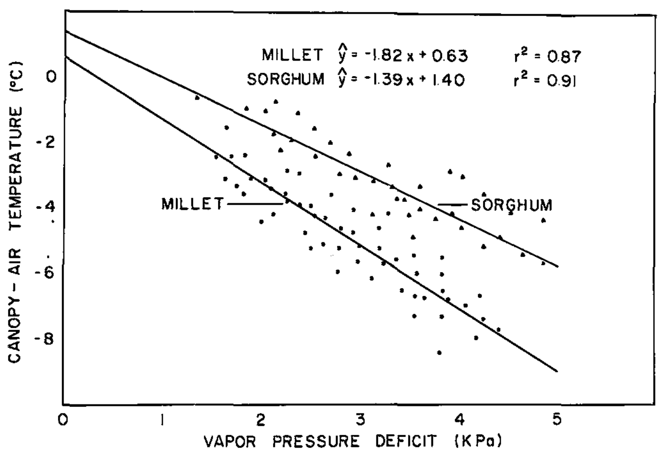


Figure. 2. Canopy minus air temperature vs. vapor pressure deficit for well-watered sorghum and millet.

Yuma, Arizona Experiment

A regression technique was used to select drought-tolerant sorghum [*Sorghum bicolor* (L.) Moench.] and pearl millet [*Pennisetum americanum* (L.) Leeke] genotypes. Two hundred and nineteen sorghum genotypes, assembled from Purdue University, University of Arizona, Texas A&M University, and commercial seed companies, and 42 millet genotypes from the University of Arizona, University of Nebraska, and Kansas State University, were planted under a line source irrigation system at Yuma, Arizona. Five common sorghum hybrids also were used as checks. The canopy temperature of the genotypes was measured for 7 days starting 67 days after planting.

A linear regression model of individual canopy minus air temperature (DT) on the observed vapor pressure deficit (VPD) was computed. This equation predicted DT at a given value of VPD for each genotype. The sensitivity of each genotype to changes in VPD was obtained by regressing the observed DT on the value from the regression model.

Genotypes showing a regression coefficient close to 1.0 are interpreted as having average sensitivity to changes in the VPD, while genotypes having coefficients greater than 1.0 or less than 1.0 are interpreted as having greater or lesser sensitivity, respectively, to changes in VPD.

Figure 3 presents a plot of these regression coefficients against the average DT for each genotype. The points in the second quadrant correspond to the genotypes which are cooler than the average genotypes and have greater sensitivity to change in the VPD. There are 60 genotypes for that quadrant. The points in the fourth quadrant correspond to the genotypes that are warmer than the average genotypes and have less sensitivity to change in VPD. The first and third quadrants are interpreted similarly.

The general regression equation line obtained from the millet genotypes was DT = – 1.523*VPD + 3.819. The mean DT for 42 millet genotypes was -3.47°C. Of 42 genotypes, 22 were cooler than normal and the rest were warmer than the mean average DT (Fig. 4). Genotypes that were warmer were also less sensitive to the change in the VPD and vice versa (Fig. 4). Genotype 81-1005 is the only genotype that was cooler than the mean average canopy temperature and also less sensitive to the change in the VPD. There were 16 genotypes in the fourth quadrant.

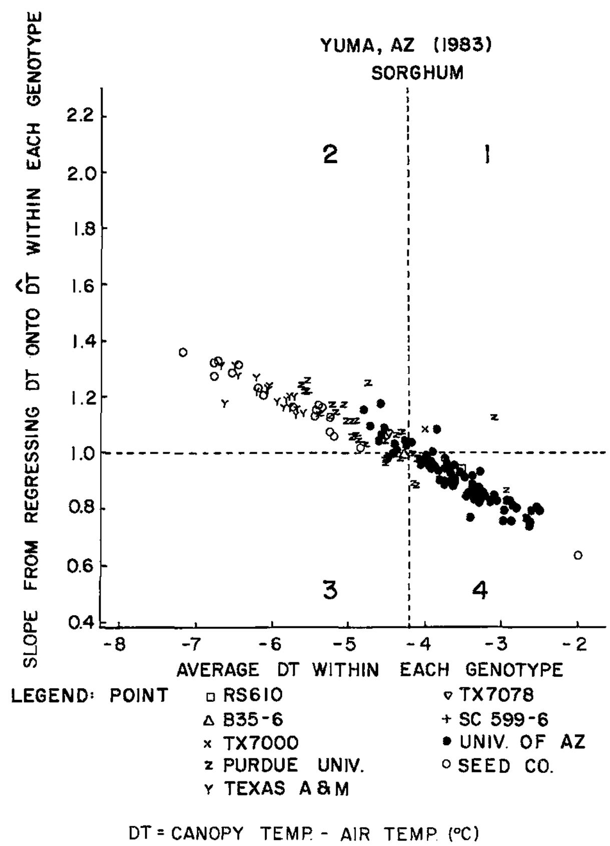


Figure 3. Plot of genotype betas vs. average genotype canopy-minus-air temperature (across all vapor pressure deficit) for sorghum.

It has been shown that warmer genotypes transpire less (Gates, 1964; van Bavel and Ehrler, 1968; Sumayao et al., 1977) to conserve soil moisture under dry conditions. Therefore, the genotypes in the fourth quadrant in Figure 3 for sorghum and Figure 4 for millet are the most desirable genotypes for arid conditions.

The genotypes in the third quadrant are suitable for areas where irrigation is physically and economically feasible. Large changes in VPD produce small changes in Tc. A lower than normal mean of canopy temperatures for all the genotypes indicates high transpirational cooling and photosynthetic rates.

By using the Tc and VPD measurements, breeders can select varieties especially suited for arid regions. The measurement methods are simple, rapid and economical.

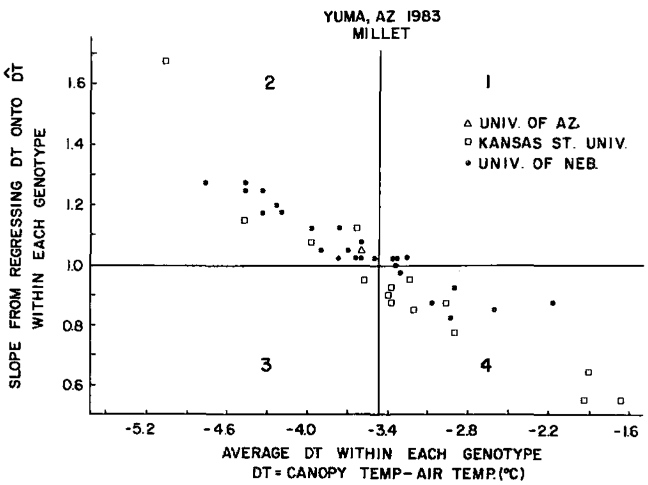


Figure 4. Plot of genotype betas vs. average genotype canopy-minus-air temperature (across all vapor pressure deficit) for pearl millet.

Figure 5. The line source irrigation system at Yuma, Arizona facilitates drought tolerance tests.

Soil Temperature Experiment — El Obeid, Sudan

A field experiment was conducted at El Obeid, Sudan by Dr. Tareke Berhe. The objective was to determine the effect of soil temperature on seedling emergence. Ten sorghum and seven millet genotypes were examined. Soil temperatures were obtained by placing a white, black, or no cover over the soil surface while keeping the soil surface moist. Thus, the effect of soil temperature could be separated from the effect of soil moisture. There were four replications with 25 seeds per replicate. The experiment was carried out in mid-May, which is one of the hottest months. The average mid-day soil temperatures for the three treatments were 19.1, 22.0, and 28.4°C. Figure 5 shows the emergence percentages for three of the millet and three of the sorghum genotypes. It appears that the modest soil temperature of 28.4°C adversely affects emergence. Thus, soil temperature must be a major factor in stand establishment of the genotypes commonly grown in the El Obeid area. Further discussions and analyses are being conducted.

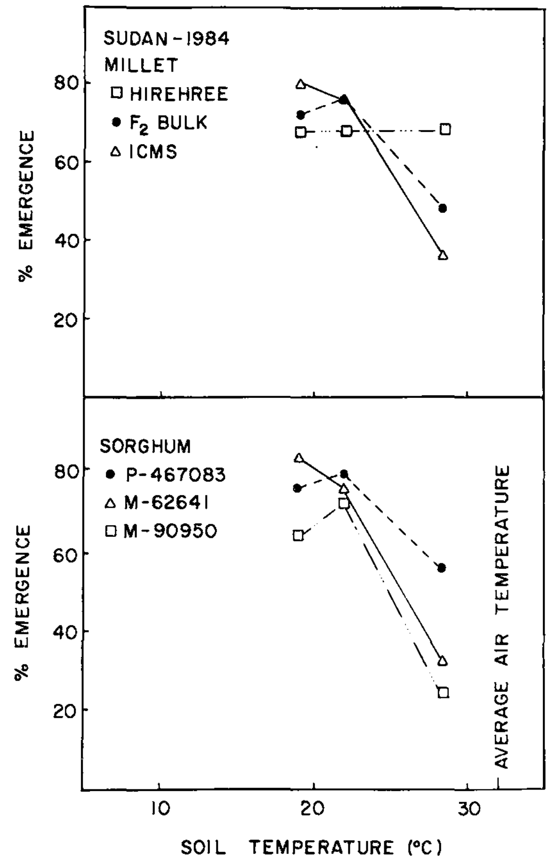


Figure 6. Percent emergence of millet and sorghum at three soil temperatures (El Obeid, Sudan).

Striga Research

Germination was measured in two lines of sorghum [Sorghum bicolor (L.) Moench.], one drought-resistant (KS9) and one drought-sensitive (IA25), to determine if drought resistance affects response to ethephone, an ethylene-releasing compound. Control seeds were germinated in filter paper-lined petri plates containing distilled water with no ethephone. Treated seeds were placed in distilled water plus 100 g/g ethephone. Germination of the treated drought-sensitive seeds was 2 percent greater than that of the drought-sensitive controls. Germination of the treated drought-resistant seeds was 15 percent greater than that of the drought-resistant controls. Clearly, ethephone stimulated the germination of the drought-resistant line more than that of the drought-sensitive line. (Seeds were supplied by Dan M. Rodgers, Kansas State.)

Cooperative field work is being carried out between the Evapotranspiration Laboratory at Kansas State and Dr. Robert E. Eplee of the USDA Animal and Plant Health Inspection Service in Whiteville, North Carolina.

Significance of Research Findings

Research to-date has studied the effects of various environmental conditions on sorghum and millet growth and yield. In relation to this work, techniques have been devised for selecting genotypes most likely to do well under adverse conditions, and for predicting which cropping sequences might be most efficient. This type of knowledge is vital to improving agricultural production in the arid, semi-tropical climates of many LDCs.

LDC Collaboration

Dr. Berhe's soil temperature experiments in Sudan have produced significant results, and are continuing. In addition, Dr. Seetharama (at ICRISAT, Hyderabad, India) has conducted research on the use of canopy temperatures to screen sorghum genotypes for drought resistance. Results of this collaborative study are expected soon.

Training and Technical Assistance

Presently, we have one Ph.D candidate from the Philippines who is studying the use of spectral measurements for assessing intercepted light. We also have a post doctoral fellow from India who is supported by INTSORMIL. A non-degree student from Morrocco is taking course work. The students are engaged in research dealing with the water use and yield of crops under stressful conditions.

The PI served as a reviewer of the water-related activities of the Farming Systems Program at ICRISAT in November 1982, and also presented seminars on several visits to ICRISAT. He presented a paper at the Agroclimatology of Sorghum and Millet meeting at Hyderabad, India in November 1982, and served on an AID design team in Morrocco in December 1983.

Implications for Future Research

The PI plans to visit Botswana in 1985 to develop collaborative projects in the areas of high soil temperature emergence problems, water use of sorghum and millet, and evaluation of intercropping sequences. The work in Sudan has indicated that soil temperature may be a problem in seedling emergence. We will also investigate the use of spectral reflectance estimates of light interception to evaluate intercropping sequences in Botswana. We will continue to refine techniques for using canopy temperatures to screen genotypes for drought resistance.

Selected Publications

Chaudhuri, U.N. and E.T. Kanemasu. 1982. Effect of water gradient on sorghum growth, water relations and yield. *Can. J. Plant Sci.* 62:599-607.

Chaudhuri, U.M., M.L. Deaton, E.T. Kanemasu, V. Marcarian and A.K. Dobrenz. 1984. A procedure to select drought tolerant sorghum and millet genotypes using canopy temperatures and vapor pressure deficits. *Field Crops Res.* (submitted).

Chaudhuri, U.N. and E.T. Kanemasu. 1984. Agronomic performance of sorghum and pearl millet. *Field Crops Res.* (in press).

Kanemasu, E.T., Piara Singh, and U.N. Chaudhuri. 1982. Water use and water use efficiency of pearl millet and sorghum. Agrometeorology of Sorghum and Millet. Hyderabad, India.

Mtui, T.A., E.T. Kanemasu and C. Wassom. 1982. Canopy temperatures, water use and water use efficiency of corn genotypes. *Agron. J.* 73:639-643.

Owonubi, J.J. and E.T. Kanemasu. 1981. Soil-water depletion and water use efficiency by three height isolines of sorghum. *Can. J. Plant Sci.* 62:35-46.

Powers, D., E.T. Kanemasu, P. Singh and G. Kreitner. 1980. Floral development of millet. *Field Crops Res.* 3:245-265.

Singh, P. an.! E.T. Kanemasu. 1982. Leaf and canopy temperature of pearl millet genotypes under irrigated and non-irrigated conditions and their correlations with crop yields. *Agron. J.* 75:497-501.

Singh, P., E.T. Kanemasu and Phool Singh. 1983. Yield and plant water relations of pearl millet genotypes under irrigated and non-irrigated conditions. *Agron. J.* 75:886-890.

Sumayao, C.R., E.T., Kanemasu and T.W. Brakke. 1980. Using leaf temperature to assess evapotranspiration and advection. *Agric. Meteorol.* 22:153-166.

Seedling Vigor and Stand Establishment in Pearl Millet

Richard L. Vanderlip, William D. Stegmeier, Merle D. Witt, F.L. Barnett and Tareke Berhe

Kansas State University

Poor or erratic stand establishment is a common constraint to pearl millet production. This is not surprising, since pearl millet is usually grown in less than ideal climates. Improving stand establishment is tremendously important in LDCs. Therefore, this project studied vigor tests and seed characteristics which might relate to stand establishment. Based on these studies, management techniques which positively affect seed characteristics were investigated.

Research Accomplishments

Mr. Mwageni in Tanzania ran laboratory vigor tests on pearl millet to see if field establishment could be adequately predicted from seed vigor measurements. The various tests resulted in different germination percentages (Table 1), and with the exception of the vigor analyzer, generally were significantly correlated with field establishment (Table 2). However, none of the vigor tests consistently accounted for more than 50 percent of the variation in field establishment and, thus, would be of limited value in predicting field establishment.

Table 1. Average Germination Percentages from Indicated Laboratory Vigor Tests.

Laboratory test	1977	1978
Standard germination	79.3	85.8
NH_4Cl treatment	71.9	81.2
NaOH treatment	51.9	58.7
Accelerated aging	30.8	65.5
Vigor analyzer: 30-min. soaking	—	63.8*
Overnight soaking	—	85.4*

*Percentage identified as vigorous by the analyzer, not percentage germinated.

In other crops, seed density, seed size, and protein content have been shown to affect stand establishment; in some cases, the effects are still evident in the yield. Gardner (U.S.) found that both seed size and seed density affected plant emergence (Figs. 1 and 2) and that these effects were still evident in final yields (Fig. 3).

Mr. Lawan in Nigeria further characterized the seed and seedling differences from seeds varying in size and density. He found that both factors were important in determining field emergence, but that the use of either large seed or dense seed was equally effective. This indicates that total seed mass might be more important than either effect independently (Table 3). These results, however, were not substantiated by seedling respiration data, which showed no significant size-by-density interaction corresponding to field emergence. Seedling respiration did provide some indication that the weight of seed material was important, in that when respiration was converted to a per-unit-weight basis the main effects of both seed density and seed size were no longer

Table 2. Simple Correlations between Pearl Millet Field Establishment and Laboratory Vigor Tests.

Laboratory vigor tests	Location, year and date		
	Manhattan 1977		
	May 12	June 7	June 27
Standard germination	0.75**	0.85**	0.72**
Germination:			
after NH_4Cl treatment	0.69**	0.75**	0.73**
after NaOH treatment	0.67**	0.74**	0.69**
after accel. aging	0.53**	0.50*	0.47*
	Manhattan 1978		
	May 30	June 13	July 7
Standard germination	0.61**	0.17	0.50**
Germination:			
after NH_4Cl treatment	0.56**	0.30	0.55**
after NaOH treatment	0.45*	0.39*	0.57**
after accel. aging	0.57**	0.16	0.56**
Vigor analyzer			
30-min. soaking	-0.06	-0.22	0.11
Overnight soaking	0.43*	0.24	0.34
	St. John 1978		
	May 10	May 30	
Standard germination	0.16	0.13	
Germination:			
after NH_4Cl treatment	0.52**	0.32	
after NaOH treatment	0.58**	0.49**	
after accel. aging	0.39*	0.27	

* Significant at .05
**Significant at .01

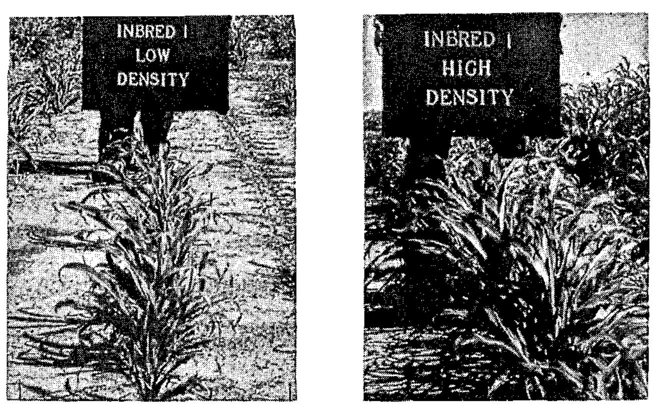


Figure 1. Millet seedlings from the same seedlot separated by density.

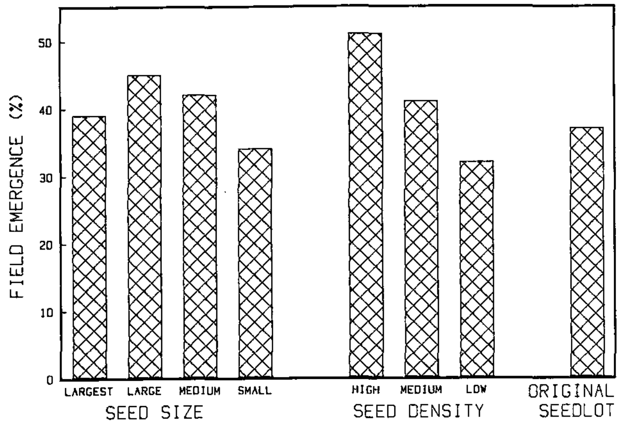


Figure 2. Percent field emergence of pearl millet as affected by seed size and density.

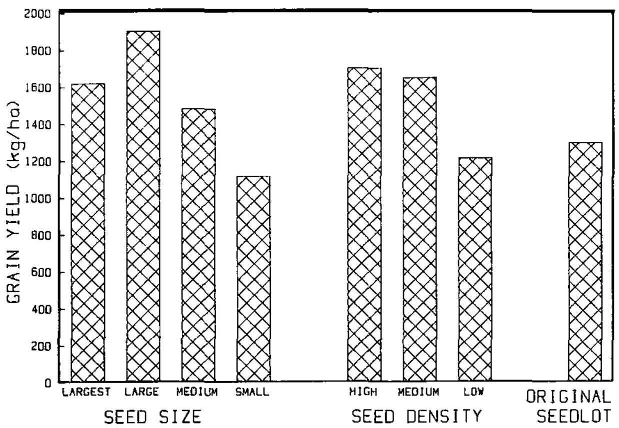


Figure 3. Grain yield (kg/ha) of pearl millet as affected by seed size and seed denisty.

significant, and only the genotype-by-size effect remained significant (Table 4).

Yield results were not as straightforward, partly because of extremely variable yields (CV = 49 percent) and partly because of the interaction between genotype, seed density and seed size. Even so, the same general trends were evident. Mean yields from low, medium and high-density seeds were 410, 636 and 714 kg/ha, respectively, and for the small, medium and large seeds 514, 644 and 606 kg/ha, respectively.

Based on the results from these studies, a new series of experiments was conducted to try to influence seed characteristics, particularly seed size and density, by management of the seed production block. Dr. Okonkwo in Nigeria applied the following treatments to millet seed production blocks: removal of all tillers; removal of a portion of the spikelets from each spike; late nitrogen fertilization; hill planting; and head selection at maturity based on visible seed size. Of these treatments, spikelet removal and head selection generally improved both seed size and seed density (Table 5). When seed produced from these two treatments were planted in field trials, they also resulted in better seedling establishment and generally higher grain yields (Tables 6 and 7).

The use of vigor tests on pearl millet seed seems to be of limited benefit, and with the difficulties of performing such tests in LDCs this does not appear to be a promising area of work. Seed characteristics, particularly seed size and seed denisity, were found to greatly affect millet stand establishment and, in most cases, these effects carried through to final yields. The effects were true both when seeds were separated on the basis of size and density and when the characteristics of the seed were manipulated through management of the seed production block. These techniques can be used by small farmers, and should be implemented to improve grain yields.

Table 3. Effects of Seed Density and Seed Size on Field Emergence.

	Seed size		
Seed density	Small	Medium	Large
Low	40	43	59
Medium	57	57	58
High	59	57	62

LSD (.05) = 6

Table 4. Analysis of Variance Summaries for Seedling Respiration.

Source of		Mean square for υmol CO_2hr.$^{-1}$	
variation	D.F.	50 seeds	1 g seed
Replication	2	40.86	114.56
Population	3	48.52	76.16
Error a	6	16.22	56.26
Seed density (D)	2	96.05**	61.58
Seed size (S)	2	23.66**	46.06
DS	4	11.23	53.79
PS	6	33.70**	102.46**
PD + PDS	9	6.59	22.74
Error b	42	5.03	22.56

* P =< 0.05
**P =< 0.01

Elijah Modiakgotla planting pearl millet of different seed quality under normal and high soil temperature (plastic cover) conditions.

Table 5. Effect of Crop Management on Seed Diameter, Seed Densisty, and Seed Weight.

Treatment and year	Average seed diameter (mm)			
	Dryland*		Irrigated	
	Senegal bulk population	Serere 3A	Senegal bulk population	Seed density
1980				
Control	2.03 b**	2.40	2.11 b	1.23 a
Tillage removal	1.98 b	2.43	2.20 ab	1.23 a
Spikelet removal	2.17 a	2.50	2.27 a	1.22 b
Nitrogen	2.08 ab	2.44	2.06 c	1.23 a
Hill planting	2.15 a	—	2.10 b	1.23 a
1981				
Control	2.34 c		2.40 b	1.20 b
Tiller removal	2.38 b		2.42 b	1.20 b
Spikelet removal	2.58 a		2.54 a	1.25 a
Nitrogen	2.34 c		2.40	1.22 b
Hill planting	2.40 b		2.40 b	1.18 c
Head selection	2.53 a		2.54 a	1.26 a

**Duncan's multiple range test: Means with the same letter within a column are not significantly different. Alpha level 0.05.
*Seed produced under these conditions.

Table 6. Effect of Crop Management on Subsequent Seedling Establishment and Grain Yield of Pearl Millet, 1981 (1980 seed).

Treatment	St. John				Manhattan			
		Grain yield (kg/ha)			% Seedling establishment			
		Dryland*		Irrigated	Dryland		Irrigated	
	% Seedling establishment	Senegal Bulk population	Serere 3A	Senegal Bulk population	Senegal Bulk population	Serere 3A	Senegal Bulk population	Grain yield (kg/ha)
Control	37 b**	2210 bc	2144 b	2129 c	52 c	63	52 c	3039 b
Tiller removal	39 b	2079 c	2535 b	1997 c	57 b	59	56 bc	2956 b
Spikelet removal	48 a	3354 a	2095 b	3459 a	63 a	61	65 a	3777 a
Nitrogen	45 ab	2671 b	3039 a	2671 b	61 ab	62	58 b	3126 b
Hill planting	40 b	2409 bc	—	2117 c	52 c	—	57 b	3463 ab

*Seed produced under these conditions.
**Duncan's multiple range test: Means with the same letter are not significantly different. Alpha level 0.05.

Table 7. Effect of Crop Management on Subsequent Seedling Establishment and Grain Yield of Pearl Millet, 1982 (1980 and 1981 seed).

Treatment	St. John		Manhattan		Garden City	
	% Seedling establishment	Grain yield (kg/ha)	% Seedling establishment	Grain yield (kg/ha)	% Seedling establishment	Grain yield (kg/ha)
Control	54 c*	1742 c	56 bc	3793	34 b	1581 b
Tiller removal	59 b	1788 c	54 c	3685	35 b	1695 b
Spikelet removal	59 b	1998 b	56 bc	4077	42 a	1907 a
Nitrogen	63 a	1824 bc	58 ab	3964	37 b	1693 b
Hill planting	52 c	1717 c	56 bc	3943	34 b	1684 b
Head selection	62 a	2242 a	59 a	4126	43 a	2119 a

*Duncan's multiple range test: Means with the same letter are not significantly different. Alpha level 0.05.

Table 8. Comparison of Millet Genotypes Treated by Partial Head Removal 2 Days after Anthesis (El Obeid, Sudan, 1982).*

Genotype	Treatment			
	Whole head	One-Third cut	Half cut	Two-thirds cut
ICMS 7817	12.02	12.00	12.02	12.75
Baladi White	11.83 b	14.33 a	14.43 a	15.33 a**
Ugandi	12.75	13.00	13.33	14.25
Baladi Yellow	11.67 b	16.17 a	12.56 b***	18.00 a

*1000 seed weight (gms).
**In each row numbers followed by the same letter are not significantly different from each other at 0.05 probability level, according to Duncan's Multiple Range Test.
***Possibly an error in recording.

Table 9. Effect of Seed Weight and Planting Depth on Seedling Emergence* of Baladi Millet Planted on Sandy and Clay Soils.

Genotype	Seed Source	Depth of planting (cms)				
treatment		2	3	4	5	6
Baladi white	Check	2.30 f	2.50 e	3.00 c	3.30 b	3.50 a**
On sand	1/3 of head	2.00 g	2.80 d	3.00 c	3.30 b	3.50 a
Baladi White	Check	3.25	3.75	4.50	4.00	4.25
On clay	1/3 of head	3.25	3.75	3.75	4.50	4.00

*Measured in days.
**In each pair of rows, numbers followed by the same letter are not significantly different from each other at 0.05 probability level, according to Duncan's Multiple Range Test.

Table 10. Effect of Seed Weight and Planting Depth on Seedling Height (cms) of Baladi White Millet (El Obeid, Sudan, 1983).

Genotype	Seed	Depth of planting (cms)				
treatment	source	2	3	4	5	6
Height at 7 days after emergence						
Baladi White	Check	3.06 a	2.25 ab	2.75	2.69 ab	1.88 b*
On sand	1/3 of head	3.50 a	3.75 a	3.44 a	3.13 ab	2.25 b
Baladi White	Check	5.60 bc	4.40 d	4.00 d	5.80 bc	5.70 bc
On clay	1/3 of head	7.20 a	5.50 c	6.80 a	6.00 b	4.20 d
Height at 14 days after emergence						
Baladi White	Check	8.00 c	7.70 c	9.10 c	10.10 c	2.10 d*
On sand	1/3 head	11.40 abc	16.60 a	14.60 ab	14.90 ab	10.50 c
Baladi White	Check	15.30 e	17.90 cd	16.60 de	15.60 e	15.80 c
On clay	1/3 head	20.46 b	24.50 a	19.90 bc	23.50 a	18.80 c

*In each pair of rows, numbers followed by the same letter are not significantly different from each other at 0.05 probability level, according to Duncan's Multiple Range Test.

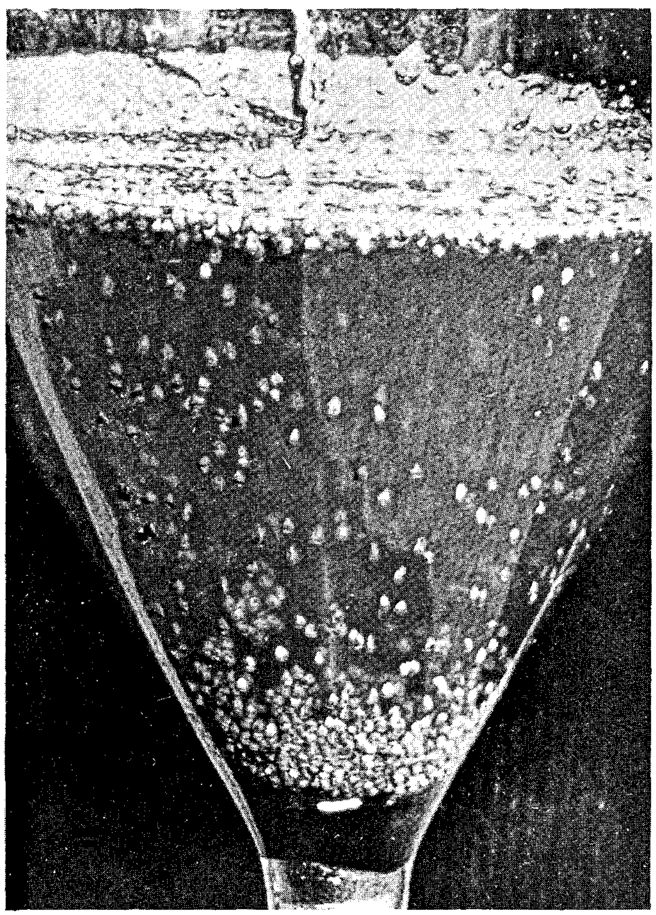
Significance of Research Findings

Undoubtedly, some of the difficulties in establishing pearl millet stands could be alleviated by improving seed quality. These improvements could be achieved either by mechanically screening or separating seed by density, or by using simple management practices in areas identified as seed production blocks. Because these are simple methods which require little or no equipment, they are applicable to individual producers in LDCs.

Dr. Berhe in Sudan has tested the ways in which removing parts of the head affects seed characteristics, rate of emergence and seedling growth. In two of four genotypes, this technique increased seed weight (Table 8), but did not increase seedling emergence (Table 9). Removing one-third of the spikelets did not increase seedling height in sandy soils, but in clay soils seedlings were significantly taller both 7 and 14 days after emergence (Table 10). The spikelet removal treatment increased yields from 0 to 62 percent, with an average yield increase of 26 percent. Thus, this treatment could significantly increase millet production in LDCs.

LDC Collaboration

Most of the collaborative work has been with Dr. Tareke Berhe, El Obeid, Sudan. We are testing the most favorable management practice identified in the U.S. to see if it has acceptance and potential in the Sudan. Preliminary results are shown in the previous sections, and Dr. Berhe reports that farmer interest is high.



Separation of pearl millet seed on the basis of seed density by flotation.

Training and Technical Assistance

Four students from Nigeria have received training through INTSORMIL. Two were Master's Degree students, one sought a Ph.D., and one was a post-doctoral student. These men are all involved in research to improve millet production in their country. Tanzania and Botswana have each had one Master's Degree student, also doing millet research. A Master's Degree candidate from Germany is studying intercropped sorghum and millet. And two Master's Degree candidates from the U.S. are researching various aspects of millet production.

The PI presented a paper entitled "Problems and Prospects in Modeling Pearl Millet Growth Development — A Suggested Framework for a Millet Model" at the ICRISAT/WMO Symposium on Agrimeteorology of Sorghum and Millet in the Semi-Arid Tropics, November 1982. He also has travelled to Sudan, Senegal and India for conferences and counselling.

Implications for Future Research

Future research will be in two general areas. First, research in millet producing areas of Africa must determine if seed separation or management can increase yields in the more tropical areas where most of the millet is grown. This is presently being conducted by Dr. Berhe in the Sudan, and that work will continue at least as long as we have a program in the Sudan. A student from Botswana is presently working on a research program at Kansas State University, and as soon as possible similar testing of management treatments will be initiated in Botswana as well.

Second, the previous research will be expanded to try to determine the conditions under which improved seedling establishment and increased grain yield can be expected. The Botswana student is studying the effects of higher soil temperatures at seeding on seedling establishment, using different quality seed lots. Additional research will involve a comparison of management treatments to improve seed quality vs. mechanical screening or flotation techniques to obtain higher quality seed from a bulk seed lot.

Selected Publications

Gardner, J.C. and R.L. Vanderlip. 1984. Effects of seed size, density and protein content on field establishment and yield of pearl millet. *Agron. J.* (submitted).

Lawan, M., F.L. Barnett, B. Khaleeq and R.L. Vanderlip. 1984. Seed density and seed size of pearl millet as related to field emergence and several seed and seedling characters. *Agron. J.* (submitted).

Mwageni, G.J. and R.L. Vanderlip. 1984. Seed vigor measurements for predicting field establishment of pearl millet. (submitted to Kansas Academy of Science).

Okonkwo, J.C. and R.L. Vanderlip. 1984. Effect of crop management on seed quality and subsequent performance of pearl millet. *Field Crops Res.* (submitted).

Stutzel, H.R.E. and R.L. Vanderlip. 1984. Grain yield of intercropped sorghum and pearl millet as influenced by sorghum genotypes and cropping patterns. *Field Crops Res.* (submitted).

Sorghum / Millet Agronomic Research in North Kordofan, Sudan

Tareke Berhe, William D. Stegmeier,
Richard L. Vanderlip and
Edward T. Kanemasu

Kansas State University

Sorghum and millet producers in LDCs are plagued by many problems, among them (a) difficulty in obtaining good stands, (b) poor soil quality, (c) the use of ineffective cultural practices, and (d) a high incidence of insect pests and plant diseases. These problems can be alleviated by the development of better quality genotypes and the application of new management techniques. These are the goals of our research in North Kordofan, Sudan.

Research Accomplishments

Genotype Selection

The genotype research seeks to identify varieties, lines, cultivars, etc. that are adaptable to the area and which exhibit yield stability, early maturity (80 to 90 days), drought tolerance, and disease and insect tolerance (especially to *Striga hermonthica*). Genotypes also should be suitable for intercropping. The crops studied during the 1982 and 1983 seasons were millet, sorghum, cowpeas and tepary bean.

Millet. Among the five millet genotypes tested in variety trials, the variety Ugandi produced the highest yields. Its earliness (70 to 80 days) can provide early food and guarantee a harvest in years when there is no late-season rain. Ugandi's bristles render some protection against birds, mice and grasshoppers. It produces few tillers but has large heads.

The next highest yielder was ICMS-7817. This variety is also early, and has short, thin stems. Since millet stalks are used for construction, farmers may be reluctant to adopt it.

Ugandi and ICMS-7817 were also the top two yielders in the observation nursery at Banjedid.

An ICRISAT/INTSORMIL hybrid millet, 68A, had an excellent stand, as did a bristled population developed by Dr. R.P. Jain of ICRISAT.

Several local genotypes also were tested, with Eish Bornu performing the best. Its compact heads resist attack from burrower larvae, and to some extent from birds and grasshoppers.

Sorghum. Sorghum varieties were tested at Kaba and at Banjedid. The top yielder at both locations was IS 9830 (developed in the Khartoum University Striga Project). It was the earliest to mature, and in one of the

*Many millet and sorghum fields are killed by **Striga**, a parasitic weed.*

1983 farm trials at Um Araada IS 9830 yielded 325 kg/ha in spite of being planted very late (in August).

Other good yielders were Um Bernin, SRN-39, and P 898012. The latter genotype seems well adapted to the area because it grows best on clay soils and is drought tolerant.

Cowpea. In 1982, market samples of local cowpeas were collected from El Obeid, Kazgail, El Kharta and Hamadiua. These were planted at the Kaba Experiment Station and individual plant selections made on the basis of earliness, vigor and good pod set. One plant, the El Kharta selection, was so distinctly different from the others (very early with excellent pod set) that it is being increased in our nursery. If enough seeds are produced, they will be planted in intercropping trials in the coming season. The other types will be planted on a plant-to-row basis and evaluated further.

Tepary Bean. Germination and stand of the four tepary bean genotypes tested were not as good as those of the local cowpeas with which they were planted. They will be tested again.

Germplasm. Efforts are being made to collect, maintain, describe and use local genotypes of millet, sorghum and cowpeas. At present we have mass collections of the three local millet types, 19 head collections of sorghum and 24 single plant selections of cowpeas.

Table 1. Comparison of Yield and Agronomic Data in Four Sorghum Genotypes Planted at Kaba Experiment Station in 1983.

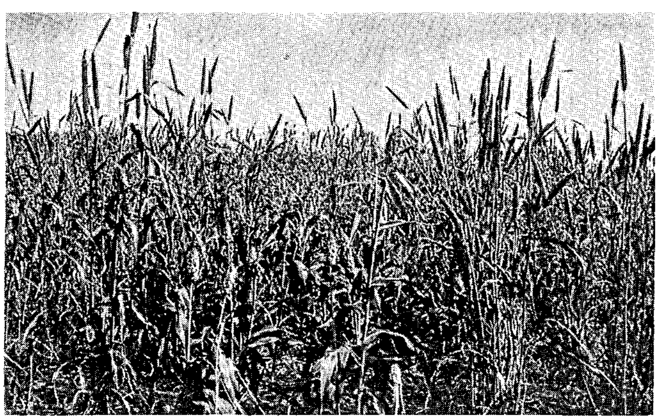
Treatment	Height (cms)	No. heads per plot	Yield/head (gms)	Yield (kg/ha)
P 898012 (+)	133	88	29.91	2207
P 898012 (0)	118	78	25.01	1709
IS 9830 (+)	307	90	37.13	2686
IS 9830 (0)	303	82	40.09	2744
SRN-39 (+)	132	50	34.70	1484
SRN-39 (0)	138	40	40.48	1228
Um Benin (+)	148	81	37.36	2690
Um Benin (0)	152	67	38.96	2287

(+) = fertilizer; (0) = no fertilizer

Table 2. Comparison of Yield and Agronomic Data in Four Sorghum Genotypes Planted at Banjedid in 1983.

Treatment	Height (cms)	No. heads per plot	Yield/head (gms)	Yield (kg/ha)
P 898012 (+)	116	30	19.84	595
P 898012 (0)	101	30	18.87	567
IS 9830 (+)	231	35	24.12	844
IS 9830 (0)	210	33	21.04	794
SRN-39 (+)	103	30	24.20	726
SRN-39 (0)	112	31	25.41	788
Um Benin (+)	108	15	27.78	416
Um Benin (0)	135	15	26.47	397

(+) = fertilizer; (0) = no fertilizer



This intercropping experiment included Ugandi millet and P898012 sorghum.

Intercropping

The objective of the cereal:cereal test was to determine the compatibility of Ugandi millet and P 898012 sorghum. These genotypes are proving well adapted to the El Obeid area of North Kordofan. Results showed that the two can be intercropped successfully in different row arrangements. Combinations of 2:2, 3:1 and 1:3 (millet to sorghum) resulted in total yields equal to yields of either crop alone.

A 3:1 ratio of groundnut to sorghum or millet planted in the clay soil near Banjedid showed favorable results in spite of severe drought stress. The groundnut variety Barberton planted with P 898012 sorghum produced a yield of 70 percent groundnut and 30 percent sorghum. Barberton planted with Ugandi millet yielded 60 percent groundnut and 50 percent millet. The short height and less vegetative growth of the 68A millet variety make it an excellent candidate for future groundnut/millet intercropping studies.

Intercropping trials with cereal and sesame were not successful because of late planting and severe drought. These tests will be repeated.

Cultural Practices

Two cultural practices were tried with Ugandi millet and P 898012 sorghum — fertilization and plant density variation. Tests were carried out at Kaba (millet) and Banjedid (sorghum).

Low levels of nitrogen and phosphorus were applied to test plots at Kaba. A very heavy rain fell soon after, and it may have washed away some of the fertilizer. Fertilized plots did not have larger yields than unfertilized plots. The sorghum at Banjedid received only one shower after fertilizer was applied. Plant stand was poor, and there was also cattle damage on some plots. There was only a slight yield increase with fertilization on these plots. Tables 3 and 4 show the results of the fertilization studies. Obviously, the tests should be repeated, especially since 20-20-0 fertilizer significantly increased yields in millet and sorghum variety trials.

As shown in Tables 5 and 6, plant population variations did not produce any yield patterns. Low population plots compensated either by tillering more or by increasing seed weight per head.

Table 3. Yield of Ugandi Millet in Response to Fertilizer, Kaba Experiment Station, 1983.

Treatment	No. of heads/plot	Yield gms/head	Yield kgs/ha
0-0-0	113	10.97	1096
20-0-0	99	10.95	965
0-20-0	100	10.56	938
20-20-0	120	8.06	1127

Table 4. Response of P 898012 Sorghum to Applied Fertilizer at Banjedid in 1983.

Treatment	No. of heads/plot	Yield gms/heads	Yield kgs/ha
0-0-0	44	14.99	330
20-0-0	55	18.31	504
0-20-0	48	18.23	438
20-20-0	58	14.03	407

Seedling Establishment

Eight sorghum and eight millet genotypes were planted in October when soil temperatures ranged between 30 and 40°C. All germinated well. The next experiment will be conducted in May to determine the effect of highest soil temperatures on germination.

Another experiment involved the partial removal of sorghum and millet heads immediately after anthesis to study the effects on seed production. Plumper, heavier seeds were obtained in both sorghum and millet by reducing head size one-half to two-thirds after flowering (Table 7). Seeds from reduced heads had a better rate of emergence from deeper planting as well as superior seedling vigor. The effect was more pronounced in millet than in sorghum.

Seed weight did not influence the rate of germination. Seeds from whole heads and reduced heads germinated at the same rate. Seeds planted at 2 cm depth germinated fastest, and those planted at 5 cm slowest. Millet germinated 1 to 2 days earlier than sorghum at all depths. Millet germinated 1 day earlier in sand than in clay. Sorghum was not affected by soil type.

Heavier seeds produced taller and more vigorous seedlings. This was true for both millet and sorghum and for both soil types.

Farm Trials

Eleven farmers in the El Obeid area were selected to test newly released sorghum and millet varieties for yield and adaptation. Farmers were given seed and planting instructions. However, many problems occurred. The millet seed was late in arriving from Wad Medani, and many of the farmers delayed planting the trials until they finished their own planting. The growing season had

Table 5. Yields of Ugandi Millet in Response to Plant Population Study, Kaba Experiment Station, 1983.

Treatment*	No. of heads/plot	Yield gms/head	Yield kgs/ha
1	167	12.73	959
2	193	10.98	919
3	185	11.70	983
4	224	9.67	932

*No. of plants/hill

Table 6. Response of P 898012 Sorghum to Varying Plant Populations, Banjedid, 1983.

Treatment*	No. of heads/plot	Yield gms/head	Yield kgs/ha
1	22	16.5	182
2	36	17.8	320
3	31	17.1	265
4	24	20.8	249

*No. of plants/hill

Table 7. Comparison of Millet and Sorghum Genotypes treated by Partial Head Removal 2 Days after Anthesis (El-Obeid, 1982).*

Genotype	Treatment			
	Whole head	One-third cut	Half cut	Two-thirds cut
Millets				
ICMS 7817	12.02	12.00	12.02	13.75
Baladi White	11.83	14.33	14.43	15.33
Ugandi	12.75	13.00	13.33	14.25
Baladi Yellow	11.67	16.17	12.56	18.00
Sorghums				
P 898012	41.15	41.43	39.97	47.90
IS 9830	36.07	38.60	46.49	44.00
SRN 39	34.90	39.80	39.20	39.70
Zinnari	54.00	55.00	56.00	64.67

*100 seed weight (gms)

drought, and pests such as Striga, Sinta, birds, and grasshoppers. Out of eleven trials, it was possible to get some harvest in only four.

However, some information was gained from the trials. Farmers are excited about the millet variety Ugandi. They like its earliness and hairiness. Demand for Ugandi seed will be greater than the supply for the near future. The trials also confirmed that the sorghum genotypes P 898012 and IS 9830 are early and drought tolerant. IS 9830 also is Striga tolerant.

Significance of Research Findings

Great strides are being made toward improving sorghum/millet production. Especially promising are the new varieties which have been developed, because of their adaptability to harsh environments and tolerance of common pests. We hope, also, to identify the best possible intercropping and cultural practices for the area.

Of major significance is the research to improve quality and, ultimately, sorghum and millet yields.

LDC Collaboration

All of this research was conducted in North Kordofan, Sudan. This program is a cooperative effort with the Agricultural Research Corporation and the Western Sudan Agricultural Research Project (WSARP). The program would not be possible without the help of USAID, ICRISAT and the Ministry of Agriculture of Sudan.

Implications for Future Research

Our agronomic research in this western area of Sudan has been in process for only a short time. We will continue the program as it is currently organized in order to get a better data base. Other projects with potential for increasing agricultural production will be added in the future.

In some areas of Sudan grasshoppers cause extensive damage; compact heads and/or hairiness help some in reducing damage.

Selected Publications

Berhe, Tareke. 1982. INTSORMIL agronomic activities in North Kordofan, Western Sudan.

INTSORMIL KSU/INTSORMIL Project. April-September 1983. Agronomic research in North Kordofan, Sudan. Progress Report #2.

INTSORMIL KSU/INTSORMIL Project. 1983. Sorghum/millet agronomic research in North Kordofan, Sudan. Progress Report #3, Annual Report.

Agricultural Climatology of Sorghums and Millets

Ralph E. Neild, Joanne Logan and Lorenzo Aceves-Navarro

University of Nebraska

Sorghum/millet ranks third only to wheat and rice among the world's most important food grains. Wheat and rice are commodities in international commerce; their production is closely monitored. These crops are also extensively researched for ways of increasing yield. Much of the world's sorghum and millet is consumed by the poor people who grow it. Therefore, it has received much less research attention.

More information is needed about the requirements of these crops and the locations where they may be grown. Nearly 51,000,000 hectares of sorghum, producing 67,000,000 tons of grain, are harvested in the world each year. Although only 19 percent of these hectares are in the Western Hemisphere, they yield 48 percent of the total grain produced. Development of hybrids and other technologies since 1960 has had a dramatic effect on sorghum production in the Americas. For example, in Nebraska sorghum yield has tripled and the acreage planted has increased seven times since hybrids became available. Sorghum is displacing corn in the drier, hotter regions of the U.S. corn belt.

The success or failure of introducing new crop varieties or transferring technologies from one region to another depends largely on similarities of climate. The primary objective of this project is to develop agroclimatic procedures to help improve sorghum/millet production in LDCs.

Research Accomplishments

Models of the phenological response to growing day temperatures have been developed for groups of sorghum, pearl millet, proso millet and corn of differing maturity. Plots planted in Nebraska on a seasonal temperature gradient were compared with plots planted in the Dominican Republic on an altitudinal gradient. Day neutral sorghum in these tests showed similar phenological responses to temperature in both temperate and tropical regions.

Agroclimatic parameters were developed to determine the beginning and end of the growing seasons in temperate and tropical regions. These parameters were then used to evaluate the phenological response to available rainfall for sorghum strains of different maturity at different planting dates and locations.

Another part of the project is the development of a computer program called CLIGEN. It is designed to compute daily temperatures, number of growing degree days, accumulated precipitation, evapotranspiration and day length from monthly temperature, precipitation and latitude. Simple monthly climatic summaries are the most common, often the only, data available in developing countries. Therefore, CLIGEN could be enormously helpful. Since last August, agriculturalists from 25 countries have asked INTSORMIL for information about CLIGEN. Planners of resettlement programs in Zimbabwe view it as a possible tool for battling the severe drought in Africa. Agricultural planners in Papua, New Guinea may use it to evaluate the agricultural potential of that country. And researchers in Mexico and the Philippines could use the program to determine agroclimatic zones for sorghum.

We are also using models to compare the phenology and yield of corn and sorghum to climate. When preseason rainfall is above normal, corn is likely to produce higher yields than sorghum. But when preseason rainfall is below normal, sorghum is less likely than corn to suffer yield reductions. Sorghum is more vulnerable than corn to excess moisture and low temperatures during germination and seedling establishment. Both crops suffer yield reduction when temperatures reach 35°C or higher during ear/head formation, reproduction and grainfill. This critical period begins later with sorghum and is only one-third as long as with corn.

Finally, we have developed agroclimatic procedures to evaluate the use of sorghum in rice-based cropping systems. This research is determining the risks of rainfall patterns as they relate to various crop sequences in tropical locations.

Significance of Research Findings

This project has drawn together climatic records from LDCs and phenological and yield information from government agencies and international test plots. These data are the inputs for computer-generated agroclimatic parameters which can benefit agricultural producers in many parts of the world.

LDC Collaboration

At present, this project involves researchers in the Dominican Republic, Mexico, the Philippines and Tanzania. Climatic data from these countries contributes to our data base. We also collaborate with scientists at ICRISAT and CIMMYT.

Training and Technical Assistance

Supervisors of this project have been involved in the training of Master's Degree candidates from the Philippines, Mexico, Tanzania and Belize. One U.S. student conducted her Ph.D. research in the Dominican Repulic as a part of the INTSORMIL project, and was instrumental in obtaining the letter of understanding between INTSORMIL and the Dominican government. As a prerequisite to training, foreign students must have access to their national data sources.

In 1984, INTSORMIL co-organized, with the Secretary of Agriculture of the Dominican Republic, the first National Seminar on the Production and Utilization of Sorghum in that country.

Papers were presented at the International Symposium on Agrometeorology of Sorghum in Hyderabad, India in 1982; at Beijing University and Nanjing University in the People's Republic of China in 1982; and at the Sorghum Research and Development in the Philippines conference in 1984.

Implications for Future Research

We will continue to expand our data base in order to:

- determine zones and seasons in new areas where improved varieties and new technologies are likely to be effective;
- determine the potential for replacing corn and other cereals with sorghum/millet in arid regions and seasons:
- determine the ways in which sorghum/millet could be used in new cropping systems; and
- construct weather/crop models to predict phenology and yield.

Selected Publications

Cardenas, A. and R.E. Neild. An analogue approach in characterizing the growing season for sorghum production in the Philippines.

Cardenas, A., L. Nelson and R.E. Neild. 1983. Phenological stages of proso millet. Neb. Agric. Exp. Sta. Mins. Pub. 45.

Neild, R.E. Nov. 15-19, 1982. Agroclimatology of sorghum: The Americas. International Symposium Agrometeorology of Sorghum. Sponsored by ICRISAT, WMO and INTSORMIL. Hyderabad, India.

Neild, R.E. 1983. Temperate and rainfall influence on phenology and yield of grain sorghum and maize: A comparison. *Agric. Meteol.* 27:79-88.

Neild, R.E., J.A. Logan and A. Cardenas. 1983. Growing season and phenological response of sorghum as determined from simple climatic data. *Agric. Meteol.* 30:35-50.

Smith, Douglas, J.A. Logan and R.E. Neild. 1983. CLIGEN—a computer program that generates daily agroclimatic parameters from simple climatic data. INTSORMIL Project Report NU-8. University of Nebraska, Lincoln.

June 14-15, 1984. Proceedings, Sorghum Research and Development Program in the Philippines. Philippine Council for Agriculture and Resources Research and Development. Los Benos, Laguna.

Agronomy and Cropping Systems

Max D. Clegg and C.A. Francis*

University of Nebraska
(presently with Rodale Research Inc.)

Much emphasis has been placed on developing improved sorghum and millet varieties and hybrids. However, under the poor agricultural conditions normal in LDCs, new varieties will not succeed without better cultural practicies.

This project was established in 1982 to emphasize the importance of soil fertility, which often is a problem in areas that are intensely farmed. Because farmers in LDCs usually cannot afford to purchase fertilizer, we began to study the planting of the legumes as a way of improving soil fertility. The objectives of this project are to: (1) explore the soil fertility relationships of sorghum/millet and grain legumes in temperate and tropical conditions; (2) determine the effectiveness of intercropping and rotation schemes; (3) determine the adaptibility of genetically improved varieties to these systems; (4) develop new germplasm and cropping practices for testing where rotations and multiple cropping patterns are currently used; (5) determine how soil fertility is improved with cereal/legume systems; and (6) integrate the research results with ongoing farming systems projects.

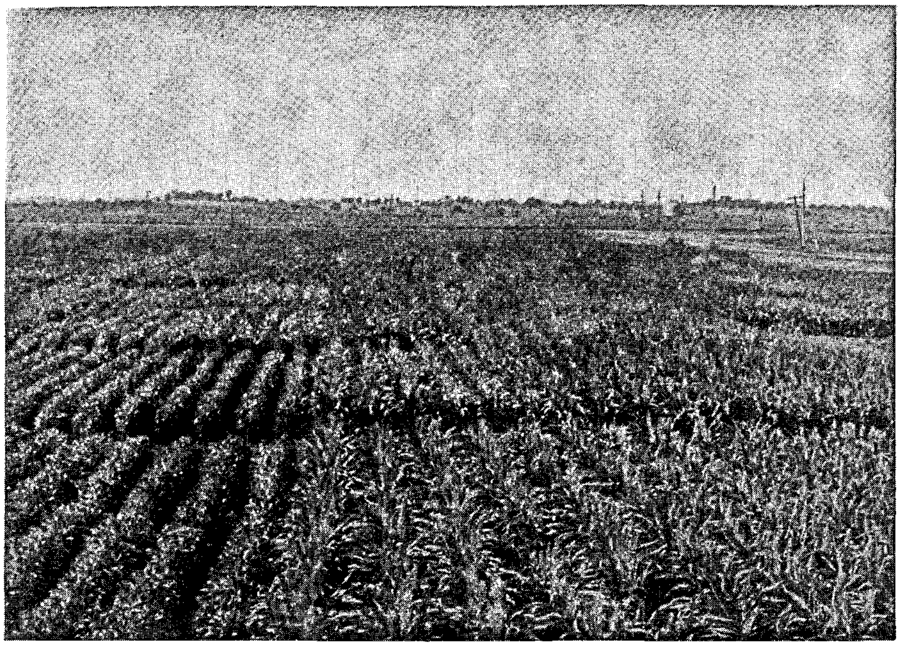
Research Accomplishments

The equivalent of about 50 kg/ha of nitrogen (N) (as measured by sorghum grain yield) has been gained from growing sorghum and soybeans in rotation in Nebraska (Table 1). The use of cowpeas and groundnuts as nitrogen sources for cereal crops is being investigated in Botswana. Maize seedlings in a field previously planted to cowpeas were considerably higher than those in a field previously planted to sorghum or fallowed. Visual observation of cereal/legume experiments in February 1983 indicated that there would be increased yields of sorghum following cowpeas and groundnuts. This was confirmed with harvest in the fall. Sorghum planted

Table 1. Yield of Grain Sorghum Grown in Continuous and Sorghum/Soybean Rotation Systems (Means of 4 Years).

Cropping system	Applied N (kg/ha) 0	57	114	171
Continuous	4600	6300	6800	7200
Rotation	6500*	7000	7200	6700
Cont./Rot.	0.70	0.90	0.94	1.07

* Yield equal to yield of plots with 57 kg/ha applied.



The plot in the background is continuous sorghum with no added nitrogen. In the foreground is sorghum rotated with soybeans with no added nitrogen.

after groundnuts also had better stand establishment.

The biomass of soils was estimated when sorghum was planted continuously and fertilized with 0, 57, 114 and 170 kg/ha N, when soybeans and sorghum were rotated and the sorghum fertilized with the same N levels, and when soybeans were planted continuously. Highest biomass yields were obtained with continuous soybeans. The sorghum/soybean pattern had the next highest yield (Table 2). Plots with 57 kg/ha N had the highest biomass, followed by 0, 170 and 114 kg/ha N (Table 3). Highest nodulation per plant was observed on soybeans grown in rotation with 0 nitrogen. Nodulation of soybeans decreased as applied nitrogen rates to the preceeding sorghum crop increased. Lowest nodulation was on continuous soybeans. Mineralization studies also show that soil from plots with different cropping patterns has different rates of nitrogen release.

The nitrogen-fixation potentials of both symbiotic and associative nitrogen-fixing organisms were measured in an enviroment that reflects the plant-microbe system reaction to soil water (i.e., pH, nitrogen). The technique used a 1-month-old soybean plant grown in a nitrogen-free sand culture. Acetylene reduction was done on freshly detached roots and 4 ml of soil solution. This method differentiated each treatment better than using roots alone, soil solution alone or roots dipped in soil solution.

Intercropping research in two locations over 2 years with sorghum and pearl millet revealed a marginal increase in efficiency when these two crops of contrasting plant type are grown together. This is a common system in Tanzania, and further on-site work will better demonstrate advantages of the system and allow more detailed work on components of the system. Planting intercropped sorghum and soybeans has shown a clear advantage to planting both crops in narrow, alternating strips, both under irrigation and dryland conditions. This work is continuing, with emphasis on studing yield components and the causes of overyielding in the intercrop. The specific effects of genotype in sorghum/maize, sorghum/cowpea, and maize/cowpea intercrops have been studied in Tanzania in three environments. These studies suggest that farmers in the Ifakara-Kilosa area would benefit by growing maize and cowpea mixtures (Table 4). Genotype-cropping pattern interactions suggest that breeding for specific cropping patterns may be necessary in complex systems. Finally, precise density studies of monocultured and intercropped sorghum and soybeans have been run in Nebraska in two locations for 2 years.

Table 2. Soil Biomass of Different Cropping Patterns of Sorghum and Soybeans.

Pattern	Biomass (kg/ha)
Cont. Sorghum	684
Cont. Soybeans	1155
Soybeans/Sorghum*	570
Sorghum/Soybean**	771

*Last crop sorghum
**Last crop soybean

Table 3. Soil Biomass as Influenced by Applied Nitrogen in a Sorghum/Soybean Rotation.

Nitrogen (kg/ha)	Biomass (kg/ha)
0	809
57	830
114	514
171	720

Table 4. Evaluation* of the Advantages of Intercropping Systems in Tanzania.

Crop/Culture	Sorghum	Cowpea	Maize
Sorghum	576**	3019	4587
Cowpea	—	1475**	4536
Maize	—	—	3096**

*Gross economic return in shilling/ha (12 shilling = US $1.00)
**Monoculture

Significance of Research Findings

The production of approximately 50 kg/ha N equivalent from legume/cereal cropping systems is a significant amount. In fact, this amount of nitrogen is equal to the general rate recommended for many developing countries. The introduction of legume/cereal systems in LDCs will quickly establish good fertility levels and increase crop yields.

Studies of biomass, mineralization and nodules indicate that the previous crop and/or the N rate applied influence the microbial content of the soil. This in turn affects crop yields. At some point a complementary state exists wherein both crops benefit.

The various sorghum/soybeans intercropping studies are giving basic information about plant equivalents, inter- and intra-specific competition, and alternative methods of analyzing and interpreting experiments. They also suggest that breeding for specific cropping patterns may be necessary.

LDC Collaboration

With this project it is not possible to establish cooperative projects in every developing country. Most of the cooperative research is done in Botswana; other countries involved are the Philippines, Dominican Republic, Egypt, Sudan, Mexico and Tanzania.

Training and Technical Assistance

Project members have been involved with the training of 16 graduate students from five foreign countries and the U.S. We have also participated in workshops in the Dominican Republic and Mexico.

Implications for Future Research

Our present research will continue, with emphasis on rotation and microbial-soil-plant relationships. New research will investigate the water use efficiency of cereal/legume systems, and the competitive effects between crops in intercropping systems. We will also attempt to determine whether different genotypes of cereals and legumes vary in intercropping efficiency.

Fertility studies in Botswana will consist of work with cereal/legume systems and millet/forage sorghum systems. There also will be stand establishment studies in Botswana.

Technology transfer studies have been proposed in cooperation with Dr. G. Mitawa in Tanzania.

And in Sudan and the Philippines work on production systems will continue.

Selected Publications

Carter, D.C. and C.A. Francis. 1983. Density interactions in sorghum/soybean intercrops in two environments in Nebraska. *Agron. Abst.*

Clegg, M.D. 1980. Physiological responses of grain sorghum following soybeans in rotation. *Agron. Abst.* p. 100.

Clegg, M.D. 1982. Effect of soybean on yield and nitrogen response of subsequent sorghum crops in eastern Nebraska. *Field Crops Res.* 5:233-239.

Clegg, M.D. 1982. The yield response of different sorghum plant types grown in 38, 76, and 114 cm row spacings. *Agron. Abst.* p.188.

Clegg, M.D. 1982. Crop management. Sorghum in the Eighties. International Sorghum Symposium, Hyderabad, India. p. 491-497.

Francis, C.A. 1978. Multiple cropping potentials of beans and maize. *Hortscience.* 13:12-17

Francis, C.A. 1980. Developing hybrids of corn and sorghum for new cropping systems. Proceedings 35th Annual Corn Sorghum Pres. Conf., Chicago (ASTA). p. 32-47.

Francis, C.A. 1981. Rationality of farming systems practiced by small farmers. KSU Symposium on Small Farms in a Changing World: Prospects for the Eighties.

Francis, C.A., M. Prager and G. Tejada. 1982. Effects of relative planting dates in bean (*Phaselus vulgaris* L.) and maize (*Zea mays* L.) intercropping patterns. *Field Crops Res.* 5:45-54.

Francis, C.A., M. Prager and G. Tejada. 1982. Density interactions in tropical intercropping. I. Maize (*Zea mays* L.) and climbing beans (*Phaseolus vulgaris* L.). *Field Crops Res.* 5:253-264.

Francis, C.A. 1983. Agronomic components of adaptation in sorghum. Proceedings, Sorghum Breeding Workshop, ICRISAT—CIMMYT—INTSORMIL, Mexico.

Francis, C.A. 1983. The role of cropping systems in farming systems research/extension. Proceedings, Farming Systems Research and Extension Workship, Univeristy of Missouri, Colombia.

Francis, C.A., M. Prager, G. Tejada and D.R. Laing. 1983. Maize genotype by cropping pattern interactions: Monoculture vs. intercropping. *Crop Sci.* 23:302-306.

Mitawa, G.M. and C.A. Francis. 1983. Genotype by cropping pattern effects in sorghum, maize, and cowpea in Tanzania. *Agron. Abst.*

Pavlish, L.A., C.A. Francis, T.R. Zweifel and J.F. Rajewski. 1983. Intercropping versus monoculture of sorghum and soybeans in two contrasting environments in Nebraska. *Agron. Abst.*

Santos, J.R. and M.D. Clegg. 1983. Dinitrogen fixation and biomass production under different sorghum and soybean cropping patterns with four fertilizer rates. *Agron. Abst.*

Mineral Element Uptake, Use, Efficiency and Tolerance in Sorghum and Millet

R.B. Clark and J.W. Maranville

University of Nebraska

Sorghum, the fifth most abundant cereal crop in the world, is a food staple and an important feed grain in many LDCs such as Africa and India. Unfortunately, it is in the relatively poor soils of these countries that crops such as sorghum and millet are subjected to the severest mineral stress.

In alkaline soils, iron (Fe), zinc (Zn) and phosphorus (P) deficiences and salinity are common; in acid soils, phosphorus, calcium (Ca) and magnesium (Mg) deficiencies and aluminum (Al), manganese (Mn) and iron toxicities are prevalent. Most soils also are deficient in nitrogen (N). Mineral element stress is due not only to insufficient or excess amounts of minerals, but also to differences in (a) chemical and physical reactions of the elements in soils, (b) abilities of plants to make elements available, (c) tolerance of plants to specific elements, (d) plant requirements for elements, and (e) efficiency of element uptake, distribution and use.

The traditional method of improving soil quality is to add fertilizer and other soil amendments such as lime and Fe compounds. But because these materials add considerably to the costs of production, their use in LDCs is rarely practical or even possible.

The most promising way of reducing mineral element stress in LDCs is to develop genotypes that tolerate or adapt to these stresses without loss of productivity. Plant breeders are recognizing that plant traits can be genetically manipulated. There has been success in this field; plant varieties have been developed which are fairly tolerant of Al and Mn toxicity and P, N and Fe deficiency.

Since sorghum and millet genotypes exhibit a wide range of adaptability to mineral stress, it should be possible to identify the specific genes which produce these traits and use them to improve germplasm. Sorghum/millet varieties that are suited to particular soils might then be developed.

Research Accomplishments

We are developing laboratory and field methods of screening sorghum/millet varieties for mineral element tolerances. The laboratory methods are relatively simple and inexpensive so that foreign scientists can readily conduct them. These methods are being used to screen genotypes for N, P and Fe deficiency and for Al and Mn toxicity. The results of laboratory screening are being tested in the field. In some cases field tests confirm laboratory findings and in some cases they do not. Additional tests are being made so that these discrepancies can be explained.

We need to understand the effects of element concentrations and NO_3^-/NH_4^+ ratios on growth media pH, and on plant growth and composition, in order to determine how plants should be grown in controlled media.

Field tests have included visual screening and measurement of dry matter and grain yields. Measuring plant height, weight, appearance or productivity may not provide information relevant in the laboratory. We are studying genotypes that show different tolerances and use efficiencies for particular elements in order to understand how these traits affect chemical and physiological properties.

The uptake, distribution and use of N, Fe and Al have been studied. Root measurements help determine the effects of Al on plants. Daily fluctuations of ferrous Fe and total Fe in leaves helped explain why Fe concentrations

These sorghum plants are being screened for tolerance or susceptibility to mineral element deficiencies or toxicities in nutrient solutions.

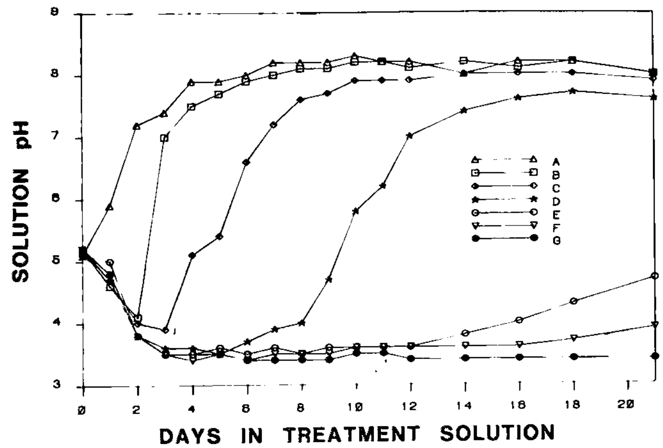
seldom related to Fe deficiency chlorosis in various genotypes. These properties may become part of future screening procedures.

Since most soils in LDCs are deficient in N, it is important to identify genotypes that use the element efficiently. A group of 36 sorghum hybrids screened under high and low N fertility and under dry and irrigated conditions showed a wide variety of N use efficiency values. The best hybrid was 60 percent more efficient than the poorest. Soil moisture seemed not to affect the results. There also were differences among millets tested. Pearl millets were generally less efficient in N use than sorghums, but more efficient than either proso or foxtail millets. Sorghums responded better to non-nitrate N sources such as urea. It was also determined that among later-maturing genotypes, the types that produced the most dry matter used N more efficiently than early-maturing genotypes.

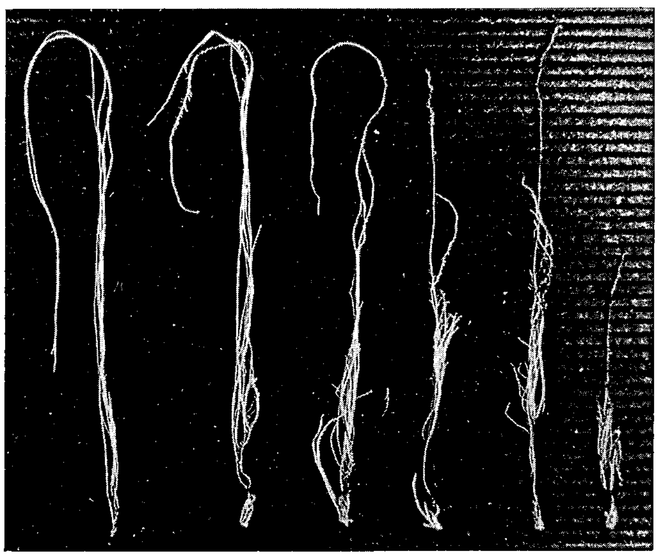
The analysis of mineral elements in plant tissues has been greatly improved with a multi-element analysis procedure [energy-dispersive X-ray fluorescence (EDXRF)]. This rapid, inexpensive procedure for analyzing small samples has greatly facilitated the interaction of plant physiologists and breeders. This method has improved the detection of Al and S-amino acids in grain. Using this new procedure, cooperative studies have been conducted to evaluate sorghum grown in acid, tropical soils for Al tolerance, and on low P soils for P efficiency.

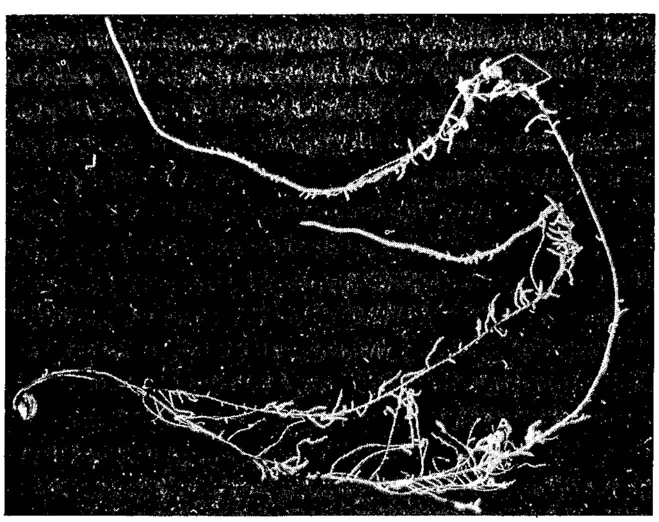
For the last 3 years from 6,000 to 12,000 samples have been analyzed annually to evaluate the mineral tolerances and efficiencies of sorghums and millets. About 5,000 of these samples have been from Brazil, Colombia, India and the Philippines.

An important area of research concerns the heritability of mineral element tolerance and efficiency traits. So far, studies have shown that Al toxicity is associated more with the male parent than the female parent, and is not associated with cytoplasm. Phosphorus efficiency is also more influenced by the male parent. Inheritance of Fe use efficiency traits in dry beans shows a 2-gene dominance. Progress is being made in improving the sorghum NP21 population for tolerance to Fe deficiency chlorosis.

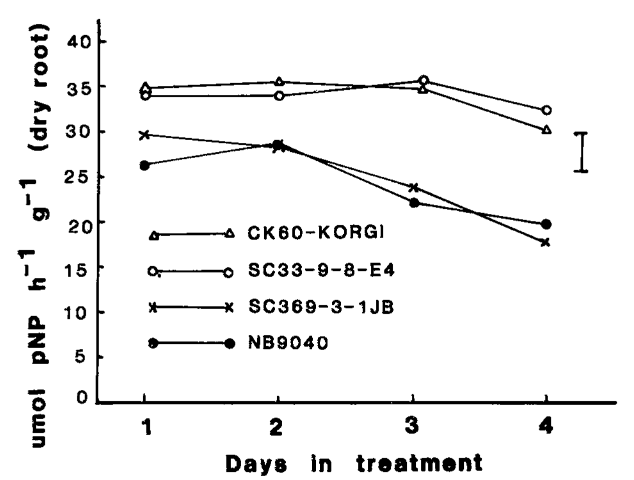


No_3^-/NH_4^+ *ratio effects on the pH of nutrient solutions where sorghum was grown (2 plants per 1.9-liter container).*



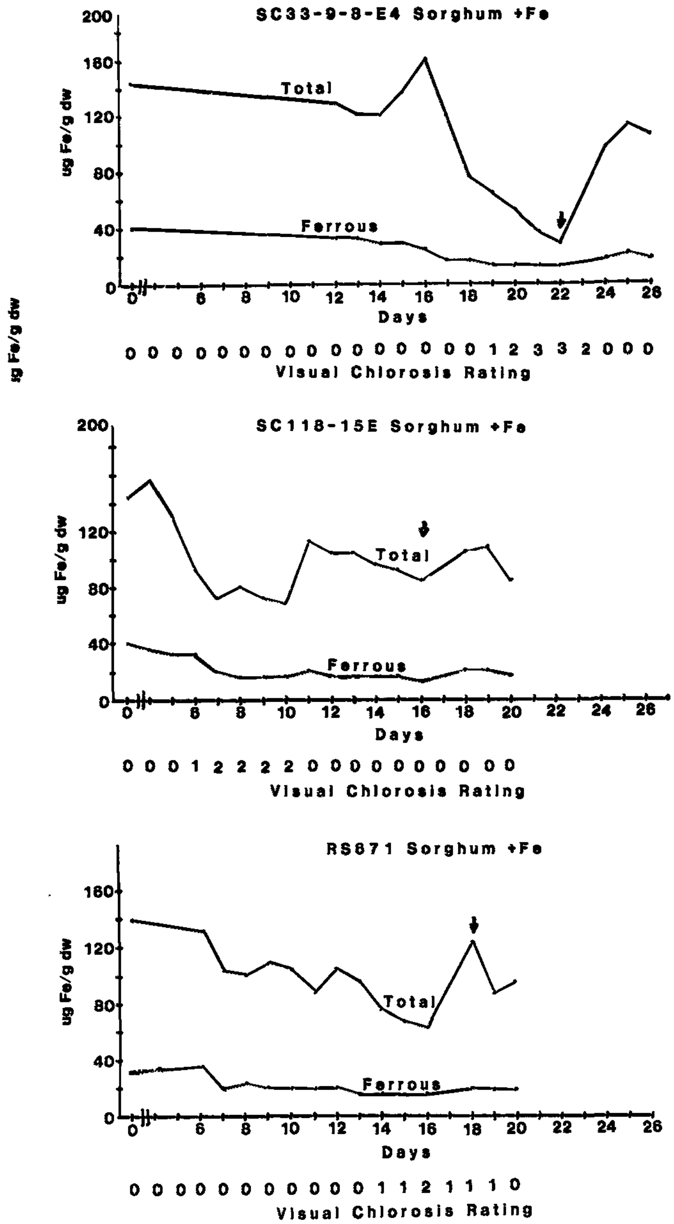


Differences in tolerance of sorghum genotypes to Al (top), and a close-up of Al toxicity symptoms on roots (bottom).



Root phosphatase activities of sorghums grown under slight P deficiency conditions.

We have taken color photographs of mineral deficiency and toxicity symptoms on sorghum leaves, and are using them extensively in training scientists from many countries to recognize these problems.



Daily fluctuations of total and ferrous Fe in sorghums grown in Fe-deficient conditions. The arrow indicates the point at which adequate Fe was added to the plants. Chlorosis ratings: 0 = no chlorosis and 4 = severe deficiency.

Significance of Research Findings

This research has had several significant achievements. The most important has been gaining the interest and involvement of plant breeders in genetically determining mineral element tolerance and use efficiency. This has been abetted by the development of field and laboratory screening procedures, especially the multi-element analysis process. Plant breeders now know that the diversity of mineral response among genotypes can be exploited in breeding plants suited to particular soils. While this new technology may never totally eliminate the need for fertilizer and other soil amendments, any methods which will improve yields while reducing production costs will be of great benefit to the subsistence farmers of poorer countries.

Energy-dispersive x-ray fluorescent (EDXRF) analysis of mineral elements in solid plant samples: a) putting sample tray into instrument chamber; b) electronic frame, keyboard and cathode ray tube; and c) peaks for mineral elements found in the sample.

Table 1. Frequency Distribution for Al Toxicity of Sorghum Lines (I) and S_1 Progenies from the NP16BR Sorghum Population (II).

	RRL†			ALTS‡	
Increment of distribution	I	II	Increment of distribution	I	II
	Number of genotypes within each increment				
1.11 - 1.20	2	3	<1.0	1	0
1.01 - 1.10	5	34	1.0 - 1.3	3	0
0.91 - 1.00	20	54	1.4 - 1.6	0	1
0.81 - 0.90	24	50	1.7 - 1.9	1	7
0.71 - 0.80	21	46	2.0 - 2.2	1	4
0.61 - 0.70	19	17	2.3 - 2.5	4	9
0.51 - 0.60	2	2	2.6 - 2.8	11	11
			2.9 - 3.1	5	30
N	93	206	3.2 - 3.4	14	36
			3.5 - 3.7	29	37
			3.8 - 4.0	25	65
			N	94	200

† RRL = relative seminal root length. Increments of distribution are RRL of plants used as standards.
‡ ALTS = Visual Al toxicity symptom rating on roots. Increments of distribution are ALTS where 0 = no symptoms and 4.0 = severe toxicity symptoms.

Table 2a. Frequency Distribution for Fe Deficiency of Some Sorghum Lines of Nigeria (I) and Lines Often Used in Plant Breeding Programs (II).

Increment of distribution †	I	II
	Number of genotypes within each increment	
0 - 0.5	1	0
0.6 - 1.0	3	0
1.1 - 1.5	2	0
1.6 - 2.0	2	2
2.1 - 2.5	1	8
2.6 - 3.0	1	6
3.1 - 3.5	0	10
3.6 - 4.0	0	3
N	10	29

† Increment of distribution are Fe deficiency ratings where 0 = no deficiency and 4.0 = severe Fe deficiency for plants grown in treatment solutions 7 days.

Table 2b. Frequency Distribution for Fe Deficiency of Sorghum Lines Used in the Texas Insect and Disease Nursery (II) of 1980 and Nebraska Experimental Lines (III).

	SFeDR †			DSFeD ‡	
Increment of distribution	II	III	Increment of distribution	II	III
	Number of genotypes within each increment				
<16.0	0	0	<4.0	0	0
			4.1 - 4.5	1	0
16.1 - 17.0	0	2	4.6 - 5.0	0	2
17.1 - 18.0	1	0	5.1 - 5.5	1	6
18.1 - 19.0	1	2	5.6 - 6.0	4	6
19.1 - 20.0	7	2	6.1 - 6.5	2	9
20.1 - 21.0	8	7	6.6 - 7.0	7	5
21.1 - 22.0	7	3	7.1 - 7.5	6	8
22.1 - 23.0	4	7	7.6 - 8.0	10	5
23.1 - 24.0	2	12	>8.0	0	0
24.1 - 25.0	0	5			
25.1 - 26.0	0	0			
26.1 - 27.0	1	1			
>27.0	0	0	N	31	41
N	31	41			

† SFeDR = Sum of daily Fe deficiency ratings of plants grown 9 days in treatment solutions.
‡ DSFeD = Days to severe Fe deficiency for plants grown 9 days in treatment solutions.

Table 2c. Frequency Distribution for Fe Deficiency of S_1 Progenies from the NP20BR Sorghum Population.

Increment of † distribution	DSFeD	SFeDR
	Number of genotypes within each increment	
<-2.5	0	1
-2.1 - -2.5	0	4
-1.6 - -2.0	1	4
-1.1 - -1.5	7	10
-0.6 - -1.0	38	29
0.0 - -0.5	62	39
0.0 - 0.5	47	64
0.6 - 1.0	30	32
1.1 - 1.5	10	14
1.6 - 2.0	4	3
2.1 - 2.5	1	0
>2.5	0	0
N	200	200

† Increments of distribution are in standard deviation (SD) units from the mean for DSFeD = days to severe Fe deficiency and SFeDR = sum of daily Fe deficieny ratings where 0 = no deficiency and 4 = severe deficiency. Plants were grown 9 days in treatment solution.

Table 3. Frequency Distribution of Sorghum Genotypes for Dry Matter Yield When Grown in Carimagua (I) and Palmira (II), Colombia Soils in a Greenhouse without Lime, and in the Field in Carimagua (Colombia) Soil Limed with 2 Ton/Ha^{-1} (III) and 6 Ton/Ha^{-1} (IV).

Increment of distribution †	I	II	III	IV
	Number of genotypes within each increment			
<-3.0	1	0	0	0
-2.6 - -3.0	2	1	0	0
-2.1 - -2.5	4	2	0	0
-1.6 - -2.0	6	5	1	2
-1.1 - -1.5	6	12	5	7
-0.5 - -1.0	5	4	14	6
0.0 - -0.5	8	11	10	14
0.0 - 0.5	4	4	10	8
0.6 - 1.0	7	4	10	6
1.1 - 1.5	4	6	1	2
1.6 - 2.0	4	5	3	4
2.1 - 2.5	3	2	3	0
2.6 - 3.0	4	3	0	1
>3.0	2	1	0	0
N	60	60	50	50

† Increments of distribution are in standard deviation (SD) units from the mean.

Table 4. Relationship of Laboratory Ratings for Tolerance to Al Toxicity and Field Ratings for Tolerance to Acid Soils.

Sorghum genotype	Laboratory response †	Acid soil response ‡
	% of highest	ASFTR
SC0283	105	2.69
SC0056	119	1.95
SC3541	76	1.42
SC0112	68	1.25
SC0599	46	1.21
P731	34	0.63
SC0170	45	0.56
NB9040	22	0.16
LSD	26	0.78

† Net seminal root lengths of plants grown with Al divided by lengths of roots of plants grown without Al or with a small amount of Al that was beneficial.
‡ Acid soil field tolerance ratings calculated according to the formula: AFSTR = Dry wt./(sum of mineral element ratios x visual stress rating) x 10.

Table 5. Low Detection Limit (LDL) for Mineral Elements Analyzed in Plant Materials by EDXRF (Silver X-Ray Tube).

Element †	LDL ‡	Element§	LDL
	ug g^{-1}		ug g^{-1}
Na	170		
Mg	135	Cd	9.0
K	40	Cr	2.3
Al	32	Co	2.0
Ca	30	Rb	2.0
Si	28	Sr	1.5
S	19	Ni	1.2
Cl	9.3	Pb	1.2
Mn	1.9	Hg	1.0
Fe	1.4	As	1.0
Ca	1.1	Br	0.8
Zn	1.0	Ba	0.5
Mo	1.0	Se	0.5

† These elements are determined in the normal analysis program.
‡ For reliable quantitative values, element concentrations should be about 3-fold higher than the LDL.
§ These elements may be determined in plant tissue using special programs.

Table 6. Frequency Distribution of Sorghum Genotypes for Mineral Element Contents in Leaves of Plants Grown in a Field in Carimagua, Colombia Soil Limed with 2 Ton/Ha.[-1]

Increment of † distribution	Element										
	Al	Si	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn
	Number of genotypes within each increment										
<-3.0	0	0	0	0	0	0	0	0	0	0	0
-2.6 - -3.0	0	0	0	0	0	0	0	0	0	0	0
-2.1 - -2.5	0	0	0	0	0	0	1	0	0	0	0
-1.6 - -2.0	4	0	1	1	1	1	0	1	1	0	1
-1.1 - -1.5	14	9	6	5	6	5	6	5	5	3	6
-0.6 - -1.0	9	10	12	14	7	13	11	14	13	15	10
0.0 - -0.5	12	9	8	9	19	10	9	9	12	13	11
0.0 - 0.5	6	6	9	8	6	8	10	7	5	6	10
0.6 - 1.0	2	9	6	4	4	4	5	7	4	5	5
1.1 - 1.5	1	5	4	5	2	2	2	2	5	4	3
1.6 - 2.0	1	1	1	3	1	6	4	3	3	0	2
2.1 - 2.5	0	0	2	1	2	1	2	0	1	2	1
2.6 - 3.0	0	0	1	1	2	0	0	2	1	1	0
>3.0	1	1	0	0	0	0	0	0	0	1	1
N						50					

† Increments of distribution are in standard deviation (SD) units from the mean.

Table 7. Effect of Male and Female Parents on Heritability of Al Toxicity in Sorghum.

Experiment	Male parent		Female parent			
1			CK60	K35	Mean	
				ALTS ratings †		
			(3.0) b	(3.0) b		
	TX415	(4.0) a	3.2 a	3.2 a	3.2 A	
	SC33-9-8-E4	(3.1) b	2.8 b	2.8 b	3.2 A	
	NB9040	(1.2) c	1.5 c	1.0 c	1.2 C	
	SC369-3-1JB	(1.2) c	1.0 c	1.0 c	1.0 C	
	Mean		2.1 A	2.1 A		
2			Wheatland	Martin	Redlan	Mean
				RARL ratings ‡		
			(0.73) bc §	(0.63) c	(0.36) d	
	NB9040	(0.93) b	1.19 a	0.93 b	0.90 b	1.00 A
	SC500-1	(1.18) a	0.87 b	1.17 a	0.82 b	0.95 A
	Plainsman	(0.60) c	0.58 c	0.47 c	0.49 c	0.51 B
	TX415	(0.60) c	0.58 c	0.52 c	0.47 c	0.52 B
	Mean		0.81 A	0.77 A	0.67 B	

† ALTS = Visual Al toxicity symptom ratings on roots of parental lines (in parenthesis) and single-cross hybrids.
‡ RARL = relative longest adventitious root length of parental line (in parenthesis) and single-cross hybrids.
§ Means followed by a common letter within experiments are not significantly different at P = 0.05, according to Duncan's multiple range.

Table 8. Effect of Cytoplasm on Heritability of Al Toxicity in Sorghum.

Parents	ALTS †
TX415	4.0 a ‡
CK60A	3.0 b
CK60B	3.0 b
Hybrids	
CK60 x TX414	3.2 ab
KS34 x TX414	3.0 ab
KS35 x TX414	3.2 ab
KS36 x TX414	3.0 ab
KS37 x TX414	2.8 b
KS38 x TX414	3.5 a
KS39 x TX414	3.0 ab

† ALTS = visual Al toxicity symptom ratings on roots.
‡ Means followed by a common letter are not significantly different at P = 0.05, according to Duncan's multiple range test.

LDC Collaboration

At present we have collaborative programs with scientists in Australia, Botswana, Brazil, Colombia, India, Mali, Mexico, the Philippines, West Germany and Yugoslavia. These programs cover a wide range of work, from screening for Al toxicity to identifying acid soil tolerance problems.

Training and Technical Assistance

Dr. Clark is consultant to scientists in Australia and Latin America on problems concerning Al toxicity and mineral nutrients. He has presented papers at workshops and symposia in India, Mexico, Italy and Colombia.

Dr. Maranville is Country Coordinator for INTSORMIL in the Philippines, and helped initiate INTSORMIL research in Sudan. He has also consulted with scientists in Thailand, India and Egypt, and addressed an ICRISAT/INTSORMIL conference in Italy.

Twenty-six graduate students from ten countries have received training through this project.

Implications for Future Research

We will conduct additional field and laboratory experiments on N uptake, translocation and efficiency in sorghums and millets, and on the effects of environment on N use. Inheritance studies of certain hybrids will be continued.

Sorghum genotypes will be screened for tolerance to Fe deficiency and alkaline soils. Selected types will be field tested in the U.S. and Mexico.

Additional sorghum and millet genotypes will be screened for tolerances to excess Mn and to P deficiency, which are common conditions in acid soils. Field tests will be done in cooperation with ICRISAT in India, Mali and Brazil. Acidity studies will be done in Colombia and Brazil.

Methods of rapidly screening large numbers of samples for Zn and Mn stress will be refined.

Research on the desirable N and mineral factors in grain will include studies of protein solubility, the effects of heat on protein quality, N fractions and N incorporation, and S-amino acids.

We will cooperate with ICRISAT in publishing a booklet on mineral element deficiency and toxicity, and in determining why the hematoxylin Al toxicity method is not working for sorghum.

Selected Publications

Bernardo, L.M., R.B. Clark and J.W. Maranville. 1984. Nitrate/ammonium ratio effects on solution pH, dry matter yield, and nitrogen uptake of sorghum. *J. Plant Nutr.* (in press).

Bernardo, L.M., R.B. Clark and J.W. Maranville. 1984. Nitrate/ammonium ratio effects on mineral element uptake of sorghum. *J. Plant Nutr.* (in press).

Clark, R.B., J.W. Maranville and H.J. Gorz. 1978. Phosphorus efficiency of sorghum grown with limited phosphorus. p. 93-99. *In:* A.R. Ferguson, R.L. Bieleski and D.B. Ferguson (eds.) *Plant nutrition 1978.* Proc. 8th Int. Colloq. Pant Anal. Pert. Prob., Auckland, New Zealand. (DISP Inform. Ser. No. 134).

Clark, R.B., H.J. Gorz and P.A. Haskins. 1979. Effects of mineral elements on hydrocyanic acid potential in sorghum. *Crop Sci.* 19:757-761.

Clark, R.B., P.A. Pier, D. Knudsen and J.W. Maranville. 1981. Effect of trace element deficiencies and excesses on mineral nutrients in sorghum. *J. Plant Nutr.* 3:357-373.

Clark, R.B., Y. Yusuf, W.M. Ross and J.W. Maranville. 1982. Screening for sorghum genotypic differences to iron deficiency. *J. Plant Nutr.* 5:587-604.

Clark, R.B., P.R. Furlani, G.E. de Franca, A.M. Furlani and Y. Yusuf. 1982. Screening sorghum genotypes for tolerances to mineral element deficiencies and toxicities. p. 742. *In:* L.R. House, L.R. Mughogho and J.M. Peacock (eds.) *Sorghum in the eighties.* ICRISAT, Hyderabad, India.

Clark, R.B. 1983. Laboratory screening techniques for tolerance to aluminum toxicity. p. 323-344. *In:* F.R. Miller, V. Guiragossian and A. Betencourt (eds.) *Breeding of sorghum.* INTSORMIL/ICRISAT/INIA ICRISAT (CIMMYT), Mexico City, Mexico.

Clark, R.B. Sorghum diseases. II. Non-infectious (abiotic) diseases. A. Nutrient deficiencies and excesses. *In:* R.A. Frederiksen (ed.) *Compendium of sorghum diseases.* Am. Phytopath. Soc. (in press).

Clark, R.B. and L.M. Gourley. Evaluation of Mineral elements of sorghum grown on acid tropical soils. *In:* L.M. Gourley (ed.) *Evaluating sorghum for tolerance to aluminum-toxic tropical soils in Latin America.* CIAT, Cali, Colombia. (submitted).

Coyne, D.P., S.S. Korban, D. Knudsen and R.B. Clark. 1982. Inheritance of iron deficiency in crosses of dry bean (*Phaseolus vulgaris* L.). *J. Plant Nutr.* 5:575-585.

Duncan, R.R., R.B. Clark and P.R. Furlani. 1983. Laboratory and field evaluations of sorghum for response to aluminum and acid soil. *Agron. J.* 75:1023-1026.

Furlani, P.R. and R.B. Clark. 1981. Screening sorghum for aluminum tolerance in nutrient solutions. *Agron. J.* 73:587-594.

Furlani, A.M., R.B. Clark, J.W. Maranville and W.M. Ross. 1982. Sorghum genotype differences to organic and inorganic sources of phosphorus. p. 751-752. *In:* L.R. House, L.K. Mughogho and J.M. Peacock (eds.) *Sorghum in the eighties.* ICRISAT, Hyderabad, India.

Furlani, P.R., R.B. Clark, W.M. Ross and J.W. Maranville. 1982. Variability and genetic control of aluminum tolerance in sorghum genotypes. p. 363-370. *In:* M.L. Saric (ed.) *Genetic specificity of the mineral nutrition of plants.* Vol. 13. Serbian Acad. Sci. Arts, Scientific Assemblies. Belgrade, Yugoslavia.

Furlani, P.R., R.B Clark, W.M. Ross and J.W. Maranville. 1983. Variability and genetic control of aluminum tolerance in sorghum genotypes. p. 453-461. *In:* M.R. Saric and B.C. Lougham (eds.) *Genetic aspects of plant nutrition.* Martinus Nijhoff/Dr. W. Junk Publ. The Hague, Netherlands.

Furlani, A.M.C., R.B. Clark, J.W. Maranville and W.M. Ross. 1984. Sorghum genotype differences in phosphorus uptake rate and distribution in plant parts. *J. Plant Nutr.* (in press).

Furlani, A.M.C., R.B. Clark, J.W. Maranville and W.M. Ross. Root phosphatase activity of sorghum genotypes grown with organic and inorganic sources of phosphorus. *J. Plant Nutr.* (submitted).

Furlani, A.M.C., R.B. Clark, W.M. Ross and J.W. Maranville. Differential phosphorus uptake, distribution, and efficiency by sorghum inbred parents and their hybrids. Proc. 2nd Int. Symp. Genetic specificity of mineral nutrition of plants. Madison, Wis. (submitted).

Haskins, P.A., H.J. Gorz and R.B. Clark. 1982. Influence of radiation level on apparent hydrocyanic acid potential of sorghum seedlings. *Crop Sci.* 22:101-105.

Knudsen, D., R.B. Clark, J.L. Denning and P.A. Pier. 1981. Plant analysis of trace elements by X-ray. *J. Plant Nutr.* 3:61-75.

Kofoid, K.D., J.W. Maranville and W.M. Ross. 1982. Relationship of the testa to agronomic and nutritional traits in sorghum. *Crop Sci.* 22:352-356.

Maranville, J.W. and R.B. Clark. 1979. Growth and nutrient uptake in grain sorghum under mulch. *J. Plant Nutr.* 1:255-272.

Maranville, J.W., R.B. Clark and W.M. Ross. 1980. Nitrogen efficiency in grain sorghum. *J. Plant Nutr.* 2:577-589.

Maranville, J.W., J.C. Larson and W.M. Ross. 1980. Uptake and distribution of nitrogen and phosphorus in grain sorghum hybrids and their parents. *J. Plant Nutr.* 2:267-281.

Maranville, J.W., P.J. Mattern and R.B. Clark. 1984. Estimation of sulfur in grain by X-ray flourescence spectrometry and its relation to sulfur and amino acids of field crops. *Crop Sci.* 24:303-305.

Pierson, E.E. and R.B. Clark. 1983. Contamination of laboratory glassware with iron. *Common. Soil Sci. Plant Anal.* 14:1201-1206.

Pierson, E.E. and R.B. Clark. 1984. Chelating agent differences in ferrous iron determinations. *J. Plant Nutr.* 7:91-106.

Pierson, E.E. and R.B. Clark. 1984. Ferrous iron determinations in plant tissue. *J. Plant Nutr.* 7:107-116

Pierson, E.E., R.B. Clark, J.W. Maranville and D.P. Coyne. 1984. Plant genotype differences to ferrous and total iron in emerging leaves. I. Sorghum and maize. *J. Plant Nutr.* 7:371-387.

Ross, W.M., R. Ritter and J.W. Maranville. 1980. Sampling sorghum plots for kernel protein. *Crop Sci.* 20:280-281.

Ross, W.M., K.D. Kofoid, J.W. Maranville and R.L. Voight. 1981. Selecting for grain protein and yield in sorghum random-mating populations. *Crop Sci.* 21:774-777.

Wallace, A., E.M. Romney and R.B. Clark. 1980. Corn inbreds differing in efficiency to zinc. *J. Plant Nutr.* 2:225-229.

Wallace, A.M, T. Kawasaki, E.M. Romney and R.B. Clark. 1980. Trace metal interactions in corn inbreds differing in efficiency of Mg uptake. *J. Plant Nutr.* 2:231-235.

Williams, E.P., R.B. Clark, Y. Yusuf, W.M. Ross and J.W. Maranville. 1982. Variability of sorghum genotypes to tolerate iron deficiency. *J. Plant Nutr.* 5:553-567.

Water and Temperature Effects on Sorghum and Millet as Related to Production and Breeding

J.D. Eastin and C.Y. Sullivan
University of Nebraska

M.W. Witt
Kansas State University

Water and temperature stresses cause substantial reductions in grain yields everywhere in the semi-arid tropics that sorghum and millet are grown. Water stress is believed to be the most universal problem. However, both high and low temperatures probably cause greater yield losses than is commonly realized. The high temperatures which often accompany drought are particularly damaging. The main objectives of this project are: to identify the effects of temperature extremes and water deficits on grain yield and use the results to develop cropping systems and agronomic practices which maximize and/or stabilize yields; to define the physiological processes which are affected most by heat and drought stress, and identify both tolerance and avoidance mechanisms which may improve stress resistance; and to develop and implement practical techniques of screening for drought and heat stress tolerance.

Research Accomplishments

Developmental Research

Using growth chambers, we determined that panicle development is very sensitive to temperature stress. Yield reductions resulted from reductions in seed numbers. These results were confirmed by field tests in Nigeria (Table 1). Tests in Mexico evaluated the effects of both water and temperature stress on stress-resistant and susceptible sorghums. Responses of two sorghums to low, medium and full irrigation levels are illustrated in Figure 1. Seed number reductions paralleled yield reductions.

Based on the above research, Mr. Dhopte, a student from India, detailed flower development events which lead to seed number reduction. His work and that of Mr. Lee from Taiwan (Fig. 2) is used for training all ICRISAT students in sorghum development and growth stage sensitivities. Dhopte showed that both low and high temperatures can cause pollen development problems about 3 to 6 days following initiation of stamen and pistil primordia (floret differentiation, #7 of Fig. 2).

Table 1. **Influence of Night Temperature on Yield and other Characteristics of RS 671 Grain Sorghum at Lincoln, Nebraska in 1979. Night Temperatures (field) were Regulated at 5° C. Values in Parenthesis are Percent Reduction from the Control, Except for 1000 Seed Weight which is Change from Control. Ogunlela, 1979.**

	(Ambient + 5°C)			
	G grain/ plant	Seed no.	1000 seed[1] wt. g	G grain/GS[3] day/plant
Control	66.9	2659	26.6	2.09
PI_1 to PI_7[1]	59.3 a	2333	27.2	1.85
	(11)	(12)	(2)	(11)
PI_8 to FD_1[2]	53.4	2174	27.8	1.71
	(20)	(18)	(5)	(18)
FD_1 to FD_7	48.0	1855	29.7	1.49
	(28)	(30)	(12)	(29)
FD_8 to BL_1[4]	52.7	2176	27.8	1.66
	(21)	(18)	(5)	(21)
BL_1 to BL_7	55.9	2223	25.5	1.80
	(16)	(16)	(−4)	(14)

[1] PI is panicle initiation (subscripts are days)
[2] FD is floret differentiation (stamen and pistil primordia)
[3] Percent reduction from controls
[4] BL is bloom

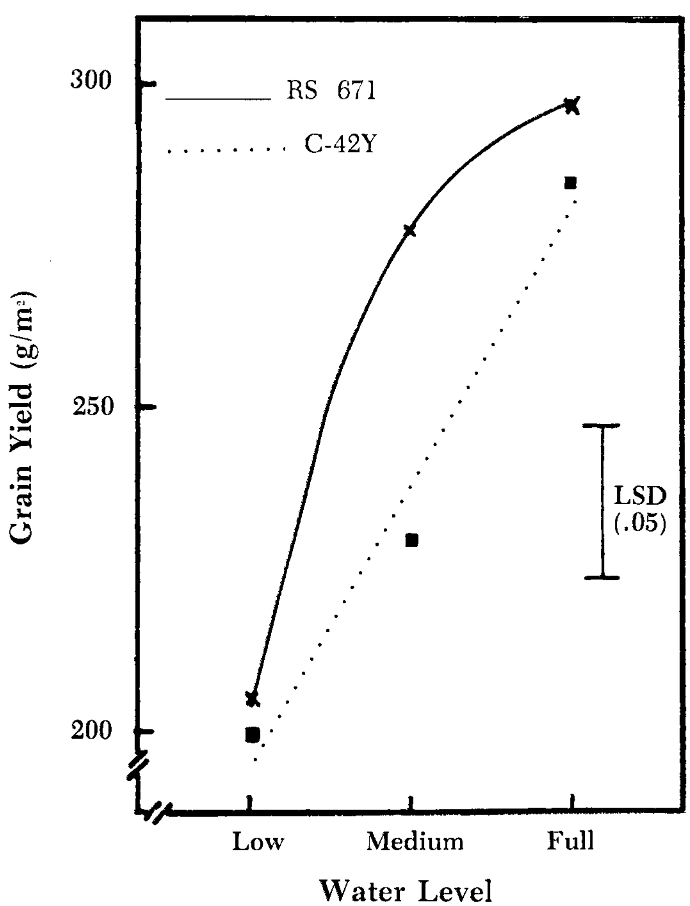


Figure 1. Grain yield response of RS 671 and C-42Y to three water levels at Garden City, KS in Experiment Two (1982).

Female sterility (pistil) problems develop about 7 to 10 days after floret differentiation. The ovule tends to separate from the ovary wall under stress.

The field and controlled environment data thus collected has been used to initiate and test a field breeder screening system. The test helps compare stress tolerance with seed number loss, measure the seed size compensation capacity when stress reduces seed number, and determine yield stability. In this test, water is withheld early to stress plants during the third week after panicle initiation; this enables researchers to check for stability in seed number, which correlates positively with grain yield. Percent seed number reduction due to stress is measured, along with the percentage yield compensation realized when seed size increases. This compensation is substantial in some genotypes and slight in others. Genotypes which resist losing seed numbers under stress and/or compensate in terms of seed size are the most stable. This breeder screening technique is being refined by ongoing research in Kansas, Nebraska and Sudan. Kansas and Sudan are hot, dry areas, while the Nebraska site is a dry, higher elevation area with hot days and cool nights. International cooperation in evaluating and refining this technique is excellent.

Physiological Research

Several students have been doing research to find out which plant mechanisms confer stress resistance to the different genotypes. Differences in the use of water and nutrients by different plant parts during floret development may relate to stress tolerance. A comparison of one stress-tolerant and one normal hybrid showed a nearly 50 percent greater root mass in the stress-tolerant hybrid. In addition, its respiration rate was about 40 percent slower, and the production of roots per unit of 0_2 consumed was nearly twice as great as that of the normal

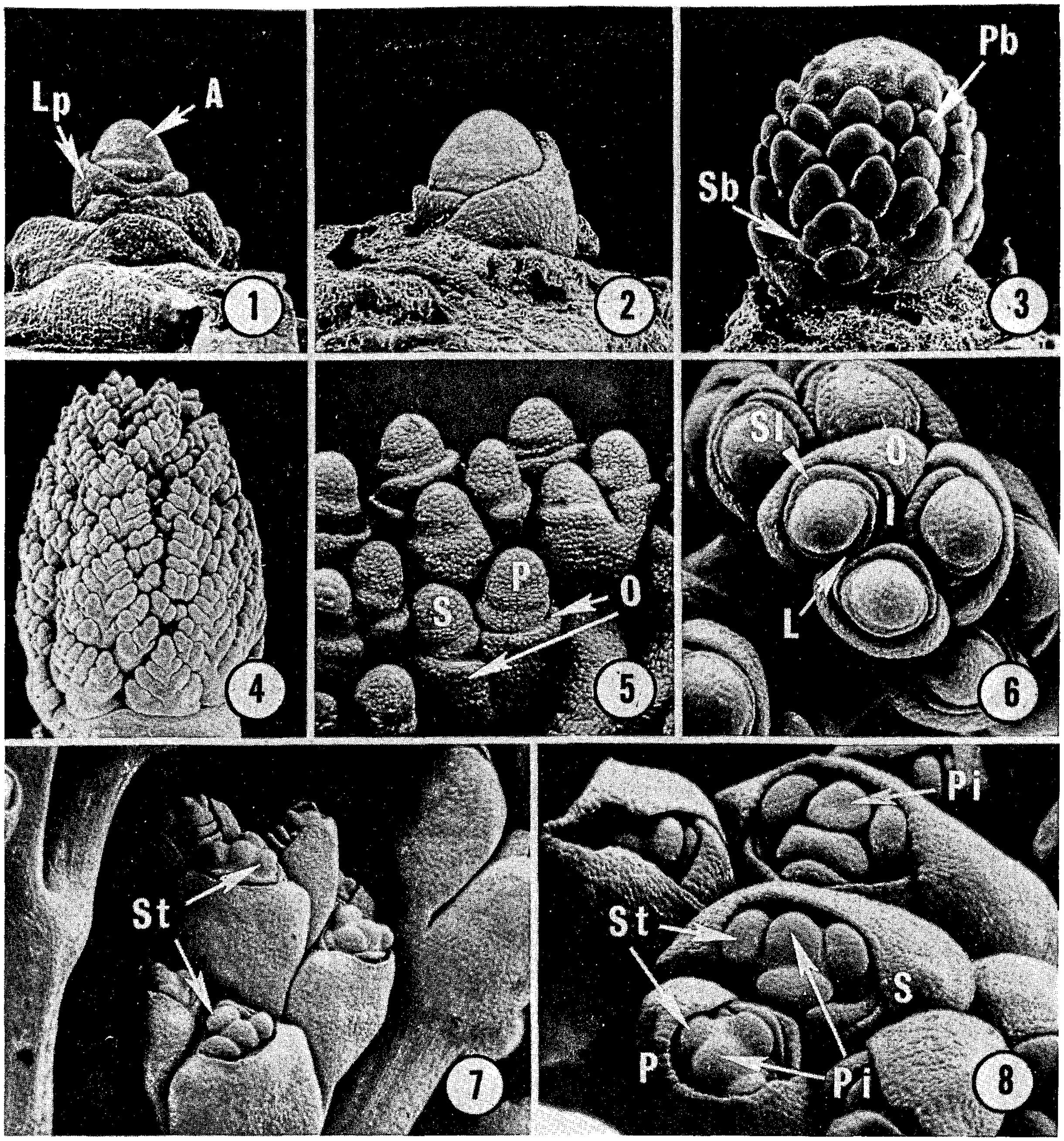


Figure 2. The vegetative and floral apices of sorghum bicolor (L.) Moench: (1) Leaf primordium (Lp) and shoot apex (A) of a 3-week-old seedling. (2) Enlargement of the apex before floral development. (3) Initiation of primary branch primordia (Pb) on the floral apex; secondary branch primordium (Sb) starts to form before primary primordia are completely formed at the apical dome. (4) Enlargement of floral apex due to the formation of more branch primordia of higher order. (5) Initiation of the outer glume primordia (O) on both sessile (S) and pedicellate (P) spikelets. (6) Sterile lemma (Sl) and lemma (L) are initiated on floret enclosed by outer (O) and inner (I) glumes. (7) Initiation of stamen primordia (St) in florets. (8) Both stamen (St) and pistil (Pi) primordia are initiated in the florets of the sessile (S) and pedicellate (P) spikelets.

hybrid. Therefore, three physiological traits relating to stress resistance appear to be (1) the ability to polarize assimilates for use in root development versus floret development; (2) a reduced rate of respiration under normal and stress conditions; and (3) a higher efficiency in using respiratory energy to synthesize root and/or floral tissue.

Root studies of sorghums grown hydroponically in plastic tubes have shown that plants could grow to maturity and produce some grain yield with only 3 to 10 percent of their total root dry weight in contact with water during the grain filling stage. Inducing drought stress in this way has enabled us to study the potential for deep rooting of various genotypes. Results of one experiment are shown in Table 2. Generally, those lines which had the least yield reduction due to drought stress in the field (grown in sandy soil with an irrigation gradient) also had the greatest increase in rooting depth. Tests with three commercial hybrids grown both hydroponically under water stress (Table 3) and in the field (Fig. 3) showed good correlations in root depth.

The hydroponic method appears to have potential for screening and selecting hybrids for deep rooting characteristics. This easy method could replace an expensive operation which needed specialized equipment and intensive labor. An example of selecting for root growth is shown in Table 4. Seed from the selected plant is being grown and the progeny will be tested for inheritance of the root growth characteristic.

Table 2. A Comparison of Grain Sorghum Root Growth in Hyproponic Tubes when Drought Stressed, and Field Reduction in Grain Yield from the Wet Side of an Irrigation Gradient to the Dry Side.

	Hydroponic tubes		Field
Genotype	Max. root length (drt.)	% Increased root length	% Yield reduction
	(cm)		
9	106	58	36
121	94	47	28
22	89	41	39
126	98	38	27
142	88	26	30
160	69	23	50
174	68	10	45

Table 3. Maximum Depth of Rooting in Hydroponic Tubes (cm).

Sorghum	Cont.	Droughted	% Increase
A 28	70	95	36
RS 626	67	77	15
RS 671	66	77	17

Physiologists are still unable to relate CO_2 exchange to grain yield as closely as we would like. Research needs to continue in this area because (1) photosynthesis is the primary physiological process on which everything else depends, and (2) instruments are available to make rapid field measurements needed in breeder screening, if we can determine which measurements should be made. Mr. Gonzalez in Mexico recently did some useful work in the area of photosynthesis-transpiration. He tested a stress-tolerant hybrid (STH) versus a normal sorghum hybrid (3-1) under three water levels at 30, 35 and 40°C (day). The STH grain yield was clearly superior under water stress at 40°C. The temperature-water-genotype interaction was obvious. While PHS and TR differences were hardly perceptible, growth factors relating to floret development were drastically different. There seem to be obvious differences in osmoregulation related to seed number development and/or abortion. Leaf development under stress was not greatly different between the two, but leaf senescence was much lower in the STH. Clearly, we need to research growth characteristics and gas exchange properties as they relate to yield limitation, and develop improved screening techniques and agronomic practices.

Current gas exchange work being done by Mr. Livera in Mexico includes measuring respiratory CO_2 to get a carbon balance picture. This is considered important because night temperatures which increase respiration rate can be very deleterious at the floret differentiation

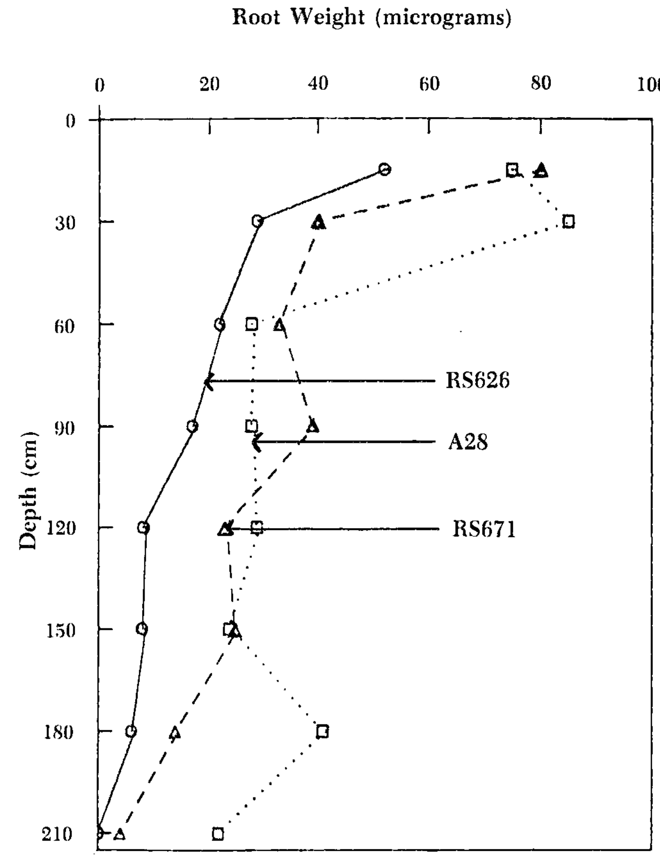


Figure 3. Root dry weight profile under dry land conditions (0-0-0).

Table 4. Selection for Root Growth in Hydroponics from Experimental Sorghum Line 121 (a Selection from Population NP9BR).

	Dry wt. roots (g)	
Dept (cm)	Mean of 10 plants	A selected plant
0-20	1.51	2.91
20-40	0.95	1.63
40-60	0.92	1.61
60-80	1.00	1.65
80-100	0.68	1.57
100-120	0.48	2.79
120-140	0.34	3.97
140-160	0.16	1.83

stage. He is doing field canopy carbon balance studies which may help relate CO_2 exchange to yield-limiting growth characteristics.

Growing plants in hydroponic tybes also enables us to accurately measure water use efficiency (WUE) in terms of production per unit of water transpired. Separation of evaporation and transpiration is difficult under field conditions. It was shown that WUE increased when root contact with available water was restricted. However, WUE for grain yield was sometimes decreased by the water stress (Table 5).

The WUE of some glossy sorghum lines (selected by R. K. Maiti, ICRISAT) was measured by growth in hydroponic cultures for up to 63 days. The glossy varieties were generally found to be more efficient than the nonglossy sorghums. The mean water use efficiency in terms of grams of dry matter produced per liter of water used was 12.6 for six glossy lines and 9.3 for seven nonglossy lines grown under identical conditions. The advantage of the glossy characteristic tended to be reduced as the plants aged. This characteristic may be useful in improving seedling drought resistance.

Sorghum genotypes selected from areas representing a gradient of normal annual rainfall across a north-south transect of Mali and Sudan were studied for possible differences in drought resistance. Similarly, pearl millet genotypes selected from different rainfall areas of India were studied (Table 6). Plants were grown in growth chambers in pot mixes or in hydroponic cultures. Water stress was imposed by additions of polyethylene glycol 8000. A total of 21 variables were evaluated. Of the physiological characteristics measured, only osmotic adjustment of leaf cells under water stress correlated with their growth in the native arrid areas (Fig. 4). That is, genotypes selected from drier regions had the highest osmotic adjustment. Also, plants that had a high capacity for osmotic adjustment had low rates of leaf

Table 5. Water Use Efficiency of Well Watered and Droughted Sorghums.

	WUE, Liters/Kg			
	Total dry matter		Grain	
Genotype	Watered	Droughted	Watered	Irrigated
9	187	131	941	586
22	199	182	1205	796
121	164	138	995	1052
126	191	180	1077	1394
142	186	125	879	621
145	173	146	821	896
146	229	157	1234	818
160	201	130	1170	987
174	226	153	827	788
226	170	141	815	698
272	175	134	715	612
Martin	199	145	982	691
A28	190	128	979	660
RS626	184	140	860	571
RS671	156	140	637	621
Mean	189	145	942	786

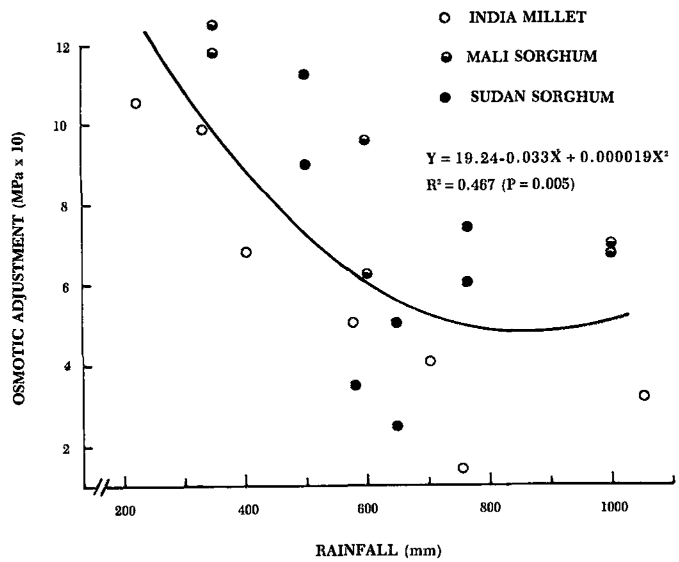


Figure 4.

senescence when water stressed. Photosynthesis slightly increased per unit leaf area in the more drought-susceptible genotypes, although total photosynthesis per plant decreased. There appeared to be an attempt at compensation for the loss of leaf area. The stress-resistant genotypes maintained higher transpiration rates under water stress than the susceptible genotypes.

Germination and Seedling Development

We are screening for cool temperature germination and seedling growth, as well as post anthesis development under cool conditions. Important germplasm sources for this work are Dr. Vartan Guiagossian at CIMMYT, Enrique Roma at INIA, and Leopoldo Mendoza at the Post Graduate College in Texcoco, Mexico.

The ability of germinated seeds and seedlings to tolerate stress conditions differs among genotypes. An understanding of the mechanisms involved at this stage of growth may be important to an effective breeding and selection program. Acclimation to drought stress was shown to occur in the seedling stage as well as at older stages. In seedlings exposed to two bars lower water potential, the photosynthesis reduction was as much as 50 percent greater than in plants subjected to a milder stress at the seedling stage. The stress conditioning response occurred at near -4 bars water potential. Photosynthetic rates of 3-week-old plants were more stable and generally higher when the seedlings had been stressed at -4 bars than when the seedlings had not been stressed.

Seedling establishment is a major problem in West Africa and other sorghum producing areas. Mr. Traore in Mali is studying the effects of various seed and seedling treatments on seedling survival during drought stress. Early results indicate that treatment with some growth regulators markedly increases seedling drought tolerance. Experiments are continuing in controlled environments and under field conditions.

Screening

The investigators of this project first demonstrated that the line source sprinkler irrigation gradient was an

Table 6. Millet and Sorghum Genotypes Selected for Study.

Species	Race	Country	Regions	Coordinates†	Mean annual rainfall†
				-degrees-	mm
Millet	SAR 170	India	Jodhpur, Rajasthan	26°N 72°E	220
	SAR 289		Gangenogon, Rajasthan	29°N 74°E	230
	SAR 1254		Kutch, Gujarat	23°N 70°E	400
	SAR 116		Jaipur, Rajasthan	27°N 75°E	570
	SAR 1435		Saborhontha, Gujarat	23°N 72°E	700
	SAR 2127		Aligarth, Uttar Pradesh	22°N 78°E	750
	SAR 2387		Fatehpur, Uttar Pradesh	25°N 82°E	1050
Sorghum	Safra	Sudan	Gadambalia	14°N	500
	Ajebsido		Gadambalia	14°N	500
	Korky		Elobeid	13°N	600
	Gadam El Hamam		Agadi	12°N	650
	Dabar		Agadi	12°N	650
	Kurgi		Kadugli	11°N	770
	Kulum		Kadugli	11°N	770
Sorghum	CSM 228	Mali	North	14°N	350
	CSM 63		North	14°N	350
	CSM 414		Center	12°N	600
	CSM 192		Center	12°N	600
	CSM 387		South	10-11°N	1000
	CSM 388		South	10-11°N	1000

† Approximate

effective method of screening genotypes for response to continuously increasing drought stress conditions (Table 7). Screening for water stress was initiated in 1979 and is being done now in Sudan, Kansas, Nebraska and Arizona. Some germplasm crossing has been done. Hybrids developed compare very favorably with commercial hybrids. New lines have been developed recently by crossing F_2 and F_3 material with a stress-resistant commercial female, and are among the best performers in recent Arizona tests. Collaboration with commercial companies has been productive, and should be expanded to take advantage of the widest possible range of sorghum expertise available.

Leaf discs cut from plants are used to evaluate cellular heat and desiccation tolerance. Sorghum and pearl millet genotypes selected from Africa, India and the U.S. were treated for stress tolerance with this technique. Exposure to both water stress and elevated temperatures increased heat and desiccation tolerance of the sorghums. Genotypic differences tended to decrease with plant age, increased water stress, and extended exposure to elevated temperatures. Plants that acclimated to the stresses more quickly, and at an earlier age, had a stress resistance advantage.

Heavy emphais has been given to comparative water use and water use efficiency of pearl millet, sorghum and corn. Corn was included in a limited number of experiments because of its importance in such countries as Tanganyika, Kenya, Egypt and Mexico. About half of the WUE work was done on an AID contract and half under the INTSORMIL contract.

Table 7. Yields of S_1 and S_2 Selections from Sorghum Population NP9BR on an Irrigation Gradient at the Sandhills Ag. Lab., Nebraska.

	ET replacement level		
Genotype	90%	50%	10%
		(Kg/Ha)	
121	6110 a*	5446 a	4422 a
22	5925 ab	4242 a	3438 ab
142	5904 ab	5145 a	4156 abcde
272	5825 ab	4092 bcd	3803 abc
279	5028 abc	4397 abc	3419 abcde
251	4987 ab	4100 bcd	3385 abcde
145	4916 ab	3459 cd	3079 bcde
30	4864 cb	4130 bcd	3385 abcde
146	4764 ab	3777 cd	3569 abcd
9	4732 ab	3993 bcd	3253 abcde
117	4722 ab	3640 cd	3008 bcde
174	4656 ab	3477 cd	2811 cde
Martin	4584 ab	4372 abc	2495 de
98	4550 ab	3930 bcd	2749 cde
126	4369 b	4256 abc	3666 abcd
76	4150 b	3757 cd	2928 bcde
226	4089 b	4139 bcd	3675 abcd
51	3732 b	3380 cd	2761 cde
160	3728 b	3177 cd	2267 e
103	3706 bc	2909 d	2529 de

*Values not followed by a common letter in a column are significantly different at the 5% level.

Comparisons of peal millet, sorghum and corn under a line source system were done in the U.S. Tables 8,9 and 10 give water applied, grain yield and WUE for pearl millet, sorghum and corn respectively. WUE varied little for millet, primarily because yield response to water was very low. This work needs to be repeated on superior millet hybrids now becoming available. WUE in sorghum generally improved slightly as water was added (Table 9). The improvement in yield and WUE in corn increased at a much greater rate than in sorghum. However, WUE was much lower in corn (216 lbs/in) compared to sorghum (350) under normal rainfall. Approximately 20 inches (508 mm) of water was needed for corn to achieve the WUE possible in sorghum with only 14 inches (356 mm). Seasonal water availability should be considered carefully when choices between corn and sorghum are made in developing countries.

Millet has been found to have a higher WUE than sorghum above 30°C, with the reverse being true below 30°C. This trait may explain why millet is tradionally grown closer to the desert. Genotype variability for WUE needs to be checked in the field now that portable equipment is available.

The data in Table 12 show the extremely close correlation between yield and seeds/M^2 in cereal grains. A drought screening program has been developed based on stability in seed number under stress. The essence of the screening procedure is to withhold irrigation to induce stress between panicle initiation and bloom, when seed number potential is being set. Grain yield and seeds/M^2 are then compared to a fully irrigated set of genotypes to see which genotypes are the most stable in terms of seeds/M^2 under stress. Screening was initiated in 1979. An example of results is shown in Table 12, where 81 genotypes were tested. Hybrids A, B and C are good commercial hybrids. Hybrid A yielded 5613 kg/ha compared to an average of 6989 kg/ha^{-1} for the top three hybrids chosen in the drought screening program. The 24.5 percent greater yield is encouraging, but more testing is underway to get better comparative data. Six of the top 15 hybrids in a similar dry-land test were also in the top 13 of the irrigated test. Note that the hybrids are decidedly superior to RS 671 and RS 626. Also, two of the lines selected (820158 and 820154) averaged 32 percent higher than TX430. The lines tested do very well in Egypt and are being tested more extensively in Sudan and the SADACC program. Drought screening activities need to be expanded in Sudan, Botswana, Egypt, the U.S. and other areas.

More recent WUE, drought screening, cool tem-

Table 8. Water Use by Pearl Millet under a Water Gradient System.

Irrigation	Water applied (in)		Seasonal water use (in)		Grain yield (Bu/A)		WUE[2] (lbs/in)	
level	1978	1979	1978	1979	1798	1979	1978	1979
Dry	0	0	13	14	52	51	224	209
Low	4	2	16	15	57	55	200	207
Med	9	5	17	16	60	58	198	203
Wet	13	8	19	18	64	61	189	191

Table 9. Water Use by Grain Sorghum[1].

Irrigation	Water applied (in)		Seasonal water use (in)		Grain yield (Bu/A)		WUE (lbs/in)	
level	1978	1979	1978	1979	1978	1979	1978	1979
Dry	0	0	14	14	86	93	340	359
Low	4	2	17	16	104	104	342	364
Med	9	5	18	17	124	113	385	370
Wet	13	8	19	18	123	117	378	363

Table 10. Water Use by Corn[1].

Irrigation	Water applied (in)		Seasonal water use (in)		Grain yield (Bu/A)		WUE (lbs/in)	
level	1978	1979	1978	1979	1978	1979	1978	1979
Dry	0	-	14	-	54	-	216	-
Low	4	-	16	-	86	-	301	-
Med	10	-	20	-	135	-	378	-
Wet	17	-	23	-	151	-	372	-

1 Averages of three hybrids for each crop at Garden City, KS.
2 Water use efficiency.

Table 11. Grain Yield and Water Use by Corn and Sorghum under a Gradient System at Mead, NE, 1980.

Water level	Inches water added	Water use (in)	Grain yield (bu/A)	WUE[1] (lb/in)	Seeds/M^2	Bu/A" added
			CORN			
Dry	0	19.1	70	207	1620	
Low	1	20.1	86	241	1929	15.7
Med	2.8	21.0	105	280	2303	12.5
Wet	5.7	22.7	112	274	2397	7.3
			SORGHUM			
Dry	0	17.5	89	286	21227	
Low	1	18.6	99	297	23904	10.0
Med	2.8	19.0	100	297	23291	3.9
Wet	5.7	20.3	101	280	21009	2.1

[1] Water use efficiency.

perature screening and rotational production systems are being evaluated for dry, higher elevation (1330 meters) areas that have cool nights. Tillage variables in rotations with sorghum, wheat and field beans are being investigated for possible use in Mexico, Kenya, Ethiopia and Sudan.

Significance of Research Findings

Our research has pinpointed the growth periods during which drought stress is most apt to reduce the seed number and/or seed size. This in turn tells us when stress resistance mechanisms are most critical. Knowing when seed number losses can be the greatest has enabled us to develop a simple breeder screening technique now being tested in the Sudan and the U.S. The developmental sequence photographs (Fig. 2) are being used to help ICRISAT trainees know when sorghum is susceptible to stress. That information is useful in plant breeding selection, and in selecting appropriate maturities for particular climates in order to minimize stress.

Table 12. 1983 Garden City, Kansas Irrigated Test (81 Genotypes).

Yield Rank	Kg ha^{-1}	Pedigree
1	7040*	Wh x 820137 S
2	7009*	623 x 820147 S
3	6919	Wh x 820139
4	6822	623 x 820157
5	6786*	623 x 820149
6	6683	Wh x 820155
7	6430	623 x 820158
40	5088	623 x 820158
8	6358*	623 x 820137 S
9	6284	Wh x 820149
10	6205*	Wh x 820154
26	5414	Wh x 820154
11	6060	623 x 820156
12	6047	623 x 820150
13	5918*	623 x 820155
18	5613	Hybrid A
35	5199	Hybrid B
41	5055	Hybrid C
68	3980	Tx430
70	3831	RS 626

*Ranked in the top 15 in the dryland test.

The physiological research has successfully defined stress resistance and avoidance mechnanisms such as osmoregulation, high photosynthesis to transpiration ratio, low metabolic demand root systems when seed number potential is being set, efficient water extraction by roots, deep soil water extraction, etc. Breeding for these improvements in sorghum is futile without an understanding of the mechanisms and interactions involved.

The comparisons of WUE in sorghum/millet show sorghum to be superior below 30°C and millet to be superior above that temperature. These findings are significant. We need to understand how millet controls transpiration in order to make further genotype improvements.

The development of simple screening techniques such as those for cold, drought and heat resistance are applicable in developing countries.

LDC Collaboration

Collaboration with LDC and ICRISAT scientists is increasing. Cooperative temperature adaptation research has been done at three loactions in Mexico, and is underway in Sudan. Other countries involved in the project are the Philippines, Zimbabwe, Colombia, Botswana and Niger.

Training and Technical Assistance

Ten graduate students from Nigeria, Mexico, the Philippines, India and the U.S. have completed their training in this project. Eight other students are still conducting their research. These students are or will be instrumental in establishing new INTSORMIL linkages as they continue their work in their home countries.

We have participated in the Agronomy Physiology Workshop for Latin America, the Sorghum in the 80's conference, Bellagio Stalk Rot Conference, a breeding workshop in Mexico, the INTSORMIL-ICRISAT Plant Breeding Workshop at CIMMYT, and several others. There is an ongoing schedule of consultation between project leaders and foreign scientists.

Implications for Future Research

Our continuing research will have as its goals to:

- investigate the nature of osmoregulation in different plant parts as it relates to root function, floret development and growth in general;
- determine the approximate range of variability in osmoregulation among genotypes in order to determine whether a screening technique is possible;
- develop techniques to investigate growth efficiency in roots as has been done with hydroponics;
- improve screening techniques for cold temperature germination and growth in high elevation areas;
- continue water stress screening with plant breeders and expand the crossing and hybridization program;
- consider potential water conserving characteristics of glossy sorghums;
- expand cooperative drought screening work in Sudan, Egypt, Kansas, Arizona, Mexico and perhaps Botswana;
- cooperate in research on WUE of legumes, sorghum and millet in high elevation climates where different cropping systems are being tried;
- continue genetic studies just initiated on the variability of length of grain fill;
- continue studies in Sudan designed to evaluate N response in fields which have never received N fertilizer;
- expand cooperative activity with ICRISAT scientists; and
- broaden research on seed germination and seedling establishment under drought stress, and further develop screening techniques for this area of research.

Selected Publications

Bennett, J.M. and C.Y. Sullivan. 1979. A hydroponic method of decreasing root water availability for evaluating responses of sorghum to drought stress. *Agron. Abst.* p. 84.

Bennett, J.M. and C.Y. Sullivan. 1981. Effects of water stress preconditioning and net exchange of grain sorghum. *Photosynthetica.*

Blewett, T.C., J.W. Maranville, J.M. Norman, C.Y. Sullivan and R.B. Clark. 1983. Water use and dry matter production of sorghum at varied nitrogen in hydroponics. Proc. Grain Sorghum Improv. Conference, Brownsville, Texas.

Clegg, M.D., J.D. Eastin and L.A. Nelson. 1983. Field evaluation for cool-tolerance in grain sorghum. *Crop Sci.* (accepted for publication).

Eastin, Jerry D. 1983. Breeding for adaptation to environmental stress. *In:* Proceedings twenty-sixth North American grass breeders work planning conference, Logan, Utah.

Eastin, Jerry D. 1983. Sorghum. *In: Potential productivity of field under different environments.* p. 181. International Rice Research Institute, Los Banos, Laguna, Philippines.

Eastin, Jerry D., R.M. Castleberry, T.J. Gerik, J.H. Hultquist, V. Mahalakshmi, M.B. Ogunlela and J.R. Rice. 1983. Physiological aspects of high temperature and water stress. *In:* P.J. Kramer and D. Raper (eds.), *Crop Reactions to Water and Temperature Stresses in Humid, Temperate Climates.*

Eastin, Jerry D., A.B. Maunder and Todd Dickinson. 1983. Crop physiology in dryland agriculture. *In:* H. Dregne and W. Willis (eds.), *Agronomy Monograph on Dryland Agriculture.* Am. Soc. Agron., Madison, Wisconsin.

Eastin, J.D., A Dhopte, V. Gonzaliz and V.B. Ogunlela. 1983. Physiological characteristics of adaptation in sorghum. *In:* F. Miller and V. Guiragossian (eds.), *Proc. INIA-ICRISAT-INTSORMIL Sorghum Workshop for Latin America.*

Easton, J.D. and C.Y. Sullivan. 1983. Environmental stress influences on plant persistence, plant physiological processes and production patterns. *In:* M.B. Tesar (ed.), *Foundations for Modern Crop Science.* Crop Sci. Soc.

Eastin, J.D., C.Y. Sullivan, J.M. Bennett, A.M. Dhopte, T.J. Gerik, V.A. Gonzalez-Hernandez, K.W. Lee, V. Ogunlela and J.R. Rice. 1984. Sorghum sensitivities to environmental stresses. *In:* L.K. Mughogho (ed.), *Sorghum Root and Stalk Rots, A Critical Review.* International Crops Research Institute for the Semi-Arid Tropics. Patancheru, India.

_______________, 1984. Rapidly determining sorghum canopy photosynthetic rates with a mobile field chamber. *Agron. J.* 76:163-165.

_______________, 1984. Changes in grain sorghum stomatal and photosynthetic response to moisture and stress across growth stages. *Crop Sci.* 24:441-446.

Garrity, D.P., C.Y. Sullivan and D.G. Watts. 1979. Quantification of drought stress and stress conditioning of sorghum. *Agron. Abst.* p. 18.

Garrity, D.P., D.G. Watts, C.Y. Sullivan and J.R. Gilley. 1982. Moisture deficits and grain sorghum performance: Evapotranspiration-yield relationships. *Agron. J.* 74:815-820.

Garrity, D.P., D.G. Watts, C.Y. Sullivan and J.R. Gilley. 1982. Moisture deficits and grain sorghum performance: Effect of genotype and limited irrigation strategy. *Agron. J.* 74:808-814.

Garrity, D.P., C.Y. Sullivan and W.M. Ross. 1982. Alternative approaches to improving grain sorghum productivity under drought stress. *In: Drought resistance in Crops with Emphasis on Rice.* pp. 339-356. International Rice Res. Inst., Los Banos, Philippines.

Garrity, D.P., C.Y. Sullivan and D.G. Watts. 1983. Moisture deficits and grain sorghum performance: Drought stress conditioning. *Agron. J.* 75:997-1004.

Garrity, D.P., C.Y. Sullivan and D.G. Watts. 1984. Changes in grain sorghum stomatal and photosynthetic response to moisture stress across growth stages. *Crop Sci.* 24:441-446.

Jordan, W.R. and C.Y. Sullivan. 1982. Reaction and resistance of grain sorghum to heat and drought. *In:* L.R. House, L.K. Mughogho and J.R. Peacock (eds.), *Sorghum in the Eighties.* p. 131-142. ICRISAT, Andhra Pradesh, India.

Jordan, W.R. and C.Y. Sullivan. 1983. Physiological systems associated with drought resistance. Proc. Sorghum Breeding Workshop for Latin America, CIMMYT, Mexico. (in press).

Martineau, J.R., J.E. Specht, J.H. Williams and C.Y. Sullivan. 1979. Temperature tolerance in soybeans. *In:* Evaluation of a technique for assessing cellular membrane thermostability. *Crop Sci.* 19:75-78.

Maurer, R.E. , D.G. Watts, C.Y. Sullivan and J.R. Gilley. 1979. Effects of timing and amount of water applications on stress conditioning of corn. *Agron. Abst.*, p. 17.

Maurer, R.E., D.G. Watts, C.Y. Sullivan and J.R. Gilley. 1979. Irrigation scheduling and drought-stress conditioning in corn. Proc. Am. Soc. Agricultural Engineers, New Orleans, Louisiana.

Norman, J.M., C.Y. Sullivan, T. Harrison and R. Eckles. 1981. A comparison of four porometers under field conditions. *Agron. Abst.*, p. 93.

Otte, C.E., W.M. Ross, C.Y. Sullivan, R.L. Voight and F.R. Miller. 1984. Evaluation of R-lines from the sorghum random-mating population NP3R *Crop Sci.* 24:9-12.

Retta, A., C.Y. Sullivan and D.G. Watts. 1983. Root growth of sorghum genotypes grown under a gradient irrigation system. Proc. Grain Sorghum Improv. Conference, Brownsville, Texas.

Semugurka, G.H., W.A. Compton, C.Y. Sullivan and M.A. Thomas. 1981. Some measures of temperature response in corn. (*Zea mays* L.). *Maydica.* 26:209-218.

Sullivan, C.Y. and W.M. Ross. 1979. Selecting for drought and heat resistance in grain sorghum. *In:* H. Mussell and R. Staples (eds.), *Stress Phsyiology in Crop Plants*, pp. 263-281. Wiley Interscience, New York.

Sullivan, C.Y., D.P. Garrity, D.G. Watts, R.E. Maurer and J.R. Gilley. 1979. The use of an irrigation gradient for plant screening and evaluation of physiological responses to drought stress. *Agron. Abst.*, p. 18.

Sullivan, C.Y. and J.M. Norman. 1981. Reliability of photosynthesis measurements from portable chambers and glass syringes. *Agron. Abst.*, p. 93.

Sullivan, C.Y., D.G. Watts, D.P. Garrity and R.E. Maurer. 1981. Responses of sorghum and corn to limited irrigation. Proc. 35th Ann. Corn and Sorghum Ind. Res. Conference, Chicago, 1980, pp. 205-218.

Sullivan, C.Y. Genetic variability in physiological mechanisms of drought resistance. *Iowa State J. Res.* 57:423-439.

Watts, D.G., C.Y. Sullivan and J.R. Gilley. 1979. Development and operation of gradient irrigation systems for evaluation of plant response to drought stress. *Agron. Abst.*, p. 17.

Watts, D.G., J.R. Gilley and C.Y Sullivan. 1980. Management of irrigation agriculture wtih a limited water and energy supply. Final Report to Old West Regional Commission. University of Nebraska and USDA-SEA-AR, Lincoln, Nebraska. 168 pp.

Wilson, G.L. and J.D. Eastin. 1983. The Plant and its Environment. *In:* L.R. House, L.K. Mughogho and J.M. Peacock (eds.), *Sorghum in the Eighties*, pp. 101-120. International Crops Research Institute for the Semi-Arid Tropics. Patancheru, India.

Seed Factors Influencing Germination, Emergence and Stand Establishment of Sorghum and Pearl Millet

James C. Delouche, C.H. Andres, H.C. Potts, C.E. Vaughn, E. Cabrera and G. Reusche

Mississippi State University

The objectives of this project were to improve the quantity and efficiency of sorghum and millet production in LDCs by reducing stand establishment problems. This involves (1) characterizing sorghum seed germination and emergence in terms of general responses to selected environmental factors such as temperature, soil moisture potential, and mechanical impedance; (2) identifying heritable traits of sorghum seed associated with superior seed quality and germination/emergence under stress conditions; and (3) developing procedures to screen for these traits. As a result of early work, two other objectives were added: (4) developing better methods of evaluating sorghum and millet seed quality, and establishing the relationship of seed quality to storability and field performance; and (5) developing and evaluating seed treatments that improve the emergence and stand establishment of sorghum and millet under stress conditions.

A diverse group of sorghum genotypes was used to characterize germination/emergence in terms of responses to temperature (12 to 42°C), soil moisture stress (−0.01 to −13 bars) and crusts of varying strength. In addition to establishing the range of temperature, soil water potential and mechanical impedance within which emergence and stand establishment are satisfactory, this data helped pinpoint the best methods of identifying sorghum genotypes which will perform best under marginal seedbed conditions. Genotypes identified as having superior emergence or quality retention traits are referred to breeding projects, along with the suitable screening procedures for incorporating them in improved lines.

Methods for rigorous assessment of seed vigor and storability in sorghum are being developed using procedures successfully employed for other crops such as soybeans, cotton and corn. Seed-applied treatments such as fungicides, osmopriming, anti-oxidants, deterioration inhibitors, germination stimulators and extenders, and moisture intake regulators are being evaluated to identify which treatments are beneficial during temperature and/or moisture stress. Emphasis is on practical systems applicable to conditions in LDCs.

Research Accomplishments

Emergence Problems

The causes of emergence and stand establishment problems in sorghum production (and probably millet production as well) differ among climatic regions. In the humid tropics and sub-tropics poor quality of planting seed is a major cause of stand problems. The quality of the seed at harvest is low because of weathering, and poor storage conditions cause further quality deterioration. On the other hand, seed quality *per se* does not appear to be a major cause of emergence and stand establishment problems in arid and semi-aird regions such as Central West Africa. In these areas, problems are caused more by seedbed factors: insufficient moisture at planting; planting during the "first rains" followed by drought which, if long enough (8 to 10 days), results in death of the seed or seedling; formation of crusts which are not softened in time by rainfall; and high temperatures which can be lethal to the seed or seedling, and, of course, accentuate the drought problem. Although documentation is sparse, observations suggest that traditional varieties emerge better than some of the improved varieties. Poor emergence is a common complaint among farmers using improved varieties of sorghum. While this problem may reflect poor quality control on the part of the seed distribution program, there may also be inherent weaknesses in the seed of improved varieties.

Temperature

Regardless of genotype, sorghum seed of near maximum physiological quality germinated equally well at all temperatures between 18 and 34°C in our tests. However, when seed of less than maximum physiological quality were evaluated, the genotypes tested were more sensitive to marginal temperatures and the genotype quality level interaction was significant. Among the genotypes evaluated, constant germination temperatures of 16 and 42°C resulted in the best differential array of germination values. This could be useful to breeders interested in screening lines for germination temperature response.

Germination of seed of the genotypes SC 175-14, IS 1166C and P954063 was equal to or better than that of all other genotypes at all temperatures within the range 14 to 42°C (Fig. 1) These studies demonstrate the existence of considerable variation, probably genetic, in the germination temperature response of sorghum. Furthermore, the screening techniques for identifying desirable genotypes are non-destructive and reasonably simple, provided seed of high physiological quality are used. A soil micro-environment simulator was designed and tested for screening sorghum and other kinds of seed for variability to constant and oscillating temperatures.

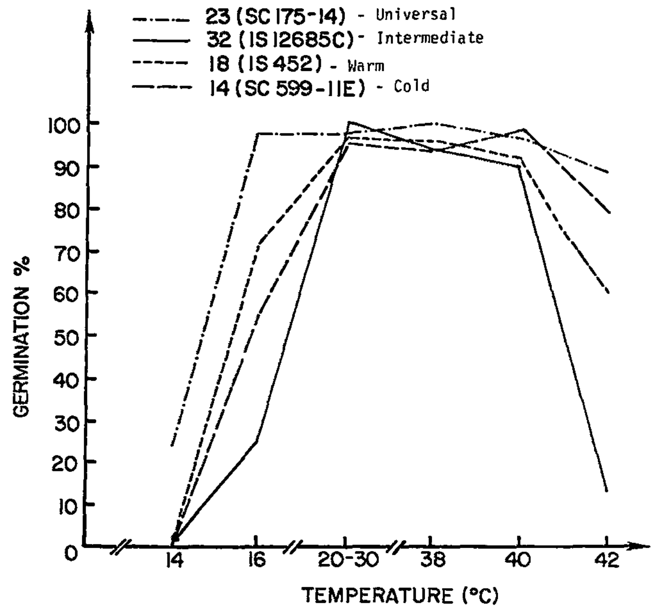


Figure 1. Germination response of four sorghum genotypes representative of the four categories based on genotypic response to a range of germination temperatures.

Soil Moisture/Osmotic Potential

Germination and emergence responses of sorghum (34 genotypes) were characterized at soil water potentials ranging from near zero to − 11.11 atm., and in osmotic systems (PEG) ranging from near zero to -16 atm. osmotic potential. In the soil studies (Prentiss silt loam), total emergence of sorghum was not greatly affected within the range of soil water potential from -0.02 to -5.70 atm. However, the rate and percentage of emergence progressively decreased as soil water potential decreased from -5.70 to -11.11 atm., or increased from -0.02 to -0.01 atm. There was considerable

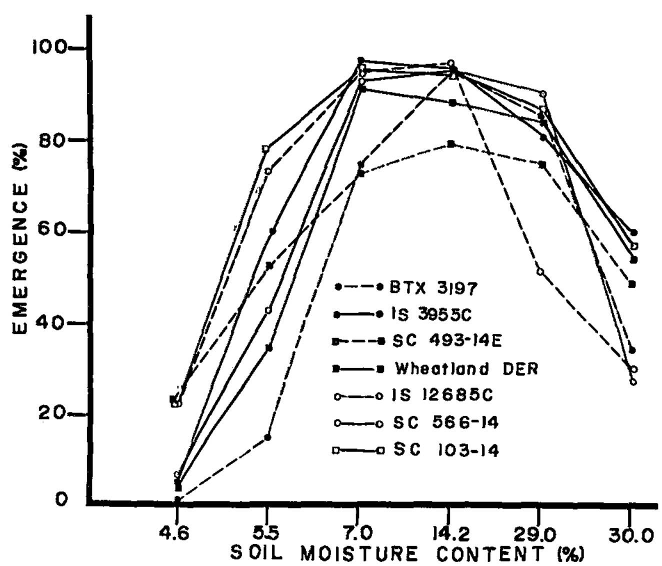


Figure 2. Emergence (%) of seven sorghum genotypes at six SMCs. (Note: soil moisture scale represents data points rather than uniform increments in SMC).

variability in emergence responses to moisture stress among the genotypes. Lines IS 12685C, SC 103-14, IS 33-2266C, TX 7078 and P95403 exhibited superior capability for emergence under low moisture stress, while lines BTX 3197, IS 1166C and TX 2536 emerged very poorly under the same conditions (Fig. 2). The best stress level for screening sorghum lines for superior emergence at low soil water potentials appears to be about -8.6 atm., with emergence determined 7 to 8 days after planting. There was also variability among the lines in the rate of emergence at favorable soil moisture levels. This variability will be important in identifying genotypes that will emerge before the soil crust dries to maximum strength. Germination and seedling growth of sorghum generally decreased as the osmotic potential of the moisture source (PEG 0600 solutions) decreased. PEG 6000 at -7.0 atm. osmotic potential, using the saturated filter paper technique, appears to be effective in differentiating among genotypes for germination responses under drought stress.

Mechanical Impedance

The crust-producing system used involved planting seed in a "crusting susceptible" soil, "sealing" the soil to varying degrees with a multiple intensity rainfall simulator, and then forming a crust by drying the soil surface to the desired level under a bank of heating lamps. This system is very good for basic studies of mechanical impedance to emergence, but has severe limitations as a screening technique because considerable quantities of soil are required for very limited screening capacity. Alternative, simpler systems are being researched. Nevertheless, the system developed and used did produce differential responses among sorghum genotypes in terms of capacity to survive under a crust for 10 days and emerge after the crust has softened. Lines SC 103-14 and IS 3911C exhibited good capacity to emerge through a strong crust and to survive under a crust and emerge when it was softened, while lines SC 326-6 and RIO OC SEL performed poorly under the same conditions. The line SC 103-14 also had excellent capacity for emergence under both low (-8.6 atm.) and high (-0.01 atm.) soil water potential.

Weathering Resistance

Sorghum lines from the GWT and SEPON tests and others were produced under ambient and artificially "misted" conditions. The lines produced under ambient conditions were harvested at black layer formation, and 15 to 30 days after black layer formation. In the case of the artificially "misted" treatment, misting was begun (2 hr/day, 5 to 7 p.m.) at anthesis and continued until 30 days after black layer formation. Harvests were made at black layer formation and 15 to 30 days later. The misting system greatly intensifies the weathering stress, and of course, ensures that there is a stress, which is problematic when research relies totally on ambient conditions. The design and materials list for the system have been made available to many interested breeding and plant pathology groups. The GWT lines SC 719-11E, SC 603-11E and IS 9630 exhibited excellent resistance to weathering deterioration, while lines TX 2536, BTX 378 and SC 798-14 were very susceptible to weathering.

Figure 3. Visual evaluation for resistance to field weathering of sorghum seed by Dr. A. A. Aziz, Sudan (MSU-1).

Response trends were similar under both ambient and misted conditions, except, of course, deterioration was generally greater under the latter treatment. Lines that were most susceptible to weathering in terms of reduction in germination also exhibited reduced kernel weight and increased mold growth (bioassay tests), and greater loss of viability under accelerated aging conditions. Some of the resistant lines, not unexpectedly, exhibited a substantial degree of seed dormancy.

Seed Size

In our research, differences in average seed size among lines had no consistent influence on emergence under non-stress conditions and subsequent growth and development. However, within a line (genotype), the smallest seed in the population produced in any one season/location were generally inferior in germination and emergence and produced plants which grew more slowly than those from seed of average size or larger.

Seed Storage Potential

The accelerated aging test appears to be promising as a predictor of the storage potential of both sorghum and millet seed. Seed lots which germinated poorly after accelerated aging at 45°C and 100 percent relative humidity for 3 (sorghum) and 4 (millet) days also decreased most rapidly in germination under warehouse storage conditions at Mississippi State University. Conductivity measurements were not as good predictors of storage potential as the accelerated aging test.

Significance of Research Findings

Discussions with John Peacock of ICRISAT and others confirm findings by the University of Missouri during the formulation stage of the sorghum and millet CRSP, and our observations during 22 years of technical

Figure 4. General view of the plots and misting system used to evaluate tolerance of sorghum seed and grain to field weathering (MSU-1).

assistance in the LDCs. That is, emergence and stand establishment problems are a major constraint in sorghum and millet production. A recent survey by Peacock's group ranked the emergence/stand establishment problem as number three behind drought and diseases. It is rather obvious that a major cause of emergence/stand establishment problems in the LDCs is the poor physical condition and uncertain moisture of the seedbed. Improvements in seedbed preparation, however, are difficult if not impossible given the limited resources of most sorghum farmers. When the only tools are the dibble stick, short handle hoe and bullock plow, there are severe limitations to what can be accomplished. Given the limitations on seedbed preparation, supplemental irrigation and similar cultural practices, the most logical alternative is to search for and use sorghum and millet genotypes that can germinate and emerge under a wide range of field conditions, or at least perform acceptably under moderate to severe stresses of the types most frequently encountered. Results of our studies clearly indicate that there is considerable variability among sorghum lines for germination/emergence under both temperature and moisture stresses. If these capabilities are heritable, their incorporation in new lines should enhance emergence and stand establishment. Conversely, advanced lines and released varieties ought to be screened for resistance to these seedbed adversities to eliminate those below average in performance, especially as compared to traditional varieties.

It has also been demonstrated that there are substantial variations among sorghum lines in their ability to withstand weathering and storage deterioration of the seed.

LDC Collaboration

Scientists in this project have cooperated with CIAT and ICRISAT, and have conducted a survey of seed usage with the National Seed Service of Upper Volta.

Training and Technical Assistance

Seventeen graduate students (14 from LDCs) have been involved in sorghum/millet research since 1979. These students represent the Philippines, Brazil, Sudan, Nigeria, Thailand, Kenya, Iraq, Iran, Togo, Niger, Malawi, Panama, and the U.S.

Dr. R.P. Jain, an ICRISAT millet breeder, spent a 6-month study leave in the U.S. in conjunction with this project.

Implications for Future Research

This project was terminated June 30, 1984 on recommendation of the TC and by action of the Board. The TC believed that the project had failed to establish collaboration with entities in the LDCs. Twenty-nine technical assistance consultations were made by project investigators to nine African, three Latin American and two Asian countries in which sorghum/millet are major crops. None of these consultations was funded by this project. Nevertheless, the observations made and information gained negated the need for additional overseas travel specifically related to INTSORMIL project objectives until field testing was appropriate. Because the research needed was not site specific, it could be done most effectively and efficiently at Mississippi State University.

Selected Publications

Reusche, G.A. and J.C. Delouche. 1983. Germination and emergence of sorghum bicolor genotypes under varing levels of soil water potential. *Agron. Abst.*, p. 120.

In many parts of the world, sorghum and millet production is limited by severe drought.

PLANT BREEDING

Because sorghum is indigenous to arid and semi-arid regions of the world and is one of the most drought-resistant cereal crops, it is of high priority for research under this CRSP. In the areas of the world where sorghum and millet are daily food staples, agricultural climates are often very harsh, and human nutrition levels marginal. Plant breeding programs must develop sorghum/millet varieties that produce high yields in these adverse environments.

A broad program of interdisciplinary research is being conducted to develop a larger, improved pool of sorghum/millet germplasm which will have the following characteristics: produces high yields of good quality grain; has resistance to insects and diseases; tolerates environmental stress; and provides good nutritive quality. When such seed is developed, it must then be made available to breeding programs in other countries so that varieties best suited to specific areas can be developed.

Major diseases of sorghum and millet are downy mildew, panicle fungi, smuts, leaf diseases, root and stalk rots, and ergot. Damaging insects include midge, shoot fly, various stem borers and others. It is important to breed genotypes resistant to these pests. It also is important to maximize the nutritive value of sorghum/millet by increasing total protein and essential amino acids and reducing polyphenols.

Major sorghum/millet breeding activities are conducted at participating INTSORMIL institutions. At most of these, breeding activities have been in progress for many years. Much of the improved sorghum germplasm being used by international centers and developing country researchers originated in the nurseries of INTSORMIL institutions. Moreover, fundamental work in breeding techniques, such as hybrid production, population improvement, and tropical germplasm conversion, is basic to the worldwide crop improvement network.

EXECUTIVE SUMMARY

Yields of sorghum and millet throughout the world are limited by various production risks. Breeding has been considered to be the best avenue for attacking these production risks. The general objective of the breeding discipline, therefore, is to create germplasm pools, lines and hybrids with high yields; good grain quality; resistance to significant diseases, pests and stress factors; and good nutritional quality. Major sorghum/millet breeding activities are conducted at participating INTSORMIL institutions and in collaborating countries.

Sorghums with multiple disease resistance and wide adaptation have been developed. These improved materials have been distributed worldwide and many are in use in national programs, specifically: Honduras—downy mildew, acremonium wilt, grain mold; Sudan—charcoal rot; Niger—general disease resistance; Mexico—charcoal rot, fusarium head blight, leaf blight. Sorghums resistant to midge also have been developed. The use of resistant hybrids allows farmers a greater latitude in selecting planting dates, thereby reducing risks and increasing yield. The use of greenbug-resistant varieties is in many instances the only control measure needed to alleviate damage. In Mali, headbugs cause poor grain quality in tight panicles but little damage in loose panicles. Damage from headbugs can be reduced by breeding for panicle type and grain characters.

Soil acidity and low fertility limit sorghum/millet production, and are objects of breeding research. There is much diversity for Al tolerance among sorghums. A field screening method has identified new Al-tolerant germplasm which is being tested in the research programs of numerous countries. Brazil and Colombia are anticipating Al-tolerant varietal releases. Research also has identified sorghums which utilize nutrients more efficiently. When we understand the mechanisms involved and their genetic control, we will be able to breed plants for specific soil conditions. This will allow farmers in LDCs to improve production without expensive fertilizers.

A worldwide effort is underway to develop drought-resistant varieties. Tests have shown that under moisture stress hybrids have higher photosynthesis and lower leaf resistance rates and produce more dry matter than parents. Root systems and field rooting patterns, especially deep rooting, epicuticular wax load, and tolerance of leaf tissue to heat and desiccation, are related to drought tolerance. The identification of two distinctly different responses to drought stress in sorghum (a pre-flowering and a post-flowering response) has led to increased efforts in breeding for drought tolerance. As predicted, drought-tolerant materials developed in Texas perform well in El Obeid (pre-flower) and at Gadambalia and Wad Medani (post-flower) in Sudan. The strong correlation between cellular level osmotic tolerance and pre-flower drought tolerance suggests that a PEG screening technology can be useful in rapidly evaluating sorghum germplasm.

The identification of different cytoplasms which induce male sterility permits nuclear and cytoplasmic diversification. Most significantly for some LDCs, this may allow development of female parents from their own adapted lines, since some lines will not sterilize in A_1 cytoplasm.

In plant breeding, the development and use of germplasm pools from which to extract superior inbreds or varieties is essential. Mass selection for simply inherited traits works well in sorghum. The success of recurrent selection, particularly S_1 family selection, implies usefulness in practical breeding situations in other countries. Selection for disease or insect resistance, or improvement of protein quantity/quality and yield, probably should use more sophisticated recurrent selection schemes.

We have found that there are sorghums specifically adapted to tropical or temperate climates. This has led to a clearer understanding of growth and development, as well as the deployment of adapted germplasm into foreign programs. The nonsenescence characteristic which affects deep rooting, drought tolerance, maintenance of green leaf area, and resistance to translocation of carbohydrates from the plant to the grain, is likely associated with higher levels of cytokinins in the xylem fluid. The fact that maturity genes not only affect photoperiod response but also change thermoperiod behavior indicates that the genes regulate hormone(s). Studying these relationships may help us understand environmental adaptation and development regulation. We are close to being able to custom-make the genetic background best adapted to a particular photoperiod-temperature pattern at a particular location.

Hybrids from INTSORMIL are being grown in Mexico, Honduras, Guatemala, Sudan, Mali, Niger, Nigeria, Tanzania, Ethiopia, Kenya, Zambia, Zimbabwe, Botswana, Egypt, Brazil, Paraguay, Uraguay, Colombia, Bolivia, Venezuela, Argentina, El Salvador, India, Philippines, People's Republic of China, Thailand and the U.S.

During the first 5 years of this CRSP, the breeding discipline has combined basic science, proven principles, and the work of multi-disciplinary teams to develop and deploy improved materials to enhance sorghum/millet production throughout the world.

Breeding for Productivity in Sorghum

F.R. Miller, W.R. Jordan, P.M. Morgan, R.A. Creelman and R.J. Newton

Texas A&M University

Plant breeding is a system of manipulating gene frequencies in such a fashion as to achieve a desirable goal. In this project, the goal of breeding is primarily to improve the stability of sorghum yields, because for subsistence farmers in LDCs stability of yield is more important than potential yield.

Breeding for productivity and stability has been successful in the past several years. It has developed sorghums that not only provide stable, high yields, but that also exhibit resistance to insects, diseases and environmental stress. In addition we have learned much about the effects of photoperiod on productivity, the relationship between yield and photosynthesis and the physiological measures of drought resistance.

Specific project goals include:

- to develop stable, high yielding, agronomically desirable sorghums;
- to determine the effects of photoperiod and temperature on growth and productivity;
- to determine the relationship between yield and photosynthetic activity;
- to determine physiological measures of drought tolerance;
- to distribute improved hybrids with superior productivity to LDCs; and
- to develop germplasm pools specifically for use in Mexico, Tanzania, Honduras and South America.

Research Accomplishments

Improved Varieties

It is known that high yielding inbreds generally produce high yielding hybrids. Therefore, germplasm sources with high yield qualities can be crossed to other germplasm sources with pest-resistance traits. The result is a group of elite varieties which can be further improved by crossing with lines that have desirable agronomic traits such as drought tolerance or early maturity. This process has been greatly aided by the USDA-TAES Sorghum Conversion Program, which identifies and makes available superior germplasm from all over the world.

Elite lines developed in this project are screened at several nurseries in Texas, as well as in Mississippi, Georgia, Puerto Rico, Mexico, Venezuela, Brazil, Argentina and Honduras.

As a result of this complex comprehensive breeding program, valuable knowledge has been gained. It has been determined that the numbers of caryopses/panicles are affected by environmental stress, while their size is not (except under very severe conditions). Cultivars with high numbers of caryopses per panicle (in both B and R line backgrounds) have been placed in the breeding programs of numerous LDCs.

A rolling-selection program, now in the third cycle of improvement, has produced sorghum with improved food quality and yield and high levels of disease resistance.

We have determined the base germination temperature for varieties within germplasm pools. This enables us to send the best suited varieties to specific regions.

A NaOH procedure is used to screen for food color in the white sorghum breeding program in Texas and Honduras. While stickiness and particle size are important factors in food quality, color of the food product is important to acceptance.

The cyanoglycoside dhurrin content in leaves and roots appears to contribute to mite resistance in sorghum.

Photoperiod/Temperature

We have fully characterized the growth and development of the twelve sorghum maturity genotypes. Results show that maturity genes not only influence photoperiod behavior, but also affect thermoperiod behavior, morphology, tillering and monocarpic senescence. This strongly suggests that the genes regulate a hormone. We have developed a hypothesis to test for two of the loci, Ma_1 and Ma_3. The gene Ma_3 affects sorghum sensitivity to photoperiod, and causes morphological development similar to a Gibberellin-surplus mutant.

In testing for photoperiod sensitivity, plants are grown under 8, 10, 12 and 14 hours of light. Plant height, culm

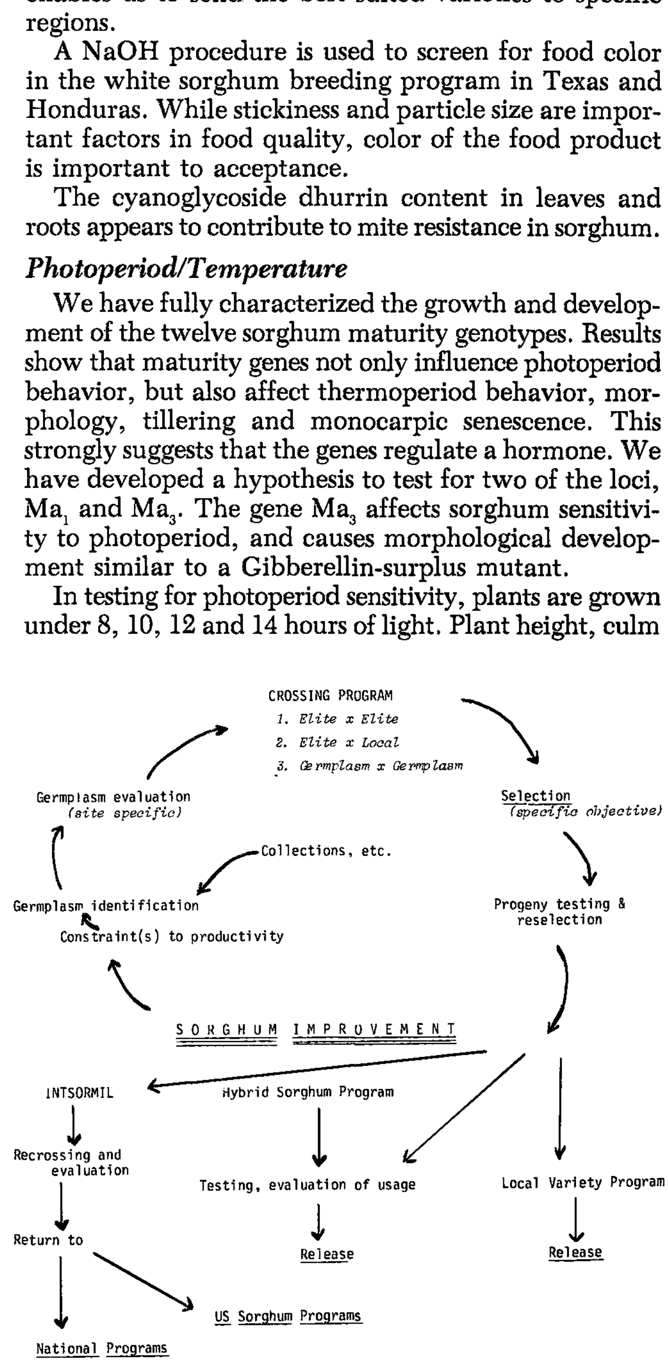


Figure 1. Scheme for Handling a Sorghum Improvement Program at the International Level

Table 1. Yield in Pounds of Grain per Acre Harvested at Tropical and Temperate Locations Illustrating the Behavior of Tropically Adapted and Temperately Adapted Hybrids.

Location	Climatic niche	RS671	RS610	ATx623 x Tx430	ATx623 x 74CS5388	TA TE X̄
Guatemala, C.A.	Tropical	4406	----	5466	8327	+57%
Rio Bravo, Mexico	"	4400	4318	5000	----	+15%
Weslaco, Texas	"	4122	4088	5090	5853	+33%
College Station, Texas	"	4840	4333	5709	5506	+22%
Lubbock, Texas	Temperate	4363	3740	4420	4363	+ 8%
Halfway, Texas	"	5440	5156	----	4647	-12%
Kress, Texas	"	6063	5100	5326	5950	+ 1%

Table 2. Summary of Base Temperatures of Tropically Adapted and Temperately Adapted Materials.

Designation	Parentages	Adaptability	Base Temperature
RS671	Hybrid	Temperate (v)	14.00 e
RTx2536	Male	Temperate	13.40
Top Hand	Hybrid	Temperate	12.00 e
NB505	Hybrid	Temperate	11.00
RS610	Hybrid	Temperate (sl)	9.96
RTx430	Male	Tropical	9.00
BTx623	Female	Tropical	9.00
W-832R	Hybrid	Tropical	7.50
W-839DR	Hybrid	Tropical	7.50
WAC 715DR	Hybrid	Tropical	7.50
ATx623 x RTx430	Hybrid	Tropical (v)	7.50

height, leaf area, dry weight, fresh weight, and days to floral initiation are measured.

The benefits of this research will be in developing genotypes particularly suited to tropical environments. Germplasm that is productive in short day-length, hot night temperature environments was crossed to an array of elite germplasm. Lines were then selected which seemed to have tropical adaptation. Necessarily, a good deal of this research was done in tropical areas such as Puerto Rico, Mexico, Honduras, Argentina, Venezuela, India and Africa.

In other physiological research, we have characterized the soluble carbohydrates in developing sorghum caryopses. The dry weight of the caryopses reaches a maximum on day 33. We conclude that this is the day of physiological maturity.

Seed Studies

Elite sorghums were studied for leaf temperature and CO_2 consumption during grain fill, 2.5 weeks later and at black layer. The flag and next three leaves were studied. Grain yield and total biomass were related to temperature and CO_2 consumption.

The genetic variation for numbers of seeds per head was used in normal single seed populations. These characteristics were transformed into improved grain sorghum male and female parents. The concept of using females with the greatest number of seeds per head and males with the largest seeds was used in order to maximize the negative correlation between seed number and seed size ($r = -.92$). Once maximum numbers of seed per head are fixed by backcrossing, selection studies will begin to select for largest seed size within the group having high numbers per head.

This has necessitated companion studies on photosynthetic efficiency. It appears that, with the advent of twin seed gene research, photosynthetic work can begin.

Drought Tolerance

Much has been learned in breeding sorghums for drought tolerance. Laboratory and field studies have helped identify varieties with this trait.

Hybrid plants function at cooler leaf temperatures than parents, and leaf temperature drops back at black layer. CO_2 uptake is higher for hybrids than for parents.

Significant variation in average epicuticular wax loads (EW) occurs among genotypes. EW loads increase under hot, dry conditions but are not closely related to rainfall. Heritability of EW is estimated at 36 percent. High EW loads contribute to drought resistance by reflecting radiation and reducing cuticular transpiration.

Roots of tropically adapted genotypes differ from those of temperately adapted varieties. Deep rooting varieties can extract water stored deep in the soil profile more efficiently. And varieties capable of forming deep, dense roots can be identified in the field.

We have strong evidence that nonsenescent sorghums have more cytokinins in the xylem fluid moving from the roots to the leaves, and that these lines have about double the number of root tips that senescent sorghums have.

Distribution to LDCs

Once superior materials are identified, both lines and hybrids are distributed to scientists in collaborating countries so that they can be used in international field trials. More than 550 sets of inbred lines, 500 F_2 populations and related breeding lines have been distributed to LDCs. More than 150 yield trials have been conducted.

Advanced testing is underway in the Dominican Republic and Honduras. In Mexico, two hybrids have been identified and named as BJ83 and 85. One hybrid (Hageen Durra-l) has been named in the Sudan using ATx623 as female, and similar testing is underway in Mali and Ethiopia.

Significance of Research Findings

Genetic improvement of the sorghum germplasm base has increased the quality of sorghum produced. The development of many new sorghums with good yield traits and tolerances to drought and high temperatures is significant. Disease resistance and tolerance for other environmental stress conditions such as short day length, high night temperatures and cold temperatures at germination and early growth are being added to superior germplasm. The genetic vulnerability of sorghum is being reduced by expanding the germplasm pool used to develop males for hybrids, and by developing new sources of cytoplasmic-genetic male sterility in females for hybrids.

As mechanisms of growth and development are elucidated, we understand the reasons why sorghums of specific types behave uniquely. For example, the influence of IAA, cytokinins, ABA and ethylene relate to differences in behavior such as photoperiod requirement, thermoperiod requirement, nonsenescence, or male sterility. When these mechanisms are completely understood we may be able to predict adaptability of crosses and do a more rapid job of breeding for specific locations on an international scale.

Future studies may open ways to manage the nonsenescent genotypes so as to use their desirable characteristics and minimize their undersirable characteristics. Since the nonsenescence character is particularly adapted to tropical environments, it is useful in many LDCs. More work will be needed to achieve this goal, but the chances of success appear favorable.

Physiological research has centered on evaluations of (a) root systems and field rooting patterns, (b)

Dr. San San Da, Upper Volta, compares higher yielding white food grain sorghums for Tô quality in relation to plant color and possible staining of the grain caused by insect damage to the developing kernel.

Table 3. Breeding Stocks Used in Collaborative Research Programs for Crossing and Selection.

Cultivar	Country	Nature of use
77CS1	Mexico, Guatemala, El Salvador, Tanzania	Increased number of seed and leaf disease resistance
77CS2	Mexico, Guatamala	Food quality, disease resistance
ADN55	Mexico, Haiti	Food quality, leaf disease resistance
TP24	Tanzania, Guatemala, Honduras, El Salvador, Upper Volta, Niger, Ethiopia	Food quality, leaf disease resistance, yield
Miscellaneous germplasm	Mexico, Guatemala, Honduras, El Salvador, Haiti, Dominican Republic, Costa Rica, Mali, Tanzania, Niger, Sudan, Upper Volta, PRC, Brazil, Venezuela, Argentina, Uraguay, Paraguay	Yield, disease resistance, leaf quality, high numbers of seed/panicle, adaptation food quality genetics stocks

Table 4. Desirability Ratings from Three Locations in Mexico from Selected Hybrids in a Uniform Yield Trial.

		Desirability ratings		
Hybrid designation	Adaptation type	Celeya	LaBarca	Zacatepec
RS610	Temperate	2.8[1]	3.0	3.0
ATx378 x RTx7000	Temperate	2.0	2.0	2.6
ATx623 x ADN#55 (SC0120-6 x Tx7000)	Tropical	1.3	1.3	1.5
ATx623 x GPR148 (Indian)	Tropical	1.2	1.5	1.3
ATx623 x 77CS256 (TS)	Tropical	1.3	1.2	1.2
ATx623 x 76CS490	Tropical	1.1	1.1	1.1
ATx623 x RTx430	Tropical	1.4	1.8	1.4
ATx623 x 77CS1	Tropical	1.3	1.4	1.2
ATx623 x CS3541 (Indian)	Tropical	1.2	1.3	1.2
ATx378 x RTx430	Tropical	1.4	1.4	1.5

[1]1 = outstanding, 2.5 = average, 5 = very poor in local environment

epicuticular wax load on leaves, and (c) tolerance of leaf tissue to heat and desiccation stresses. Lines showing deep rooting capabilities were incorporated into the breeding program and advanced materials have been tested and released in Central America, where they perform well under dryland conditions. Information on rooting patterns, soils and climate has been combined in a crop simulation model for sorghum (SORGF) which defines the production conditions in which deep rooting could contribute to yield or yield stability. This work has shown how fundamental research information can be made practical to LDCs by matching their growing conditions to the genetic characteristics of the cultivars available. Lines released from the Sorghum Conversion Program were screened and high wax lines were identified. Some have been used in the breeding program. RTx430, currently used widely in breeding programs, has high wax which may contribute to the excellent performance of RTx430 hybrids under dryland production. Productivity in LDCs will be improved with greater availability of germplasm and hybrids adapted to semiarid regions. Heat and desiccation tolerance are traits researchers are now trying to incorporate into elite lines. It is too early to determine the impact this may have in LCDs.

Researchers in this project do not work in a vacuum, but interact with other project leaders and cooperating LDC scientists. The acquisition of new, higher yielding materials by national programs has allowed new germplasm pools to be created. These new pools have all of INTSORMIL's technical competence behind them. The fact that several national programs have released or named hybrids using materials from this project testifies to the worth of the materials provided. When national program scientists use elite F_2 populations or elite lines to create new populations with local materials, those programs become more productive. The assistance provided by INTSORMIL staff is creating an international network of sorghum researchers who know they have good germplasm and technical backup at their disposal.

Table 5. Improved Sorghums Used in Collaborative Research Programs Developed by INTSORMIL.

Cultivar	Country	Nature of use
ATx623	Mexico	Hybrid
RTx430	Mexico	Hybrid
RTx434	Mexico	Hybrid
RTx432	Mexico	Hybrid
77CS1	Guatemala	Hybrid
ATx623	Guatemala	Hybrid
RTx430	Guatemala	Hybrid
ATx623	Honduras	Hybrid
ATx623	Sudan	Hybrid

LDC Collaboration

Dr. Miller is Country Coordinator for Tanzania, where the program includes a massive program of germplasm transfer and hybrid evaluation. Emphasis is on food quality, yield, disease resistance, local adaptation, and development of photoperiod sensitive and insensitive cultivars.

In the Sudan, technical assistance is being given in the area of hybrid seed production.

The program in Honduras is providing high yield, good food quality sorghum which is adpated to the tropics.

Other countries in which germplasm exchanges and evaluations are ongoing include Mali, Upper Volta, Ethiopia, Kenya, Zambia, Costa Rica, Dominican Republic, Guatamala, Jamaica, Haiti, Niger, Mexico, Argentina, Venezuela, Paraguay, Philippines, China, Egypt and Brazil. There is also collaboration with ICRISAT and CIAT.

Training and Technical Assistance

Ten students from six countries have completed doctoral research, and nine students from seven countries have completed Masters Degree research through this project. There are nineteen students currently involved.

Dr. Miller is Country Coordinator for Mexico, Tanzania and Kenya. Members of this project have traveled to the following countries to give technical assistance to sorghum programs: Mexico, Tanzania, Sudan, Ethiopia, India, Honduras, Guatemala, Paraguay, Argentina, Egypt, Brazil and People's Republic of China.

Project members have participated in the Sorghum in the '80's workshop in India, the Hybrid Sorghum Seed Workshop in Sudan, the International Symposium on Sorghum Grain Quality, the Latin American Sorghum Quality Short Course in Mexico, the Sorghum Breeding Workshop for Latin America, the International Sorghum Entomology Workshop, the Sorghum Downy Mildew Workshop, the INTSORMIL Graduate Student Workshop, and several others.

Scientists from INTSORMIL cooperating countries discuss research procedures which may improve production in LDCs.

Implications for Future Research

We will continue our successful program of developing and transferring more productive sorghum germplasm. Emphasis will continue to be on those varieties which adapt well to harsh environments and produce good food quality grain. More will be done on partitioning of photosynthate to ensure good grain fill.

Selected Publications

Ambler, J.R., P.W. Morgan and W.R. Jordan. 1983. Ctyokinin concentrations in xylem sap of senescent and nonsenescent sorghums. *Plant Physiol.* (supplement) 72:168.

Arkin, G.F., W.D. Rosenthal and W.R. Jordan. 1983. A sorghum leaf area model. Paper number 83-2098, American Society of Agricultural Engineers. 25 pp.

Duncan, R.R., A.J. Bockholt and F.R. Miller. 1982. Descriptive comparison of senescent and nonsenescent sorghum genotypes. *Agron. J.* 73:849-853.

Dunlap, J.R., A.H. Hanks and P.W. Morgan. 1981. Preflowering levels of phytohormones in sorghum. I. Analytical Procedure. *Crop Sci.* 21:82-88.

Dunlap, J.R. and P.W. Morgan. 1981. Preflowering levels of phytohormones in sorghum. II. Quantitation of internal levels. *Crop Sci.* 21:818-822.

Dunlap, J.R. and P.W. Morgan. 1981. Preflowering levels of phytohormones in sorghum. III. Photocontrol. *Crop Sci.* 21:823-827.

Earp, C.F., L.W. Rooney and F.R. Miller. 1982. Stalk structure of high energy sorghums. *Amer. Assoc. of Cereal Chem. Abst.*

Gerick, T.J. and F.R. Miller. Photoperiod and temperature effects on tropically and temperately adapted sorghum. *Field Crops Res. J.*

Isbell, V.R. and P.W. Morgan. 1982. Manipulation of apical dominance in sorghum with growth regulators. *Crop. Sci.* 22:30-35.

Jordan, W.F., Marion McCrary and F.R. Miller. 1979. Compensatory growth in the crown root system of sorghum. *Agron. J.* 71:803-806.

Jordan, W.F., F.R. Miller and D.E. Morris. 1979. Genetic variation in root and shoot growth of grain sorghum in hydroponics. *Crop Sci.* 19:468-472.

Jordan, W.R. and F.R. Miller. 1980. Genetic variability in sorghum root systems: Implications for drought tolerance. P.J. Kramer and N.C. Turner (eds.) *Adaptations of Plants to Water in High Temperature Stresses.* John Wiley & Sons, Inc., New York. pp. 383-399.

Jordan, W.R. and R.L. Monk. 1980. Seasonal and genetic variations in rooting patterns of sorghum. *Agron. Abst.* p. 85.

Jordan, W.R., R.L. Monk and F.R. Miller. 1981. Genetic and environmental modification of the epicuticular wax load of sorghum leaves. Proceedings, 12th Biennial Grain Sorghum Research and Utilization Conference, Lubbock, Texas. p. 40.

Jordan, W.R., R.L. Monk and F.R. Miller. 1981. Sorghum root systems—characterization and relation to soil water stress. *Agron. Abst.* p. 43.

Jordan, W.R. and C.Y. Sullivan. 1982. Reaction and resistance of grain sorghum to heat and drought. pp. 131-142. *In: Sorghum in the Eighties.* Proceedings, International Symposium on Sorghum, Patancheru, A.P. India (ICRISAT).

Jordan, W.R. and C.Y. Sullivan. 1983. Physiological systems associated with drought resistance. p. 367-382. Sorghum Breeding Workshop on Methods and Approaches, CIMMYT, Mexico. 520 pp.

Jordan, W.R., W.A. Dugas, Jr. and P.J. Shouse. 1983. Strategies for crop improvement for drought-prone regions. *Agric. Water Mgmt.* 7:281-299.

Jordan, W.F., R.L. Monk, F.R. Miller, D.T. Rosenow, L.E. Clark and P.J. Shouse. 1983. Environmental physiology of sorghum. I. Environmental and genetic control of epicuticular wax load. *Crop Sci.* 23:552-558.

Jordan, W.R., R.B. Clark and N. Seetharama. 1984. Edaphic factors in disease development. *In: Sorghum Root and Stalk Rots: A Critical Review.* Proceedings, consultive group discussion on research needs and strategies for the control of sorghum root and stalk rot diseases. Bellagio, Italy.

Keim, K.R., F.R. Miller and D.T. Rosenow. Survival of Genes in *Sorghum bicolor* (L.) Moench in Diverse Environments. *Crop Sci.*

Maness, Niels, G.G. McBee and F.R. Miller. 1982. Placental sac influence on grain sorghum caryopsis development: Anatomical view. *Agron. Abst.*

Mann, J.A., E.E. Gbur and F.R. Miller. A Screening Index for Adaptation of Sorghum Cultivars. *Crop Sci.*

Mann, J.A., F.R. Miller and C. Kimber. The Origin and Early Cultivation of Sorghums in Africa. Texas Agricultural Experiment Station, Bulletin, College Station, Texas.

McBee, G.G. and F.R. Miller. 1982. Carbohydrates in sorghum culms as influenced by cultivars, spacing, and maturity over a diurnal period. *Crop Sci.* 22:381-385.

McBee, G.G., R.W. Waskom, III, F.R. Miller and R.A. Creelman. 1983. Effect of Senescence and Nonsenescence on Carbohydrates in Sorghum During Late Kernel Maturity Stages. *Crop Sci.* 23:372-376.

McKenzie, D.B., L.R. Hossner and R.J. Newton. 1984. Sorghum cultivar evaluation for iron chlorosis resistance by visual scores. *J. Plant Nutrition.* 7(1-5):677-685.

Miller, F.R. and D.T. Rosenow. Registration of RTx433 Sorghum. *Crop Sci.*

Miller, F.R. and D.T. Rosenow. Registration of RTx434 Sorghum. Crop Sci.

Miller, F.R. Registration of RTx430 Sorghum. *Crop Sci.*

Miller, F.R. 1982. The genetics of pericarp color in *Sorghum bicolor* (L.) Moench. Proceedings, Sorghum Quality Workshop. Mexico City, Mexico. ICRISAT/INTSORMIL.

Miller, F.R. and R.W. Toler. 1983. Registration of Tx2786, a MDMV Resistant Sorghum. *Crop Sci.*

Miller, F.R. 1983. Release of RTx432. Texas Agricultural Experiment Station, College Station, Texas.

Miller, F.R. 1983. Registration of RTx432 Sorghum. *Crop Sci.*

Morgan, P.W. 1979. Agricultural uses of phytohormones and synthetic plant growth regulators. (In Spanish). Proceedings, Segunda Reunion Regulators de Desarrollo Plantas E Insectos. In symposium volume by Consejo Nacional de Ciencia y Technologica of Mexico (CONACYT). Conference at Instituto Technologica y de Estudios Superiores de Monterrey, Monterrey, Mexico. May 1980. Translated by Manuel Rojas-Garciduenas.

Morgan, P.W. and C-I Pao. 1983. Physiological characteristics of adaptation to photoperiod and temperature in sorghum. pp. 157-172. Proceedings, Plant Breeding Methods and Approaches Workshop for Latin America. Sponsored by INTSORMIL-INIA-ICRISAT at CIMMYT, Mexico City. April 1983.

Morgan, P.W. 1980. Synthetic growth regulators: potential for development. *Botanical Gazette.* 141:337-346.

Morgan, P.W. and J.I. Durham. 1983. Strategies for extracting, purifying, and assaying auxins from plant tissues. *Bontanical Gazette.* 144:20-31.

Morgan, P.W. Ethylene as a plant hormone. (In Spanish). Proceedings, Segunda Reunion Regulatores de Desarrollo Plantas E Insectos. In symposium volume by Consejo Nacional de Ciencia y Technologica of Mexico (CONACYT). Conference at Instituto Technologica y de Estudios Superiores de Monterrey, Monterrey, Mexico, May 1980. Translated by Manuel Rojas-Garciduenas. (in press).

Morgan, P.W. Considerations for Developing a Strategy for Extracting, Purifying and Assaying Auxins from Plant Tissues (In Spanish). *In:* M. Robert (ed.), Research Methods for Plant Growth Regulators, National Council of Science and Technology, Mexico City, Mexico (in press).

Newton, R.J., D.A. Baltuskonis, J.D. Goeschl, D.H. Meckenstock and F.R. Miller. 1980. Distribution and transformation of solution carbohydrates during germination and growth of sorghum *Crop Sci.* 20:265-268.

Newton, R.J., D.H. Meckenstock and F.R. Miller. 1983. Soluble carbohydrates in developing sorghum caryopses. *Crop Sci.* 23:80-82.

Rooney, L.W. and F.R. Miller. 1982. Variacion en la estructura y characteristicas del grano de sorgo. Proceedings, Sorghum Quality Workshop. Mexico City, Mexico. ICRISAT/INTSORMIL.

Rosenthal, W.D., P.J. Shouse, G.F. Arkin and W.R. Jordan. 1983. Water deficit effects on sorghum and cotton leaf expansion and transpiration. *Agron. Abst.* p. 97.

Shouse, P.J., W.R. Jordan and A. Blum. 1983. Sorghum epicuticular wax load and its effect on cuticular transpiration. *Agron. Abst.* p. 98.

Starr, J., R.J. Newton and F.R. Miller. 1984. Presence of dhurrin in sorghum root tissue and the effect of pathogenesis on hydrogen cyanide potential. *Crop Sci.* 24:739-742.

Toler, R.W. and F.R. Miller. 1983. Effect of Various Combinations of Inoculation Pressure and Concentration on Varietal Disease Response of Sorghum Following Spray Gun Inoculation with Maize Dwarf Mosaic Virus. *Crop Sci.* 23:83-85.

Wright, S.A., W.R. Jordan, P.W. Morgan and F.R. Miller. 1983. Genetic and hormonal control of shoot growth and root growth of sorghum. *Agron. J.* 75:682-686.

Breeding for Disease and Drought Resistance and Increased Genetic Diversity

D.T. Rosenow, L.E. Clark, K.F. Schertz, Roberta H. Smith and C.W. Wendt

Texas A&M University

Disease and drought are two serious constraints to sorghum production. Breeding for disease resistance has been very successful; resistant genotypes have been developed for nearly all diseases of economic importance. However, it is a continual process as we strive to find new and better sources of resistance, to improve the level of resistance, and to deal with changes in disease pathogens. Breeding for drought resistance is a more recent endeavor. Drought-resistant genotypes are being developed which will increase yield in current production areas and allow production to be expanded into more marginal areas.

The success of any breeding program depends on the collection, cataloging and evaluation of the natural genetic diversity of the species.

Research Accomplishments

Converted and partially converted lines from the Sorghum Conversion Program, as well as exotic lines and breeding materials, are screened and evaluated for disease resistance and drought tolerance in nurseries in South and West Texas.

Disease Resistance

Advanced generation materials derived from the initial breeding process are used in replicated trials in the U.S. and other countries. We have had significant successes in finding new sources of high level resistance to downy mildew (pathotypes and 1 and 3), head smut, anthracnose, grain mold (weathering) and charcoal rot. Excellent sources of resistance also have been found for maize dwarf mosaic, rust, grey leaf spot, zonate, fusarium head blight and acremonium wilt. Numerous original source lines and improved disease-resistant breeding lines have been distributed to LDCs.

Cooperatively with other INTSORMIL projects, we have developed two white-seeded, tan-plant food type populations which are ready for distribution. GPT-2, an anthracnose-resistant line, was developed and released cooperatively with Georgia and Puerto Rico. We have also helped establish international disease, insect and adaptation trials and nurseries, which distribute improved germplasm throughout the world.

A selection from the grain weathering test has been chosen for release in Honduras in 1985. Its grain has excellent tortilla quality.

Drought Tolerance

Drought-tolerant genotypes are crossed with elite, high yielding lines. Progeny are then selected under field conditions, and later evaluated under rainout shelters and the sprinkler irrigation gradient system.

Drought tolerance has been defined as either pre-flowering or post-flowering. The best known sources of pre- and post-flowering tolerance have been crossed with each other and with elite, high yielding lines to develop lines with both pre- and post-flowering tolerance and to combine this trait with other desirable traits. Some lines thus developed are very promising (Table 1).

Post-flowering drought-tolerant lines developed in Texas have performed very well in Sudan, especially the line SC35 (Table 2). Several of our pre-flowering drought-tolerant lines did well in the sandy, dry area near El Obeid (Table 2). It appears that sorghums adapted to Texas also do well in various parts of Sudan.

Trials in Honduras and Niger also are finding Texas-developed lines which do well in those countries.

Callus from sorghum lines with known drought tolerance in the field have been screened in vitro for tolerance to osmotic stress. Results suggest that PEG-induced osmotic stress on callus cultures can be used to screen for potential pre-flowering drought tolerance, but not for post-flowering tolerance. The implication is that pre-flowering tolerance is at least partly cellular.

Further callus culture procedures are being used to test for aluminum and salt tolerances.

Genetic Diversity

Native sorghum genotypes from other countries are continually being evaluated in Texas and crossed with appropriate U.S. elite lines. Twenty-four cytoplasms have been isolated from introduced lines. Three have been identified as definitely different and two as possibly different from milo, the standard male sterility-inducing cytoplasm (Table 3). Four lines (A and B pairs) with A_2 and one with A_3 have been released. Mitochondrial DNA was distinctive in those cytoplasms that cause different sterility reactions. One line of wild sorghum from Australia exhibited cytological characteristics of apomixis. Fifty-two lines have been collected from other countries—24 from Australia and 28 from India (Table 4).

Significance of Research Findings

Sorghums with multiple disease resistance and drought tolerance have been developed and distributed to many LDCs. Countries, and their specific stress tolerance needs, are as follows: Honduras—downy mildew, acremonium wilt, grain mold; Sudan—drought, charcoal rot; Niger—general diseases; Mexico—charcoal rot, lodging, grain mold, fusarium head blight, rust, leaf blight, downy mildew, head smut, drought; India—charcoal rot, grain mold, downy mildew, leaf diseases, drought.

Table 1. Comparison of Breeding and Parental Sorghum Lines for Lodging, Charcoal Rot, Stay-Green, and Grain Yield, Lubbock, Texas, USA, 1983.

Designation	Lodging[1] (%)	Charcoal rating[2]	LPD rating[3]	Stem base rating[4]	Peduncle rating[4]	Grain yield (kg/ha)
(BTx625 x B35-6)-HL19	0	0.70	2.9	1.2	1.8	3030
(BTx625 x B35-6)-LDEE73	0	0.45	3.5	1.2	2.1	3215
(BTx625 x B35-6)-LEC	0	0.83	2.8	1.1	1.5	3080
B35-6	0	0.48	2.7	1.1	1.7	2010
BTx625	38	3.40	4.6	4.3	3.5	3500
BTx623	40	2.00	4.7	2.8	3.5	3140
Tx7000	13	3.40	4.6	4.1	3.9	3740

1 Moisture-stress-type lodging (November 7).
2 Charcoal rot rating of toothpick-inoculated plants: 0 = no infection, 1 = one internode infected, 5 = death, sclerotia, shredded.
3 Leaf-plant-death rating (emphasis on premature leaf death): 1 = no leaf death, internode infected, 5 = death, sclerotia, shredded.
3 Leaf-plant-death rating (emphasis on premature leaf death): 1 = no infection, 5 = all dead (November 7).
4 Base of stalk and peduncle "stay-green" rating: 1 = completely green and alive, 5 = all dead (November 21).

The finding of two different responses to drought stress in sorghum (the pre-flowering and post-flowering responses) has had great impact on screening techniques.

The female sorghum line ATx623, developed in Texas, produces the best hybrids of any female in Sudan. Several other Texas-developed lines are being widely used in the Sorghum Hybrid Seed Program now underway in Sudan.

In Mali, head bugs are a major factor in the poor grain quality of tight heads (non-Guinea-type sorghums). We are studying the plant, head and grain traits of the native Guinea-type sorghums, with the hope of incorporating them into elite lines.

The identification of different cytoplasms that induce male sterility permits nuclear and cytoplasmic diversification. This may allow some countries to produce female parents from their own adapted lines.

LDC Collaboration

Dr. Rosenow is Country Coordinator for Honduras, where there is an extensive sorghum breeding program underway. Emphasis is on disease resistance, high yield and local adaptation.

In Sudan, we are working on drought-tolerant sorghums for non-irrigated areas and high-yielding, adapted genotypes for irrigated areas.

Work in Mali centers on evaluating the native Guinea-type sorghums and their grain traits, and developing disease- and drought-tolerant varieties.

In Niger, Tanzania, Upper Volta, Zambia, Zimbabwe and Botswana there are ongoing germplasm exchanges and evaluations of lines best suited to those countries.

Germplasm evaluations for disease and drought resistance also are conducted in Mexico, Brazil, Venezuela, Argentina and Australia. We collaborate with ICRISAT, CIMMYT and CIAT.

Training and Technical Assistance

Six graduate and post graduate students from five countries received technical training through this project. Project members advised 22 graudate students during the course of their studies.

Project members have made individual or team visits to Sudan, Mexico, Honduras, Guatemala, Venezuela, Mali, Niger and Upper Volta to give technical assistance to national breeding programs.

We have participated in numerous international workshops, among them the Sorghum in the '80's workshop in India, Hybrid Sorghum Seed Workshop in Sudan, the International Symposium on Sorghum Grain Quality, and the Latin American Disease Short Course.

Implications for Future Research

Our basic reseach program will continue as at present. Greater emphasis will be placed on developing early generation germplasm for distribution in specific LDCs—drought-tolerant F_2s for Sudan and food-type, disease-resistant F_2s for Honduras. The germplasm exchange with Mali will expand with inclusion of Guinea-derivative materials in our breeding research. Reciprocal crosses of the ten PEG-screened varieties will be evaluated in culture at the callus level to see if a component of osmotic tolerance is related to the genetics of the cytoplasm.

Table 2. Agronomic and Drought Notes on INTSORMIL Drought-Tolerant Sorghums at El Obeid and Gadambalia, Sudan, 1981.

	El Obeid[1]					Gadambalia[1]	
	DTR Notes						
	Desirability rating[3]	Other	Days to 50% bloom	Plant height, cm.	Agronomic score, Gebisa E.	Desirability rating[3]	Leaf-plant death rating[4]
BTx623	—	3pl	—	—	—	2.0	4.5
Tx430	—	0pl	—	—	—	2.5	4.0
BTAM618	—	3pl	—	—	—	3.0	3.2
Early Hegari	2.0	early	79	110	4	3.0	3.0
B35	4.5	v lt.			5	4.0	2.0
Tx7078	2.0		79	70	3	2.0	3.5
Tx7000	1.5		71	85	3	2.8	3.5
R9188 (599-6)	3.0		71	85	5	3.5	3.0
BTx399	3.5		79	60	5	3.2	3.5
BTx3042	3.0		79	85	4	2.0	3.5
1790E	3.0		79	70	5	2.2	2.5
SC56-6	2.0		71	70	3	3.0	2.5
R5388	3.5		78	90	4	2.0	3.5
TnGbResW	1.0		69	90	2	2.2	4.0
Tx2737	2.0	LPD3.0	61	105	2	2.1	4.0
CV182	2.5	LPD3.5	71	105	3	2.8	3.5
SC414-12	2.0		64	90	3	2.5	4.5
GPR-148	4.0	lt.	77	65	4	3.5	3.5
RS610	2.0	LPD4.0	61	100	4	2.0	4.8
A35 x Tx7078	1.2	LPD2.0	69	95	2	2.3	4.5
NP9BR-121	1.8	LPD1.8	64	120	2	2.3	3.5
NP9BR-126	2.2	thin	64	105	3	4.0	4.5
NP9BR-142	—	lpl	—	—	—	4.0	4.8
NP9BR-146	—	lpl	—	—	—	4.0	4.5
NP9BR-226	2.5	thin	71	115	3	3.5	4.0
NP9BR-272	—	3pl	—	—	—	3.8	4.8
1028-75	2.5	thin	71	95	4	4.0	5.0
1044-39-2	2.0	thin	71	110	3	3.5	5.0
1044-64-1	2.5	thin	79	120	3	3.0	3.8
1044-75-1	2.5	thin	79	95	3	2.2	3.0

1 El Obeid planted July 17, 1981. Rain before emergence, then no rain until Aug. 17. Some early maturing and pre-flowering stress tolerant lines looked very good. There was some LPD on plants with good early growth and good head development. Notes taken on Nov. 17.

2 Gadambalia planted July 22 & 23, 1981. Generally good yield potential, but very dry during grain development. Premature leaf and plant death (LPD) was very severe. Notes taken on Nov. 19.

3 Desirability based on 1 to 5 scale, where 1 = very good and 5 = very poor.

4 Leaf and plant death rating (LPD) based on 1 to 5 scale, where 1 = green and 5 = dead.

Table 3. Male-sterility Inducing Cytoplasms.

Group	Source of cytoplasm	Group	Source of cytoplasm
A1	Milo	A2	IS12662C
	IS6271C	A2′	ISS3063C
	IS3579C		IS1056C
	IS7502C		IS2801C
	IS6705C	A3	IS1112C
			IS12565C
		A4	IS7920C

Table 4. Collections of Sorghum. (Schertz)

Species	No. of collections	Origin
S. almum	3	India
S. halepense	7	India
S. arundinaceum	2	India
S. virgatum	1	India
S. verticilliflorum	9	India
S. aethiopicum	4	India
S. versicolor	1	India
S. purpureosericeum	1	India
S. macrospernum	1	Australia
S. stipoideum	5	Australia
S. intrans	5	Australia
S. stipoideum	2	Australia
S. matarankense	3	Australia
S. brevicallosum	1	Australia
S. australiense	2	Australia
S. nitidum	1	Australia
S. plumosum	4	Australia

Selected Publications

Clark, L.E., C.T. Rosenow, E.E. Gbur and C.J. Girard. 1982. Screening sorghum for drought tolerance and yield response under a moisture gradient system. *Agron. Abst.* p. 62.

Conde, J.F., D.R. Pring, K.F. Schertz and W.M. Ross. 1982. Correlation of mitochondrial DNA restriction endonuclease patterns with sterility expression in six male-sterile sorghum cytoplasms. *Crop. Sci.* 22:536-539.

Duncan, R.R., D.T. Rosenow, A. Sotomayor-Rios and R.A. Frederiksen. 1982. Registration of GPT2RB anthracnose resistant sorghum germplasm population. *Crop Sci.* 22:1247-1275.

Frederiksen, R.A., L.L. Castor and D.T. Rosenow. 1982. Grain mold, small seed and head blight: the Fusarium connection. Proceedings of 27th Annual ASTA Corn and Sorghum Research Conference. Chicago, Illinois, p. 26-36.

Frederiksen, R.A., D.T. Rosenow, L. Reyes and D. Collins. 1983. Registration of Tx2784 and Tx2785 sundangrass germplasm (Reg. Nos. GP132 and GP133). *Crop Sci.* 23:405.

Jordan, W.R., R.L. Monk, F.R. Miller, D.T. Rosenow, L.E. Clark and P.J. Shouse. 1983. Environmental physiology of sorghum. I. Environmental and genetic control of epicuticular wax load. *Crop Sci.* 23:553-558.

Keim, K.R., D.T. Rosenow, F.R. Miller and J.E. Quisenberry. 1982. Natural selection in a composite of sorghum (*Sorghum bicolor* (L.) Moench) in a semi-arid environment. Proceedings of Western Society of Crop Science. Abstract, p. 69.

Keim, K.R., F.R. Miller and D.T. Rosenow. 1983. Natural selection under diverse environments for monogenic traits in a sorghum composite. *Agron. Abst.*, p. 69.

Natural, M.P., R.A. Frederiksen and D.T. Rosenow. 1982. Acremonium wilt of sorghum. *Plant Dis.* 66:863-865.

Pring, D.R., M.F. Conde, and K.F. Schertz. 1981. Organelle genotype diversity in sorghum: male-sterile cytoplasms. *Crop Sci.* 22:414-421.

Pring, D.R., M.F. Conde, K.F. Schertz and C.S. Levings, III. 1982. Plasmid-like DNA's assoicated with mitochondria of cytoplasmic male-sterile sorghum. *Mol. Gen. Genet.* 186:180-184.

Rosenow, D.T., K.F. Schertz and A. Sotomayor. 1980. Germplasm release of three pairs (A and B) of sorghum lines with A2 cytoplasmic-genic sterility system. Tex. Agric. Exp. Sta. MP-1448.

Rosenow, D.T. 1980. Stalk rot resistance breeding in Texas. *In: Sorghum Diseases - A World Review.* Proceedings of the International Workshop on Sorghum Diseases, Hyderabad, India, p. 306.

Rosenow, D.T. and L.E. Clark. 1981. Drought tolerance in sorghum. *In:* Proceedings of the 36th Annual Corn and Sorghum Research Conference, American Seed Trade Association, Chicago, Illinois, p. 18.

Rosenow, D.T. and R.A. Frederiksen. 1981. Developing head smut resistance in sorghum populations. Proceedings of the Twelfth Biennial Grain Sorghum Research and Utility Conference, Lubbock, Texas, p. 54.

Rosenow, D.T. 1982. Potential grain quality standards for sorghum: A discussion. *In: International Symposium on Sorghum Grain Quality.* ICRISAT Center, Patancheru, A.P., India, p. 391.

Rosenow, D.T. and R.A. Frederiksen. 1982. Breeding for disease resistance in sorghum. *In: Sorghum in the Eighties.* Proceedings of the International Sorghum Workshop, Hyderabad, India, p. 447.

Rosenow, D.T., L.E. Clark and C.A. Woodfin. 1982. Screening for drought tolerance in sorghum using field nurseries. *Agon. Abst.*, p. 81.

Rosenow, D.T. 1983. Sources of resistance of pathotype 3 of *Peronosclerospora sorghi. In: Integrated Control of Sorghum Downy Mildew.* Texas Agric. Exp. Sta. MP-1535. p. 8.

Rosenow, D.T., J.E. Quisenberry, C.W. Wendt and L.E. Clark. 1983. Drought tolerant sorghum and cotton germplasm. *Agric. Water Mgmt.* 7:207-222.

Rosenow, D.T., J. Craig and R.A. Frederiksen. 1983. Sources of pathotype 3 downy mildew resistance in converted exotic sorghums. Proceedings of the 13th Biennial Grain Sorghum Research and Utility Conference, Brownsville, Texas, p. 67.

Rosenow, D.T. and L.W. Clark. 1983. Use of post flowering drought tolerance in a sorghum breeding program. Proceedings of the 13th Biennial Grain Sorghum Research and Utility Conference, Brownsville, Texas, p. 119.

Rosenow, D.T., J.E. Quisenberry, C.W. Wendt and L.E. Clark. 1983. Drought tolerant sorghum and cotton germplasm. *In: Developments in Agricultural and Managed-Forest Ecology. 12; Plant Production and Management Under Drought Conditions.* Symposium presentation, Tulsa, Oklahoma, p. 207.

Rosenow, D.T. 1984. Breeding for resistance to root and stalk rots in Texas. *In: Sorghum Root and Stalk Rots, a Critical Review.* Proceedings of the Consultative Group Discussion on Research Needs and Strategies for Control of Sorghum Root and Stalk Rot Diseases, Bellagio, Italy, p. 209.

Smith, R.H., S. Bhaskaran and K. Schertz. 1982. Variation in drought tolerance characteristics from tissue culture-derived sorghum. Proceedings of the 5th International Congress Plant Tissue and Cell Culture, Plant Tissue Culture. p. 489.

Smith, R.H., S. Bhaskaran and F.R. Miller. 1984. Screening for drought tolerance in sorghum using cell culture. *Crop Sci.* (submitted).

Smith, R.H., S. Bhaskaran, R. Newton and F. Miller. 1984. Sorghum varieties screened *in vitro* for osmotic tolerance and physiological studies. *Plant Physiol. Abst.*

Schertz, K.F., D.T. Rosenow and A. Sotomayor-Rios. 1981. Registration of three pairs (A and B) of sorghum lines with A2 cytoplasmic-genic sterility systems. *Crop Sci.* 21:148.

Schertz, K.F. and D.R. Pring. 1982. Cytoplasmic sterility systems in sorghum. *In: Sorghum in the Eighties.* Proceedings of the International Sorghum Workshop, Hyderabad, India, p. 373.

Schertz, K.F. 1983. Cytoplasms and reduction of genetic vulnerability. Proceedings of the Plant Breeding Methods and Approaches in Sorghum Workshop for Latin America, Mexico. p. 114.

Schertz, K.F. 1983. Potentials with new cytoplasmic male-sterility systems in sorghum. Proceedings of the 38th Corn and Sorghum Research Conference, ASTA.

Worstell, J.V., H.J. Kidd and K.F. Schertz. 1984. Relationships among male-sterility inducing cytoplasms of sorghum. *Crop Sci.* 24:186-198.

Breeding for Insect Resistance and Efficient Nutrient Use

Gary C. Peterson and Arthur B. Onken
Texas A&M University

Two of the major problems in sorghum production are insect damage and nutrient deficiency. This project was designed to address those problems through plant breeding.

The most economically important sorghum insect pest throughout the world is the sorghum midge [*Contarinia sorghicola* (Coquillet)]. This insect destroys developing kernels. The greenbug [*Schizaphis graminum* (Rondani)], which is economically important mainly in the Western Hemisphere, feeds on sorghum plant tissue.

Low soil fertility is a serious problem in LDCs, and farmers in these countries cannot afford the costs of fertilizer and other soil amendments.

The development of new sorghum varieties which can withstand the stresses of insect damage and nutrient deficiency offers the best hope of overcoming these problems in all parts of the world.

Research Accomplishments

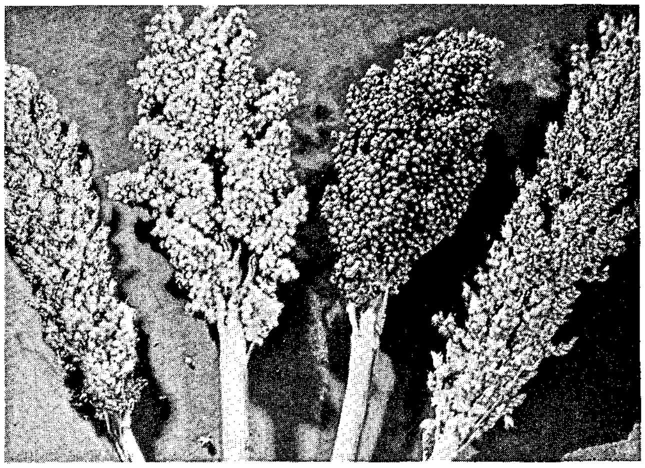
Insect Resistance

Germplasm from many countries is evaluated for resistance to midge, greenbug, Banks grass mite and other insects. Inheritance of insect resistance is usually determined in the F_2 generation. The resistance mechanism is determined if possible. F_2 generation material is evaluated in field tests in areas where known insect pests occur. Further selections are made and used in crossing programs. Advanced, elite materials are distributed for further testing both in Texas and abroad.

During the last 5 years, large numbers of sorghum varieties have been screened for insect resistance, and some have been used in the crossing/selection program. In the second year of the project, 15 midge-resistant lines and 12 biotype C greenbug-resistant lines were identified.

Subsequent yield trials of the midge-resistant hybrids indicated that adequate resistance occurs only when both parents are resistant. Emphasis in the breeding program has been for short, early maturing, tropically adapted females with resistance derived from AF28.

New midge-resistant lines recently released are Tx2801 through Tx2815. This is the first group of elite, midge-resistant germplasm released that traces its resistance to sources other than SC175.



Converted exotic sorghums exhibit a wide range of resistance levels. Note the seed set difference between the susceptible (outer) and resistant (inner) heads.

We evaluated 240 lines from the Sorghum Conversion Program to determine midge resistance. Ten lines have potentially useful levels of resistance and will be used in further breeding tests.

Work on greenbug resistance has dealt with the E and C biotypes. Biotype E greenbug resistance was determined to be a simply inherited dominant trait. Biotype E greenbug-resistant selections were made in the F_3 and F_4 generations. Potential new hybrid parents (both male and female) have been identified. Elite males were crossed to A-lines to test the hybrid combination. Sterilization of the B-line material has begun.

New biotype C greenbug-resistant sorghums have been released. They are designated as Tx2789 through Tx2800. Male lines released are tropically adapted; some lines in both germplasm groups have other desirable characteristics which may take them more useful in breeding programs.

Nutrient Use Efficiency

The nutrient use efficiency of various sorghums has been tested at several sites in Texas. In recent tests, four breeding lines were grown under both low (unfertilized) and high (160 lbs. fertilizer N/acre) soil nitrogen. Leaf area, dry weight and total nitrogen were measured on leaf and stem tissue at head initiation and at 50 percent bloom. The grain was harvested at black layer, and the grain weight, weight of 100 seeds, number of seeds per head and total N in the grain were determined. By regression analysis, grain yield was best related to total N in the plant at black layer ($R^2 = 0.84$ and 0.79) and total N in the seed ($R^2 = 0.86$ and 0.92).

Apparently a difference in root systems accounts for the difference in N uptake. In the low N test a highly significant negative relationship was found between grain yield and the grain-to-N ratio (GNR, calculated as grain weight/total plant N), as shown in the following table.

Line	Low N		High N	
	Grain/plt, g	GNR	Grain/plt, g	GNR
SC325-12	31.07 a	58.5	41.42 a	40.6
R6956	40.99 ab	54.6	73.35 bc	39.6
77CS1	48.49 b	51.5	59.51 b	31.8
SC630-11E	51.79 b	49.8	85.52 c	36.1

The results of the high N test were more complex. Neither SC325-12 nor 77CS1 responded well to the application of N, whereas SC630-11E and R6956 did respond well. We have tentatively assigned the following classification relative to N.

SC325-12	Inefficient, non-responsive
77CS1	Efficient, non-responsive
SC630-11E	Efficient, responsive
R6956	Inefficient, responsive

These same lines are being tested in low N, rainfed locations to evaluate their behavior with both low N and limited water.

Our nutrient efficiency evaluations have also studied plant use of phosphorus (P) and iron (Fe). Of 12 elite breeding lines screened for P use efficiency (mg dry matter/mg P taken up), the best performers were Tx2536, SC414-14 and SC175-14. The latter two are widely adapted, have midge resistance, and yield well in the tropics. Tx2536, which scored well in both P and N use efficiency tests, is well adapted throughout much of the world.

Since some research has indicated a possible inverse relationship between Fe and P use efficiencies, the same three lines mentioned above were screened for Fe use efficiency. We found no relationship between Fe and

Table 1: Preliminary Listing of New Converted Sorghum Lines with High or Moderate Levels of Resistance to the Sorghum Midge (*Contarinia sorghicola*).

IS no. of original line	SC no.	Working group	Midge damage rating
3390	572	Caudatum-Kafir	4.3
8232	642	Caffrorum-Darso	4.5
1340	432	Durra	5.0
7132	693	Dobbs	5.0
6911	715	Caudatum	5.0
2765	964	Dobbs	5.0
8237	644	Caffrorum-Darso	5.3
8112	725	Caudatum	5.3
12572	62	Consp-Cau-Nig	5.7
2740	708	Caudatum	5.7
TAM2566[a]			6.3
Tx2782[b]			6.3
Tx2767[c]			7.0

Rating scale: 0 = no damage, 1 = 10-20% blasted head, 2 = 21-30%, etc., 9 = 91% + blasted head.

[a] Derived from SC175.
[b] Derived from AF28.
[c] Derived from TAM2566.

Resistance genes incorporated into elite agronomic lines enable midge-resistant hybrids to be produced. Contrast the susceptible hybrid (left) with the reisistant hybrid (right).

P. In other Fe tests, Tx430 and its derivatives were less susceptible to iron chlorosis than all other entries.

Significance of Research Findings

We have made much progress in developing sorghums resistant to midge and greenbug. For farmers in LDCs, this can mean eliminating the need for chemical control (which often is beyond their resources or knowledge). The resistant sorghums also give farmers greater latitude in choosing planting dates.

Much remains to be done in breeding for efficient nutrient use. We need a better understanding of the mechanisms involved, and of the relationships between soil nutrients, available water and particular genotypes. Eventually, we may be able to develop nutrient efficient genotypes which will not need additional fertilizer.

LDC Collaboration

This project collaborates with scientists in Mali, Botswana, Guatemala, Egypt, Brazil, Honduras, Venezuela, Australia, India, Zambia, Zimbabwe and Mexico.

Training and Technical Assistance

Sorghum germplasm resistant to midge or greenbug has been distributed to the following countries: Mexico, Guatemala, Venezuela, Brazil, Argentina, China, Sudan, Mali, Uruguay, Botswana, India, Taiwan, Colombia, Ethiopia, Ghana, Japan, Kenya, the Philippines, Tanzania, Thailand, and the U.S.

Project members have travelled to Honduras, Mexico and Mali to give technical assistance to sorghum workers. Sorghum and millet lines from Mali were analyzed for nutrient efficiency in Texas. Soil samples from a Malian experiment station were shipped to Texas for analysis. And a neutron probe was provided to Malian scientists for use in their drought research.

One graduate student from the U.S. has been involved in this project.

Implications for Future Research

In the area of insect resistance, we will be emphasizing the development of new females (B lines) which are short, early maturing, tropically adpated, and which have different resistance genes than the males (R lines). We are also trying to combine resistance sources into a single genotype. Ways of doing this include: random mating populations; gene-stacking, using genetic male-sterile genes; and pedigree breeding by crossing different resistance genes into elite agronomic lines.

Work also has begun on screening sorghums for resistance to fall armyworm and mites. Many of the lines identified as mite-tolerant also have post-flowering drought tolerance. The nonsenescent characteristic may provide both kinds of protection.

A program to distribute and test a standard set of elite midge germplasm in other countries will begin.

We feel it is necessary to determine if nutrient use efficiency in plants has an effect on water use efficiency under low nutrient conditions. (This seems to be the case, judging from limited data.) Such studies will be conducted.

We suggest that there be a greater effort to collect soil data from LDCs. Analyses could be done in the U.S., followed by field experiments on-site.

These greenhouse-grown sorghum plants show different responses to iron chlorosis. Dark plants are resistant; light plants are susceptible.

Plant Breeding

W.M. Ross, D.J. Andrews, C.A. Francis and C.O. Gardner

University of Nebraska

Conventional breeding techniques have been very successful in improving grain sorghum production in the U.S. Quantitative genetic methods also have helped improve sorghum in the Nebraska program. It is important that both traditional and quantitative breeding methods be transferred to LDCs. Through this project, the transfer of technology and improved germplasm to LDCs can be supported.

Research Accomplishments

Results of various breeding experiments are reported below.

Three cycles of recurrent selection using different family selection schemes resulted in increased yield from all three methods; the best gains were from S_1 family selection (Table 1). C3 populations were improved agronomically over the CO, but tended to be slightly later.

Table 1. Results of Three Cycles of Family Selection (half-sib, full-sib, and S_1) in NP3R and S_1 Family Selection in NP5R, Evaluated over 2 Years.

Population and cycle	Yield kg/ha (%)	Flowering (days)	Height (cm)
NP3R			
C0	4775(100)	63	101
C3 HS	5251(110)	69	94
C3 FS	6021(126)	72	103
C3 S_1	6155(129)	70	99
NP5R			
C0	4886(100)	67	112
C3 S_1	5658(116)	66	95

R-lines selected in Arizona and Nebraska from the base population of NP3R produced hybrids equal or superior to ten Nebraska-adapted component R-lines of the original population. Of the 30 males evaluated, eight of the top ten hybrids had male parents selected from the population (Table 2).

Selected Publications

Archer, T.L., G.C. Peterson and A.J. Bockholt. 1984. Sorghum and corn resistance to the Banks grass mite. Annual Plant Resistance to Insects Newsletter. (in press).

Archer, T.L., G.C. Peterson and A.J. Bockholt. 1983. Sorghum and corn resistance to the Banks grass mite. Annual Plant Resistance to Insects Newsletter. 9:40.

Johnson, J.W., A.B. Onken and D.T. Rosenow. 1980. Sources of resistance to iron chlorosis. *Agron. Abst.*, p. 58.

Onken, A.B., and G.C. Peterson. 1983. Screening for nitrogen and phosphorus use efficiency in grain sorghum. *Agron. Abst.* p. 178.

Peterson, G.C. and G.L. Teetes. 1984. Sorghum germplasm resistant to the greenbug and sorghum midge. Annual Plant Resistance to Insects Newsletter. 10:43.

Peterson, G.C. and G.L. Teetes. 1984. New sources of resistance to the sorghum midge. Annual Plant Resistance to Insects Newsletter. 10:43-44.

Peterson, G.C., J.W. Johnson, G.L. Teetes and D.T. Rosenow. 1984. Registration of greenbug biotype C resistant sorghum germplasm. *Crop Sci.* (in press).

Peterson, G.C., J.W. Johnson, G.L. Teetes and D.R. Rosenow. 1984. Registration of midge resistant sorghum germplasm. *Crop. Sci.* (in press).

Peterson, G.C, J.W. Johnson, G.L. Teetes and D.T. Rosenow. 1983. Registration of Tx2783 greenbug resistant sorghum germplasm line. *Crop Sci.* 24:390.

Peterson, G.C., J.W. Johnson, G.L. Teetes, D.T. Rosenow, and R.E. Schaffert. 1983. Registration of Tx2782 midge resistant sorghum germplasm line. *Crop Sci.* 24:389-390.

Teetes, G.L., G.C. Peterson and B.R. Wiseman. 1983. Sorghum midge resistant hybrids evaluation. Annual Plant Resistance to Insects Newsletter. 9:4.

Wuensche, A.L., G.L. Teetes and J.W. Johnson. 1981. Field evaluation of converted exotic sorghums for resistance to sorghum midge, *Contarinia sorghicola.* Texas Agricultural Experiment Station, MP-1484.

Table 2. Yield Rank of Hybrids using 20 R-lines Selected from NP3R and 10 Nebraska-adapted NP3R Component R-lines Averaged over Four Environments in Arizona and Nebraska.

Genotype	Yield Rank	Genotype	Yield Rank
Exp. (AZ)	1	Tx 414	11
Exp. (AZ)	2	KS 1	14
Exp. (NE)	3	KS3	18
Exp. (AZ)	4	Redbine-60	19
KS2	5	Tx 415	20
Exp. (NE)	6	N4610	26
Exp. (NE)	7	SA7078	29
Exp. (NE)	8	N4692	30
Exp. (NE)	9		
OKY10	10		

C3 S_1 families from NP3R evaluated for a period of 2 years showed about the same yield increase (Table 3) as did NP3R populations *per se* (Table 1). Test crosses of A-lines x C3 S_1s versus test crosses of A-lines x C0 S_1s showed a yield increase of 17 percent over three cycles. C3 material also tended to be later.

Table 3. Comparison of 160 C0 and C3 S_1 Families from NP3R, and their 160 A-line x S_1 Test Crosses.

Population	Yield	Flowering	Height
	kg/ha (%)	(days)	(cm)
C0, S_1 per se	4097(100)	64	96
C3, S_1 per se	5227(128)	75	103
C0, test crosses	5570(100)	66	100
C3 test crosses	6525(117)	71	102

S_1 family testing for European corn borer resistance resulted in marked improvement (Table 4). These data reveal an average gain of 6.7 percent per cycle in the number of highly resistant families.

Table 4. Reaction of S_1 Families from NP11BR Artificially Infested with Second-Generation European Corn Borer.

Cycle +	High‡	Moderate†	Total resistant
	% families		
C0	4.3	9.3	13.6
C1	11.9	10.9	22.8
C2	17.7	16.0	33.7

\+ 300 families infested each cycle.
‡ 10 percent or less infestation.
† 10 to 20 percent infestation.

Fertile plant and male-sterile plant mass selection were practiced for high and low grain protein in NP7BR for four cycles (Table 5). Mass selection was slightly effective in increasing grain protein (realized heritability = 0.10), but more effective in decreasing it (realized heritability = 0.19). A strong negative phenotypic correlation existed between grain protein and grain yield.

Table 5. Results of Four Cycles of Fertile Plant Mass Selection for High and Low Grain Protein on Grain Yield and Protein.

Population and cycle	Grain yield	Grain protein
	(kg/ha)	(%)
HP C4	3940	11.43
HP C3	3750	11.55
HP C2	4040	11.23
HP C1	4270	11.04
C0	4210	10.93
LP C1	4060	10.85
LP C2	4180	10.34
LP C3	4320	10.10
LP C4	4480	9.87

One cycle of fertile plant mass selection was more effective than male-sterile plant mass selection for increasing grain yield, using either 100-seed weight or seed number per head as a selection criterion in NP21R (Table 6). The improved cycle using fertile plant mass selection was equal in yield to the hybrid RS 626.

Table 6. Effect of Fertile Plant and Male-Sterile Plant Mass Selection on Yield, Using 100-Seed Weight and Seed Number per Head as Selection Criteria (in NP21R).

Population selection method	Yield kg/ha
CO	5232
Fertile plant (seed wt.) C1	5706
Sterile plant (seed wt.) C1	5292
Fertile plant (seed wt.) C1	5508
Sterile plant (seed wt.) C1	5121

A comparison of twin-seeded and normal-seeded S_1 families showed a general advantage for normal seededness (Table 7). The small, light, twin seeds contributed to high threshing losses and lower yields. Protein content of the twin types was higher.

Table 7. Means of 160 Normal and 160 Twin-Seeded S_1 Progenies Evaluated from the Population NP19BR.

Trait	Normal	Twinned
Yield, kg/ha	5930	4750
Flowering, days	71	72
Height, cm	229	121
Seeds/head, no.	2130	1920
Protein, %	11.5	11.9

Topcrosses (A-lines x populations) produced some high yielding combinations that were comparable to F_1 hybrids. Table 8 lists the best and poorest populations and A-lines in an experiment, with respect to yield. Topcrosses identified superior A-lines with good general combining ability, and identified R-type populations in which to inbreed for line development.

Table 8. General Combining Ability Effects for Yield of Best and Poorest Populations and A-lines Evaluated in 114 Topcrosses.

Population	Yield +	A-line	Yield +
	(kg/ha)		(kg/ha)
RP1R	652	N37	1616
NP13R	154	KS18	679
NP1R	-269	KS23	-650
NP16R	-296	Martin	-719

\+ All values are statistically significant.

Hybrid seed production was simulated using nine A-lines and their 36 sterile F_1s. A 54 percent yield advantage was found over 2 years for the F_1 seed parents (Table 9). This is similar to the advantage of good F_1 hybrid cultivars over line cultivars. Variance components for genotype and for genotype x year generally had lower values in the F_1s compared with the A-lines.

Table 9. Means and Variance Components of Grain Yield and Seed Number for Nine A-lines and their 36 F_1 Hybrids.

Trait	F_1s	A-lines
Yield, kg/ha	5,250	3,400
Seeds per head, no.	2,200	1,450
θ_g^2 (yield)	157,321	448,197
θ_g^2 (yield)	31,839	81,049
θ_g^2 (seed no.)	52,225	73,656
θ_g^2 (seed no.)	8,782	9,232

Starch gel electrophoresis, which has been used successfully in studying other crops, has proved inadequate for the investigation of sorghum. Even sorghums of diverse origin were electrophoretically invariable for the enzymes studied, except that lines N9040 and R473 had a unique malate dehydrogenase banding pattern. The limited variation in sorghum was unexpected, and is not readily explained.

Significance of Research Findings

Recurrent selection, particularly using S_1 family selection in NP3R, is a practical breeding method. The fact that good R lines were selected from the CO of NP3R demonstrates that populations can be a source of inbred material.

The same process used to improve NP11BR for European corn borer resistance may be used to improve sorghum resistance to other stalk and stem borers that occur in Africa and Asia.

So far, improvement of protein in sorghum grain has been difficult without sacrificing yield. High lysine genes need to be used, and index selection, rather than selection for protein alone, should be undertaken.

We have determined that the twin-seed character has few advantages, if any, in sorghum breeding. Single seeds are generally perferable.

Topcrosses might be considered as cultivars in many countries where uniformity is not important. The trait variability should provide stability in harsh environments.

Hybrid seed production in LDCs probably should use sterile F_1 females because of their advantages over inbred line females.

LDC Collaboration

Specific trials for early maturing sorghum B and R lines were planted in Morocco, Tanzania, Dominican Republic and Botswana. These were evaluated by personnel in the national programs for potential use in short-season areas where drought is a problem. A dissertation study carried out with the national program in Tanzania looked at genotype-environment interactions in sorghum, maize and cowpea, both in monoculture and in intercropping systems.

Although contacts will continue with scientists in many countries, concentrated effort will be narrowed to a few country programs, probably chosen from the following: Botswana, Brazil, Dominican Republic, Egypt, Mali, Philippines, Senegal, and Sudan. Cooperation with international centers will continue. Intensified breeding support to Botswana already has been given through the transfer of funds to that country, and more support will follow.

Traning and Technical Assistance

Twenty-one graduate students from the U.S and developing countries have been involved with the project. Technical assistance has included about 20 trips to developing countries. Most of these trips were to consult with personnel in national programs or universities about sorghum breeding or cropping systems, and to help them design research programs.

Implications for Future Research

C.A. Francis resigned from the University of Nebraska on June 30, 1984, and D.C. Andrews joined the Nebraska INTSORMIL breeding project on July 1, 1984. Because of Dr. Andrews' expertise, more emphasis will be given to millet breeding and a new project on that crop will be proposed at the appropriate time. Both pedigree breeding and population breeding will be employed with sorghum and millet, and some of the objectives formerly pursued by Dr. Francis on this project will be concluded.

Elite sorghum and millet germplasm identified from LDC tests will be crossed with elite U.S. germplasm in Nebraska, and the F_2 populations will be sent to LDCs for evaluation and selection. Random-mating populations of both crops also will be obtained either in the U.S or abroad, and recurrent selection and pedigree selection will be undertaken for traits of economic importance. The same germplasm resources will be used in the Nebraska breeding program.

Selected Publications

Atkins, R.E., W.D. Guthrie, W.M. Ross and S.D. Kindler. 1983. Investigations of host-plant resistance to the European corn borer. *Iowa State J. Res.* 57:275-292.

Clark, R.B. and W.M. Ross. 1980. Genetic improvement of plant mineral nutrient efficiency and tolerance. Am. Chem. Soc., Div. of Fertilizer and Soil Chem., San Francisco, California. Abstr.

Conde, M.F., D.R. Pring, K.F. Schertz and W.M. Ross. 1983. Correlation of mitochondrial DNA restriction endonuclease patterns with sterility expression in six male-sterile sorghum cytoplasms. *Crop Sci.* 22:536-539.

Finley, W.F. and W.M. Ross. 1984. Comparison of twin- and single-seeded S_1 progenies from a sorghum population. *Maydica* 29:55-67.

Flores, C.I. and W.M. Ross. 1984. Recurrent selection in sorghum. *In:* Proceedings of the National Sorghum Research Review and Planning Workshop. Los Banos, Philippines.

Furlani, A.M.C., R.B. Clark, J.W. Maranville and W.M. Ross. 1984. Sorghum genotype differences in phosphorus uptake and distribution in plant parts. *J. Plant Nutrition* (in press).

Furlani, A.M.C., R.B. Clark, J.W. Maranville and W.M. Ross. 1984. Root phosphatase activity of sorghum genotypes grown with organic and inorganic sources of phosphorus. *J. Plant Nutr.* (in press).

Furlani, P.R., R.B. Clark, W.M. Ross and J.W. Maranville. 1983. Variability and genetic control of aluminum tolerance in sorghum. *In:* M.R. Saric and B.C. Loughman (eds.), *Genetic Aspects of Plant Nutrition.* Martinus Nijhoff Publ., The Hague, Boston, Lancaster. pp. 453-461.

Furlani, P.R., R.B. Clark, W.M. Ross and J.W. Maranville. 1983. Variability and gentic control of aluminum tolerance in sorghum genotypes. *Plant and Soil* 75:453-461.

Furlani, P.R., R.B. Clark and W.M. Ross. 1980. Differential response of sorghum genotypes to aluminum. *Agron. Abst.* p. 81.

Garrity, D.P., C.Y. Sullivan and W.M. Ross. 1983. Alternative approaches to improving grain sorghum productivity under drought stress. *In: Drought Resistance in Crops with Emphasis on Rice.* Int. Rice Res. Inst., Los Banos, Philippines. pp. 339-356.

Gorz, H.J., J.J. Toy, F.A. Haskins and W.M. Ross. 1984. Comparison of F_1s and inbreds as female parents for sorghum-sudangrass seed production. *Crop Sci.* (in press).

Hookstra, G.H. and W.M. Ross. 1982. Comparison of F_1s and inbreds as female parents for hybrid sorghum seed production. *Crop Sci.* 22:147-150.

Hookstra, G.H., W.M. Ross and R.F. Mumm. 1983. Simultaneous evaluation of grain sorghum A-lines and random-mating populations with topcrosses. *Crop Sci.* 23:977-981.

Hookstra, G.H. and W.M. Ross. 1981. Topcross evaluation of grain sorghum A-lines and random-mating populations. Proceedings of the Biennial Grain Sorghum Producers Association Research and Utilitization Conference. 21:115.

Knapp, S.J., W.W. Stroup and W.M. Ross. 1985. Exact confidence intervals for heritability on a progeny mean basis. *Crop Sci.* (accepted).

Kofoid, K.D., J.W. Maranville and W.M. Ross. 1982. Relationship of the testa to agronomic and nutritional traits in sorghum. *Crop Sci.* 22:352-357.

Maranville, J.W., J.C. Larson and W.M. Ross. 1980. Uptake and distribution of nitrogen and phosphorus in grain sorghum hybrids and their parents. *J. Plant Nutr.* 2:267-281.

Maranville, J.W., R.B. Clark and W.M. Ross. 1980. Nitrogen efficiency in grain sorghum. *J. Plant Nutr.* 2:577-589.

Odo, P.W., J.W. Maranville, R.B. Clark and W.M. Ross. 1983. Nitrogen utilization efficiency and yield in grain sorghum. Proceedings of the Biennial Grain Sorghum Producers Association Research and Utilization Conference 13:57-58.

Otte, C.E. and W.M. Ross. 1981. Evaluation of R-lines from the sorghum random-mating population NP3R.

Otte, C.E., W.M. Ross, C.Y. Sullivan, R.L. Voigt and F.R. Miller. 1984. Evaluation of R-lines from a sorghum random-mating population. *Crop Sci.* 24:9-12.,

Ross, W.M., J.W. Maranville, G.H. Hookstra and K.D. Kofoid. 1985. Divergent mass selection for grain protein in sorghum. *Crop Sci.* (accepted).

Ross, W.M. and G.H. Hookstra. 1983. Performance of S_1 progenies from a sorghum random-mating population sampled in different years. *Crop Sci.* 23:89-91.

Ross, W.M., H.J. Gorz, F.A. Haskins, G.H. Hookstra, J.K. Rutto and R. Ritter. 1983. Combining ability effects for forage residue traits in grain sorghum hybrids. *Crop Sci.* 23:97-101.

Ross, W.M. and C.O. Gardner. 1983. The Mechanics of population improvement in sorghum. Proceedings of the Latin American Sorghum Plant Breeding Workshop, CIMMYT, Mexico. pp. 8-38.

Ross, W.M., S.D. Kindler, K.D. Kofoid, G.H. Hookstra, W.D. Guthrie and R.E. Atkins. 1982. European corn borer resistance in half-sib families from a sorghum random-mating population. *Crop Sci.* 22:973-977.

Ross, W.M., K.D. Kofoid, J.W. Maranville and R.L. Voigt. 1981. Selecting for grain protein and yield in sorghum random-mating populations. *Crop Sci.* 21:774-777.

Ross, W.M., R. Ritter and J.W. Maranville. 1980. Sampling sorghum plots for kernel protein. *Crop Sci.* 20:280-281.

Ross, W.M., H.J. Gorz, F.A. Haskins and O.J. Webster. 1980. Registration of 10 sorghum parental lines. *Crop Sci.* 20:834.

Ross, W.M., H.J. Gorz and F.A. Haskins. 1980. A preliminary investigation of forage quality characters in hybrid grain sorghum residues. *Maydica* 25:41-53.

Ross, W.M. 1980. Theory and practice of population breeding. *In:* Proc. Plant Breeding Workshop. Texas Agric. Exp. Sta., Department of Soil and Crop Sciences Tech. Rep. No. 80-1. pp. 25-26.

Schertz, K.F., D.R. Pring and W.M. Ross. 1981. Sorghum cytoplasmic sterility. *Agron. Abst.* p. 72.

Sullivan, C.Y. and W.M. Ross. 1979. Selecting for drought and heat resistance in grain sorghum. *In:* H. Mussell and R. Staples (eds.), *Stress Physiology in Crop Plants.* John Wiley & Sons, New York. pp. 263-282.

Williams, E.P., R.B. Clark, W.M. Ross and J.W. Maranville. 1983. Variability of S_1 progenies from the NP20BR sorghum random-mating population for iron deficiency. Proceedings of the Biennial Grain Sorghum Producers Association Research and Utilization Conference. 13:47.

Sorghum Host-Plant Resistance and Genotype Evaluation

Lynn M. Gourley, Norman C. Merwine, S. Ann Rogers, Jacque C. Denis, H.N. Pitre, L.E. Trevathan, S.B. King and N. Zummo

Mississippi State University

The hot, humid Mississippi climate, the large areas of johnsongrass in the state which harbor most sorghum diseases and insects, and the acid soil, make sorghum production problems in Mississippi comparable to those in many LDCs. A host-plant resistance program, established before INTSORMIL, was geared to using the Mississippi environment to study sorghum problems which occur in similar climates around the world.

The purpose of this project is to evaluate sorghum genotypes which are resistant to diseases and insects.

Research Accomplishments

Breeding

Much has been done to understand and select for aluminum (Al) tolerance. In one study, 168 exotic genotypes were screened for Al tolerance in nutrient culture. Thirteen of these were classified as Al tolerant, and field tests are underway to confirm this. Two genotypes have been identified that produce white, normal looking roots in Al-saturated soils. Roots of other genotypes tested, including those with good Al tolerance, are discolored red to red-brown.

Mineral element analysis has shown that silicon (Si) may be involved in the Al toxicity resistance mechanism. The level of Si in leaf tissue of Al-tolerant plants grown in high Al soil was much less than for the same genotypes grown in low Al soil.

A greenhouse screening technique, using different lime rates to establish various Al soil levels, is being used to rapidly identify tolerant seedlings (Table 1). Results of a genetic test using the greenhouse screening technique are shown in Table 2. All hybrids were superior to parents in dry matter production, indicating overdominance or epistatic gene action.

Pathology

We have identified *F. Moniliforme, Curvularia* spp. and *Alternaria* spp. as three of the most common fungi infecting sorghum. Trials of the International Sorghum Anthracnose Virulence Nursery indicate a possible new race of anthracnose in Georgia and a possible new race of sorghum rust in Louisiana. A nematode species, *Quinisulcius acutus,* has been associated with diseased sorghum root systems. In greenhouse studies, this nematode was found to cause reduced plant height and weight.

Selections form eight F_2 lines were field tested for diseases resistance in Mexico, Colombia and the U.S. Lines from these breeding materials have been used in INIA's breeding program; others are being evaluated by ICRISAT in India and Africa.

Our research showed that Benomyl added to panicles during seed development had no significant effect on 1000-kernel weight, germination percentage, seed-borne fungal infection or yield, and did not enhance seedling growth.

In other experiments, we inoculated plant panicles during seed development with *Fusarium, Curvularia, Alternaria, Helmenthosporium,* and *Phoma* spp. Viability of inoculated seed was only slightly less than that of non-inoculted seed. The major effects of the diseases were noticed later, with significantly reduced 1000-kernel weight and root and shoot lengths.

A mist fogger nozzle system is being used to create artificial weathering conditions. This aids in evaluating seed quality and in checking for seed-borne pathogens. The system is very effective and has been copied at ICRISAT. Ergosteral analysis, which indicates fungal growth in grain, is another valuable technique being used.

Entomology

Entomological studies have dealt with fall armyworm, an insect pest of sorghum. In armyworm development trials, larvae were fed leaf material from plants high in lysine and plants high in polyphenolic compounds. There were significant adverse effects on larval development, but not on pupal weight.

Four normal bloom and four low-bloom sorghum lines were evaluated in field cages. The lines showed no differences in numbers of fall armyworm eggs per plant. In other field studies, armyworm moths showed increased oviposition with increasing age and size of plants.

We are studying several parasites of fall armyworm, to learn how they might be used in biological control. These are *Apanteles marginiventris* (Cresson), *Archytas marmoratus* (Townsend), *Campoletis flavicincta* (Ashmead), *Ophion flavidus* (Brulle), and *Euplectrus plathyhypenae* (Howard).

A sorghum line which is moderately resistant to fall armyworm has been identified. The genotype, a feterita from Sudan, is from the CIMMYT collection.

Significance of Research Findings

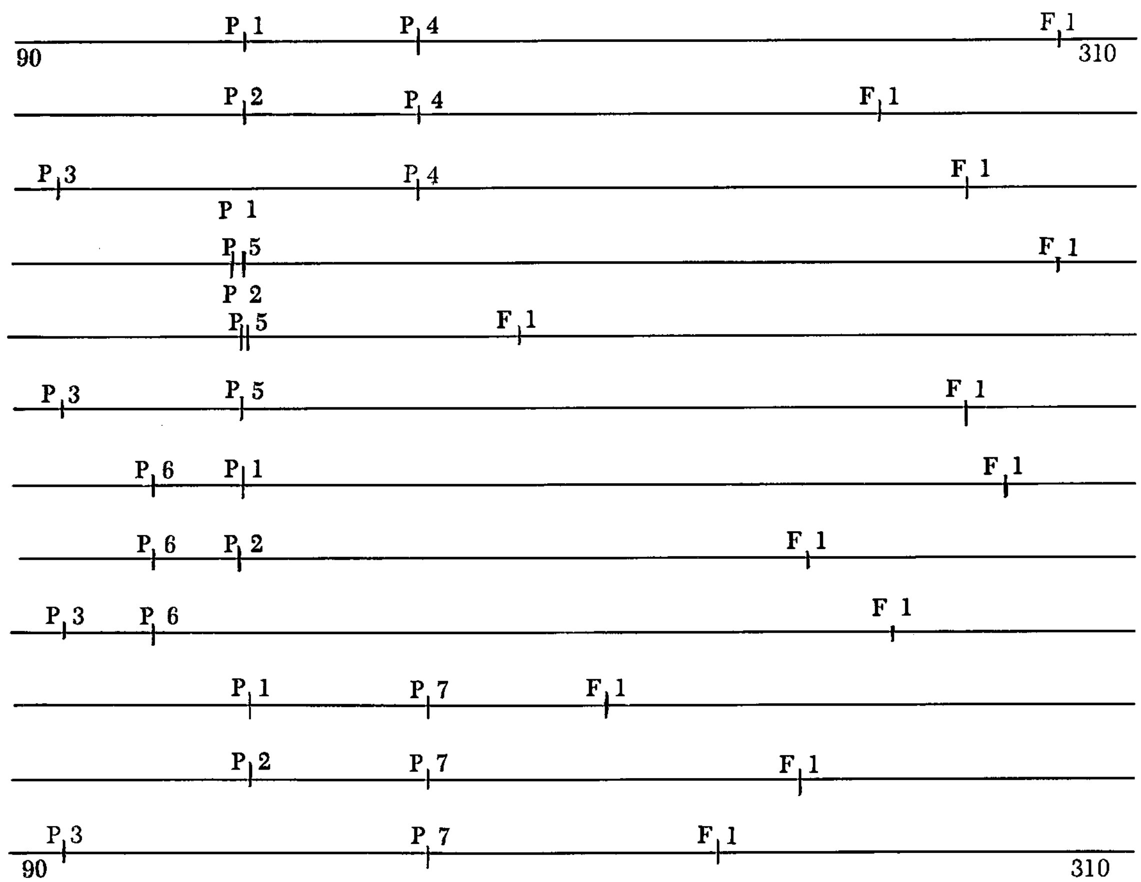
The most significant outcome of our research on breeding for Al tolerance was the decision to move the screening and evaluation of potential parents and crossing populations to the target LDCs. The soils in the U.S are unsuited for this activity, and the highly weathered acid soils of the tropics cannot be adequately duplicated in the laboratory.

Through increased knowledge of seed-borne pathogens, we have been able to select parents and lines tolerant to grain weathering. Thirty of the best lines have been sent for testing in Africa.

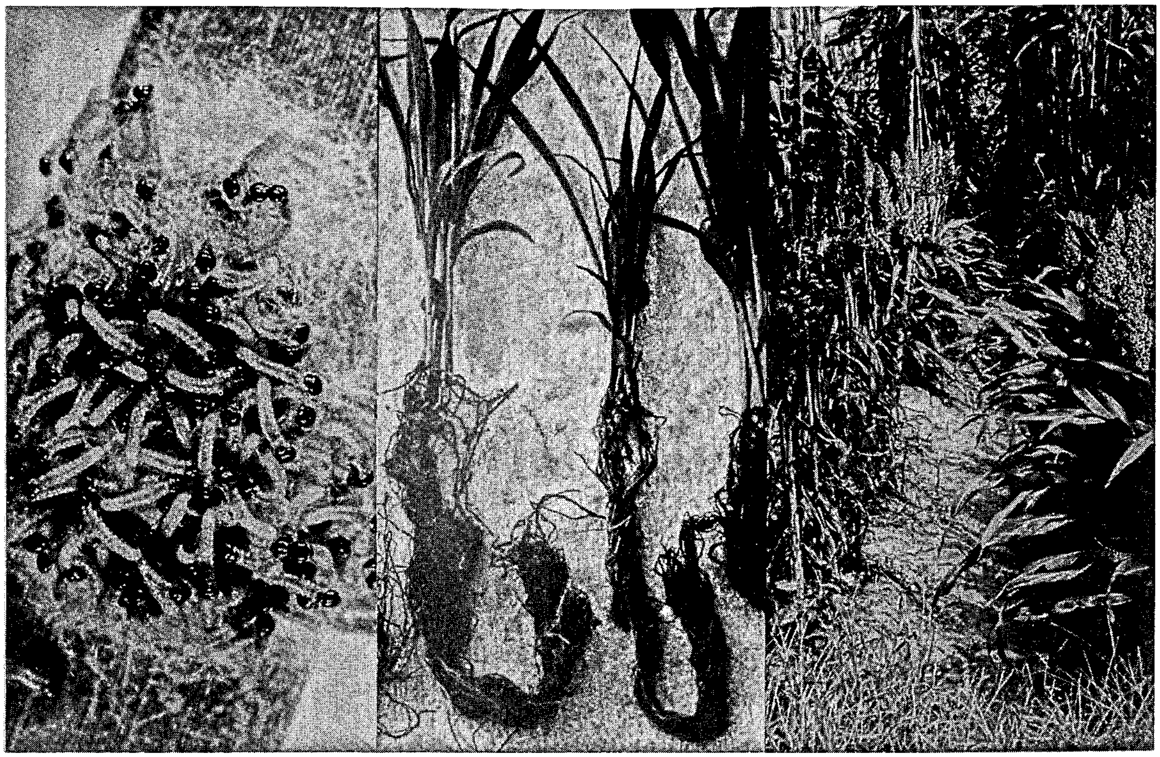
Table 1. DM Production of 3-week-old Seedlings of Ten Sorghum Genotypes Grown in the Greenhouse in Llanos Soil with Different Rates of Lime.

	DM (mg) per plant at 7 lime (kg)/Al-saturation (%) levels													
	500/80		1500/74		2500/62		3500/59		4500/55		5500/41		6500/40	
Genotype	WT	RK	WT	RK	WT	RK	WT	RK	WT	RK	WT	RK	WT	RK
SC566-14	127	(1)	170	(1)	205	(1)	193	(3)	188	(3)	238	(2)	218	(3)
MN 1706	103	(2)	111	(3)	204	(2)	212	(1)	226	(1)	248	(1)	284	(1)
SC 283	90	(3)	141	(2)	178	(3)	206	(2)	207	(2)	234	(3)	273	(2)
Wheatland	78	(4)	78	(7)	115	(6)	136	(5)	132	(7)	157	(8)	204	(4)
ICA Nataima	56	(5)	101	(4)	95	(7)	111	(7)	113	(9)	206	(4)	166	(7)
MN 1204	53	(6)	86	(6)	149	(4)	161	(4)	133	(6)	190	(6)	172	(5)
MN 1812	51	(7)	98	(5)	133	(5)	135	(6)	153	(4)	203	(5)	158	(8)
SC 574-14	48	(8)	77	(8)	85	(8)	108	(8)	141	(5)	147	(9)	168	(6)
TX 415	36	(9)	34	(10)	52	(10)	83	(9)	91	(10)	140	(10)	132	(10)
NB 9040	33	(10)	47	(9)	73	(9)	80	(10)	116	(8)	169	(7)	134	(9)

Table 2. DM Production (mg) of 3-week-old Seedlings of Parents and F_1s Grown in the Greenhouse in Llanos soil with 1500 kg/ha lime (68% Al sat.).



Female Parent	Male Parent
P1 MS B-Yel PI (114 mg)	P4 IS 7542C (134 mg)
P2 MS Wheatland (112 mg)	P5 IS 12666C (108 mg)
P3 MS Wheatland der (91 mg)	P6 SC 574-14 (101 mg)
	P7 3DX57/1/1/910 (142 mg)



Major constraints to sorghum production in Mississippi and tropical countries are (left to right) fall armyworms, acid soils and plant diseases.

LDC Collaboration

This project has linkages with several South American national programs for breeding research on Al tolerance: ICA-Colombia; EMBRAPA-Brazil; FONAIAP-Venezuela; amd INIPA-Peru. Through the acid soils research of TROPSOILS, additional collaborative testing sites in Peru and Indonesia have been added. The success of the Al tolerance screening and evaluation program in Colombia has brought requests for collaboration and germplasm from ISCRISAT-Panama, Africa and several commercial companies.

Mexico, Honduras, Panama and to some extent the national programs in South America are collaborating in armyworm and pathology research. These projects distribute germplasm to the LDCs.

Training and Technical Assistance

The PI coordinated a May 1984 workshop on "Evaluating Sorghum for Tolerance to Al-Toxic Tropical Soils in Latin America." This was co-sponsored by INTSORMIL, ICRISAT and CIAT. About 50 scientists and administrators from INTSORMIL, ICRISAT, CIAT, TROPSOILS, Colombia, Venezuela, Peru and Brazil participated. Out of this workshop there grew a coordinated regional effort to adapt sorghum to the acid soil areas of Latin America.

Eight graduate students are involved in this project; two of them conducted a portion of their research in Colombia with the support of this project. A Colombian research assistant in this project has been trained in all phases of sorghum breeding. Several national program scientists have been refused training in the project due to lack of funds.

Implications for Future Research

We will evaluate regional trials and assist with breeding activities in South America. Sorghum lines originating in acid soil areas of Africa will be sent to Colombia for evaluation. The ultimate goal of research on Al tolerance should be to develop tolerant hybrids, not just varieties. More work is needed in this area.

Interdisciplinary cooperation with plant pathology and entomology will continue.

Selected Publications

Bastos, C.R. and L.M. Gourley. 1981. ICRISAT Book II, "Sorghum in the Eighties," Brief Article-Rapid Screening of Sorghum Seedlings for Tolerance to Low pH and Aluminum. p. 742.

Canez, V.M. and S.B. King. 1981. Fungal infection of developing sorghum panicles. *J. Miss. Academy Sci.*

Clark. R.L. and L.M. Gourley. 1984. Evaluation of mineral elements of sorghum grown in acid tropical soil. Workshop, "Evaluating Sorghum for Tolerance to Al-Toxic Tropical Soils in Latin America."

Gourley, L.M. 1984. Finding and utilizing exotic al-tolerant sorghum germplasm. Workshop, "Evaluating Sorghum for Tolerance to Al-Toxic Tropical Soils in Latin America."

Gourley, L.M. 1983. Breeding sorghum for tolerance to aluminum-toxic tropical soils. Sorghum Breeders Workshop at CIMMYT.

Gourley, L.M. 1979. Breeding studies with sorghum for resistance to midge and other insects. 26th Annual Mississippi Insect Control Conference Abstract, p. 4.

Merwin, M.C., L.M. Gourley and K.H. Blackwell. 1981. The inheritance of papery glume and cleistogamy in sorghum. *Crop Sci.* 21:953-956.

Pitre, H.N. and L.M. Gourley. 1980. Johnsongrass in relation to damage by the sorghum midge in Mississippi. MAFES Research Report Vol. 5, No. 11.

Rogers, S.A. and L.M. Gourley. 1983. Screening sorghum for aluminum tolerance in Colombian soil. ASA Southern Branch. Abstract.

Schaffert, R.E. and L.M. Gourley. 1981. ICRISAT Book II, "Sorghum in the Eighties," Sorghum as an Energy Source. pp. 605-623.

Schwager, B., H.N. Pitre and L.M. Gourley. 1984. Field evaluation of sorghum characteristics for resistance to fall armyworm. *J. Ga. Entomol. Soc.*

Schwager, B. and H.N. Pitre. 1981. Evaluation of sorghum for resistance to fall armyworm, *J. Miss. Academy Sci.*

Wiseman, B.R., H.N. Pitre, L.M. Gourley and S.L. Fales. 1984. Differential growth responses of fall armyworm larvae on developing sorghum seed incorporated into a meridic diet. *Fla. Entomol.*

Wiseman, B.R., L.M. Gourley and H.N. Pitre. 1983. Some studies of resistance to the fall armyworm. 15th Biennial Grain Sorghum Research and Utilization Conference.

Wiseman, B.R. and L.M. Gourley. 1982. Fall Armyworm (lepidoptera:Noctuidae): infestation procedures and sorghum resistance evaluations. *J. Econ. Entomol.* 75:10-48-1051.

Adaptation of Sorghum to Highly Acid Tropical Soils

Lynn M. Gourley

Mississippi State University

There are more than two billion hectares of acid soils in the tropical areas of the world, with more than 860 million in tropical South America. These soils contain various chemicals which make agricultural production difficult. Since 1974, sorghum acreage in tropical South America has increased by 20.4 percent annually. Some of this increase is due to the demand for feed grain by the growing broiler industry. As sorghum production expands into marginal, acid soil areas, average yields decrease. The main problem is a lack of sorghum germplasm with reasonable tolerance to aluminum (Al).

Research Accomplishments

Greenhouse soil culture tests and field trials are used to determine sorghum tolerance to aluminum toxicity. A reliable Al tolerance field screening technique was developed at CIAT/Quilichao, Colombia. At an Al saturation level of 60 to 65 percent, susceptible genotypes die and the remaining genotypes range from severely stunted to nearly normal.

This project has screened a total of 1250 cultivars from throughout the world, 1400 breeding lines from another INTSORMIL project, and two Al-tolerant random-mating populations. The best lines were evaluated twice. Seed of the most promising lines were distributed to national programs in Colombia, Venezuela, Peru, Brazil,

Table 1. Al-Tolerance Ratings of 730 World Collection Lines by Country of Origin.

	Total	Rating‡ 1		2		3		4	
Country	lines	#	%	#	%	#	%	#	%
Ethiopia	158	20	13	33	21	59	37	46	29
Kenya	116	17	15	43	37	35	30	21	18
Nigeria	16	1	6	4	25	6	38	5	31
Tanganyika	14	2	14	5	36	4	29	3	21
Uganda	104	15	14	50	48	23	22	16	16
Upper Volta	82	3	4	30	36	26	32	23	28
Zaire	16	2	12	6	38	5	31	3	19
Misc.	224	23	10	52	23	78	35	71	32
Total	730	83	11	223	31	236	32	188	26

‡ 1 = Best, 4 = Poorest.

Training and Technical Assistance

The PI coordinated the 1984 workshop, "Evaluating Sorghum for Tolerance to Al-Toxic Tropical Soils in Latin America," cosponsored by INTSORMIL, ICRISAT and CIAT. About 50 scientists and administrators participated. As a result of this workshop, a regional network of research was established to adapt sorghum to the acid soil areas of Latin America.

Two Ph.D students conducted a portion of their research in Colombia with the support of this project. A Colombian research assistant was trained in all phases of sorghum breeding. Several national program scientists have been refused training in this project due to lack of funds.

Implications for Future Research

Additional screening of sorghum germplasm must be conducted, with primary attention to the African areas where the best Al-tolerant lines are now being found. These acid soil areas should be the source of the greatest genetic diversity.

Elite genotypes must be developed by recombining genes for Al tolerance and genes for other factors such as extensive root systems, phosphorus efficiency through mycorrhizae association, and drought tolerance. Al tolerance is a characteristic which is ideally suited for the random-mating population improvement approach. The susceptible offspring are eliminated from the population and only the tolerant lines contribute their genes to the next generation. This selective advantage can be increased by growing the population on soil with increasing levels of Al.

As we work to develop Al-tolerant hybrids, we must also give more attention to disease resistance.

Selected Publications

Clark, R.L. and L.M. Gourley. 1984. Evaluation of mineral elements of sorghum grown in acid tropical soil. Workshop, "Evaluating Sorghum for Tolerance to Al-Toxic Soils in Latin America."

Gourley, L.M. 1983. Breeding sorghum for tolerance to aluminum-toxic tropical soils. Sorghum Breeders Workshop at CIMMYT.

Gourley, L.M. 1984. Finding and utilizing exotic al-tolerant sorghum germplasm. Workshop, "Evaluating Sorghum for Tolerance to Al-Toxic Tropical Soils in Latin America."

Rogers, S.A. and L.M. Gourley. 1984. Screening sorghum for aluminum tolerance in Colombian soils. ASA Southern Branch. Abstract.

Evaluation and Development of Sorghum / Millet Germplasm for Arid Land Agriculture

V. Marcarian, A.K. Dobrenz, R.L. Voigt and O.J. Webster

University of Arizona

Project leaders identified four main objectives of their research. First, they sought to identify drought-tolerant sorghum/millet genotypes using sprinkler irrigation gradients. Second, the physiological and morphological attributes of these lines would be studied. Drought-tolerance levels would be increased through controlled crossing and selection under low moisture, high temperature conditions. Finally, drought-tolerant lines would be evaluated for other desirable characteristics.

Research Accomplishments

Drought-Tolerance Screening

A sprinkler irrigation gradient (SIG) system in Yuma, Ariz. is being used to screen both sorghum and millet entries for drought tolerance (Fig. 1). Water application rates range from approximately 650 to 0 mm during the growing season; temperatures average over 40°C (Figs. 2, 3). At water levels approximating those in LDCs, there is a wide range of response among entries (Table 1). By measuring the distance from the pipe to the last grain producing head, an estimate of productivity under a given water level can be made. Generally, any sorghum or millet which produces seed 8 to 16 meters from the pipe can be identified as capable of producing in the arid climates of LDCs. In this range of the gradient, 250 mm water or less is supplied to the plants. Sorghum/millet genotypes are evaluated for agronomic and physiological characteristics as well as for yield under water stress. The results are made available to U.S. and LDC cooperators.

The number of entries in the SIG tests has almost tripled since the INTSORMIL project began. In all, about 3,000 sorghum and millet germplasm sources have been evaluated in the last 5 years. Breeders from five states and numerous LDCs have sent germplasm for testing in Arizona. The SIG system reliably identifies drought-tolerant genotypes.

Physiological Study of Drought-Tolerant Lines

A second SIG system in Tucson, Ariz. is being used to study physiological and morphological attributes of

Training and Technical Assistance

The PI coordinated the 1984 workshop, "Evaluating Sorghum for Tolerance to Al-Toxic Tropical Soils in Latin America," cosponsored by INTSORMIL, ICRISAT and CIAT. About 50 scientists and administrators participated. As a result of this workshop, a regional network of research was established to adapt sorghum to the acid soil areas of Latin America.

Two Ph.D students conducted a portion of their research in Colombia with the support of this project. A Colombian research assistant was trained in all phases of sorghum breeding. Several national program scientists have been refused training in this project due to lack of funds.

Implications for Future Research

Additional screening of sorghum germplasm must be conducted, with primary attention to the African areas where the best Al-tolerant lines are now being found. These acid soil areas should be the source of the greatest genetic diversity.

Elite genotypes must be developed by recombining genes for Al tolerance and genes for other factors such as extensive root systems, phosphorus efficiency through mycorrhizae association, and drought tolerance. Al tolerance is a characteristic which is ideally suited for the random-mating population improvement approach. The susceptible offspring are eliminated from the population and only the tolerant lines contribute their genes to the next generation. This selective advantage can be increased by growing the population on soil with increasing levels of Al.

As we work to develop Al-tolerant hybrids, we must also give more attention to disease resistance.

Selected Publications

Clark, R.L. and L.M. Gourley. 1984. Evaluation of mineral elements of sorghum grown in acid tropical soil. Workshop, "Evaluating Sorghum for Tolerance to Al-Toxic Soils in Latin America."

Gourley, L.M. 1983. Breeding sorghum for tolerance to aluminum-toxic tropical soils. Sorghum Breeders Workshop at CIMMYT.

Gourley, L.M. 1984. Finding and utilizing exotic al-tolerant sorghum germplasm. Workshop, "Evaluating Sorghum for Tolerance to Al-Toxic Tropical Soils in Latin America."

Rogers, S.A. and L.M. Gourley. 1984. Screening sorghum for aluminum tolerance in Colombian soils. ASA Southern Branch. Abstract.

Evaluation and Development of Sorghum / Millet Germplasm for Arid Land Agriculture

V. Marcarian, A.K. Dobrenz, R.L. Voigt and O.J. Webster

University of Arizona

Project leaders identified four main objectives of their research. First, they sought to identify drought-tolerant sorghum/millet genotypes using sprinkler irrigation gradients. Second, the physiological and morphological attributes of these lines would be studied. Drought-tolerance levels would be increased through controlled crossing and selection under low moisture, high temperature conditions. Finally, drought-tolerant lines would be evaluated for other desirable characteristics.

Research Accomplishments

Drought-Tolerance Screening

A sprinkler irrigation gradient (SIG) system in Yuma, Ariz. is being used to screen both sorghum and millet entries for drought tolerance (Fig. 1). Water application rates range from approximately 650 to 0 mm during the growing season; temperatures average over 40°C (Figs. 2, 3). At water levels approximating those in LDCs, there is a wide range of response among entries (Table 1). By measuring the distance from the pipe to the last grain producing head, an estimate of productivity under a given water level can be made. Generally, any sorghum or millet which produces seed 8 to 16 meters from the pipe can be identified as capable of producing in the arid climates of LDCs. In this range of the gradient, 250 mm water or less is supplied to the plants. Sorghum/millet genotypes are evaluated for agronomic and physiological characteristics as well as for yield under water stress. The results are made available to U.S. and LDC cooperators.

The number of entries in the SIG tests has almost tripled since the INTSORMIL project began. In all, about 3,000 sorghum and millet germplasm sources have been evaluated in the last 5 years. Breeders from five states and numerous LDCs have sent germplasm for testing in Arizona. The SIG system reliably identifies drought-tolerant genotypes.

Physiological Study of Drought-Tolerant Lines

A second SIG system in Tucson, Ariz. is being used to study physiological and morphological attributes of

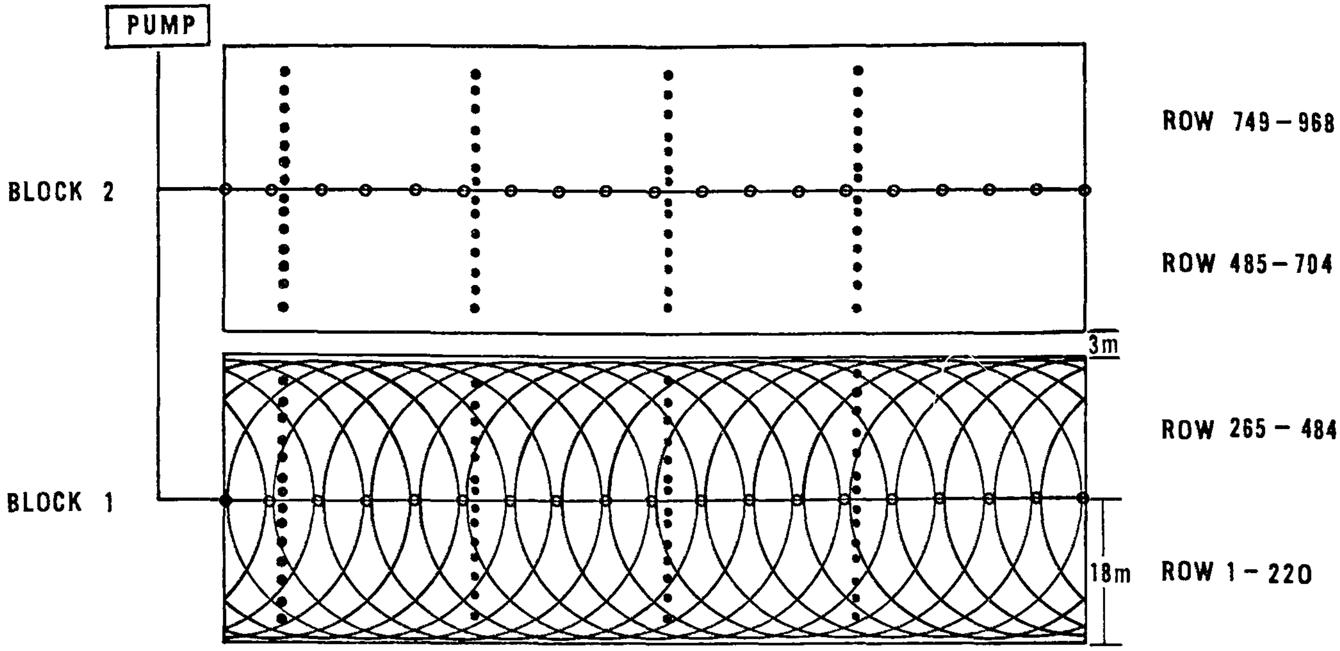


Figure 1. Plan of the sorghum/millet sprinkler irrigation gradient field. Blocks I and II had a sprinkler line, with risers every 6 meters, running down through its center, thus dividing each block into two 18-meter widths. Blocks were separated by a 3-meter alley. Rows 1-220 and 265-484 were in Block I. Rows 485-704 and 749-968 were in Block II. Water application measurements were replicated three times in each block. Water application catch cans were placed on both sides of the sprinkler lines at 0, 1.5, 4.5, 7.5, 10.5, 13.5 and 16.5 meters from the line.

millets and sorghums under water stress. Genotypes are planted in parallel rows which form a block running perpendicular to a single sprinkler line. This results in multiple water levels, with many plants in each level, for detailed study. This system facilitates replicating experiments and enables us to make comparisons among moisture levels with statistical reliability.

Using this system, a comprehensive study of the drought-tolerance characteristics of millet hybrids has been completed.

Physiological measurements of sorghum parents and hybrids grown with a wide range of available soil moisture show that hybrids have higher photosynthesis and lower leaf resistance, and produce more dry matter than the parents regardless of the moisture stress. Stomate density did not appear to be a characteristic which displayed heterosis.

Experiments in growth chambers used to evaluate early germination and seedling drought tolerance did not appear to usefully predict drought tolerance of sorghum lines at later stages of development. Selection for drought tolerance in sorghum/millet germplasm should definitely be done in a moisture stress environment.

A modified aquarium method is being used to test sorghum seedlings for aluminum tolerance. Screening for salt tolerance takes place under field conditions. Irrigation water contains 1,800 ppm salt and soil salinity reaches 34,000 ppm in the test field. Seedling assays conducted at -18 bars have shown that caudatum and bicolor sorghums are fairly salt tolerant; durras and kafirs are extremely salt susceptible.

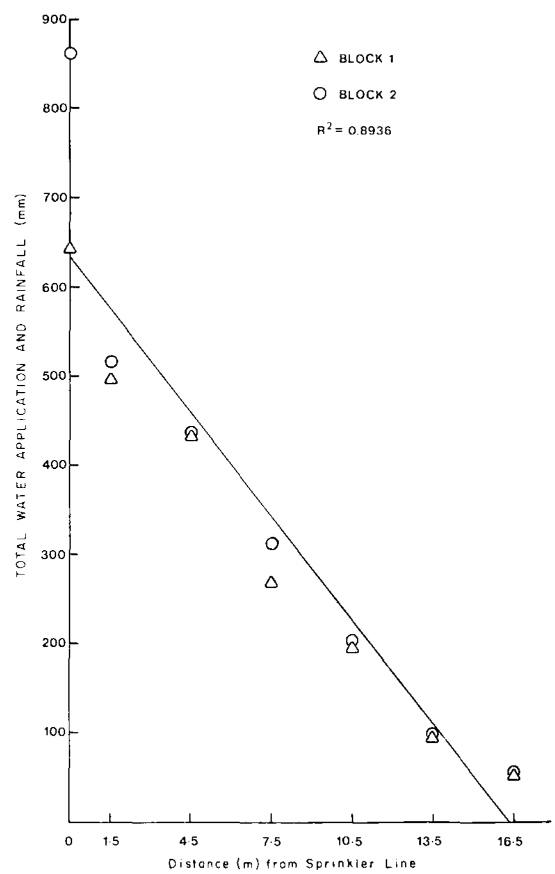


Figure 2a. Regression line of total water application at distances of 0, 1.5, 4.5, 7.5, 10.3, 13.5 and 16.5 meters from the line source.

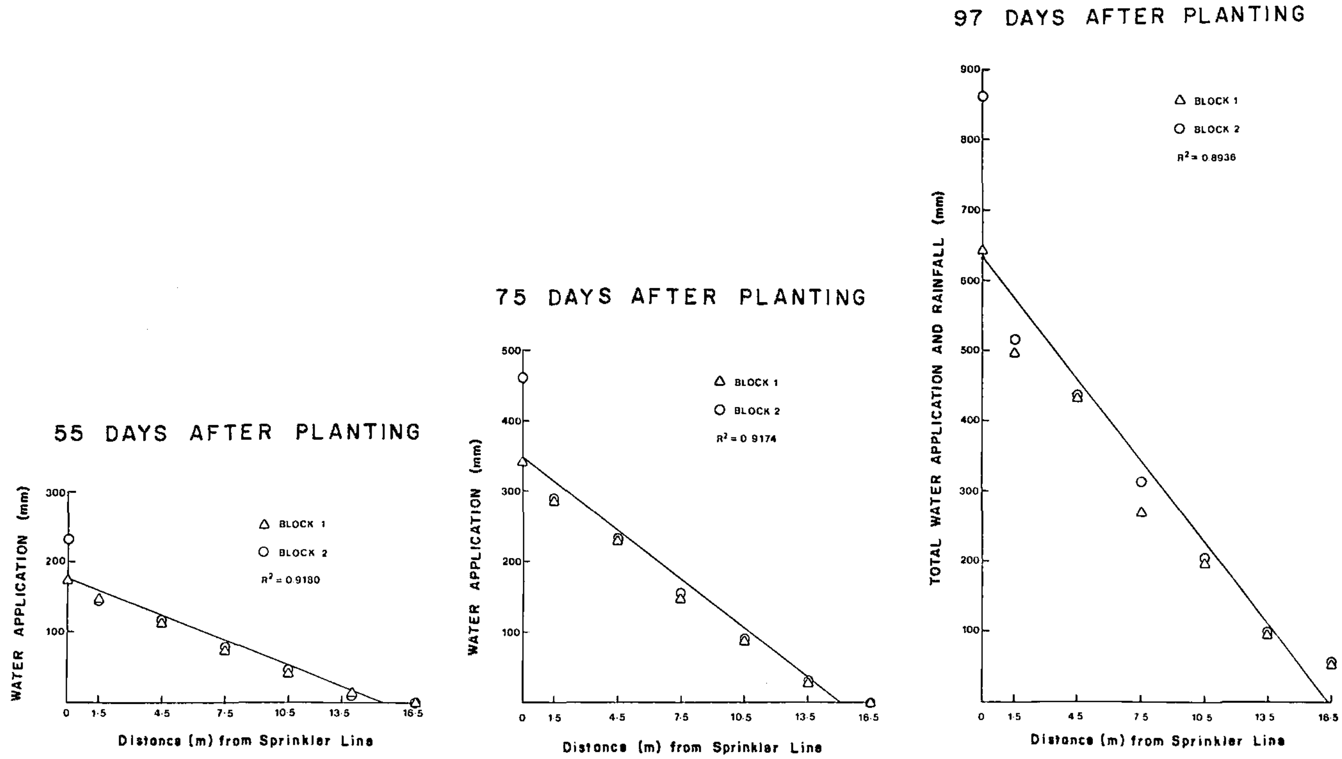


Figure 2b. Regression lines of water application during the growing season.

Breeding for Drought Tolerance

Development of tolerance to heat and moisture stress is being accomplished through crossing, evaluation and selection under field conditions of desert heat and drought. Experimental genotypes which appear to have potential for LDC breeding programs are furnished to cooperators for further evaluation.

Two sorghum populations had been intercrossed and re-selected under heat and drought before the INTSORMIL program—NP9BR for nine cycles and NP3R for six cycles. About 500 single plant selections have been made and are in various test stages: head rows; preliminary yield tests; advanced yield test; B and R evaluations; and testing in LDCs. About 5 percent of the selections from NP9BR and about 10 percent from NP3R exceeded drought-tolerant commercial hybrids in grain yield tests. The re-selected NP9BR and NP3R populations have been combined in one cycle of intercrossing for selection on ms_3 sterile.

Crosses were made among selected tolerant and susceptible sorghum genotypes. The F_1 and F_2 generations were grown and F_2 selections made for further studies.

A large number of pearl millet genotypes have been evaluated under heat and drought and are being intercrossed into a random-mating population.

About 4,500 lines of sorghum were collected from the sorghum growing areas of the Yemen Arab Republic from 1976 to 1978 and brought to Arizona in 1980. From these lines, non-photoperiod-responsive genotypes have been selected and increased, and the seed sent to many Central and South American and African countries for evaluation. More lines are being selected and increased for testing in LDCs.

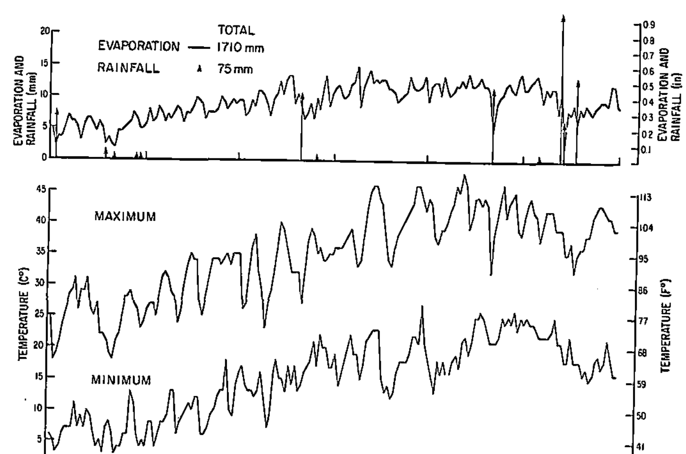


Figure 3. Meteorological data for Yuma Mesa Agricultural Experiment Station, Yuma, Az., during the growing season.

Table 1. Sorghum and Millet Grain Production Along a Sprinkler Irrigation Gradient.

Row #	Days to Anthesis	Rank	Height (cm) Hi	Height (cm) Low	Distance (m) from sprinkler line after 96 days		Distance (m)
148	72	1	54	30	AT X 622 X 72T123-1	Sorghum	5
149	72	1	49	35	AT X 622 X SC56-14E	"	5
150	69	2	57	46	A4R X CS 3541	"	6
151		1	49	32	Ks9	"	3
152		1	61	31	CV182E	"	0
153		1	55	34	CV182M	"	0
154	99	1	61	28	CV182L	"	2
155	86	1	43	25	CV215	"	5
156	82	1	51	30	CV223	"	5
157	69	2	43	32	CV53	"	6
158	69	2	43	34	CV303	"	7
159	72	1	53	22	CV318	"	6
160	65	3	49	28	RS 610	"	14
175	59	4	41	34	RS 610	"	14
176	65	1	47	36	80-4032	Pearl millet	9
177	67	2	40	22	80-4151	"	9
178	83	1	25	22	80-4154	"	3
179	72	1	33	33	80-4157	"	4
180	58	3	30	34	80-4306	"	6
181	72	2	97	29	80-4327	"	5
182	59	3	40	31	80-4369	"	12
183	67	4	54	41	80-4370	"	14
184	74	1	57	31	80-4378	"	4
185		1	25	26	80-4422	"	0
186	56	5	71	44	80-4425	"	14
187	59	3	59	27	80-4435	"	14
188	81	1	21	18	80-4439	"	3
189	65	2	36	27	80-4442	"	10
190	58	2	56	22	80-4468	"	12
191	67	2	46	41	80-4492	"	6
192	56	5	38	35	2037/78-7024	"	14
193	54	5	60	42	2037/78-7088	"	14
194	59	3	86	34	2037/79-1137	"	7
195	58	2	51	28	2037/79-4104	"	7
196	59	3	76	47	2037/Senegal	"	14

Significance of Research Findings

The sprinkler irrigation gradient system has greatly speeded up the process of identifying drought-tolerant sorghums and millets. It can help evaluate thousands of plants each year.

Results of studies on photosynthesis, transportation, leaf temperature, leaf resistance and other features are helping us understand how drought-tolerant plants respond to moisture stress. With this information breeders can provide germplasm with the necessary characteristics for survival in adverse environments.

LDC Collaboration

Sorghum/millet genotypes have been sent to Yemen, Sudan and Senegal for testing by national programs in those countries. Sorghums have been screened by ICRISAT/CIMMYT under the sprinkler irrigation gradient.

The project leader has accepted a 3-year assignment to Cape Verde Islands under a USAID contract. It is likely that INTSORMIL research will be intitiated there in the near future.

Table 2. Sorghum and Millet Entries from INTSORMIL Institutions Screened under the Sprinkler Irrigation Gradient in Yuma, Az.

Cooperators — U.S. institutions — 1982 to 1984		
Institution	Sorghum	Millet
	(No. rows)	(No. rows)
Arizona	323	25
Texas A&M	250	
Purdue	212	
Kansas State	187	273
Nebraska	166	52
DeKalb	110	

Training and Technical Assistance

Six students from Ghana, Malawi, Congo and the U.S. have completed their graduate degrees using research in this project. Twelve others from Yemen, Sudan, Tunisia, Somalia, Botswana, Libya and the U.S are conducting research at present.

Implications for Future Research

We will continue screening millet and sorghum lines for drought tolerance using the SIG system. We will encourage breeders from throughout the world to send germplasm for these evaluations. We will also continue identifying the physiological and morphological characteristics of drought-tolerant genotypes.

The breeding program will continue the selection and development of improved sorghum and millet lines. Annual recycles of two heat- and drought-tolerant sorghums (NP3R and NP9BR) for selection of fertiles and steriles will continue. After single plant selections are made and field-tested, they will be sent for further trials in LDCs.

The grow-out of seed from the Yemen collection will be completed, and non-photoperiod-sensitive lines identified will be tested in LDCs.

Seedling aluminum tolerance screening will continue if results from field trials in Colombia indicate a high correlation with controlled environment studies. We will also continue developing salt-tolerant sorghum genotypes.

Selected Publications

Abbas, Mohamed and V. Marcarian. 1984. Effect of intercropping on sorghum and cowpeas. ,*Proc. Az.-Nev. Acad. Sci. Abst.* 19:20-21.

Agbary, Abdul, Robert L. Voigt and Albert K. Dobrenz. 1984. Genotypic response of several lines of sorghum (*Sorghum bicolor* (L.) Moench) to water stress. I. Photosynthesis, diffusive resistance, leaf temperature and epicuticular wax content. *Proc. Az.-Nev. Acad. Sci. Abst.* 19:45.

Agbary, Abdul, Robert L. Voigt and Albert K. Dobrenz. 1984. Genotypic response of several lines of sorghum (*Sorghum bicolor* (L.) Moench) to water Stress. II. Transpiration, diffusive resistance, leaf temperature and epicuticular wax content. *Proc. Az.-Nev. Acad. Sci. Abst.* 19:45.

Agbary, Abdul, Robert L. Voigt and Albert K. Dobrenz. 1984. Screening for drought resistance in several lines of sorghum (*Sorghum bicolor* (L.) Moench.). *WSCS Abst.* p. 17.

Boyne-Goni, Sylvestor. 1982. Combining ability and inheritance of aluminum tolerance in grain sorghum (*Sorghum bicolor* (L.) Moench). Publ. No. 8217397. Univeristy Microfilms, Ann Arbor, Michigan (Diss. Abstr. 43:582-83).

Boyne-Goni, Sylvestor and V. Marcarian. 1984. Diallel analysis of aluminum tolerance in selected lines of grain sorghum. *Crop Sci.* (in press).

Bimpolo, Paul and Robert L. Voigt. 1984. Physiological aspects of reduced tillage on double crop grain sorghum after barley in central Arizona. *Proc. Az.-Nev. Acad. Sci. Abst.* p. 47.

Chigwe, Charles F.B. and Robert L. Voigt. 1984. Performance of NP9BR sorghum progenies under heat and drought. *Proc. Az.-Nev. Acad. Sci. Abst.* p. 46.

Chigwe, Charles F.B. and Robert L. Voigt. 1984. Improvement of NP9BR random-mating sorghum population using genetic male sterility. *Proc. Az.-Nev. Acad. Sci. Abst.* p. 46-47.

Hofmann, C.W. and A.K. Dobrenz. 1983. Stomate density and physiological characteristics of sorghum hybrids and parents. *WSCS Abst.* p. 14.

Hofmann, W.C. and A.K. Dobrenz. 1982. The physiology of stressed and non-stressed sorghum (*Sorghum bicolor* (L.) Moench). *WSCS Abst.* p. 2.

Hofmann, W.C., M.K. O'Neill and A.K. Dobrenz. 1984. Physiological responses of sorghum hybrids and parental lines to soil moisture stress. *Agron. J.* 76:223-228.

Marcarian, V., A.K. Dobrenz, M. O'Neill and W. Hofmann. 1982. Evaluation of drought tolerance in sorghum and millet under a sprinkler irrigation gradient system. *WSCS Abst.* p. 2.

O'Niell, J.K., W. Hofmann, A.K. Dobrenz and V. Marcarian. 1981. Differentially irrigated sorghum and millet on the Yuma Mesa. Az. Coop. Ext. Serv. and Agric. Exp. Sta. Report Series P-54. pp. 55-59.

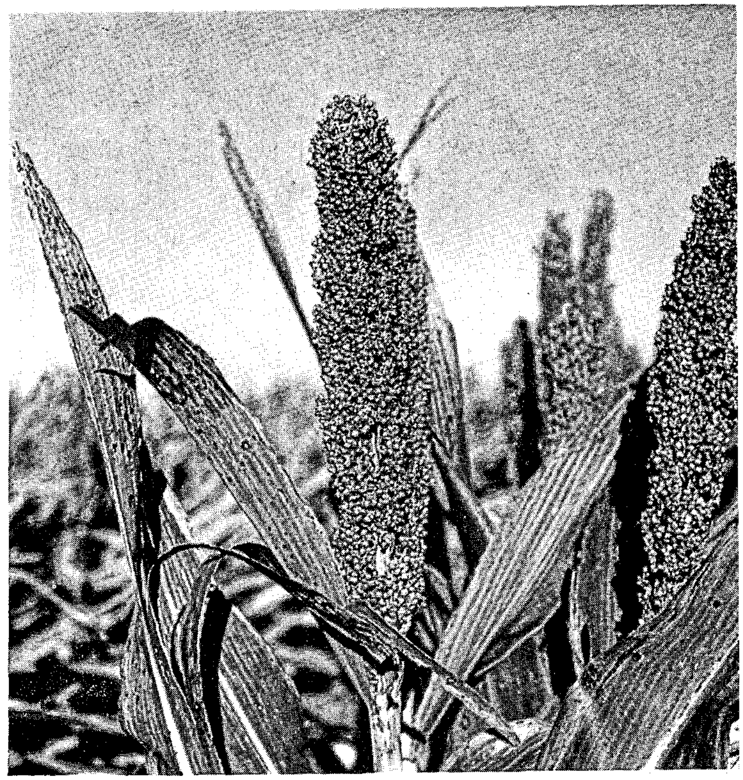
O'Neill, M.K., W.C. Hofmann, A.K. Dobrenz and V. Marcarian. 1983. Drought response of sorghum hybrids under a sprinkler irrigation gradient system. *Agron. J.* 75:102-107.

Robinson, D.L. and A.K. Dobrenz. 1984. Evaluation of drought tolerance in sorghum. *Az.-Nev. Acad. Sci. Abst.* p. 46.

Yassin, Ibrahim and V. Marcarian. 1984. Agronomic and physiological characters of pearl millet (*Pennisetum americanum* (L.) K. Schum) grown under a sprinkler irrigation gradient. *Proc. Az.-Nev. Acad. Sci.* 19:14-15.

This tall Egyptian sorghum grown in the sprinkler irrigation gradient system shows the effects of water stress.

The sorghum midge causes extensive damage to sorghum crops in many parts of the world.



ENTOMOLOGY

Sorghum and millet are attacked by a large and diverse group of insects. Some are serious, perennial pests, some are secondary pests, and some are occasional pests which cause problems only at certain times or in certain locations. Some pests are widely distributed, while others are found only in particular locations.

Sorghum/millet insect control is no simple matter. Some control strategies are quite species specific, while others can be effective with a number of species. In some cases the controls used against one pest species increase damage by another. Important considerations in any insect control program are preserving the environment and keeping production costs as low as possible. Because of these things, the integrated pest management (IPM) approach, which combines biological, chemical and cultural control practices, offers tremendous benefits. The INTSORMIL entomology projects are based on IPM.

This discipline consists of three projects, involving five scientists from three universities. One project (now terminated) had responsibility for developing and/or evaluating grain storage procedures for controlling insects which damage stored grain. A second project deals with controlling the fall armyworm. And a third project emphasizes biological control and the development of resistant plants to deal with a variety of insect pests. This project also is seeking ways to adapt technology to the sorghum ecosystems of LDCs.

The responsibility of INTSORMIL entomologists is to share technology with producers and scientists in LDCs while keeping in mind their local needs. We have focused on insect control methods that are directly applicable to LDCs and that are the least disruptive to the cultural and production histories of the people. Those methods include the planting of resistant varieties, biological and cultural control. The use of chemical insecticides is based on ecological knowledge of the area and the recognized need to keep production costs low.

Although our collaboration with LDCs has been productive, the lack of trained entomologists in those countries is a limitation.

Executive Summary

We studied stored-product insects by exposing millet kernels to 15 different species and analyzing the results. Different millet cultivars showed considerable variation in susceptibility to rice weevil, lesser grain borer and Angoumois grain moth. The red flour beetle was more damaging to ground and cracked millet than to whole kernels; the opposite was true of the maize weevil. Threshing method and kernel size seemed to affect the susceptibility of some cultivars to certain insect species. It was found that use of ventilated storage containers reduced damage from stored-product insects.

Research on the fall armyworm was extensive. Numerous lines were screened for resistance, and natural parasites and predators of fall armyworm are being studied. We are improving sampling techniques and measuring differences in plant age as they relate to insect damage.

Sorghum lines resistant to greenbug, sorghum midge, corn leaf aphid, sugarcane aphid, maize weevil and Banks grass mite have been identified. We have conducted ecological and biological studies that help us in transferring technology to LDCs. One resulting effort will be the collection of parasites and predators in one part of the world to be shipped to and released in another country to aid in biological insect control.

In addition to these general programs, there are efforts to alleviate the problems caused by specific pests in individual countries such as Niger, Mali and Honduras.

Storage and Preservation of Pearl Millet and Sorghum

Robert B. Mills and John R. Pedersen

Kansas State University

Initially this project dealt only with millet. Sorghum was included in our research later, but the emphasis on millet is probably appropriate because so little research has been done on storage losses in pearl millet. Our initial studies demonstrated the relative damage caused by common storage insects in millet. Later tests demonstrated that among 76 pearl millet cultivars tested there were wide differences in susceptibility/resistance to three insect species; thus there is potential for developing millet resistance to storage insects. Further studies were done on the possible causes of different susceptibility/resistance responses in millet (seed size, hardness, etc.). Investigations of sorghum resistance to storage insects were begun.

We studied three threshing methods to see if they affected susceptibility of stored millet to insects. Grain threshed with the native mortar and pestle method was much less susceptible to secondary insects, such as flour beetles and sawtoothed grain beetles, than grain threshed by two mechanical methods.

Little research has been done on the effectiveness of traditional methods of millet storage. We used large plastic containers simulating basket and mud-block storage to test in-head and threshed millet for rice weevil and red flour beetle damage. Pit storage is commonly used by subsistence farmers for millet and sorghum in drier areas. Five-gallon cans of millet with different moisture contents were used to study the atmospheric gas changes that might occur during pit storage. The atmospheric gases, moisture, and temperature of millet stored in six underground pits are being monitored to determine the changes in atmospheric conditions in the pits.

We have studied the biology of selected stored-grain insects. Specific areas include the effects of seed size on insects, the olfactory attractiveness of millet and millet products to insects, and the development of insects in millet as compared to other grains.

Research Accomplishments

Infestibility of Millet

Since little has been reported on the infestibility of pearl millet by stored-product insects, in the first experiment we exposed it to 15 species. Thirty adults were introduced into each 35-g sample of millet. After 6 weeks at 27°C and 67 percent relative humidity, samples contained from 32 to 474 adults each. The most successful insect species tested are listed in the following table.

Species	$\overline{X}$ no. adults	% wt. loss of grain
Maize weevil	474.3	44.3
Rice weevil	442.7	30.5
Confused flour beetle	283.3	8.69
Sawtoothed grain beetle	276.0	3.41
Cigarette beetle	243.3	13.56
Granary weevil	145.0	17.28
Merchant grain beetle	142.3	3.59

Host Resistance of Pearl Millet

In a free-choice test, 11.5-g samples of 76 pearl millet entries were exposed to the rice weevil (10/sample) for 7 days. After 54 days the number of adult progeny for each entry ranged from 10.3 to 125.7.

Thirty-seven of the above entries (showing all levels of resistance to rice weevil) were evaluated against the lesser grain borer in the same way, except that 15 insects per sample were used. The numbers of progeny ranged from 27.0 to 126.3.

These 37 entries were then exposed to Angoumois grain moths by placing 20 eggs in each sample (no-choice test). The mean percent of hatched larvae resulting in adults ranged from 46.0 to 89.1

These tests showed that wide differences exist among millet cultivars in their susceptibility/resistance to stored-grain insects. The responses to rice weevil and Angoumois grain moth were similar; the smaller-seeded entries tended to be more resistant. Resistance to the lesser grain borer did not seem to be associated with seed size. The resistant entries tended to be "harder" as measured by a pearling index, the depth of the impression of a weighted diamond crystal, and percent vitreous endosperm.

Influence of Millet Condition

The red flour beetle was much more successful in ground and cracked millet, while the maize weevil was much more successful in whole kernels. The following table includes the numbers of insects produced after 76 days and 78 days for red flour beetle and maize weeveil, respectively, in 300-g samples of each medium. The data indicate that flour beetles can develop populations in whole millet.

Medium	No. insects
Maize weevil	
Whole kernel	1341.8
10% cracked	1149.2
Cracked	75.3
Flour	50.2
Red flour beetle	
Whole kernel	268.7
10% cracked	244.7
Cracked	612.0
Flour	1417.0

Effect of Threshing Method

Threshing method affects millet's susceptibility to certain species. The table below shows the mean numbers of adult progeny produced by 20 adults of each species during 6 weeks.

The two mechancial threshing methods were beneficial to the last three species.

Species	Combine (10.8%)*	Lab. (1.8%)	Mortar/pestle (0.5%)	Hand (0.0%)
Maize weevel	67	68	53	57
Lesser grain borer	33	8	3	6
Confused flour beetle	160	108	6	4
Sawtoothed grain beetle	134	109	8	1.5
Angoumois grain moth	25	28	12	21

*Dockage

Biology of Angoumois Grain Moth

The results of our studies of the biology of the Angoumois grain moth in millet as compared to other grains are given below.

Developmental period (days)			
Corn	Millet	Wheat	Sorghum
47.6	45.5	43.5	36.7
Number of eggs/female			
Wheat	Corn	Sorghum	Millet
62	53	44	27
Adult size (mg)			
Corn	Sorghum	Wheat	Millet
3.5	3.0	3.0	2.6

Effects of Seed Size

Data in the following tables show the effect of kernel size on the biology of the Angoumois. The moths from the small kernels were smaller, produced fewer eggs, and caused less weight loss to the millet kernels.

Wing length, body weight, and developmental time for Angoumois grain moths reared in millet kernels of three sizes.

Cultivar	Wing length (mm)		Body weight (mg)		Devel. time (days)[1]	
	female	male	female	male	female	male
1 (L)	5.14 a**	4.73 a	4.04 a**	2.44 b	40.1 a	42.1 b
1 (M)	4.40 b	4.28 b	2.46 d**	1.82 c	44.4 a	45.4 ab
1 (S)	3.81 c	3.59 c	1.42 e	1.01 d	42.3 a	48.0 ab
2 (L)	4.93 a*	4.66 a	3.53 b**	2.71 a	44.6 a	42.0 b
2 (M)	4.58 b	4.55 a	2.84 c*	2.40 b	42.7 a	50.2 a
2 (S)	3.78 c	3.84 c	1.44 e	1.34 d	4.70 a	44.3 ab

[1] Hatching to adult. (L), (M), (S) = large, medium, small

Numbers of eggs, hatchability, and adult longevity of Angoumois grain moths reared in millet kernels of three sizes.

Cultivar	$\overline{X}$ eggs/ female	$\overline{X}$ % hatch.	No. females	Adult Longevity Female	Adult Longevity Male
1 (L)	72.6 a	85.4 a	16	9.6 a	8.8 a
1 (M)	43.8 b	87.4 a	17	10.3 a	8.0 a
1 (S)	21.3 c	85.0 a	7	8.3 a	7. a
2 (L)	64.3 ab	91.9 a	18	9.9 a	8.4 a
2 (M)	29.1 c	85.8 a	13	12.3 a	8.9 a
2 (S)	21.3 c	90.8 a	6	8.6 a	8.5 a

(L), (M), (S) = Large, medium, small.

Mean initial dry weights of pearl millet kernels from which male or female Angoumois grain moths emerged.

Cultivar	$\overline{X}$ initial dry wt. of kernel (mg)		$\overline{X}$ kernel wt. loss (mg)	
	Females	Males	Females	Males
1 (L)	15.9	16.8	11.1	9.5
1 (M)	8.2	8.2	6.7	6.4
1 (S)	5.4	5.2	4.5	4.4
2 (L)	13.8	15.2	9.4	8.6
2 (M)	9.3	9.4	7.3	7.5
2 (S)	5.3	5.2	4.5	4.4

(L), (M), (S) = large, medium, small

Maize and Rice Weevils in Millet

Maize weevils and rice weevils, reared for many generations in maize and wheat, respectively, became significantly smaller during two generations in pearl millet.

Generation	Elytron length	
	Males	Females
Maize weevil		
P_1 (from corn)	1.89mm	1.94mm
F_1 (from millet)	1.63	1.65
F_2 (from millet)	1.44	1.5
Rice weevil		
P_1 (from wheat)	1.67	1.64
F_1 (from millet)	1.51	1.55
F_1 (from millet)	1.39	1.42

Susceptibility to Rice Weevil and Angoumois Grain Moth

Twenty-seven millet lines (mostly hybrids) were raised in two locations in Kansas. No consistent location differences were found in resistance to the rice weevil or to the Angoumois grain moth. More rice weevils were produced in threshed grain than in heads; Angoumois grain moth exhibited no such differences.

Attraction of Red Flour Beetle to Millet

As indicated by the number of "visits" near the millet test materials and the length of visits, the millet products (flour, fermented millet flour, and millet starch) were much more attractive to the red flour beetle than whole millet kernels.

Responses of Adult *Tribolium castaneum* to volatiles from whole millet kernels, whole millet flour, or millet products.

	Mean number of visits[b]	Mean time spent (min)[b]
A. Sex		
Female	10.750 a	0.445 a
Male	8.083 b	0.713 a
Mixed-sex	9.458 ab	0.728 a
B. Test material		
Whole millet kernel	9.333 c	0.832 b
Whole millet flour	18.556 ab	1.435 a
Fermented millet flour	20.444 a	1.806 a
Millet starch	15.556 b	0.704 b
Control	2.889 d	0.063 c

[a]Means of responses of: (A) beetles (by sex) to four test materials considered together; (B) beetles (all sex groups) to each of the test materials. For each test, ten 72- to 96-hr-old beetles were observed for three 10-min. periods.

[b]Means followed by the same letter are not significantly different at the 5% level, (Duncan's multiple-range test).

Rice Moth in Millet

The rice moth, a common pest of millet in Africa, survived much better in millet kernels than in other raw grains, and equally well in millet kernels as in milled or broken rice. This insect did best in broken millet of all the media tested.

Number of rice moths emerged from various grains, and days to first moth emergence (each grain infested with 25 mg eggs).

Grain	No. emerged	Days to first emergence
Whole millet	87	50
Broken millet	93	43
Whole sorghum	63	50
Whole corn	40	55
Whole wheat	34	85
Milled rice	84	53
Broken rice	85	50
Whole rough rice	3	116

Pit Storage

Pits are used by subsistence farmers to store millet and sorghum in some of the drier areas of the world. We simulated pit storage with airtight 5-gallon cans. Into these "pits" we placed millet with three different moisture levels. To some pits we also added rice weevils (10/kg). The pits were monitored for CO_2 and O_2 concentrations, relative humidity and temperature for 74 days. Significant biological activity occurred in containers with 15.5 percent moisture, with or without weevils, and in containers with 13 percent moisture plus weevils. In these containers the CO_2 concentration increased and the O_2 concentration decreased. Insets died in all containers, probably from lack of O_2 in those with biological activity, and from lack of moisture in the 10.0 percent moisture containers.

Concentration (percent) of O_2 and CO_2 in sealed 5-gal. cans of millet having 10, 13, or 15.5 percent moisture content, and with or without rice weevils (10/kg).

	Days after infestation and sealing						
Treatment	1	4	7	15	29	51	74
Oxygen concentration							
RW[1] (10%)[2]	19.6	18.8	17.6	14.8	12.4	12.8	12.9
RW (13%)	19.7	18.0	16.7	8.0	3.9	5.1	6.4
RW (15.5%)	19.2	15.3	13.8	3.0	1.3	1.4	1.3
NRW (10%)	20.2	19.6	20.3	20.3	20.1	18.4	19.6
NRW (13%)	18.7	20.1	20.0	18.3	19.6	19.0	18.6
NRW (15.5%)	19.6	17.0	16.8	14.7	1.5	1.6	1.7
Carbon dioxide concentration							
RW (10%)	0.3	1.1	1.8	3.2	3.9	3.7	3.4
RW (13%)	0.6	1.2	2.2	6.9	10.3	9.9	9.4
RW (15.5%)	0.9	3.7	6.2	15.8	19.8	24.0	28.9
NRW (10%)	0.1	0.1	0.1	0.2	0.2	0.2	0.3
NRW (13%)	0.1	0.2	0.2	0.3	0.5	0.7	0.8
NRW (15.5%)	0.7	2.3	3.5	6.7	16.2	20.0	23.6

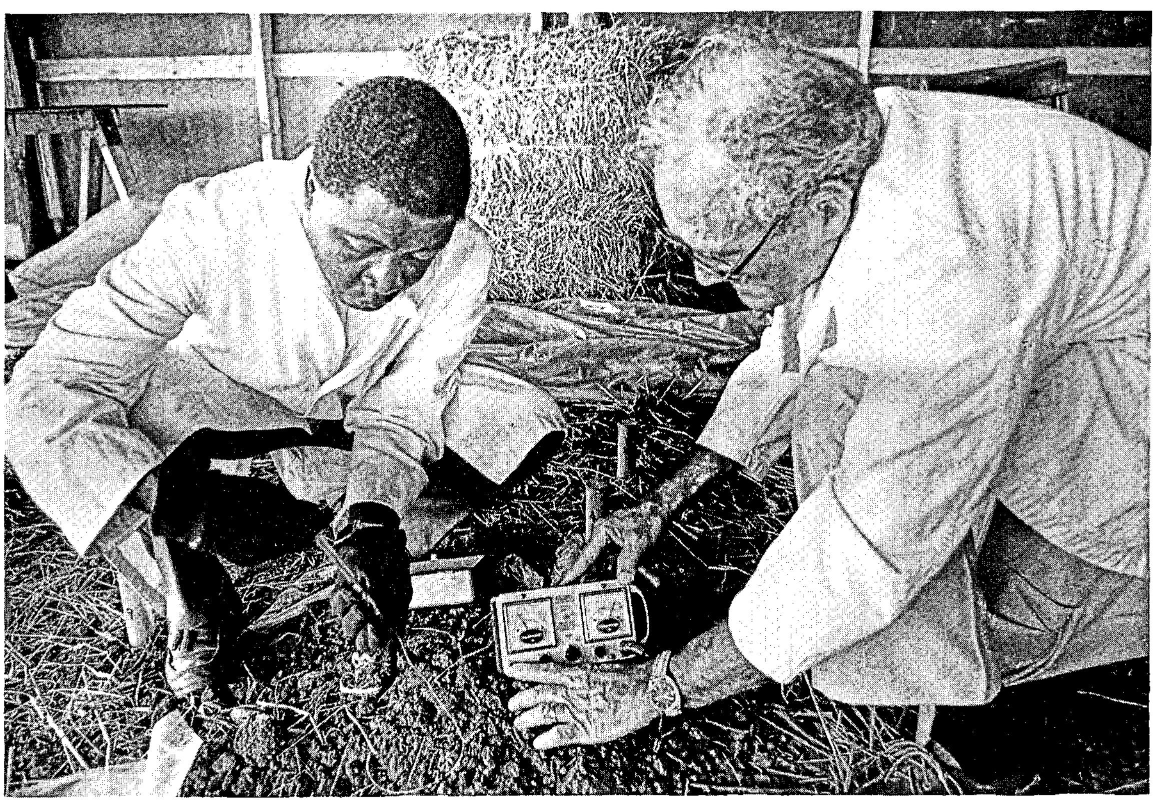
[1]RW = rice weevil included; NRW = no rice weevils
[2]Moisture content

Sorghum Resistance to Rice Weevil and Angoumois Grain Moth

Twelve sorghum varieties, some from Sudan, were evaluated for resistance to rice weevil and Angoumois grain moth. The smallest number of rice weevil progeny were obtained from Tatel and Shallu in no-choice tests and from Shallu, Sagrain and Tatel in free-choice tests. Tannin content correlated negatively with numbers of progeny: free-choice, -0.373; and no-choice, -0.026. Hardness contributed to rice weevil resistance, but not to Angoumois grain moth resistance. Removal of the pericarp, in general, made most varieties more susceptible to both species.

Traditional Storage Systems for Pearl Millet

Three traditional on-farm storage methods of pearl millet were simulated using 20-gallon (76-1) plastic garbage cans. The storage units were infested with rice weevils alone or with both rice weevils and red flour beetles. After 14 weeks insect populations and grain losses were measured. Under controlled conditions, pearl millet stored on-head in ventilated conditions (simulating woven seed storage units) was less damaged than millet stored on-head in non-ventilated containers (simulating mud-plastered storages). Both on-head systems offered more protection against insect population increase than bulk storage of threshed millet in non-ventilated storage bins.



Cletus Asanga, a Kansas State University graduate student from Cameroon, monitors conditions in millet storage pits by withdrawing a sample of the atmospheric gases. The pits are infested with red flour beetles and rice weevils. Assisting Mr. Asanga is Robert B. Mills, his advisor.

Significance of Research Findings

The common stored-grain insects of millet were studied. Millet varieties vary significantly in their susceptibility/resistance to these insects. This demonstrates the potential for using host resistance in breeding programs to reduce storage losses. Hardness and small kernel size were found to be important factors associated with resistance. Small kernel size was associated with fewer insect progeny, smaller adults, fewer eggs, and less grain damage per insect. There should be further investigations of factors causing resistance and ways they can be applied to breeding programs.

The finding that mechanical threshing methods increase the susceptibility of millet to stored-grain insects has serious implications, since increased production usually necessitates mechanical threshing and handling.

Olfactometer studies demonstrated that insect losses could be reduced by storing millet in the whole kernel form rather than as ground millet or flour.

And our evaluations of simulated traditional and modern forms of storage could have direct application in developing countries. Traditional ventilated, on-head storage seems to have advantages.

LDC Collaboration

No formal LDC linkages for cooperative research had been established when this project was terminated. However, project members have many contacts in LDCs, some of whom have indicated a strong interest in cooperative research.

Training and Technical Assistance

Training of students from LDCs has been an important part of this project; eleven students from seven countries have or are receiving research training in grain storage and stored-product entomology in the Department of Entomology or the Department of Grain Science and Industry at Kansas State University. Their research was or is supported at least in part by INTSORMIL funds. Project members frequently participate in grain storage training programs for LDC participants in their countries or in the U.S.

Implications for Future Research

Our research has shown the potential of breeding millet and sorghum for resistance to stored-grain insects, and that should be pursued. It was determined that millet is as susceptible as other cereals to common stored-grain insects, and that good storage practices are required to minimize losses. Equal emphasis should be given to sorghum storage. As production increases, present storage practices may not suffice. Traditional practices (underground and aboveground) used for generations should be critically studied to determine which features are good and which may need to be modified. More information is needed on the extent of storage losses in various LDCs.

Selected Publications

Kossou, D., R. Burroughs and J.R. Pedersen. 1983. Evaluation of traditional storage systems for pearl millet. (in preparation).

Meagher, R.L., Jr., C. Reed and R.B. Mills. 1982. Development of *Sitophilus zeamais* and *Tribolium castaneum* in whole, cracked and ground pearl millet. *J. Kansas Entomol. Soc.* 55(1):91-94.

Seifelnasr, Y.E., T.L. Hopkins and R.B. Mills. 1982. Olfactory responses of adult *Tribolium castaneum* (Herbst) to volatiles of wheat and millet kernels, milled fractions, and extracts. *J. Chem. Ecology* 8(12):1463-72.

Seifelnasr, Y.E. and R.B. Mills. Varietal pearl millet grain resistance to *Sitophilus oryzae*, *Sitotroga cerealella*, and *Rhyzopertha dominica*. *J. of Economic Entomol.* (submitted).

Biological Investigations and Management of the Fall Armyworm on Sorghum

Henry N. Pitre
Mississippi State University

Billy R. Wiseman
United States Department of Agriculture

The fall armyworm (FAW), *Spodoptera frugiperda*, attacks many grain crops, has a wide geographical distribution, and is a major constraint to sorghum production in some areas of North, Central and South America. This INTSORMIL project is designed to investigate FAW for the purpose of developing control tactics for use in developing countries. The objectives are to investigate aspects of the biology, ecology, and population dynamics of the fall armyworm in relation to specific pest control strategies that may be applicable in developing countries; identify natural enemies and determine their impact on fall armyworm populations; identify sorghums with resistance to the fall armyworm and determine resistance mechanisms; and determine effective interacting cultural, biological and chemical control strategies for fall armyworm management. Foreign student training is an important part of this program.

Research Accomplishments

Behavior and Population Dynamics

Egg and larval sampling techniques were evaluated for use in estimating populations of FAW on plants in different phenological growth stages. Specific attention was given to early detection of larvae to enhance control efforts during early stages of larval development. Distribution of eggs and larvae on sorghum plants and within the field was investigated. We also studied oviposition patterns, egg laying preferences, larval feeding and survival, and adult survival in relation to growth stages of plants.

Fall armyworm moths showed oviposition preferences for several closely related host plants, with sorghum being one of the preferred species in the grass family (Table 1). Number of eggs per mass was determined, but this information may not be as important to pest control decisions as the number of egg masses deposited, particularly since mortality (abiotic and biotic) of the young larvae is high. The number of egg masses laid increased with the increased age and size of the sorghum plants (Table 2). This plant age-ovipositional relationship apparently contributes to FAW survival. Mature plants give more protection to adults, eggs and larvae; oviposition at or near the reproductive stages of the plants has nutritional benefits; and larvae are more easily disbursed from larger plants. On sorghum, eggs were concentrated on leaves between nodes 5 and 9 ($\bar{x}$ = 7.7), with the under surface of the leaves preferred over other plant surfaces for egg deposition. This information is particularly useful in sampling for the FAW in the field. Sampling for eggs will be expedited by knowing where to look for this stage of this pest. This information can also help in developing cultural strategies (i.e., trap crop or trap plant interplantings) for developing countries.

Table 1. Fall Armyworm Oviposition on Crop Plants—Greenhouse Test.

Crop plant	Mean no. of egg masses and eggs per mass per treatment in 72 h	
	Egg masses	Eggs/mass
Ryegrass	2.8	159.0
Wheat	2.6	79.3
Corn	2.2	133.8
Sorghum	2.2	155.5
Bermudagrass	1.6	146.3
Rye	1.6	44.5
Cotton	1.4	116.7
Soybean	1.1	

The relationship of temperature to the development of the immature stages of FAW was studied in the laboratory (Table 3) and in the field. Information from these studies was used to develop a procedure for examining the early-season phenology of the FAW by estimating the ages of field-collected larval cohorts. Application of this procedure to FAW larvae collected in an extensive survey in Mississippi during the spring provided evidence that the observed populations were initiated by immigrant adults.

To develop methods of controlling an insect pest it is important to know about its behavior and conditions that affect it. The age structure of the FAW on sorghum through one crop growing season was determined at LaLujosa, Honduras. Infestations increased to a peak in late June, then declined through July and August (Fig. 1). There were two complete generations on sorghum planted in mid- to late May. This information will help in planning FAW management strategies on sorghum.

Biological Control

Studies of age specific mortality and partitioning of mortality of FAW immatures are in progress in four developing countries. The composition and impact of parasitoids is being defined.

Five parasite species from four families were reared from larvae collected on corn in Mississippi. Parasites collected included *Apanteles marginiventris* (Cresson), *Archytas marmoratus* (Townsend), *Campoletis flavicincta* (Ashmead), *Ophion flavidus* (Brulle) and *Euplectrus plathyhypenae* (Howard). Similar surveys were conducted on sorghum in 1983 in Mississippi and in cooperating developing countries (Colombia, Hon-

Table 2. Age, Mean Height (Ht.) and Node (No.) Development of Plants Tested for Oviposition Preferences (Mean Number of Egg Masses (EM) Deposited in 72 h) by the Fall Armyworm in Greenhouse and Field Cage Studies.

Plant age (days)	Corn Ht (m)	Corn No (no.)	Corn EM (no.)	Cotton Ht (m)	Cotton No (no.)	Cotton EM (no.)	Sorghum Ht (m)	Sorghum No (no.)	Sorghum EM (no.)	Soybean Ht (m)	Soybean No (no.)	Soybean EM (no.)
22	0.30	7	0.2	0.10	3	0.0	0.28	6	0.4	0.10	3	0.2
32	0.36	8	0.4	0.18	5	0.0	0.46	6	0.4	0.23	5	0.2
42	0.74	10	9.6	0.20	6	0.4	0.58	8	1.4	0.36	8	0.4
54	1.09	13	2.4	0.36	10	1.0	1.02	10	1.1	0.69	11	0.8
64	1.27	14	2.0	0.41	10	1.2	0.99	10	1.9	0.43	9	1.4

Table 3. Developmental Time (Days) of the Immature Stages of the FAW on Artificial Diet at Constant Temperatures.

Stage	Sex	20° n[a]	20° x ± SD	25° n	25° x ± SD	30° n	30° x ± SD
Egg	M + F	20	4.25 ± 0	21	2.75 ± 0	21	1.75 ± 0
Larva	M + F	40	24.3 ± 3.4	48	14.0 ± 2.6	47	9.3 ± 1.0
Pupa	M	22	22.1 ± 1.5	31	12.5 ± 0.8	23	8.5 ± 0.7
	F	15	19.5 ± 1.1	17	11.1 ± 0.9	23	8.0 ± 0.6

[a] For eggs, this represents the number of masses.

duras and Mexico). The survey results in Mississippi suggest that FAW larval parasitization may affect the early-season dynamics of pest populations, and that parasite species composition and parasitization rate can vary with latitude.

In Colombia, Honduras and Mexico, armyworm larvae were collected on whorl stage sorghum at various times during the growing season, and were shipped to the ARS-USDA Stoneville Research Quarantine Facility (SRQF) in Mississippi. The larvae were identified to instar at the time of collection in the field, and confined individually in 1-oz. plastic cups containing artificial diet. The material received at the SRQF was held for observations of parasite emergence (Table 4), larval mortality, and identification of adult parasites and moths. Parasites were submitted to the Insect Identification and Beneficial Insect Introduction Institute, Beltsville, Maryland, for species identification (Table 5). Dead larvae and pupae from selected sample collections were submitted to Mississippi State University for pathological analysis.

In Honduras, FAW larvae of all ages were collected at weekly intervals from June 9, 1983, one week after germination, until July 27, 1983. Larvae collected in the field were held for parasitoid emergence and adult identification. The most prevalent parasite was *Hexamermis* sp., a nematode, which parasitized up to 56 percent of the fall armyworm larvae when the pest population was at highest density. This nematode appeared to be more active during wet periods. The second most common parasite was *Chelonus insularis* Cresson, which showed stable populations through the sampling period except during the peak population of *Hexamermis*, at which time *C. insularis* was absent. Several tachinids were present, but they were not all present throughout this growing season and none was responsible for a high level of parasitization.

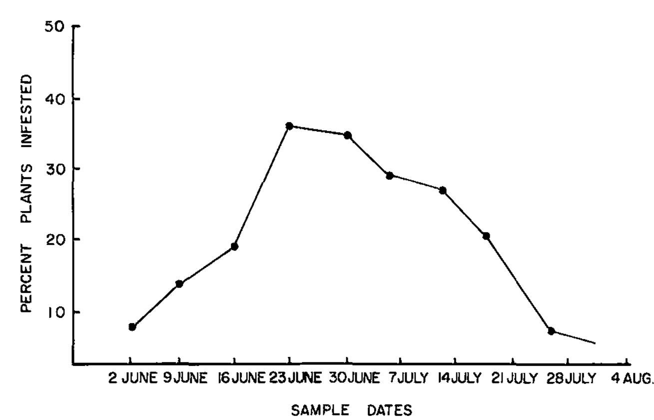


Figure 1. Fall armyworm infestation on sorghum at Choluteca, Honduras, 1983.

Table 4. Observations of Fall Armyworm Mortality for Insects Collected on Whorl Stage Sorghum.

			Inventory		
Location	Date	No. Larvae collected	% Parasitized	% Mortality[1]	% Adult emergence
MEXICO					
Posa Rico	4/14/83	97	18	37	45
Guadalajara	7/18/83	57	37	7	56
Celaya	7/20/83	61	20	26	54
HONDURAS					
Choluteca	4/18/83	75	37	21	42
COLOMBIA					
Cali	7/7/83	100	51	19	30

[1] Mortality due to factors other than parasitization, i.e. NPV or bacteria.

Table 5. Parasites on Sorghum (Collections in Mexico, Honduras, and Colombia).

Location	Parasite		classification (host stage)
Mexico	Hymnoptera		Diptera
Posa Rico	Braconidae		Tachinidae
	Rogas laphygmae Viereck	(L)	*Archytas* sp. (L.)
	Chelonus sp.	(E)	
	Ichneumonidae		
	Campoletis sp.	(L)	
	Unidentified spp.		
	Eulophidae		
	Euplectris sp.		
Guadalajara	Ichneumonidae		
	Campoletis sp.	(L)	
Celeya	Braconidae		
	Chelonus insularis Cresson	(E)	Unidentified spp.
	Apanteles sp.	(L)	
	Micropletis croceipcs	(L)	
Honduras			
Choluteca	Braconidae		
	Chelonus insularis Cresson	(E)	
Colombia			
Cali	Braconidae		Tachinidae
	Meteorus laphygmae Viereck	(L)	*Archytus marmoratus* Townsend (L)
	Chelonus sp.	(E)	
	Ichnoumonidae		
	Eiphosoma vitticolle Cresson	(L)	

E = Egg; L = Larva

Host Plant Resistance

In this project, many sorghum cultivars have been evaluated in the field and in the greenhouse for resistance to FAW. We have observed the behavior of adults and larvae on plants with different morphological and physiological characteristics.

Natural infestations of the FAW occur annually in Mississippi, which allows for a successful field research program. However, the mass rearing of this pest at Mississippi State University provides the source of insects required for intensive host plant resistance investigations in both field and greenhouse. These studies are conducted throughout the year.

Field evaluations of more than 550 sorghum lines were completed during 1979 and 1980. The next year about 50 lines selected as having the least amount of damage by the FAW were evaluated. There were significant differences in foliage damage among genotypes. Many field and greenhouse tests with large numbers of sorghum lines were conducted in Mississippi, Georgia, Honduras and Mexico. These revealed that only two lines, 1821 c.m. and QL-3 showed less feeding damage by the FAW. None of the materials tested showed resistance to this pest.

Twenty-five sorghum lines selected for a wide range of physiological and morphological characteristics were evaluated in 1980. Significant ($P = 0.05$) differences in cumulative leaf feeding damage were observed among the entries, which included lines with high and low tannin, brown midrib, low bloom (reduced wax) and high and low lysine. Less damage was consistently observed on three of four low-bloom lines, compared to the high-leaf phenolic, non-isogenic lines. However, none of the sorghums demonstrated resistance to fall armyworm larval feeding.

Four select sorghum genotypes, infested at the 6- to 8-leaf stage and at the 10-leaf stage, were evaluated for resistance. Damage ratings indicate that 1821 c.m. was the least damaged of the lines tested (Table 6). However, no clear-cut differences were found for larval weights or larval numbers. Apparently both larval numbers and weight per plot could indicate a low level of resistance.

Tests were conducted to determine differences in FAW responses to soft dough stage grain sorghum. First-instar FAW were placed into diet cups and fed for 9 days. The soft dough grain of Sav. 5 (high tannin) or Funks MR (low tannin) was ground up and mixed into the diet. The FAW larvae grew less on the low tannin line, but more so as concentration of the material was increased to 75 g.

We obtained sorghum seed from India and several international lines that have resistance to shoot fly and borer. These lines are under investigation. Twenty-five additional lines (glossy types) from India are in Washington and will be obtained soon. These lines have been tested for resistance to drought at the seedling stage and to shoot fly. All are medium to heavy trichome types.

Significance of Research Findings

The knowledge we have gained about the behavior of the FAW and ways it interacts with host plants will greatly help in determining the best control strategies for LDCs. Special attention has been given to early detection of FAW on sorghum.

Since our studies provided evidence that FAW populations in Mississippi are initiated by immigrant adults, adult movement and its role in FAW population dynamics is of economic and ecological importance. A better understanding of the timing and magnitude of immigration, and the relationship of local conditions to the probability of population establishment, could be used to develop an "early warning" system for predicting the severity of the FAW population in a given year in specific areas. This should be an important objective in developing control strategies for LDCs.

Table 6. Sorghum Mechanisms of Resistance—Georgia, 1980.

Stage and line	FAW damage rating		No. larvae per plot		Larvae wt. per plot (mg)		Larvae wt. per larvae	
	Mean	Group	Mean	Group	Mean	Group	Mean	Group
I. SGIRL-MR-1	4.60	a	33.20	ab	271.94	a	8.08	a
Huerin	5.20	a	32.60	ab	292.98	a	9.02	a
Funks 522 DR	4.60	a	39.40	a	356.52	a	9.10	a
1821 c.m.	2.60	b	24.60	b	227.76	a	9.30	a
II. SGIRL-MR-1	4.20	a	15.60	a	260.44	a	12.40	a
Huerin	3.20	b	10.80	b	147.50	b	13.76	a
Funks 522 DR	2.80	b	12.20	ab	207.74	ab	16.80	a
1821 c.m.	1.00	c	7.00	c	150.56	b	20.74	a
Combined								
SGIRL-MR-1	4.40	a	24.40	a	266.19	ab	10.24	b
Huerin	4.20	ab	21.70	ab	220.21	ab	11.39	ab
Funks 522 DR	3.70	b	25.80	a	282.13	a	12.95	ab
1821 c.m.	1.80	c	15.80	b	189.16	b	15.02	a

The use of naturally occurring parasites and predators of FAW may be the most economical and practical control technique in many developing countries.

We have established procedures for studying the development of FAW in the laboratory or greenhouse using live plant material. This will help us determine mechanisms of host plant resistance which may in the future be incorporated into plant breeding programs.

LDC Collaboration

This project has collaborative relationships with Colombia, Brazil, Honduras and Mexico.

Training and Technical Assistance

A Master's Degree student from Honduras and a doctoral student from the Dominican Republic are working under this project. Project members took part in several international sorghum seminars and workshops.

Implications for Future Research

Basic aspects of FAW biology and behavior will continue to be studied. We will also be working to learn more about seasonal population dynamics, and biological control with parasites, date-of-planting and intercropping and other farm management systems.

We have successfully screened large numbers of sorghum lines and hybrids for sources of resistance to the FAW. Sorghum selections from several countries will be further evaluated in Mississippi and Georgia for FAW resistance, and some of the best germplasm will be sent to Mexico and Honduras. Glossy lines from India have been tested for drought and shoot fly resistance at the seedling stage. Related lines with different leaf trichome densities will be used to test FAW biology and behavior, as well as characteristics of host plant resistance. The new technique using soft dough grain mixed into a meridic diet will be used to evaluate FAW feeding response and mechanisms of resistance in different grain sorghums.

Selected Publications

Castro, Marco, Henry Pitre and Rigoberto Nolasco P. 1984. Influencia de sistemas de siembra maiz-macicillo en infestaciones de cogollero. Departamento de Investigacion Agricola Reporte Annual, Recursos Naturales. Tegucigalpa, Honduras.

Castro, Marco, Henry Pitre and Rigoberto Nolasco P. 1984. Investigaciones de control biologico de cogollero. Departmento de Investigacion Agricola Reporte Annual, Recursos Naturales. Tegucigalpa, Honduras.

Castro, Marco, H. Pitre and Rigoberto Nolasco P. 1984. Densidad de poplaciones de larvas de cogollero en sorgo. Departamento de Investigacion Agricola Reporte Annual, Recursos Naturales. Tegucigalpa, Honduras.

Hogg, D.B., R.E. Anderson and H.N. Pitre. 1983. Early-season parasitizaion of fall armyworm (Lepidoptera:Noctuidae) larvae in Mississippi. *Florida Entomol.* 65:584-85.

Hogg, David B., Henry Pitre and Ronald E. Anderson. 1982. Assessment of early-season penology of the fall armyworm (Lepidoptera:Noctuidae) in Mississippi. *Environ. Entomol.* 11:705-10.

Pitre, Henry N. and David B. Hogg. 1983. Development of the fall armyworm on cotton, soybean and corn. *J. Georgia Entomol. Soc.* 18:182-87.

Pitre, Henry, Joseph E. Mulrooney and David B. Hogg. 1983. Fall armyworm oviposition: Crop preferences and egg distribution on plants. *J. Econ. Entomol.* 76:463-66.

Schwager, Brenda, Henry Pitre and Lynn Gourley. 1984. Field evaluation of sorghum characteristics for resistance to fall armyworm. *J. Georgia Entomol. Soc.* (in press).

Wiseman, B.R., H.N. Pitre, L. Gourley and S.L. Fales. 1984. Differential growth responses of fall armyworm larvae on developing sorghum seeds incorporated into a meridic diet. *Fla. Entomol. Soc.* (in press).

Wiseman, B.R., Lynn Gourley and Henry N. Pitre. 1983. Some studies of resistance to the fall armyworm. Thirteenth Biennial Grain Sorghum Research and Utilization Conference. Tex. Grain Prod. Board. p. 135.

Development and Evaluation of Systems for Controlling Insect Pests of Sorghum by Integration of Resistant Varieties, Cultural Manipulation and Biological Control

George L. Teetes and Frank E. Gilstrap

Texas A&M University

Insects and mites reduce sorghum yields and grain quality in the U.S. and in many developing countries. Insecticides, so widely used in the developed world, are mostly unavailable in LDCs. In these countries other insect control techniques are required.

The objectives of this INTSORMIL entomology project are to:

- identify and evaluate sorghums resistant to insects, and determine resistance mechanisms;
- identify cultural practices which can reduce insect damage; and
- identify indigenous and exotic natural enemies of sorghum insect pests, and evaluate their potential as biological control agents.

The project is a cooperative effort between entomologists, plant breeders, plant pathologists, plant physiologists, agronomists and cereal quality specialists in the U.S. and abroad.

Research Accomplishments

Plant Resistance

More than 400 sorghums have been screened for resistance to sorghum midge. At least 11 new lines have been identified as midge-resistant. Midge-resistant parental lines and F_1 hybrids have been developed from TAM 2566, and inbred lines have been derived from TAM 2566, AF28 and SGIRL-MR-1. Agronomically improved resistant sorghums have performed well in international tests.

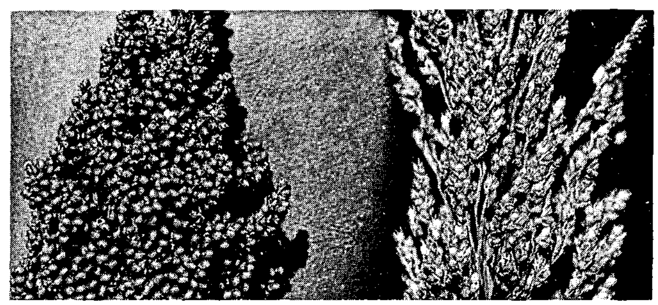
We performed extensive studies of midge behavior on resistant versus susceptible sorghums. Resistant hybrids caused a 40 to 60 percent reduction in the number of progeny per female as compared to susceptible hybrids.

The percentage of midges in diapause generally increased as the season progressed. Based on seasonal mean numbers of diapausing larvae, we observed that there were more diapausing larvae in resistant than in susceptible sorghums. However, there were no differences in percentage of diapausing larvae between hybrids, so obviously plant resistance does not induce diapause.

The searching time (interval between successive oviposition attempts) was shorter for females on a resistant hybrid (5.9 sec.) than on a susceptible hybrid (7.2 sec.), but the number of flowers searched by females on both types of hybrids was not significantly different. Oviposition efficiency was about four times greater on susceptible hybrids, which may be related to differences in spikelet morphology. Midge-resistant hybrids have small glumes and less anther extrusion.

Survival of eggs and larvae and destruction of grain were both lower in resistant varieties, and developmental time of the midges was slightly longer.

Our experiments showed that resistant hybrids suffer one-fifth as much damage as susceptible hybrids. A midge-resistant hybrid treated with insecticide three times at 5-day intervals yielded as much as a susceptible hybrid treated five times at 3-day intervals. This represents a considerable cost saving for the farmer.



Sorghum midge-resistant (left, TAM 2566) and susceptible (right) sorghum.

Biological Control

We conducted studies of sorghum midge attacking johnsongrass, an alternate host plant. From the studies we identified four species of midge parasites and learned much about their behavior. *Eupelmus popa* and *Aprostocetus diplosidis* are ectoparasitic, while *Tetrastichus blastophagi* and *Tetrastichus venustus* feed both externally and internally. Over the course of the season, 20.0 and 8.2 percent of midges were parasitized in johnsongrass and sorghum, respectively.

A survey of greenbug parasites showed only three species in Texas. These were studied in sorghum and wheat, an alternative greenbug host. Greenbug emigration lowered population density as the season advanced. Larval hymenopterous parasites also increased at this time.

In cages which excluded natural enemies, greenbug densities rapidly grew until the plants were killed. Greenbug densities in cages which allowed natural enemies to enter remained far smaller. Predators provided more control than parasites during our study, and in the absence of greenbugs they fed on corn leaf aphids. Important predators are *Hippodamia convergens* (Guerin Meneville) and *H. sinuata* (Mulsant).

Stem borers are another insect pest of sorghum. Indigenous and exotic parasites of stem borers were studied in South Texas where the climate is similar to that in some African countries. Much of this research was conducted by a Senegalese graduate student at Texas A&M University. It was found that three species of stem borer attack sorghum, mainly in late summer or early fall, and that stem borers are in turn attacked by at least two species of parasite. *Costesis flavipes* and *Iphiaulax* sp. are indigenous larval parasites, and *Allorhogas* sp. and *Rhaconotus roslinensis* are newly introduced larval parasites.

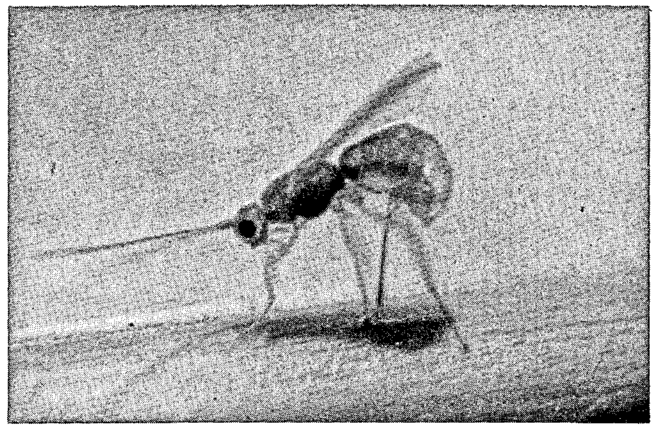
Studies of millet stem borer parasites in Niger created the opportunity for an exchange of parasites between Niger and Texas. In these experiments, biological control agents were collected from two research station plantings in Niger. Although samples were taken early in the season, stem borer populations were large (Table 1). At least eight different species of parasite/predator were found in the study. The two hyperparasites found primarily attack parasites of stem borers.

In Honduras, project researchers have focused on *Doru taeniatum*, a predator of fall armyworm. We learned that *D. taeniatum* lives in the plant whorl, prefers to feed on moth eggs, and can survive periods of fall armyworm scarcity and then reproduce rapidly when armyworms become available. This parasite occurs in sorghum, corn, and intercroppings of the two.

A fairly new control technique is the release of predators to control spider mites in sorghum. Additional work is needed to determine the proper timing and methods of mass releases, but in our initial research this type of control looks promising.

Biological and Ecological Studies

Temperature, moisture and time of day govern the patterns of sorghum midge emergence from infested spikelets, and oviposition in flowering spikelets. Midge did not emerge at night, but began to emerge at dawn.



Parasite of a common insect pest of sorghum.

Peak male emergence preceeded female emergence by 1 to 3 hours. Minimum emergence temperatures for males (10 to 16°C) were lower than for females (20 to 22°C), and peak emergence of males occurred before and at lower temperatures than that of females. Cool temperatures (23°C) delayed midge emergence. Peak female oviposition occured 2 hours after peak female emergence. More midges emerged from spikelets maintained at 90 percent relative humidity than at 10 or 50 percent relative humidity. Artifically wetting infested panicles for 3 hours, or a heavy rain, caused reduced adult emergence. Increased adult emergence occurred during periods of high relative humidity before and after heavy rainfall. Mated female midges produce exclusively male or female progeny.

Two temperature-dependent models were formulated to describe spring emergence for overwintering midges and development of nondiapausing midge generations. These models have worldwide application for describing midge dynamics. Adult emergence rates and distributions were determined for diapausing and nondiapausing midges reared at constant temperatures. These data were used to develop stochastic, two-

Table 1. Results of Collections from Millet near Niamey during August, 1983.

Category	Total number	Percent of total/category
Host larvae/pupae (n = 306)		
Acigona ignefusalis	227	74.2
Sesamias.	15	4.9
Not adequate for identification	64	10.9
Parasitized/preyed upon	87	28.4
Biological Control Agents (n = 87)		
Syzeuctus senegalensis (Benoit)	43	49.4
Phoridae	10	11.5
Sarcophagidae (2 spp.)	10	11.5
Not identifiable	10	11.5
Euripia sp.	9	10.3
Chalcididae	3	3.4
Ceraphronidae (Hyperparasite ?)	1	1.1
Eurytomidae (Hyperparasite ?)	1	1.1
Total natural enemies produced	87	100.0

component, temperature-based models which predict the emergence of adult midges in the field. The first component of each model is a poikilotherm rate equation to predict emergence rates as a function of temperature. The second model component distributes emerging adults over time using a temperature-independent, cumulative Weibull distribution. When coupled, the two components form temperature-dependent simulation models which distribute emerging adults over time and can be incorporated into a larger, seasonal dynamics model for the sorghum midge.

Adult emergence from diapause occurred when temperatures were held constant between 15°C and 35°C. When temperatures were greater or less than 20°C, numbers of emerged adults declined sharply. As temperatures increased, fewer days were required for adult emergence. Above 35°C, emergence times were longer. The poikilotherm rate equation and Weibull distribution accurately described emergence data. Simulations of spring emergence tended to predict emergence before it actually occurred in the field. Incorporating a 1.27 cm precipitation threshold modified emergence rates to reflect daily rainfall totals and corrected the discrepancy.

Constant temperature data also were used to construct a model for midge development from egg to adult emergence (nondiapausing generation). When temperatures were between 20 to 36°C, nondiapausing midges completed development and emerged as adults. Emergence times decreased as temperatures increased within this range. Above 34°C, however, emergence times increased and numbers of emerged adults declined. The poikilotherm rate equation and cumulative Weibull distribution provided excellent descriptions of the emergence data from johnsongrass and sorghum throughout the season (Fig. 1).

Damage Assessment

The nature and intensity of damage to sorghum grain by rice stink bug, southern green stink bug, leaffooted bug and conchuela stink bug were assessed by maintaining different infestation levels of adult bugs on panicles for various periods during grain development. Regression analysis indicated that percent yield loss per panicle was a quadratic response to the number of adult bugs per panicle. The equations we developed estimated percent yield loss for infestations from milk and soft dough to maturity using the number of bugs per panicle. These equations were used to calculate economic injury levels. Numerous alternate host plants were identified for these insects.

A study of true panicle-feeding bugs in Niger and Mali revealed that a complex of species is associated with the pathogens that cause grain deterioration and quality loss. Infestations of head bug complex are related to panicle configuration and glume characteristics, and this is extremely important to sorghum improvement programs in West Africa.

Sorghum in the seedling stage is very sensitive to damage by the yellow sugarcane aphid. We observed infested plants to be much shorter than uninfested plants. Aphid infestations delayed maturity by about 1

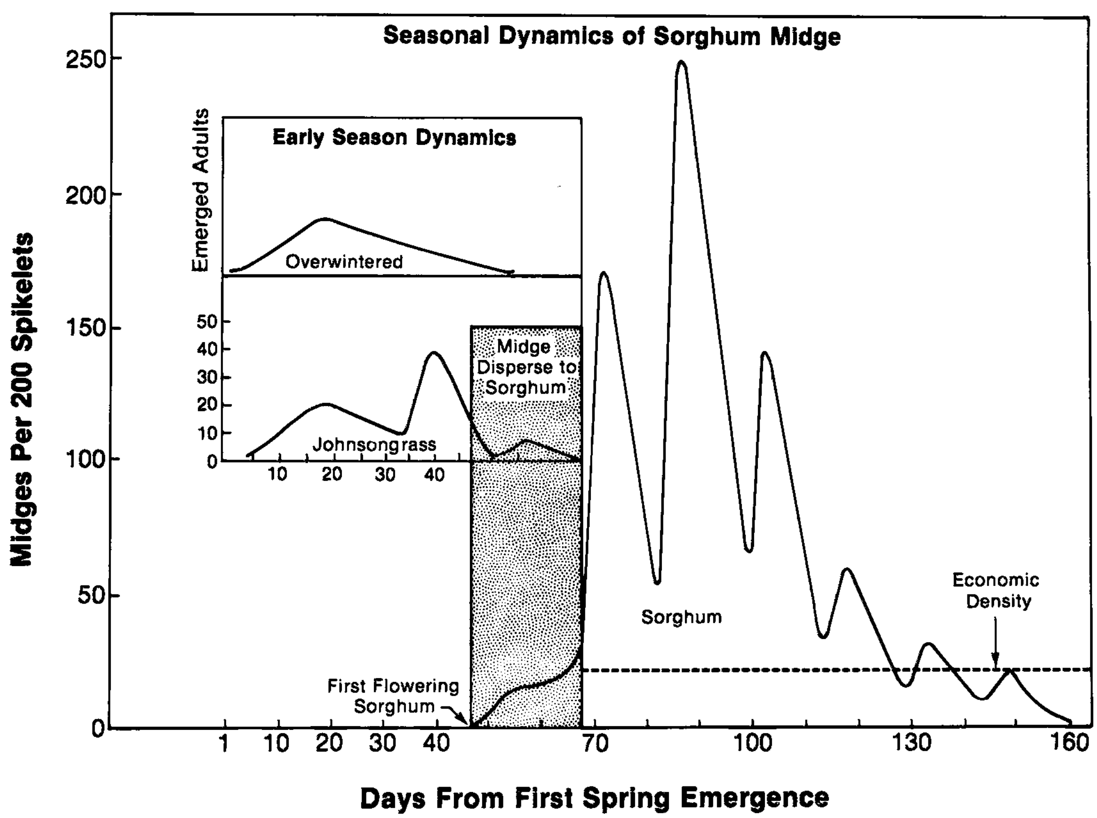


Figure 1.

week, depending on aphid density. Grain weight per panicle was 68 g for uninfested plants and 43 to 53 g for infested plants. There was an inverse relationship between aphid numbers and yield. Plant damage and yield reductions were greater in plants infested at 4.5 cm height than in those infested at 6.7 cm. The longer the infestation lasted, the more plant growth rates declined.

Significance of Research Findings

This project has had several important successes. We have helped in the selection, improvement and evaluation of sorghums that are resistant to six insect pests. These sorghums have been tested in several parts of the world. We still need to assess the damage caused by insects for which genetic resistance has not been found.

Population abundance studies, coupled with biological and ecological information on various pests, has helped us produce biophysical mathematical models for predicting various aspects of insect infestation. These tools will be very valuable in planning integrated pest management programs for LDCs.

Our work with biological control agents has been very productive. We have gained valuable knowledge in this area, and believe this can be an extremely cost-effective approach to insect control. More scientists from LDCs need to be trained in biological control techniques.

LDC Collaboration

We have collaborative programs with Honduras, Nicaragua, El Salvador, Guatemala, Argentina, Brazil, Uruguay, Mexico, Niger, Mali, Senegal, Kenya, Sudan, India and Sri Lanka. These programs deal with evaluation of insect-resistant sorghums, biological control, insect damage assessment and training.

Training and Technical Assistance

Nine students from Thailand, Brazil, Colombia, Botswana, Sri Lanka, Senegal, Nicaragua and Sudan have been trained in various aspects of sorghum entomology. In addition, project members have participated in international workshops and symposia such as the Biennial Plant Resistance Workshop, the International Short Course in Host Plant Resistance, and the International Sorghum Entomology Workshop. A "Sorghum Insect Identification Handbook," developed with ICRISAT scientists, has had worldwide usefulness.

Implications for Future Research

Most of the major sorghum insect pests were included in current research. But we need to extend our work to pest species not yet studied. Stem borer species and panicle-feeding bugs need particular attention. To accomplish more we will need the cooperation of more trained scientists in LDCs. Therefore, training will continue to be a very high priority.

Selected Publications

Baxendale, F.P., G.L. Teetes and P.J.H. Sharpe. 1984. Temperature-dependent model for sorghum midge (Diptera:Cecidomyiidae) spring emergence. *Environ. Entomol.* (in press).

Baxendale, F.P., G.L. Teetes, P.J.H. Sharpe and H. Wu. 1984. Temperature-dependent model for development of nondiapausing sorghum midge (Diptera:Cecidomyiidae). *Environ. Entomol.* (in press).

Baxendale, F.P., C.L. Lippincott and G.L. Teetes. 1983. Biology and seasonal abundance of hymenopterous parasitoids of sorghum midge (Diptera:Cecidomiidae). *Environ. Entomol.* 12:871-7.

Baxendale, F.P. and G.L. Teetes. 1983. Factors influencing adult emergence from diapausing sorghum midge, *Contarrinia sorghicola* (Diptera:Cecidomyiidae). *Environ. Entomol.* 12:1064-7.

Baxendale, F.P. and G.L. Teetes. 1983. Thermal requirements for emergence of overwintered sorghum midge. (Diptera:Cecidomyiidae) *Environ. Entomol.* 12:1078-82.

Baxendale, F.P. and G.L. Teetes. 1981. Production of unisexual progenies by the sorghum midge, *Contarinia sorghicola. Ann. Entomol. Soc. Amer.* 74:412-3.

Boozaya-Angoon, D., K.J. Starks, D.E. Weibel and G.L. Teetes. 1984. Inheritance of resistance in sorghum, *Sorghum bicolor*, to the sorghum midge, *Contarinia sorghicola*. (in press).

Fisher, R.W. and G.L. Teetes. 1982. Effect of moisture on sorghum midge (Diptera:Cecidomyiidae) emergence. *Environ. Entomol.* 11:946-8.

Fisher, R.W., G.L. Teetes and F.P. Baxendale. 1982. Effects of time of day and temperature on sorghum midge emergence and oviposition. Tex. Agric. Exp. Stn. PR-4029.

Friese, D.D. and F.E. Gilstrap. 1982. Influence of prey availability on reproduction and prey consumption of *Phytoseiulus persimilis*, *Amblyseius califronicus*, and *Metaseiulus occidentials* (Acarina: Phytoseiidae). *Internat. J. Acarol.* 8:85-9.

Gilstrap, F.E., K.R. Summy and D.D. Friese. 1979. The temporal phenology of *Amblyseius scyphus* a natural predator of Banks grass mite in West Texas. *Southwestern Entomol.* 4:27-34.

Gilstrap, F.E., T.J. Kring and G.W. Brooks. 1984. Parasite fauna attacking aphids associated with Texas sorghum. *Environ. Entomol.*

Gilstrap, F.E., K.R. Summy, L.D. Chandler, T.L. Archer and C.R. Ward. 1980. Within plant distribution of Banks grass mite on corn in West Texas. *Eviron. Entomol.* 9:546-8.

Gilstrap, F.E., G.W. Brooks and T.J. Kring. 1980. Status of greenbug biological control in Texas sorghum. TAES MP-1538.

Hall, D.G., IV and G.L. Teetes. 1980. Damage to sorghum seed by four common bugs. Tex. Agric. Exp. Stn. PR-3647.

Hall, D.G. and G.L. Teetes. 1981. Alternative host plants of sorghum panicle-feeding bugs in southeast central Texas. *Southwestern Entomol.* 6:220-8.

Hall, D.G., IV and G.L. Teetes. 1982. Damage by rice stink bug to grain sorghum. *J. Econ. Entomol.* 75:440-5.

Hall, D.G., IV and G.L. Teetes. 1982. Yield loss-density relationships of four species of panicle-feeding bugs in sorghum. *Environ. Entomol.* 11:741.

Hall, D.G., IV and G.L. Teetes. 1982. Damage to grain sorghum by southern green stink bug, conchuela, and leaffooted bug. *J. Econ. Entomol.* 75:620-5.

Hall, D.G., IV, M.L. Howell, G.L. Teetes and R.A. Frederiksen. 1982. Grain molds associated with infestations of sorghum panicle-feeding bugs. Tex. Agric. Exp. Sta. PR-4028.

Hall, D.G., IV, G.L. Teetes and C.E. Hoelscher. 1983. Suggested guidelines for controlling panicle-feeding bugs in Texas sorghum. Tex. Agric. Ext. Ser. B-1421.

Hallman, G.J., G.L. Teetes and S.W. Johnson. 1984. Weight compensation of undamaged kernels in response to damage by sorghum midge (Diptera:Cecidomyiidae). *J. Econ. Entomol.* 77:1033-1036.

Hallman, G.J., G.L. Teetes and J.W. Johnson. 1984. Relationship of sorghum midge (Diptera:Cecidomyiidae) density to damage to resistant and susceptible sorghum hybrids. *J. Econ. Entomol.* 77:83-7.

Hobbs, J.R., G.L. Teetes, J.W. Johnson and A.L. Wuensche. 1979. Management tactics for the sorghum webworm in sorghum. *J. Econ. Entomol.* 72:362-6.

Johnson, J.W., D.T. Rosenow, G.L. Teetes and F.R. Miller. 1982. Registration of TAM2566 sorghum germplasm line. *Crop Sci.* 22:1271.

Johnson, J.W., G.L. Teetes and D.T. Rosenow. 1982. Registration of TAM2567 and TAM2568 greenbug resistant sorghum germplasm lines. *Crop Sci.* 22:1271.

Johnson, J.W., R.E. Schaffert and G.L. Teetes. 1982. Registration of ISRI germplasm line. *Crop Sci.* 22:1271-2.

Johnson, J.W., D.T. Rosenow, G.L. Teetes and J.M. Phillips. 1982. Registration of 19 greenbug resistant sorghum germplasm lines. *Crop Sci.* 22:1272.

Johnson, J.W., D.T. Rosenow and G.L. Teetes. 1982. Registration of four composites of greenbug-resistant sorghum germplasm. *Crop Sci.* 22:1273.

Johnson, J.W., D.T. Rosenow, B.R. Wiesman and J.M. Phillips. 1982. Registration of 28 midge resistant sorghum germplasm lines. *Crop Sci.* 22:1273.

Johnson, J.W. and G.L. Teetes. 1980. Breeding for arthropod resistance in sorghum. *In:* M.K. Harris (ed.), *Biology and Breeding for Resistance to Arthropod and Pathogens in Agricultural Plants.* Tex. Agric. Exp. Stn. MP-1451.

Kring, T.J. and F.E. Gilstrap. 1984. Efficacy of the natural enemies of grain sorghum aphids: An exclusion study. *J. Kans. Entomol. Soc.*

Kring, T.J. and F.E. Gilstrap. 1984. Population dynamics of the greenbug and its parasitoids on winter wheat in Central Texas. TAES PR-4140.

Kring, T.J. and F.E. Gilstrap. 1982. Within field distribution of greenbug and its parasitoids in winter wheat. *J. Econ. Entomol.* 76:57-62.

Lippincott, C.L. and G.L. Teetes. 1983. Biology and nature of parasitism of hymenopterous parasitoids of sorghum midge. Tex. Agric. Exp. Stn. PR-4146.

Melton, K.D. and G.L. Teetes. 1984. Effects of resistant sorghum hybrids on sorghum midge (Diptera:Cecidomyiidae) biology. *J. Econ. Entomol.* 77:626-631.

Peterson, G.C., J.W. Johnson, G.L. Teetes and D.T. Rosenow. 1984. Registration of Tx2782 midge resistant sorghum germplasm line. *Crop Sci.* 24:389-90.

Peterson, G.C., J.W. Johnson, G.L. Teetes and D.T. Rosenow. 1984. Registration of Tx2783 greenbug resistant sorghum germplasm line. *Crop Sci.* 24:390.

Peterson, G.C. and G.L. Teetes. 1983. Technology of breeding for insect resistance. Proceedings of the Sorghum Breeding Workshop for Latin America. pp. 256-74.

Petralia, R.S., A.L. Wuensche, G.L. Teetes and A.A. Sorensen. 1979. External morphology of the mouthparts of larvae of sorghum midge, *Contarinia sorghicola. Ann. Entomol. Soc. Amer.* 72:850-5.

Pickett, C.H. and F.E. Gilstrap. 1984. Phytoseiidae associated with Banks grass mite infestation in Texas. *Southwestern Entomol.* (in press).

Pickett, C.H. and F.E. Gilstrap. 1984. Dynamics of species composition for spider mites infesting corn on the Texas High Plains. *J. Kans. Entomol. Soc.*

Rosenow, D.T., J.W. Johnson, G.L. Teetes, D. Pietsch and H.J. Walker. 1979. Grain sorghum hybrid performance. Tex. Agric. Exp. Stn. PR-3542.

Summy, K.R. and F.E. Gilstrap. 1984. Facultative alate production by greenbug and corn leaf aphid on sorghum and implications for parasitism. *J. Kans. Entomol. Soc.*

Summy, K.R. and F.E. Gilstrap. Greenbug populations: Within-plant distribution on grain sorghum. Tex. Agri. Exp. Sta. Prog. Rept. PR-3967-E.

Summy, K.R., F.E. Gilstrap and S.M. Corcoran. 1979. Parasitization of greenbug and corn leaf aphid in West Texas. *Southwestern Entomol.* 4:176-80.

Teetes, G.L. 1982. Sorghum insect pest management. *In: Sorghum in the Eighties.* Proceedings of the International Symposium on Sorghum. 1:225-35.

Teetes, G.L., W. Chantrason, J.W. Johnson, T.A. Granovsky and L.W. Rooney. 1981. Maize weevil: a search for resistance in converted exotic sorghum kernels. Tex. Agric. Exp. Stn. B-1371.

Teetes, G.L. 1981. The environmental control of insects using plant spacing. *In:* D. Pimental (ed.), *Handbook of Pest Management in Agriculture.* CRC Press, Boca Raton, Florida. 1:209-21.

Teetes, G.L. 1980. Review of sorghum entomology research. Proceedings of the Texas Inegrated Pest Management Conference, College Station, Texas. pp. 14-15.

Teetes, G.L. 1980. Progress and breakthroughs in breeding for insect resistance in sorghum. Proceedings of Plant Breeding Workshop. Dept. Tech. Report. 80-1. pp. 3-4.

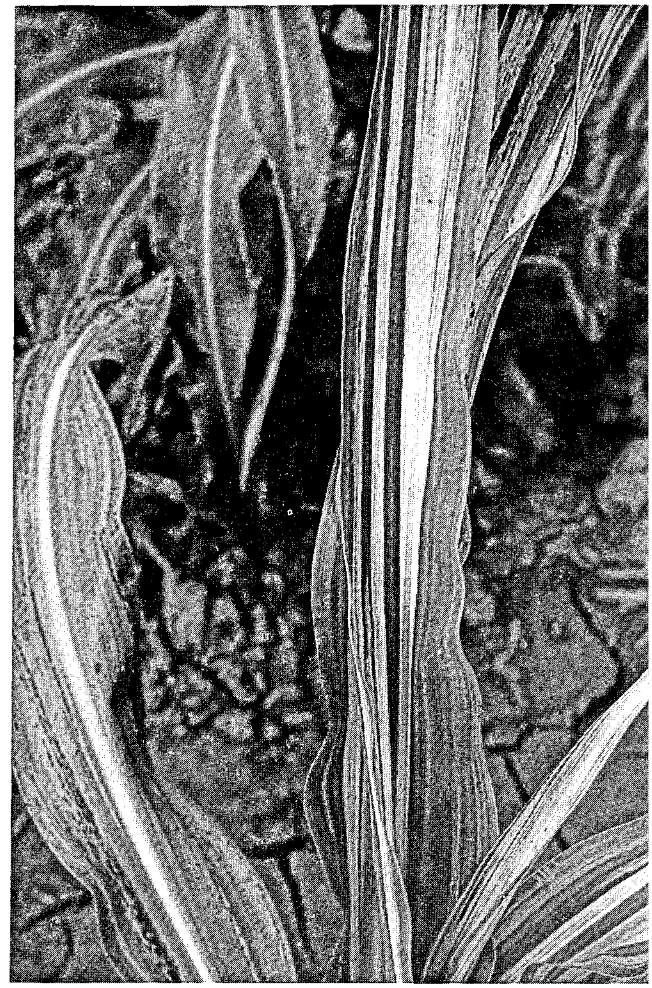
Teetes, G.L. 1980. Overview of pest managment and host plant resistance in U.S. Sorghum. *In:* M.K. Harris (ed.) *Biology and Breeding for Resistance to Arthropods and Pathogens in Agricultural Plants.* Tex. Agric. Exp. Stn. MP-1451. pp. 181-223.

Teetes, G.L. 1980. Breeding sorghums resistant to insects. *In:* F.G. Maxwell and P.R. Jennings (eds.), *Breeding Plants Resistant to Insects.* John Wiley Publishing Co. pp. 457-85.

Teetes, G.L., W.R. Young and M.G. Jotwani. 1980. Elements of integrated control of sorghum pests. Food and Agriculture Organization of the United Nations Plant Production and Protection Paper. 19:159.

Teetes, G.L. and B.R. Wiseman. 1979. Economic threshold of *Heliothis* species in sorghum. *In:* Southern Cooperative Series Bulletin 231. USDA. pp. 57-61.

Wuensche, A.L., G.L. Teetes and J.W. Johnson. 1981. Field evaluation of converted exotic sorghums for resistance to sorghum midge, *Contarinia sorghicola.* Tex. Agric. Exp. Stn. MP-1484.



An important goal of INTSORMIL is to bring sorghum downy mildew under control. It is a major disease in most sorghum-growing areas of the world.

PATHOLOGY

Sorghum and millet diseases cause economic losses in all parts of the world. Losses caused by diseases are reflected in lower yields, poor grain quality and expensive control measures. Diseases reduce the plants' ability to cope with other environmental stresses.

The importance of each of the many major diseases of sorghum and millet varies from region to region and field to field. Slight variations in the environment, host genotype, or management dramatically affect disease severity from year to year.

Diseases can be controlled in several ways. In resistant varieties the plant actually protects itself from invasion by a pathogen. Avoidance is a strategy that permits plants to grow or mature in an environment unfavorable for disease development. An example of this is the photosensitive sorghums. These sorghums escape disease because they flower and mature in the dry season. Occasionally, pesticides such as seed treatment fungicides can be used economically, even in very marginal production areas. Regulatory programs have been useful in delaying the movement of some pathogens; however, the programs are often biologically unrealistic and may be more of a handicap to control than an aid.

EXECUTIVE SUMMARY

The plant pathology program of INTSORMIL is reaching all areas of sorghum and millet production. It has grown from a small program to one that collaborates with more than 20 sorghum growing countries. Much of the work relates to methods of evaluating host resistance, pathogen or pathogen strain identification, and collaborative distribution of germplasm. Students from sorghum growing regions have received graduate training and training in techniques that will permit them to continue work in their own countries. Collaboration among disciplines is encouraged as an effective means of advancing research.

Sorghum and Millet Pathology

R.A.Frederiksen, G. Odvody, R.W. Toler, J. Craig and L. Reyes

Texas A&M University

This project has emphasized integrated control of all economically important diseases of sorghum and millet. Our initial work was in identifying sources of disease-resistant germplasm. These sources were bred into agronomically useful genotypes. Multiple disease control was achieved by incorporating resistant sources for several major disease. Consequently, the program developed resistance to many diseases in one cultivar. The extensive use of host resistance led to the development of a disease and pathogen monitoring system and studies on pathogen biology.

With the increasing success of plant resistance, we began to study tactics that could prolong the resistance in the face of pathogen variation. Researchers in this project are frequently called upon for help in identifying pathogens (particularly the virus and virus-like diseases), screening of diseases, and evaluating plant reaction to disease. We design national programs and train additional sorghum workers in methods of disease management.

Research Accomplishments

Sources of resistance to sorghum head smut, downy mildew, anthracnose, leaf blight, grey leaf spot, grain mold, charcoal rot, maize dwarf mosaic, head blight and several other diseases have been combined in agronomically superior sorghums. Many of these superior sorghums have multiple resistances.

The disease-resistant cultivars are improving crop production in LDCs. A notable example is TX623, a multiple disease-resistant inbred used as a female parent for the development of hybrids in a number of countries. A selection from a bulk of SC103 x SC326 was developed as the male of the disease-resistant sorghum in Brazil. TAM428, a multiple disease-resistant sorghum, is an entry in the ICRISAT, leaf disease-resistant nursery. SC103 der. was the principle pollinator of all sorghum hybrids in Argentina. Several hybrid sorghums such as TX3197 and TX398 are resistant to sooty stripe, the major foliar disease in West Africa.

The release of germplasm as lines, bulks or parental material documents the progress of research. Numerous collaborative contacts are made because of the information reported from germplasm releases.

Screening for host plant disease resistance is crucial to our program. We have developed specific screening methods for most sorghum pathogens. And we have taught methods to scientists from LDCs. Any country that has its own crop improvement program must have researchers who know how to select disease-resistant cultivars.

Some evaluation of plant resistance is done through uniform disease nurseries which were distributed to many countries. But the main purpose of these nurseries is to aid in identifying disease pathogens. The following disease nurseries are in operation:

International Disease and Insect Nursery

Brazil	Egypt
Upper Volta	Honduras
Mali	Philippines
Niger	Argentina
Sudan	

International Sorghum Virus Nursery

Mexico	Tanzania
Honduras	Argentina
Venezuela	

All Disease and Insect Nursery

Honduras	Egypt
Mexico	

Sorghum Downy Mildew Virulence Nursery

Brazil	India
Mexico	Honduras
Puerto Rico	

International Sorghum Anthracnose Virulence Nursery

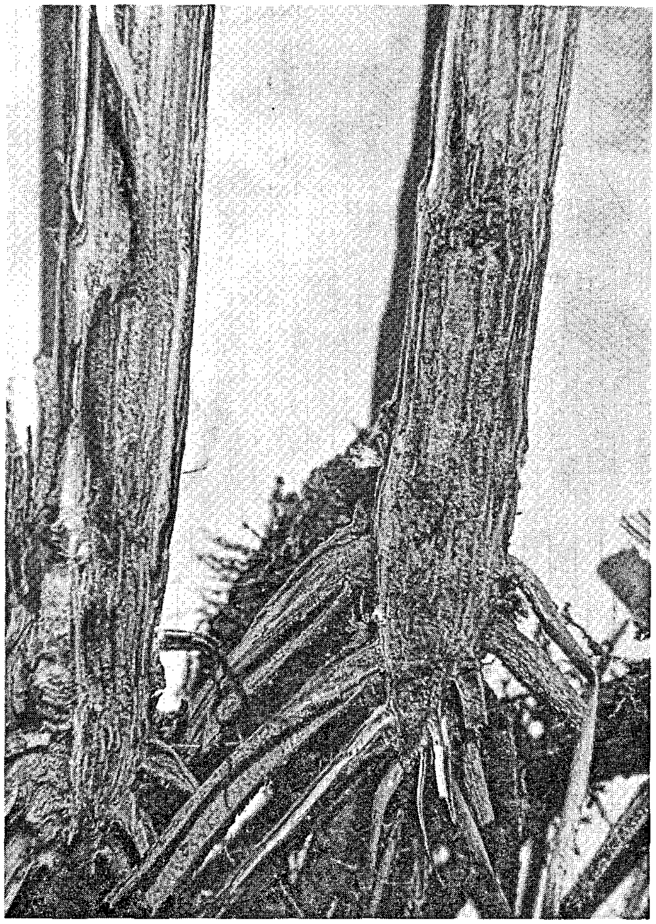
Brazil	Sudan
India	Venezuela

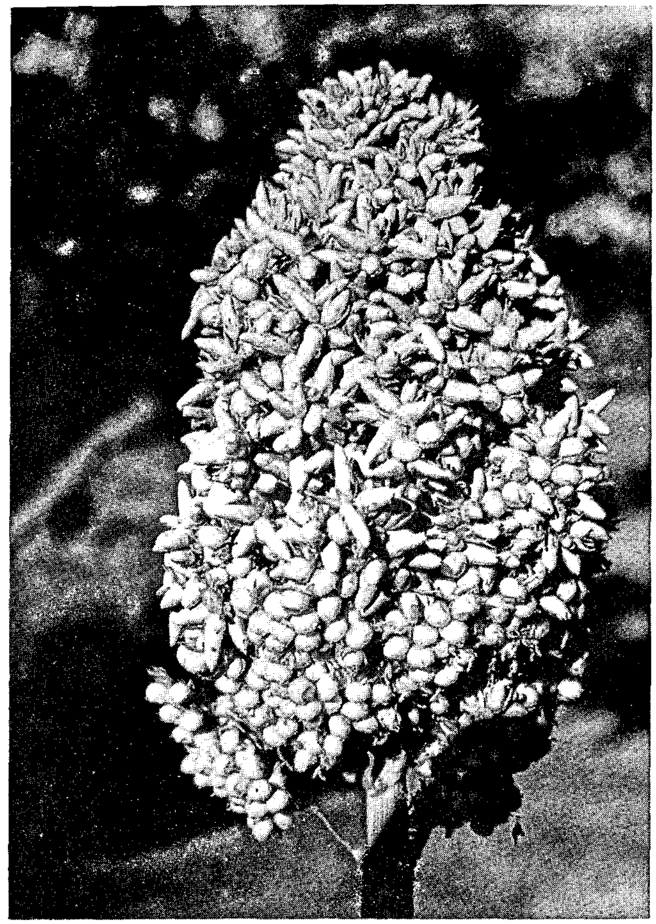
International Cercospora Test

Honduras	Philippines

The Internatonal Sorghum Virus Nursery (ISVN) has been instrumental in virus detection worldwide. The International Sorghum Virus Antiserum Bank (ISVAB) has aided in determining virus distributions and relationships. The ISVN and ISVAB have contributed to identification of specific viruses in Mexico, Honduras, Venezuela, Tanzania and Argentina, and aided in comparison of strains in South Africa, Australia and France. We are encouraged by the number of countries interested in growing these uniform disease nurseries.

Another important area of research has to do with identifying and studying soil-borne pathogens. We have learned more about the occurrences and severity levels of soil-borne diseases, and better ways of controlling them. For example, interactions between temperature, moisture, relative humidity, host and pathogen determine disease level. To control a disease we must eliminate the pathogen, change the environmental conditions which cause disease development, or both.





Stalk rots (left) are major sorghum diseases being attacked cooperatively by pathologists and plant breeders in Sudan. Progress has been made in controlling covered kernel smut (right).

We have identified new diseases—*Acremonium* wilt, a "scleriform" Cercospora leaf spot, and a new bacterial disease not yet named.

As part of this project, fungicides are evaluated for use by farmers. Apron seed treatment was labeled for use in the U.S. and other countries as a result of feasibility studies we conducted. This treatment eliminates seed transmission of the pathogens causing downy mildew.

Because diseases vary in importance from year to year and location to location, farmers and technicians must know how to predict and assess economic losses. Procedures for doing so have been sent to Mexico, Brazil, West Africa, Egypt and Sudan.

Finally, this project emphasizes the transfer of technology to collaborating LDCs. For example, procedures for inoculating sorghum with the long smut pathogen were developed in collaborative efforts in Egypt and Nigeria. They are now being used in Sudan and Mali.

Significance of Research Findings

Because of the strong disease resistance screening programs taking place in the U.S. and many other countries, great strides have been made in developing sorghum/millet genotypes resistant to major diseases. The wide participation in growing uniform disease nurseries has contributed not only to plant breeding work, but also to the identification and study of many disease pathogens and symptoms.

The worldwide research network that has been established has helped in the transfer of technology to combat sorghum/millet diseases all over the world.

LDC Collaboration

Countries collaborating with this project include Mexico, Brazil, Honduras, El Salvador, Argentina, Venezuela, Colombia, Uruguay, Mali, Upper Volta, Niger, Sudan, Egypt, Botswana, Nigeria, Tanzania, Ivory Coast and the Philippines. In almost all of these countries the research includes disease diagnosis and evaluation of host plant resistance, among other areas.

Training and Technical Assistance

The sorghum and millet disease handbook, written in Spanish, English and French, has been widely distributed and favorably received by workers at all levels. Another joint ICRISAT/INTSORMIL publication is *Sorghum Diseases: A World Review*.

Three programs on sorghum disease control were presented in Texas for workers from the U.S. and LDCs. A short course on sorghum pathology in Latin America was presented in Mexico. A similar short course is proposed for West Africa. The purpose of these short courses is to demonstrate disease screening methods to sorghum workers. We are also teaching virus identification and inoculation techniques.

Implications for Future Research

Much remains to be done. As we strengthen national programs through training and diagnosis, there will be a greater need to evaluate disease losses in both traditional and mechanized systems. Diseases causing the greatest losses will receive the most attention. National programs will be encouraged to establish their own priorities and seek their own solutions. However, we can assist them in defining certain biologically sound approaches and alternatives, particularly as host morphology is altered for the sake of increased production.

We can boost disease control by combining host resistance with chemical and biological control, including the use of beneficial organisms.

The prevalence of viruses in East Africa and other sorghum growing areas of the world indicates a continuing need for the sorghum virus nursery and a supply of antiserum for virus detection and identification. New antisera must be produced as new viruses and strains are found. The discovery of new strains of maize dwarf mosaic (MDMV) and sugarcane mosaic that differ from those in the U.S. points out the need to search continuously for sources of resistance. The enzyme-linked immunosorbent assay (ELISA) technique may allow us to send antisera to LDCs in a more usable form. The plates with the dried antisera can be easily shipped, and the juice from the infected plants added on arrival. The plates would then be dried and returned to our laboratory for development and reading. This technique will help us study virus concentration and its relationship to basic host resistance.

Because of the continued emergence of new strains of MDMV (six since 1964) we need to use capsid protein analysis, peptide mapping and amino acid sequencing to learn about the basic relationship of these variants.

The effects of single sorghum viruses on growth and yield have been studied. But in many cases multiple virus infection occurs. It is important to learn more about the effects of multiple virus infection on yield in various resistant/susceptible genotypes.

Selected Publications

Berger, P.H. and R.W. Toler. 1983. Maize dwarf mosaic virus transmission by greenbug biotypes. *Plant Dis.* 67:496-497.

Craig, J. Sorghum downy mildew research at Texas A&M University. Proceedings of the International Workshop Sorghum Dis. pp. 195-199.

Craig, J. 1980. Comparative reactions of corn inbreds to oospore and conidial inoculum of *Peronosclerospora sorghi. Phytopathology* 70:313-315.

Craig, J. and R.A. Frederiksen. 1980. Pathotypes of *peronosclerospora sorghi. Plant Dis.* 64:778-779.

Craig, J. and R.A. Frederiksen. 1983. Effect of light on reaction of sorghum to *Peronosclerospora sorghi. Phytopathology.* 73:803.

Craig, J. and R.A Frederiksen. 1983. Differential sporulation of pathotypes of *peronosclerospora sorghi* on inoculated sorghum. *Plant Dis.* 67:278-279.

Craig, J. 1983. Pathotype 3 of *Peronosclerospora sorghi.* Tex. Agric. Exp. Stn. MP-1535. p. 5.

Craig, J. and K.F. Schertz. 1983. Inheritance of resistance to sorghum downy mildew. Proceedings of the Biennial Grain Sorghum Research Utilization Conference. pp. 109-110.

Duncan, R.R., D.T. Rosenow, A. Sotomayor-Rios and R.A. Frederiksen. 1983. Registration of GPT2RB anthracnose resistant sorghum germplasm population (Reg. No. GP 130). *Crop Sci.* 22:1274-1275.

Frederiksen, R.A. 1980. The current status of sorghum downy mildew of maize and sorghum. *Plant Dis.* 64:903-908.

Frederiksen, R.A., D.T. Rosenow, L. Reyes and D. Collins. 1983. Registration of Tx2784 and Tx2785 Sudangrass Germplasm. *Crop Sci.* Vol. 23:405.

Harris, M.K. and R.A. Frederiksen. 1984. Concepts and methods regarding host plant resistance to arthropods and pathogens. *Ann. Rev. Phytopathology.* 22:247-272.

Natural, Marina and R.A. Frederiksen. 1982. Acremonium wilt of sorghum. *Plant Dis.* 66:863-865.

Odvody, G.N. and R.A. Frederiksen. 1984. Use of systemic fungicides metalaxyl and fosetyl-Al for control of sorghum downy mildew in corn and sorghum in South Texas. I: Seed Treatment. *Plant Dis.* 68:604-607.

Odvody, G.N. and R.A. Frederiksen. 1984. Use of systemic fungicides metalaxyl and fosetyl-Al for control of sorghum downy mildew in corn and sorghum in South Texas. II: Foliar application. *Plant Dis.* 68:608-609.

Odvody, G.M. and D.B. Madden. 1984. Leaf sheath blights of *Sorghum bicolor* caused by *Sclerotium rolfsii* and *Gloeocercospora sorghi* in South Texas. *Phytopathology.* 74:264-268.

Salumu-Shabani and R.A. Frederiksen. 1982. Symptoms of sorghum downy mildew on maize following inoculation with conidia and oospores. *Plant Dis.* 66:1006-1008.

Tuleen, D.M. and R.A. Frederiksen. 1982. Evaluating a crop loss model for head smut of sorghum. *Phytopathology.* 72:1278-1280.

Tuleen, D.M. and R.A. Frederiksen. 1981. Simulating yield losses in grain sorghum due to sorghum downy mildew. *Agron. J.* 73:983-987.

Tuleen, D.W., R.A. Frederiksen and P. Vudhivanich. 1980. Cultural practices which reduce the incidence of sorghum downy mildew. *Phytopathology.* 70:905-908.

Yeh, Y. and R.A. Frederiksen. 1980. Sorghum downy mildew: Biology of systemic infection by conidia and a resistant response in sorghum. *Phytopathology.* 70:372-376.

Ziv, O. and R.A. Frederiksen. 1983. Control of foliar diseases with epidermal coating materials. *Plant Dis.* 67:212-214.

Studies on Mechanisms of Disease Resistance and Susceptibility and Screening for Improved Resistance to Fungal Pathogens, with Emphasis on Colletotrichum Graminicola

Herman L. Warren

Purdue University

The objectives of this project are:

- to increase the diversity of resistance to *Colletotrichum graminicola* (Anthracnose) in sorghum;
- to examine the inheritance of resistance to *C. graminicola,* and the influence of its isolates;
- to determine genetic variations in fungal pathogens of sorghum; and
- to study the influence of seed and oil microflora on seedling emergence, vigor, disease development and yield.

Research Accomplishments

In 1982 we developed a method of evaluating sorghum seedlings for anthracnose resistance in the greenhouse. Germplasm was also evaluated in the field. Seedling blight reactions in the greenhouse were significantly correlated with leaf blight reactions of adult plants in the field. From this study we will determine how resistance is inherited so that we can determine the most efficient means of incorporating resistance genes into germplasm adapted to LDCs.

Nine sorghum isolates of *C. graminicola* obtained from different regions of the U.S. were tested for pathogenicity on six sorghum lines. Differential responses exhibited by the six sorghum lines to the *C. graminicola* isolates made it possible to separate the isolates into five physiological races.

Yield losses from foliar anthracnose are caused by both smaller seed and reduced number of seed per inflorescence. Protein and elemental content also were affected by foliar infection.

Seed of 23 sorghum lines were stored at 0° and 24°C for 5 years to determine the effect of storage conditions on viability, fungal colonization and survival of pathogenic organisms. Seeds were obtained from heads of plants with visible mold. After 5 years, viability was not significantly reduced in kernels from plants resistant to fungal pathogens; however, viability was significantly reduced at 6 months in kernels from susceptible cultivars, and by 48 months none of the kernels from susceptible cultivars germinated. *Fusarium moniliforme* and *C. graminicola* were the most common pathogens in kernels. These pathogens were still viable after 5 years. Since pathogens survive for a long period in/on kernels, caution should be exercised when germplasm is exchanged with areas where the pathogen is not known to occur.

Significance of Research Findings

The results of our experiments should contribute to breeding for resistance to *C. graminicola.* As we learned when comparing our data with that of the International Uniform Anthracnose Virulence Nursery, some genotypes are resistant in one country and susceptible in others.

Our seed storage studies confirmed that pathgens can survive in seeds for long periods. Seed transferred from one country to another must be handled with extreme care to prevent introducing new diseases into areas where they have not previously occurred.

LDC Collaboration

This project collaborates with the Egyptian Major Cereals Improvement Program and the Agricultural Research Center at Giza. The PI has been a consultant to these organizations for more than 10 years.

Training and Technical Assistance

An Ethiopian and a Sudanese student are studying for their Ph.D. degrees in plant pathology under this project. Both students receive stipends from INTSORMIL.

Implications for Future Research

More research will be done on seedling emergence. Resistances to drought stress and soil-borne pathogens will be correlated. We will study resistance to head mold and its effect on seed quality, storage and viability.

Research on the inheritance of resistance to *C. graminicola* will continue so that resistance genes and cultivars can be identified.

Finally, we will develop a set of defined genotypes to aid in race differentiation.

Selected Publications

Ali, M.E.K. and H.L. Warren. 1981. Variations in pathogenicity within sorghum isolates of *Colletotrichum graminicola. Phytopathology.* 74:883.

Ferreira, A.S. and H.L. Warren. 1982. Resistance of sorghum to *Colletotrichum graminicola. Plant Dis.* 66:773-775.

Sorghum Disease Resistance Evaluation and Pathogenicity Investigations

Natale Zummo and Larry E. Trevathan

Mississippi State University

The environment of Mississippi, with its high rainfall and humidity, broad temperature range, and high incidences of insects and diseases, makes the state an ideal site for conducting INTSORMIL research. These environmental conditions are similar to those in some LDCs, and the efforts of state leaders to increase sorghum production places the state in a similar situation to many of the LDCs. In this situation, development of stress-tolerant sorghum varieties and hybrids is a priority.

Research Accomplishments

We have identified sources of resistance to rough leaf spot *(Ascochyta sorghi)* in sorghum. This may be important in wet areas (rainfall above 1.5 meters). We have also identified sources of resistance to maize dwarf mosaic virus.

New races of the pathogens which cause anthracnose, rust and downy mildew have been discovered in Brazil. These are different from the pathogens occurring in the U.S.

A 3-month study of soil-borne fungi and nematodes attacking sorghum was conducted in Colombia and Brazil. Of 18 nematode genera associated with sorghum roots, *Pratylenchus zeae* and *Helicotylenchus dihystera* were most common. The fungi *Curvularia lunata* var. *aeria, Phoma macrostoma,* and *Fusarium moniliforme* occurred most often in root and crown samples from soils both high and low in aluminum.

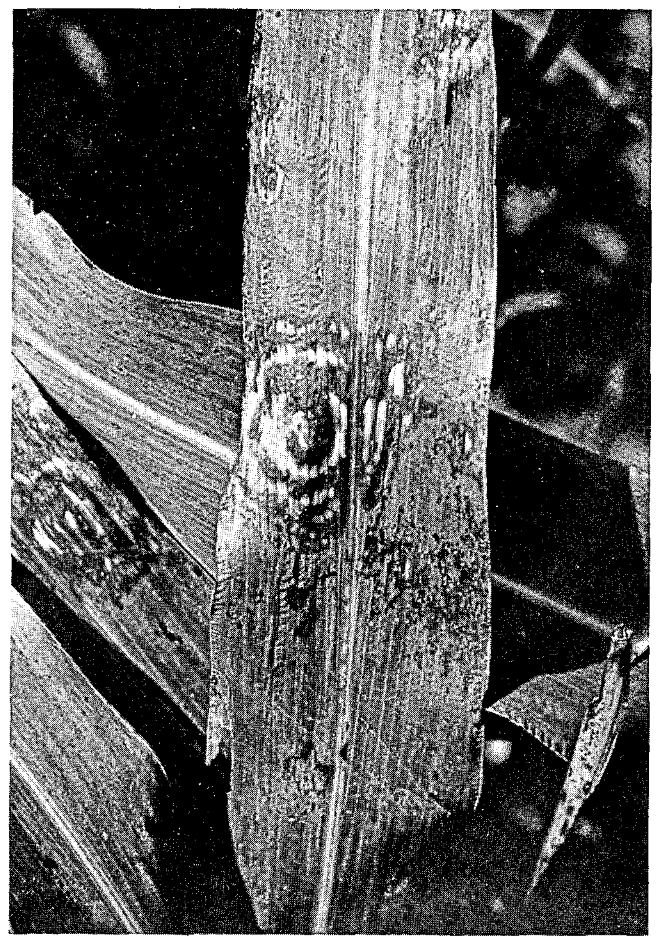
Pratylenchus zeae and *Quinisulcius acutus* were the most common plant parastic nematodes recovered from sorghum in Mississippi. A significant negative correlation occurred between *P. zeae* populations and soil pH and percent base saturation. A highly significant positive correlation occurred between *P. zeae* and total nematode populations. Correlations of soil phosphorus and potassium were both positive and highly significant in relation to population levels of *Q. acutus.*

Many sorghum plants in fields infested with *P. zeae* and *Q. acutus* were stunted. Previous studies have not reported the high incidence of concomitant populations of these two nematodes. Other investigators have reported that *Pratylenchus* spp. prefer acid soils, and *P. zeae* was negatively correlated with soil pH in this study. The high frequency of occurrence of *Q. acutus* where phosphorus and potassium levels were high suggest that these elements may favor increased population densities. The widespread and frequent occurrence of these nematodes in Mississippi sorghum fields suggests that they are involved in sorghum root disorders. Under greenhouse conditions both nematodes were pathogenic to sorghum, either alone or in combination. According to our calculatons, the effect on a sorghum crop would be much worse if the two occurred together.

Significance of Research Findings

Our identification of sorghums resistant to various diseases will help plant breeders incorporate these characteristics into improved genotpyes.

Research on disease pathogens in Brazil and Colombia also will benefit plant breeders as they try to combine disease resistance and tolerance to high aluminum soils into genotypes particularly suited for these countries. Since nematodes and fungi common to South America are also found in the U.S., sources of resistance discovered here may be directly applicable to Colombia and Brazil.



These are symptoms of zonate leaf spot, one of many foliar diseases which are best controlled by host resistance and cropping procedures.

LDC Collaboration

In Brazil we are working with EMBRAPA to screen sorghum varieties for the strains of anthracnose, rust and downy mildew endemic to this country.

Experiments in Colombia are checking the relationship of soil-borne pathogens to sorghum grown on highly productive and marginally productive land, and soils high and low in aluminum.

Resistance to foliar pathogens is the basis of collaborative work in the Dominican Republic. And in Niger we are determining how to study sorghum and millet disease problems, especilly *Striga*.

Training and Technical Assistance

Seven students from LDCs are part of this project. Project members participated in the Sorghum in the '80s conference, the Sorghum Disease Short Course for Latin America, a *Striga* workshop and other meetings.

An important training tool has been developed. The illustrated "Diseases of Sorghums in West Africa" will improve disease identification and lead to better disease control.

Implications for Future Research

We need to search continually for sources of resistance to diseases, especially to new strains of pathogenic organisms which occur. And we must continue basic research to identify soil-borne pathogens in the U.S. and in LDCs. We need to strenghten overseas collaboration and train more graduate students from LDCs.

The relocation of Dr. Stan King to ICRISAT reduces expertise available for grain mold studies. In the future the project should concentrate on leaf and soil-borne pathogens.

Selected Publications

Broadhead, D.M. and N. Zummo. 1983. Registration of M 81E Sweet Sorghum. *Crop Sci.* (in press).

Broadhead, D.M., K.C. Freeman and N. Zummo. 1981. Registration of Wray Sweet Sorghum. *Crop Sci.* 21:987.

Broadhead, D.M., K.C. Freeman and N. Zummo. 1981. M 81E, A new variety of sweet sorghum. *MAFES Research Highlights*, Vol. 45, No. 1.

Broadhead, D.M., K.C. Freeman and N. Zummo. 1980. The use of trichlorfon to identify insecticide-resistant sweet sorghum cultivars. *Proc. ASSCT.* 10. (in press).

Cuarezma-Teran, J.A., L.E. Trevathan and L.M. Gourley. 1984. Soilborne fungi and nematodes associated with sorghum in tropical aluminum soils in Colombia. (submitted).

Cuarezma-Teran, J.A. and L.E. Trevathan. 1984. Response of sorghum to the ectoparasitic nematode *Quiñisulcius acutus*. *J. of Nematology.* (submitted).

Cuarezma-Teran, J.A., L.E. Trevathan and S.C. Bost. 1984. Nematodes associated with sorghum in Mississippi. *Plant Dis.* (accepted for publication).

Freeman, K.C., D.M. Broadhead and N. Zummo. 1982. Sweet sorghum for sirup production. USDA Agriculture Handbook. (in press).

Freeman, Kelly C., D.M. Broadhead and N. Zummo. 1980. Registration of ramada sweet sorghum. *Crop Sci.* 20:672.

Freeman, Kelly C., D.M. Broadhead and N. Zummo. 1979. A new high sucrose sweet sorghum with potential for sugar production. *MAFES Research Report.* 4:8.

Trevathan, L.E. and J.A. Cuarezma-Teran. 1984. Effects of *Quinisulcius acutus* and *Pratylenchus zeae* alone and in combination on sorghum. *J. of Nematology* (submitted).

Zummo, N. 1984. Diseases of pearl millet: an assessment in consideration of growing the crop. *J. of the Mississippi Academy of Sci.* (in press).

Zummo, N. 1984. Sorghum diseases in West Africa. An illustrated text. Published by USAID.

Zummo, N. and D.M. Broadhead. Sources of resistance to rough leaf spot disease in sweet sorghum. *Plant Dis.* (in press).

Zummo, N. 1983. Sections of a compendium of sorghum diseases on rough spot, zonate leaf spot, pokkah boeng, and yellow sorghum stunt. *The American Phytopathological Society* (in press).

Zummo, N. and D.M. Broadhead. 1983. Diseases of pearl millet: An assessment in consideration of growing the crop in the United States. *J. of the Mississippi Academy of Sci.* 27:4.

Zummo, N. 1982. Metodo para esterilizar y conservar material de plantas enfermas que se puedan enviar por correo internacional. Proceedings of short course on sorghum diseases for Latin America sponsored by INIA-ICRISAT/CIMMYT-INTSORMIL. Mexico City, Mexico.

Zummo, N. 1982. Prueba de vairedades de sorgo dulce por su reaccion a enfermedades foliares en Estados Unidos de Norteamerica. Proceedings of short course on sorghum diseases for Latin America sponsored by INIA-ICRISAT/CIMMYT-INTSORMIL. Mexico City, Mexico.

Zummo, N. 1981. Pest management systems for sorghum diseases. *In: Handbook of Pest Management in Agriculture.* Vol. 3. CRC Press, Inc., Boca Raton, Florida. pp. 563-574.

Zummo, N. and K.C. Freeman. 1981. Brandes: a source of resistance to maize dwarf mosaic in sweet sorghum. *Phytopathology.* 71:914.

Zummo, N., W.R. Findley, K.C. Freeman and M.J. Bitzer. 1981. Resistance of sweet sorghum cultivars and lines to maize dwarf mosaic in Kentucky, Ohio and Mississippi. *Plant Dis.* 65:241-242.

Zummo, N. 1980. Fusarium disease complex of sorghum in West Africa. Proceedings of the International Workshop on Sorghum Diseases. Sponsored jointly by Texas A&M University and International Crops Research Institute for the Semi-Arid Tropics, Hyderabad, India.

Identification of Genes Controlling Reaction of Sorghum to MDMV

S. G. Jensen, Manuel K. Palomar and Cecira de Martinez
University of Nebraska

Sugarcane mosaic virus and the closely related maize dwarf mosaic virus are found in various strains throughout the world, wherever corn, sugarcane or sorghum are grown. In many LDCs there are no pathologists or breeders to attack the problem or even to assess the damage. A screening program to identify tolerant material could help reduce the losses to manageable levels. However, it would be better to develop sorghums with known high levels of genetic resistance to serve as the base for a breeding program to develop genotypes tailored for specific areas. International programs would benefit from a broader understanding of the number and types of genes which control resistance.

The objectives of this research are to describe the types of virus reactions or symptoms that are under the control of the host genotype; to identify as far as possible the number and types of genes involved; and to describe any linkages that may occur between these genes.

Research Accomplishments

Of 157 lines and hybrids tested, 128 developed mosaic symptoms, 47 had the non-temperature-sensitive "red stripe" symptoms and 55 had the temperature-sensitive "red leaf" necrosis. At least two genes, and probably more, are involved in each of these types of response.

The hybrid Asgrow Bugoff is an excellent diagnostic sorghum for identifying strains of maize dwarf mosaic virus (MDMV). We found that the inheritance of resistance is independent for the strains MDMV-A and MDMV-B. Plants susceptible to MDMV-B are also susceptible to MDMV-A, but not all plants resistant to B are also resistant to A.

The use of the enzyme-linked immunosorbent assay (ELISA) has demonstrated different virus titers in different sorghum lines. We are studying the gentics of this.

We examined 50 land races and 50 breeders' lines from the world collection of pearl millet, and found varied susceptibility to inoculation and relatively mild symptoms. However, millets supplied by Dr. Charles Francis had high susceptibility and severe symptoms.

Significance of Research Findings

Each individual virus strain may interact differently with a susceptible host. Because of the numerous types of resistance observed and the large number of genes involved, many strategies suggest themselves for breeding for resistance. For example, a look at suitable types in a specific locality might point out types of resistance which should be exploited in that area.

Resistance to various viruses in pearl millet seems adequate at present, but before materials are distributed they should be checked for their reaction to the local virus strains.

LDC Collaboration

Dr. Manuel Palomar from the Philippines is a research associate on this project. When he returns to his country he should be instrumental in establishing collaborative programs with INTSORMIL both in the Philippines and in other Asian countries.

Research projects in cooperation with ICA in Colombia are dealing with the mycorrhizal associations of sorghum grown on acid and aluminum-toxic soils.

Training and Technical Assistance

At present, three graduate students from Colombia, Nigeria and Iraq are being trained in the project.

In 1981 the PI served as instructor for a sorghum disease workshop held in Mexico.

Implications for Future Research

We plan to develop techniques for measuring virus titer in plant tissue so that general conditions influencing virus titer can be measured and the effects of genotype determined. We will make self-pollinations with progeny of selected lines and assay the reaction of the F_2. A program of mycorrhizal research will begin, with the goal of establishing stock cultures of fungi and developing physiological techniques for measuring the influence of mycorrhizae on sorghum.

Other future efforts will include: 1) identifying gentoypes useful for breeding stock in different geographic or environmental areas; 2) studying linkages in resistance between strains A and B of MDMV; and 3) establishing a disease survey and screening nursery in the Phillipines.

Selected Publications

Jensen, S.G., J.K. Palomar, E.M. Ball and R. Samson. 1984. Factors influencing the virus titer in maize dwarf mosaic virus infected sorghum. *Phytopathology.* (in review).

Jensen, S.G., D.J. Andrews and N.E. DeVries. 1983. Reactions of pearl millet from the world collection to maize dwarf mosaic virus strains A and B. *Plant Dis.* 67:1105-1108.

Palomar, M.K. and S.G. Jensen. 1984. The use of enzyme linked immunosorbent assay (ELISA) as an assessment of virus purification methods. *Phytopathology* (in preparation).

Palomar, M.K., S.G. Jensen and E.M. Ball. 1984. Maize dwarf mosaic virus (MDMV) titer in sorghum tissue. *Phytopathology* 74:847-848.

Partridge, J.D., J.E. Reed, S.G. Jensen and G.S. Sidhu. 1983. Spatial and temporal succession of fungal species in sorghum stalks as affected by environment. Research Needs and Strategies for the Control of Sorghum Root and Stalk Rot Diseases. Bellagio Italy.

Sixty-seven percent of preschool children in southern Honduras have some degree of malnutrition. Research in Sudan indicates that malnutrition is just as severe in that country.

FOOD QUALITY AND UTILIZATION

There were several reasons for including grain and food quality and utilization within the INTSORMIL program. First, most sorghum research in the past dealt with the grain as an animal feed, and the goal of breeding was to increase yields. It was felt that without special emphasis on utilization of sorghum as human food, the germplasm improved by INTSORMIL breeding programs might be unacceptable for human consumption in developing countries.

Second, compared to other major cereal grains such as wheat and rice, research on the cereal chemistry and cereal technology of sorghum and millet has hardly begun. There is considerable indigenous knowledge about sorghum and millet processing and the utilization of these grains in local food products, but most of this information has neither been recorded nor defined scientifically. The reason for this is probably that sorghum and millet are indigenous foods of Africa and Asia, and were therefore not of great interest to the colonial powers.

Finally, sorghum has been widely considered to be a "coarse" feed grain, relatively undesireable as a food and perhaps inferior to rice and wheat in nutritional quality. This negative image of sorghum limits its utilization.

Two major events have brought to light the food quality importance of sorghum and millet. The first was the publication in 1980 of "Sorghum and the Millets: Their Composition and Nutritive Value" by J.H. Hulse, E.M. Laing and O.E. Pearson (Academic Press). This is a comprehensive compendium of available information on all nutritional aspects of sorghum and millets, their processing and utilization. The second event was the International Symposium on Sorghum Grain Quality, which took place at ICRISAT in India in 1981. INTSORMIL was one of the co-sponsors of the symposium, the first international meeting devoted exclusively to "quality" characteristics of this major cereal crop. The compendium by Hulse *et al.* and the proceedings of the Symposium on Sorghum Grain Quality (published by ICRISAT) provide a convenient benchmark by which our progress toward improving sorghum and millet quality in the future can be measured.

Definitions of the food quality of sorghum and millet are necessarily subjective, in that they depend upon the particular processing technique and on local preference. But several characteristics which strongly affect the quality of the food are readily recognizable. Some of these characteristics are evident from examination and/or analysis of the grain itself. The relatively low content of the essential amino acid lysine in sorghum grain constitutes a major nutritional constraint. Other characteristics of the grain which affect the quality of the food include the degree of corneousness of the endosperm, the presence of pigment, the presence of tannins and other phenols, and the tendency of the grain to deteriorate by weathering.

Other characteristics which influence the quality of the food include those which affect processing (thickness of pericarp, corneousness of endosperm, rate and/or extent of water uptake, presence of inhibitors of fermentation or germination) and those which are affected by processing (texture, flavor, color, digestibility, stability in storage).

In the developing world, sorghum is used in more different ways than are wheat, rice and maize. Unlike these other cereals, no single criterion for sorghum grain quality or food quality is satisfactory. There is no sorghum equivalent of "all-purpose flour." Descriptions of sorghum grain quality or food quality cannot be developed unless indigenous methods of grain utilization are well known.

Executive Summary

The resources of the INTSORMIL program are not sufficient to attack all the problems of sorghum/millet food quality and utilization. For example, little of this research has yet been done on millet; nor have we fully assessed the nutritional values of sorghum in indigenous foods.

However, much has been accomplished. We have documented the wide variety of traditional foods which are made from sorghum, such as porridges and breads in Africa. This indicates the importance of sorghum to human nutrition in LDCs.

We are developing food quality standards for sorghum. As a result, the potential nutritional quality of sorghum has been increased. High-lysine sorghums are being adapted into agronomically desirable lines with good food quality. The apparent low digestibility of sorghum protein in human foods has been traced to certain processing techniques. Traditional processing methods, especially fermentation, largely overcome this problem.

We have determined how sorghum can best be substituted for maize in tortillas. And we are examining the antinutritional effects of the polyphenols in sorghum.

The reports which follow describe the substantial progress which has been made in overcoming factors which limit the food quality and utilization of sorghum and millet in LDCs.

Sorghum Consumption and Diet in Southern Honduras

Kathleen M. DeWalt
University of Kentucky

The farming systems research carried out in Honduras, and reported elsewhere in this publication, included a study of the dietary and nutritional impacts of sorghum production and consumption. Honduras is the second poorest country in the Western Hemisphere. Nutritional surveys conclude that around 76 percent of preschool children suffer from some form of protein calorie malnutrition. The problem is most severe in the southern part of the country where population density is highest. This is also the area in which sorghum is a basic food grain.

This project had four major objectives. The first was to gather information on the uses and preparation methods of sorghum foods. This will improve the chances that new varieties of seed developed have the characteristics that make them acceptable to the families of small farmers.

The second objective was to review the diet of the area in order to assess the role of sorghum in solving specific nutritional problems. Within this context specific issues such as the benefits of improving the protein quality of the grain, the effects of post-harvest processing on protein digestibility and the availability of other nutrients, and the impact of sorghum consumption on vitamin C nutriture can be addressed.

Also, we assessed the impact of existing farming systems on the diets and nutritional status of farming communities. Such information is important in predicting the probable impact of agricultural innovation on household diets and nutritional status.

Within these objectives the research addressed several specific questions:

- What is the dietary and nutritional status of families in sorghum growing areas of southern Honduras?
- What is the extent to which sorghum is used as a basic grain?
- What is the pattern of consumption of sorghum and other foods among different social groups and families following different patterns of agricultural production and resource allocation?
- How is sorghum prepared and consumed?
- What is the acceptibility of sorghum as a grain, especially in comparison with the more traditional grain, maize?
- What grain quality characteristics are desirable in food quality sorghums in this area?
- What specific nutritional issues could be addressed through improvement in sorghum production?
- What nutritional issues need to be addressed concerning the appropriateness of promoting sorghum consumption in the area?

The research used both qualitative and quantitative approaches to the study of diet. Informal and formal surveys were conducted in seven communities representing different ecological and social conditions. These were an agrarian reform settlement on the Pacific coastal plain in which agriculture is heavily commercialized; three communities in zones of intermediate altitude in which semi-subsistence agriculture is based on the intercropping of maize and sorghum; and three communities in which semi-subsistence agriculutre is carried out at high elevations and which include beans in maize and sorghum intercroppings. Communities were surveyed at least twice at different seasons of the year.

Research Accomplishments

Sorghum has probably been a part of the diet in southern Honduras for about 100 years. The criollo grains used have been selected for their appropriateness as food as well as for their agronomic qualities. Many products are made from sorghum; some are sorghum equivalents of foods also prepared from maize.

Tortillas are prepared from sorghum by essentially the same method as from maize. The grain is nixtamalized by heating in an alkaline solution. Either ashes or lime is used. Ashes are more commonly used in the preparation of sorghum tortillas than maize tortillas in the highlands. It is said that the pericarp of sorghum peels more easily with ashes than with lime. In the coastal lowlands the available firewood leaves a salty ash that is said to be unsuitable for preparing tortillas. Here lime is always used. Cooking time for sorghum (10 minutes) is about a third that for maize (30 minutes). The hot mixture is then allowed to sit briefly. Some women claim that the shorter the cooking time the better (whiter) the appearance of the sorghum tortilla. It is claimed by some that the quality of sorghum tortillas is equal to that of maize tortillas if the sorghum is not overcooked. After cooking and soaking, the grain is washed and the pericarp removed. It is then ground in a hand mill and reground on a stone quern. The resulting masa is formed into flat rounds and baked for several minutes on a griddle.

While the tortilla is the most common and important product made from sorghum, a number of other foods are also prepared. Rosquillas and rosquetes, hard cookie-like products, are prepared from either maize or sorghum masa to which ground fresh cheese, sugar and other ingredients are added. The resulting dough is formed into a variety of shapes and baked in an oven. Rosquillas and rosquetes are snack foods often sold by enterprising women.

During the winter months, popped sorghum and honey are formed into balls called albarotes. A soft drink, aqua fresca, is made from ground sorghum mixed with water and sugar. An atole, or thin porridge, is made from sorghum masa cooked in either water or milk. In the past a coffee substitute was prepared by roasting sorghum grains that had been soaked first to prevent popping, and then grinding them into a coffee-like consistency. The beverage was then prepared as one would prepare coffee. Sorghum was either used alone or mixed half and half with coffee beans. Sorghum coffee has all but disappeared with the increased availability of true coffee.

All of the products mentioned above were recognized in all of the communities we surveyed. In all areas maize was preferred over sorghum for use in tortillas and most other products. However, the perceived acceptability of sorghum as a maize replacement differed from area to area and time to time.

In general, sorghum was more likely to be considered acceptable in the highland communities in which it has an important role as an insurance crop in the subsistence system. In the lowland areas, commercialization of agriculture results in a diet that is more likely to be purchased. In this instance, when resources permit, maize is more likely to be purchased. In our first survey of the lowland communities few households reported using sorghum to make tortillas. Women often reported that for 2 or 3 weeks of the year when maize was unavailable sorghum would be used, but that the "hill people" were sorghum users, not they. The second dietary survey was conducted in the lowland communities after a year of drought in which almost all crops were lost. At this time many households had been using sorghum all year and responses concerning sorghum were much less negative. Ironically, the drought was less severe in the highland communities and many families there still had a supply of maize they were using for tortillas. When some maize is available it is preferable to prepare tortillas with half maize and half sorghum to stretch the maize. The important characteristic for the making of sorghum tortillas is that the grain be as white as possible.

Sorghum is considered to be "cooler" in essential quality than is maize, which is considered neutral. Although not all people still follow the hot/cool food classification system that is traditional in this area, some people reported that nursing women should not eat sorghum tortillas because the excess coolness could cause the nursing child to become ill. Several nursing women were preparing sorghum tortillas for their families and maize tortillas for themselves.

Although sorghum is not considered by some to be appropriate for nursing mothers, foods prepared from sorghum are considered appropriate for children, and children consume all products made.

Sorghum tortillas are considered less filling than maize tortillas. A common formula reported is that five sorghum tortillas are as filling as four maize torillas.

The degree to which sorghum is used as a basic grain in various communities is noted in Tables 1 and 2. For the highland communities in which land tenure is more diverse, landholders have more resources and produce more crops than those who rent or sharecrop land. For this reason, landholders and tenant farmers have been disagregated in Table 1. In fact, those families with less access to land use more sorghum than families with better access to land. Sorghum, because it is cheaper, is the grain more likely to be providing basic nutrition for the poor in highland communities.

While our survey data cannot directly address questions concerning the nutritional impacts of improving protein quality, or the effect of a sorghum-based diet on nutritional requirements, our research has led us to some conclusions concerning these issues.

High Quality Sorghum Protein

Although the diets of communities in southern Honduras are poor, the limiting nutrient appears to be energy rather than protein. On the average, families in highland communities met 116 percent of their energy needs and about 200 percent of their protein needs, adjusting for the poorer quality of sorghum and maize protein as compared with animal protein (Table 3). The averages mask the great amount of variation in dietary adequacy. Forty percent of households in the highland community of Cacauatare, in which there is a very skewed distribution of land with several large landholders and many sharecroppers and tenant farmers, and 22 percent of households in the highland community of El Naranjito, in which land is more equitably distributed, failed to meet energy requirements. In lowland agrarian reform communities engaged in commercial agriculture, energy needs were not adequately met. However, protein needs, on the average, were greatly exceeded and the intake of few families fell below 100 percent of estimated need.

The need for high quality protein is of course greater among small children than among adults. We surveyed the diets of children separately from families as a whole to determine how food resources are distributed within the family. We found that children were fed high protein foods such as milk and eggs.

While high quality sorghum protein may benefit communities with a severely limited diet, in southern Honduras it appears that sufficient protein sources are available and used. The nutrient contributing most to protein calorie malnutrition is energy.

Table 1. Number of Households Using Sorghum and Maize, Highlands, 1981.

	Landowners	Renters	All others	Totals
Used corn exclusively	17(71%)	12(46%)	4(27%)	33(51%)
Used sorghum	7(29%)	14(54%)	11(73%)	32(49%)
				N = 65
Children under 4				
Ate corn tortillas only	8(62%)	5(63%)	1(25%)	14(56%)
Ate some sorghum tortillas	5(38%)	3(37%)	3(37%)	11(44%)
				N = 25

Table 2. Number of Households Using Sorghum and Maize, Highlands/Lowlands, During 1 week in April 1983.

	Used maize exclusively	Used sorghum
Highlands	55(33%)	110(67%)
Lowlands	30(75%)	10(25%)

Increased Ascorbic Acid Requirements

Some research has suggested that sorghum-based diets increase ascorbic acid requirements in laboratory animals. In addition, some dietary research has suggested that ascorbic acid may be a limiting nutrient in Central American Diets. We have not yet analyzed our dietary data for ascorbic acid content, but we have documented the wide availability and use of fruits and vegetables with high ascorbic acid content. Our qualitative data on the seasonal availability of fruits and vegetables suggests that there are few times of the year when wild or cultivated fruits are not available. In April mangos and a wild fruit called tiquilote are available. During April and May of 1983 highland households were using approximately 200 wild plums (jacote) per week. Acerola (nance), a wild fruit with one of the highest known ascorbic acid contents, is available from May through June. We saw children carrying pails of gathered fruit home daily. A second harvest of mango begins in August. The mangos harvested in the second season are of inferior quality and often wormy. They are not suitable for sale and more likely to be consumed within the household. Many wild fruits are available throughout the fall until the rains end. During the dry season some local citrus fruits are available. This is the time of the year when the greatest amount of cash is available, and households purchase more of the staple vegetables such as cabbage and potatoes. Cabbage is used several times a week by most families, either cooked or raw in a salad. Market basket surveys show that potatoes are purchased at least once a week by almost all families. At the end of the dry season, in February and March, cashew fruits are a favored snack food.

Our information on the availability and use of the fruits containing ascorbic acid differs somewhat from other studies. We are tempted to conclude that because many of these foods are gathered from the wild and consumed casually, their use has been underreported in dietary surveys. Whatever the final conclusions are concerning the effect of sorghum consumption on ascorbic acid requirements, our surveys indicate numerous sources of ascorbic acid available to families in southern Honduras.

Protein Digestibility

There is a considerable amount of controversy surrounding the digestibility of sorghum protein and its effect on human nutrition. Studies carried out with children recovering from malnutrition show poor digestibility of sorghum protein, using a product made from whole ground sorghum. The digestibility appears to be affected by the method of grain processing used. Sorghum that has been decorticated and heat extruded, however, has been found to have significantly better digestibility. There has been relatively little testing of sorghum prepared in traditional dishes. It has been known for some time that the preparation of maize for the making of tortillas alters the availability of several nutrients, including niacin and several amino acids. Recent studies with young pigs at Texas A&M have demonstrated that protein digestibility of pearled sorghum cooked in a lime solution is equivalent to or better than that of similarly prepared maize. We feel that further testing of sorghum products, using traditional techniques such as nixtamalization, would help us understand potential nutritional problems inherent in sorghum-based diets.

Significance of Research Findings

The inclusion of dietary and nutritional data within the context of farming systems research in southern Honduras has served several important purposes. It has provided information on the uses of sorghum, the preparation techniques, and the grain quality characteristics important in producing improved varieties with acceptable food quality. It has evaluated the potential for dietary improvement through improvement of the crop. Finally, it has provided baseline information concerning the quality of nutrition which will be crucial in evaluating the benefits of improved sorghum varieties.

LDC Collaboration

INTSORMIL researchers collaborate with host country agencies through the exchange of information. Honduran agencies involved are the Nutrition Division of

Table 3. Average Percentage of Family Energy and Protein Needs Met in April 1983.

	Family energy needs met		Family protein needs met	
	Average	% less than 100%	Average	% less than 100%
Highlands				
Cacautare	116%	40.4	196%	6.0
El Naranjito	126%	22.6	213%	0
Lowlands				
Sta. Erlinda	105%	—	17%	—
El Tular	92%	—	17%	—

the Ministry of Public Health, the National Planning Commission, and the Ministry of Natural Resources.

Training and Technical Assistance

Our research has provided training opportunities for a number of students from the University of Kentucky. One master's practicum report and one master's thesis have been produced.

Implications for Future Research

The collection of baseline data was completed late in 1983. The more complicated analyses of the relationships among alternative cropping sytems and diet and nutrition are now being completed. No further data collection is anticipated in the near future. However, future planning calls for evaluations of the effects of improved seeds now being developed by INTSORMIL staff in southern Honduras on the quality of life of small farmers and their families.

Selected Publications

DeWalt, K.M. 1983. Usos del sorgo en Honduras: el caso de pespire. Proceedings of the Grain Quality Workshop for Latin America. INTSORMIL/INIA/ICRISAT.

DeWalt, K.M. and K.S. Thompson. 1983. Nutritional anthropology and farming systems research in southern Honduras. *Practicing Anthropology.* 5(3):15.

DeWalt, K.M. 1983. Nutrition strategies and farming systems research in southern Honduras. The international sorghum and millet project (INTSORMIL). Proceedings of the Farming Systems Research Symposium, Kansas State University, Manhattan, Kansas (in press).

Thompson, K.S., K.M. DeWalt and M.A. Fordham. 1982. Sorghum as human food in southern Honduras. *In: Farming Sytems Research in Southern Honduras.* University of Kentucky INTSORMIL Technical Report #1.

An Interdisciplinary Approach to Nutrition, with Grain Sorghum and Pearl Millet as the Staple Food

Mary Futrell, Lois Kilgore, Eunice McCulloch and Mary Dundas

Mississippi State University

For this study, both objective economic factors and subjective cultural factors were considered to be important. Our goal was to evaluate the capability of the subsistence farmer to supply adequate nutrition for his household within existing technological and economic constraints, and within the present system of dietary preferences or habits.

For the research in Honduras, several methods were used to obtain desired information. A comprehensive questionnaire dealing with sociological variables, agricultural activities, food habits and food attitudes most relevant to sorghum growing and use was constructed in English and translated into Spanish. Cross-cultural conceptual problems and interpretations were dealt with by conferring with a number of persons experienced in Latin American sociological field work. In addition to interviews in which the questionnaire was used, participant observation and lengthy informal discussions furnished supplementary data and permitted a check on the information collected with the questionnaire.

Sorghum is not eaten without some processing. The way sorghum is processed and combined with other foods influences its digestibility. Baseline data concerning the influence of food processing and preparation on the nutritive value of sorghum products will enable future researchers to design digestibility studies that will reveal the true availability of protein in sorghum products.

Research Accomplishments—Honduras

Sociological and nutritional field research in southern Honduras from 1981 to 1983 documented farming methods, social and economic factors and the nutritional conditions of subsistence farming family members in various localities where grain sorghum is a staple food. The chief sources of livelihood are the production of interplanted maize, sorghum and beans in the upland areas of El Corpus and Guajiniquil, and of maize and sorghum in the lowlands of Pavana. Each household relies on the produce from small plots of land, even though some of the farmers are organized into cooperatives. The average size of these plots is 1.1 *manzanas* (about 1.9 acres) on the hillside areas and 1.8 *manzanas* (about 3 acres) in the lowlands.

For this study, the average yield of crops in a variety of cropping systems and the daily diets of household members were documented. The average household size was found to be seven persons. The composition of the household in terms of age-sex categories used in FAO nutritional tables was calculated. With linear programming we analyzed the abilities of subsistence farmers to provide adequate nutrition through agriculture. It was found that the average crop yields of maize, sorghum and beans grown on farms of 1.1 *manzanas* could provide the minimum recommended amounts of calories and protein. Farmers produce the calories needed for their households with very little surplus. According to these findings, there is an average surplus of 595 pounds of sorghum, which is worth $47.60.

According to our model, cereal consumption is 7.7 pounds per day, very close to the 8-pound figure given by informants. This subsistence diet is deficient in vitamin A, riboflavin, ascorbic acid and calcium. As shown in Table 1, only 31 percent of the calcium requirement is supplied. However, the calcium deficiency is offset by the practice of steeping the maize or sorghum in lime water before the grain is ground and made into tortillas.

A linear programming model used to develop a nutritionally complete low-cost diet (using familiar and readily available foods) shows that such a diet would cost $1,165 at the prevailing market prices. This is $703 more than the value of the products grown (for the three-crop system). Clearly, crops produced on the amount of land available can not supply all nutritional requirements, and money for additional food items is needed.

Table 1. Optimum Land Use for Supplying Nutrients.

Combination of cropping activities	Land needed (mzs.)	Amount needed for complete nutrition (lbs.) Yearly	Daily
Sorghum (at 2-crop intercropping yields)	2.1	4,597	12.6
Beans (at sole crop yields)	14.8	4,770	13.1

Nutrient	Percentage of requirements supplied
Calories	286
Protein	974
Vitamin A	100 (limiting)
Thiamin	890
Riboflavin	205
Niacin	341
Ascorbic Acid	100 (limiting)
Calcium	309
Iron	623

Blood tests helped determine levels of malnutrition in Honduran children.

The women and children appear to be severely affected by these deficiencies. Of the children surveyed, 65 to 68 percent suffer some degree of malnutrition with 29 to 30 percent having second and third degree or severe malnutrition. The high prenatal, neonatal and infant mortality rates documented are believed to reflect the poor diets of the mothers: 28.6 percent of the women contacted had suffered miscarriages; 55.1 percent had had children who died before age 1; 24.8 percent had lost babies before the eleventh day; and 33.7 percent had lost babies before the end of the third month.

Sorghum Uses

Twenty-nine percent of the families in Corpus, 80 percent in Guajiniquil, and 37 percent in Pavana use the traditional tall white sorghum varieties for tortilla making. Both ashes and lime are used; this varies according to village. Methods of grinding and time of steeping also vary. The bias in favor of corn tortillas over sorghum seems to be on the grounds of taste, texture and appearance. The sorghum tortillas we saw were heavier, darker and more grainy in texture than corn tortillas. Every adult interviewed eats tortillas daily.

When the sorghum is in the dough stage, 43 percent of the households in El Corpus, 40 percent in Guajiniquil and 5 percent in Pavana enjoy atole, a custard-like product. Rosquetes, baked cakes about 5 cm in diameter made from ground sorghum, egg, oil, sugar and cinnamon, are sold for extra income. Families in all villages pop sorghum, and often combine it with honey or brown sugar syrup to make balls.

Anthropometric Studies

We studied preschool children in three rural villages and one village feeding center. Children in the El Corpus feeding center receive a diet deficient in calories, vitamin A and vitamin C, as do children not attending

Table 2. Incidence of Malnutrition of Preschool Children in Pavana, El Corpus, Guanijiquil and Feeding Center.

Nutritional status (% standard)	Pavana	El Corpus-Guanijiquil	Feeding center	El Corpus	Pavana	El Corpus	Pavana
	.... 1981%		....	..... 1982%		.... 1983%	
Weight/age (Gomez)							
greater than 90%	3.50	32.0	33.0	20.0	18.5	39.4	36.7
90-75%	36.0	32.0	33.0	50.0	51.9	39.4	44.3
75-60%	24.0	28.0	28.0	27.5	18.5	21.2	16.5
less than 60%	5.0	8.0	6.0	2.5	11.1	0	2.5
Weight/height (Waterlow)							
greater than 90%	56.8	52.0	38.9	27.5	40.7	28.1	36.1
90-80%	29.7	32.0	52.7	22.5	18.6	53.1	41.8
80-70%	10.8	12.0	8.4	47.5	40.7	18.8	20.3
less than 70%	2.7	4.0	0	2.5	0	0	1.2
Height/age (Waterlow)							
greater than 95%	45.7	42.8	43.7	45.5	59.3	27.3	24.0
95-90%	31.4	21.4	25.1	18.2	25.9	54.5	45.6
90-85%	22.9	28.6	6.2	27.2	3.7	9.1	22.8
less than 85%	0	7.2	25.0	9.1	11.1	6.1	7.6

Table 3. Weight, Height, Serum Carotene and Proteins by Site: (1983) (Mean ± Sem)

Variable	Pavana	El Corpus	P
Weight (kg)	12.29 ± .31	13.27 ± .49	NS
Height (cm)	88.06 ± 1.2	91.9 ± 1.9	NS
Carotene (ug/dl)	71.89 ± 7.86	112.53 ± 9.72	less than .01
Serum proteins			
Total serum protein (g/dl)	7.05 ± .07	7.47 ± . 0.09	less than .01
Transferrin (mg/dl)	268.69 ± 9.49	280.04 ± 12.09	NS
Albumin (g/dl)	4.57 ± .12	4.84 ± .14	NS
Gamma globulin (g/dl)	1.01 ± .67	1.05 ± .79	NS
Immunoglobulin M (mg/dl)	65.74 ± 12.8	140.52 ± 16.7	less than .01
Immunoglobulin G (mg/dl)	1283.59 ± 53.43	1560.87 ± 69.58	less than .01
Immunoglobulin A (mg/dl)	96.38 ± 5.72	98.83 ± 7.45	NS

the feeding center in all villages studied. Malnutrition, as determined by weight for age, is widespread (Table 2). Stunting, as determined by deficient height for age, fluctuates with seasonal harvests. Wasting, as determined by deficient weight for height, increases when food is scarce in the village, and is also prevalent among feeding center children.

In southern Honduras, tortillas are prepared from corn, sorghum or corn-sorghum mixtures.

Hemoglobin values were mostly marginal; few deficient children were observed. Transferrin levels decreased as severity of malnutrition increased. Total serum proteins and albumin concentrations were within the normal range in children in both Pavana and El Corpus feeding centers (Table 3). Gamma-globulin levels were higher among El Corpus feeding center children. IgG and IgM were significantly higher (P less than .01) in the feeding center children than in Pavana children, indicating more infection among feeding center children. Serum carotene levels were significantly higher (P less than 0.1) in feeding center children than in Pavana children because of availability of green vegetables. Parasite ova observed in all stools examined were *Ascaris lumbricaides, Trichuris trichuiria, Entamoeba histolytica, Giardia lamblia*, hookworm, tapeworm and *Stronglyoides stercoralis*. Parasites were more common in malnourished children. A higher incidence of parasites was observed in the El Corpus children.

Research Accomplishments—Sudan

From September 1983 through March 1984 we studied food consumption and food practices of families in three rural villages in Sudan. We found that the average adult male intake for kilocalories of energy, calcium, vitamin A, riboflavin and niacin is about half of the FAO (1974) requirements for persons in Africa. The caloric intake of all men in UmSagata and Oliab and 97 percent of the men in Nuba is below the FAO requirement. Eighty-three percent of the men in UmSagata had an inadequate intake of calcium. Seventy-eight percent of the men in Oliab, 83 percent in Nuba and 77 percent in UmSagata had vitamin A intakes below the FAO recommendation. All men in the three villages had inadequate riboflavin and niacin intakes.

Average protein consumption by men in all three villages exceeded the FAO recommendation, but 50 percent of the men in Oliab did not receive adequate protein. Average iron consumption by men in the villages met the FAO requirement, but 63 percent ot the men in Oliab had inadequate intakes of iron. Average thiamin intake was adequate in UmSagata and Oliab, but inadeqate in Nuba. Vitamin C average intake was adequate in Nuba and Oliab but inadequate in UmSagata.

We determined the type of sorghum consumed by people in the villages, the frequency of consumption and the meal at which the sorghum is served. The feterita type is preferred by 43 percent of the people of UmSagata and 63 percent of the people in Oliab. In Nuba, 83 percent of those interviewed prefer the Mayo variety because of its white color. In Oliab all of those interviewed eat sorghum for breakfast, 87 percent eat it for lunch and 23 percent eat it for dinner.

All of the women interviewed in Nuba, 97 percent in Oliab and 87 percent in UmSagata breastfeed their babies. The usual length of time for breastfeeding is 1.5 to 2 years, but most mothers begin giving supplemental foods when children are 6 months old.

Questions concerning food attitudes and beliefs were asked, including foods good for babies and not good for babies, foods good for lactating mothers, weaning foods for children and foods served on holidays. Milk was the food mentioned most frequently as being good for babies. Foods most frequently mentioned as not good for babies were okra and kisra. Food considered good for lactating mothers were nasha, a beverage made from fermented sorghum flour, and milk. The weaning food most often mentioned was milk. Foods most frequently consumed during holidays include meat, candy and abrey, a beverage made from sorghum and consumed especially during Ramadan, the Moslem holy month of fasting.

Malnutrition among children was assessed by weight for age, height for age, and weight for height. Weight for age data indicate that first degree malnutrition among the children in Nuba is 56 percent, in UmSagata 27 percent, and in Oliab 22 percent (P less than .05). Second degree malnutrition is 66 percent in UmSagata, 67 percent in Oliab and 42 percent in Nuba (P less than .05). All of the children in UmSagata had chronic malnutrition.

Weight for height data indicate that 95 percent of the children in UmSagata and 83 percent in both Nuba and Oliab are below normal, and thus malnourished in some degree. Height for age data indicate that 84 percent of the children in UmSagata, 83 percent in Nuba, and 97 percent in Oliab have chronic malnutrition. Stunting occurs in 50 percent of the children in Nuba, 44 percent in Oliab and 16 percent in UmSagata. Wasting occurs in 39 percent of the children in UmSagata, 17 percent in Nuba and 6 percent in Oliab. Children both stunted and wasted totaled 44 percent in Oliab, 41 percent in UmSagata and 22 percent in Nuba.

Weight for age data indicate that the percentage of children with first and second degree malnutrition increases with age in all villages. Weight for age data indicate that more female children than male children suffer malnutrition in all three villages. This reflects the common belief in Sudan that male children are more important than female children.

Malnutrition is widespread in Sudan particularly in villages where a variety of food is not available. But food intake is not the only factor causing malnutrition. Custom and culture, income level of the family, location of the village, knowledge of the family member making food purchases, and environmental factors such as rainfall or availability of water all contribute to the problem.

Sorghum Products

Sorghum flour (100 g) and lentils (50 g) from Sudan were mixed and the amino acid content of this mixture was determined. The chemical score was calculated. The lowest percentage was for methionine + cystine, however that score was 89 percent. Therefore, this mixture provides 25 g protein for a child, plus the amino acid requirements. However, the biological value of products made from sorghum flour was 50 percent (Eggum *et al.*, 1983), which means that although the chemical score was acceptable, only one half of the amino acids were available. Further research on the digestibility and biological value of sorghum products needs to be done with both animals and human subjects.

We also developed a sorghum product comparable to casein in protein quality. Formulations included sorghum plus wheat plus soy flour (SWSoy), sorghum plus wheat plus cowpea plus soy flour (SWCSoy), sorghum plus wheat plus cowpea plus peanut butter (SWCP), sorghum plus wheat flour plus peanut butter (SWP), and sorghum plus wheat flour plus peanut butter and soy flour (SWPSoy). Sensory evaluation by adult tasters showed a significant difference (P less than .05) among the products; no difference was observed by African children. Values for protein efficiency ration (PER) were 2.37, 2.24, 2.02, 1.81, 1.78 and 1.47 for diets containing casein, SWSoy, SWCSoy, SWCP, SWPSoy, and SWP, respectively. The PER for the SWSoy diet was not different from the diet containing casein. Heat improved protein utilization for SWSoy and SWCSoy products. Net Protein Ratio values ranked the same as PER for SWSoy, SWCSoy, SWCP, SWPSoy, SWP and casein, with values of 3.62, 3.60, 3.39, 3.37, 3.21, and 3.80 respectively. Order of rank was the same for ADG, feed intake and feed efficiency.

The *in vivo* protein digestibility values ranged from 91.8 percent for SWP to 88.82 percent for SWPSoy products. The SWSoy product was 90.19 percent, SWCSoy was 80.57 percent, SWCP was 90.19 percent, and casein 94.73 percent digestible. The *in vitro* protein digestibility showed lower values—86.11 percent, 80.48 percent, 81.57 percent, 82.48 percent, 81.93 percent, and 94.78 percent—for SWSoy, SWCSoy, SWCP, SWP, SWPSoy formulations and casein, respectively, than the *in vivo* protein digestibility. There was a high correlation (r-.896, P less than .05) between the *in vitro* and *in vivo* protein digestibility.

Significance of Research Findings

This research has confirmed that neither the quantity nor nutritional quality of crops grown by subsistence farmers in Honduras and Sudan is adequate to supply well-balanced diets for all household members. The cropping systems are viable in the sense that production is sufficient to furnish enough staples for the traditional diet. These staples provide the recommended allowances of calories, protein and some of the essential nutrients. However, because some nutrients are not present in the staple crops in sufficient amounts, additional foods are needed. The absence of any surplus of the crops produced makes the purchase of additional food unlikely. Other food-producing activities, such as growing small plots of vegetables or fruits or raising chickens and pigs, are engaged in on such a small scale that they do not overcome the deficiencies. In addition, families' needs for cash are met by selling part of the crop, so that at times even calorie requirements might not be met.

Farmers cannot raise enough crop surplus and cannot work enough at outside employment to purchase supplemental food items needed. Thus, economic, farming, and nutritional factors interact to produce a self-sustaining situation in which chronic malnutrition seems inevitable.

The most obvious and feasible solution is to grow additional fruits and vegetables on a year-round basis. Each household has enough land near the house so that small vegetable gardens could be grown.

We wish to emphasize the necessity of considering many interrelated factors when agricultural innovations are planned. We have given an example of how the introduction of new grain varieties may not by itself solve the problem of malnutrition in areas where people possess only marginal resources. To solve the problem requires careful planning and nutrition education. In addition, possible consequences must be anticipated. If better diets result in lower child mortaility rates, then population growth might lead to the need for further intervention. Or, equally possible, a desire to limit the number of children might result from the fact that fewer would be expected to die. It is also possible that, with better nutrition, farmers would be able to work harder and aspiration levels would rise.

The data collected by this project will be used to evaluate nutritional benefits of agricultural changes, and to plan future nutrition activities and research.

A high protein product comparable to casein was produced by carefully blending vegetable proteins of soybean flour, sorghum and wheat flour at a ratio of 2:1 of soybean to sorghum flour. One of the products, SWSoy, met the FAO essential amino acid patterns. It also had a PER above 2:1, a low fiber content, more than 25 percent of calores provided by fat, available protein of 7.9 percent, and NDPCal of 10 percent as recommended by the Protein Advisory Group (1971) in formulating high protein foods for children. Therefore, this product can be used in programs to feed children in deprived areas of the world where sorghum and legumes are cultivated.

LDC Collaboration

Collaboration in Honduras was with the Ministry of Natural Resources, Ministry of Public Health, Department of Parasitology-Medical School of Honduras, Peace Corps and CARE. Blood samples from the children were drawn by a technician from the Ministry of Health.

In Sudan the research was coordinated through faculty members at AhFad Univiersity. Dr. Kristjan Arinbjarnarson with the Sudan Council of Churches made arrangments for the work in UmSagata. Edward McKenzie of Foster Parents Plan International made arrangements for work in Nuba and Oliab. We were also assisted by AID, the Food Research Center in Khartoum, and faculty members from the University of Khartoum.

Training and Technical Assistance

Six graduate students have completed their training in this project; five others are currently engaged in research.

Implications for Future Research

We propose a 3-year research project to collect more data on the foods eaten by young children, especially sorghum and millet. Other factors such as cyanide content and aflatoxins will be assessed.

We propose to research weaning practices and provide technical assistance to improve weaning behavior in four LDCs—Egypt, Sudan, India and Honduras. Final country selection will be done in consultation with the contracting agency. The aim is to study traditional and recommended practices to determine how detrimental practices may be modified, and how the use of highly nutritional, low-cost weaning foods may be introduced without harmful effects such as increased risk from inadequate sanitation.

The study will examine: governmental policies and programs in health, population, education and agriculture as they relate to child health; the programs of various private voluntary organizations; and the availability, price and nutritional quality of locally available commercial weaning foods. If possible, low-cost formulas made with local foods will be devised. The project staff will provide technical assistance in the promotion of recommended weaning practices, primarily through an intensive educational program for local personnel, private organizations and governmental agencies.

Mississippi State University will provide three full-time professionals to the project. These persons have conducted research in the countries to be studied and have extensive contacts in them.

We feel this project would contribute significantly to realizing both AID and INTSORMIL goals.

Selected Publications

Futrell, M.F., E. McCulloch and R. Jones. 1982. Use of sorghum as food in southern Honduras. Proceedings of the International Symposium on Sorghum Grain Quality, ICRISAT. Patancheru, India.

Futrell, M.F., E. McCulloch, R. Jones and L. Bluhm. 1982. Factors affecting sorghum consumption in Honduras. *In: Sorghum in the Eighties.* Proceedings of the International Symposium on Sorghum. ICRISAT. Patancheru, India.

Futrell, M.F. and R. Jones. 1982. Use of grain sorghum as food in southern Honduras. Proceedings of the Grain Quality Workshop for Latin America. International Maize and Wheat Improvement Center. Mexico City, Mexico.

Okeiyi, F. and M. Futrell. 1983. Evaluation of protein quality of formulations of sorghum grain flour and legumes seeds. *Nutr. Reports Int.* 28:451-461.

Food and Nutritional Quality of Sorghum

L.W. Rooney

Texas A&M University

Sorghum and millet food quality, especially in traditional foods, has not been defined. The major goals of this project are to:

- identify how sorghum and millet are used in Asia, Africa and Latin America;
- determine the major grain characteristics that affect food quality;
- determine the effect of processing on the nutritional value of sorghum products; and
- evaluate the ways other factors such as molds, weathering and sprouting affect grain quality.

This project is designed to provide practical information needed to improve sorghum food quality through breeding and selection. Information on the basic chemical, physical and processing properties of sorghum are being determined so that we can define quality and develop simple tests to predict it. We interact with scientists around the world to develop the information and disseminate it to appropriate users.

Research Accomplishments

Traditional Methods of Producing Sorghum and Millet Foods

Field investigation in Mali, Upper Volta, Niger, India, Honduras, Dominican Republic, and Mexico, and participation in International Sorghum Food Quality Trials, has increased our knowledge of the attributes of sorghum and millets important in producing various traditional foods. We have developed laboratory tests for measuring these attributes as well as analyzing milling procedures.

Traditional sorghum and millet foods have been grouped into categories based upon similarities in processing. Table 1 shows the major categories of foods, the procedures, and common names of products. The terms fermented and unfermented refer to leavened and unleavened breads. Alcoholic beverages are of two types: slightly sour or sweet liquids; and the sour, thick, viscous beer typical of southern Africa, Sudan and other areas. The latter product is the more important.

Dry milling properties of sorghum are very significant for porridges and steamed products in which decorticated sorghum usually is used. Sorghums with a thick pericarp and hard endosperm are preferred because they are more easily decorticated. Thin pericarp sorghums require longer decortication times and are not liked by consumers. Use of mechanized milling systems may change this situtation.

Table 1: Traditional Foods Made with Sorghum and P. Millet.

<table>
<tr><th>Type of Food</th><th>Common Names</th><th>Countries</th></tr>
<tr><td>Unfermented bread</td><td>Chapati, roti, rotti</td><td>India</td></tr>
<tr><td colspan="3">95 to 100% extraction flour is mixed with water, kneaded into a dough, and the dough is formed into a thin circular piece about 8 to 10 in. in diameter. The dough piece is cooked on a hot grill at 345°C for 25 sec. on each side. Then the outside is sprinkled with water, the dough piece is turned over, and it is cooked for 25 sec. or until it puffs. Sorghums differ in extent of puffing, texture, color, taste and keeping quality. White sorghum makes the best chapati.</td></tr>
<tr><td></td><td>Tortilla</td><td>Central America</td></tr>
<tr><td colspan="3">A 3:1 ratio of lime solution to sorghum is boiled for 15 to 40 min. The line solution contains 0.8% lime based on grain weight. The cooked sorghum is cooled, washed with water to about 8.5 pH, ground into masa and pressed into tortillas. The tortilla is cooked on each side for 30 sec. at about 345°C on a grill. Sorghum tortillas are off-colored compared to white maize. Usually mixtures of maize and sorghum are used. Pearled millet has not been used in tortillas.</td></tr>
<tr><td>Fermented bread</td><td>Kisra, dosa, dosai</td><td>Sudan, India</td></tr>
<tr><td colspan="3">Whole sorghum is ground into flour. A starter is made by mixing yeast and warm water. Usually it is obtained by saving part of the last batter. The starter is mixed with water and flour (1:2:9 ratio, respectively) to form a paste which is fermented overnight. The fermented batter will be thin enough to spread in a thin layer on the surface of a hot grill. The Kisra is cooked for about 30 sec. Good Kisra is paper thin with a sour taste and fermented flavor.</td></tr>
<tr><td></td><td>Injera</td><td>Ethiopia</td></tr>
<tr><td colspan="3">Whole sorghum flour is mixed with about 40% of the total water and yeast. Usually starter from a previous batch is used. The mixture is kneaded into a dough which is fermented overnight. Then about 10% of the fermented dough is mixed with water and cooked. The cooked material is added to the remaining dough with the remaining water. The batter is allowed to undergo vigorous fermentation for 2 hrs. Then the batter is poured in a thin layer onto a hot griddle and baked. The injera is a large, thin layer with numerous fish eyes on the surface. Injera batter is thicker than that of kisra.</td></tr>
<tr><td>Stiff porridge</td><td>Ugali, Tuwo, Saino, Dalaki, aceda, atap, bogobe, ting, tutu, kalo, karo, kwon, nshimba, tô, tuo, zaafi, asidah, mato, sadza.</td><td>Africa India</td></tr>
<tr><td colspan="3">Decorticated sorghum flour is stirred into boiling water until the sorghum flour is completely gelantinized. Additional flour is added until a very stiff paste is formed. The paste is stirred vigorously while it is cooked. A color change of the paste indicates sufficient cooking. The porridge is placed in a calabash (gourd), cooled for an hour and eaten with a sauce. Sometimes acid or base will be mixed into the cooking water. In Upper Volta, tamarind pods are steeped overnight in the cooking water. In Mali, alkali is added to the cooking water. Granulation of the flour, composition of the sauce and consistency varies among countries and tribes within a country.</td></tr>
<tr><td>Thin porridge</td><td>Uji, ambali, edi, eko, kamu, koko, nasha, obungi bwa, kal, obushera, atole</td><td>Africa, India</td></tr>
<tr><td colspan="3">Decorticated sorghum flour is mixed into boiling water until a thin paste is formed. The consistency is similar to cream. It is made with acid or alkali in the cooking water. Sometimes a part of the flour is fermented 24 hrs. prior to cooking. Particle size varies; flour is made from sprouted grain, pearled grain and whole grain. It is served with milk, sour milk, sugar, honey, fruit and other variations, depending on local preference.</td></tr>
</table>

Sorghums used in brewing are typically brown B_1-B_2-S- genotypes, even though red sorghums without a testa are preferred. The brown grains are used because they often yield more grain and are less preferred for other food uses. Special processing steps are used with brown grains. The grain is cooked in wood ashes or alkali, which may overcome the deleterious effects of the tannin content of brown sorghum. Tô from brown sorghums is taken by new mothers and farmers doing heavy work because it gives more energy. Thus, the information in Table 2 has some variations and exceptions.

Environmental conditions during and after maturation of the grain affect food quality. Molds, insects, sprouting and drought, alone or in combination, can destroy the grain prior to harvest, or damage it so that it produces inferior products. For example, Maldani 35 has excellent grain quality for rotis when grown in the dry season in India, but is unacceptable when grown under moist conditions. Exotic sorghums introduced into West Africa often produce poor quality grain that cannot be milled because the kernels are soft when drought stressed. The local Malian varieties form hard kernels that can be milled. Plant breeders are now aware of this problem.

The major food uses of pearl millet are similar to those listed in Table 1, except that millet is not used for tortillas. Millet is more difficult to decorticate than sorghum. Kernel size and shape varies among types. Those with spherical kernels decorticate most completely. Couscous, Tô, roti and beer are major products made from millet.

The thick and thin porridges and nonalcoholic beverages are made in a very similar manner. The ratio of water to flour determines the viscosity and thus the

Type of Food	Common Names	Countries
	Ogi, oko, akamu, kafa	**Nigeria, Ghana**
Sorghum grains are steeped in water for 2 to 4 days at room temperature. The fermented grain is milled; the bran is removed by screening. The sediment in the pot is ogi, which is cooked in water to produce a porridge which is consumed warm or cooled to form a gel or pudding. It is preferred as a weaning food and for elderly people.		
Steam cooked products	**Couscous**	**West Africa**
Finely ground sorghum or millet flour is kneaded with water until the flour particles stick together. Then the particles are pushed through a coarse screen. The particles are placed in a container with a perforated bottom which is placed on top of a pot filled with boiling water. Steam penetrates through the agglomerated particles. Several times during cooking the couscous is removed from the pot, stirred and returned to the cooker. Usually ground baobob leaves, peanut butter, okra or some other additive is mixed with the couscous during steaming. The cooked product is consumed with a sauce. Sometimes it is dried and used as a convenience food.		
Boiled sorghum-cooked whole or pearled grain	**Acha, pearl dura, sorghum, sankati, mudde, kali**	**Africa, India**
Sorghums are pearled to remove the pericarp and cooked like rice. Usually varieties with a high proportion of corneous endosperm are preferred. Whole grains are sometimes boiled, parched or steamed and consumed with legumes or a sauce. It is mixed with rice as an extender.		
Snack foods		**Worldwide**
The sorghums are popped, puffed and parched. They may be consumed directly or ground and mixed with other ingredients. Fried snacks are popular. There are endless variations in snacks.		
Alcoholic beverages	**Burukutu, dolo, pito**	**West Africa**
Sorghum is steeped, germinated and dried. Mash is prepared by mixing the ground malt with water. The mixture is brought to boiling; the material is filtered to remove the bran. The wort is boiled, cooked and inoculated with yeast from a previous batch of beer. Fermentation occurs overnight and actively fermenting beer is drunk the next day. Beer is a relatively clear red liquid with a sweet, pleasant taste and low solids content. Continued fermentation produces a sour taste. Alcohol content is about 1 to 5 percent.		
	Marisa, busaa	**Sudan, Southern Africa**
Ground sorghum malt is mixed with water, allowed to sour, boiled with adjunct (corn grits), cooled to 60°C, and saccharified with more sorghum malt. Maize grits are often unavailable so sorghum is used in many areas. The mixture is filtered to remove the larger particles and fermented with top-fermenting yeast. Beer has a high solids content, a sour taste, bright pink color and the consistency of a milk shake. Alcohol content depends on length of fermentation time and ranges from 1 to 8% by volume.		
Nonalcoholic beverages	**Mahewu, amaheu, marewa, magou, leting, nasha**	**Africa**
Ground sorghum, sometimes mixed with sprouted sorghum, is exposed to boiling water and held at elevated temperatures for up to 20 hrs. *Lactobacilli* and other microorganisms cause souring of the mixture. Very little alcohol is produced. Concentration of dry substances distinguishes sour nonalcoholic beverages from thin porridges.		

classification of the product. Ugi and atole are thin porridges that are often drunk warm. Upon cooking they generally form a solid. pH of the products varies, and affects the kind of sorghum preferred for each product. In general, sorghums that make acceptable thick porridges also produce acceptable thin porridges and nonalcoholic beverages.

Traditionally, sorghum milling is done by hand with a wooden mortar and pestle. Milling usually consists of decortication to remove the percarp, followed by crushing of the decorticated grains into flour or semolina. The grain is washed, placed in the mortar and pounded vigorously with the pestle. The pericarp is freed from the kernel. During pounding, additional water may be added to the sorghum. Finally, the decorticated grain is separated from the bran by washing with water or winnowing after the milled sorghum has been dried in the sun. The decorticated grain is ground into flour by additional pounding with the pestle or by use of commercial attrition mills if they are available in the village. In many cases, the women decorticate the sorghum by hand and have the commercial attrition mill grind it into flour. In the urban areas, decortication is often done with rice milling equipment.

Table 2 shows the types of sorghum preferred for each of the major categories of traditional foods. This information will undoubtedly change as we learn more about sorghum quality in each of the foods. The kernel characteristics described in Table 2 conform to the descriptions presented in proceedings of the Sorghum Food Quality Symposium (Rooney and Miller 1982). They are based on the International Food Quality Trials and workers' observations (Rooney and Murty 1982b). In general, sorghums with a white pericarp and without

Table 2. Kernel Characteristics of Sorghums Used to Make Traditional Foods.

Food products	Milling	Pericarp thickness	Pericarp	Testa	Plant color	Texture
Unfermented breads						
Chapati	Whole grain	Thin	White	None	Tan	Intermediate
Tortilla	Whole grain	Thick?	White	None	Purple****	Intermediate to corneous
Fermented breads	Whole grain	Thick	White	Yes*	No preference	Soft, floury
Stiff porridges	Decorticated	Thick	White	None**	No preference	Corneous
Thin porridges	Decorticated	Thick	White	None**	No preference	Corneous
Steamed products	Decorticated	Thick	White	None	No preference	Corneous
Boiled sorghum	Decorticated	Thick or thin	White	None	No preference	Corneous
Beer	Whole grain	No prefere-nce	Red	Yes***	No preference	Intermediate

* Sorghums with a testa are widely grown and used for kisra and injera. Color is not the most important criteria.

** Local types with thin pigmented testa are grown and used for Tô.

*** Sorghums available for brewing have pigmented testa with dominant spreader gene present. For industrial brewing, red sorghums without a pigmented testa are best.

**** Sorghums with tan plant and straw-colored glumes are most desirable. Thus, dramatic improvement in sorghum quality for tortillas is possible.

a pigmented testa are preferred in many areas of India, but not in many African areas. For example, Mali grows many sorghums with pigmented testa which are used to make Tô and couscous. One of the major quality criteria in Mali is the ability to dehull the sorghum. The sorghum should produce Tô that is nonsticky and that keeps overnight. Color is less important. Floury sorghums require less cooking time than corneous sorghums. Sorghum tortillas appear to change color when stored after baking. The pericarp and plant color affect sorghum quality for use in tortillas. Sorghums with tan plant color, thick white pericarp, normal endosperm, intermediate texture, freedom from splotching and mold tolerance are required. The thick pericarp is preferred by Honduran housewives since it can be removed more easily and completely.

Methods of determining cooking time, effect of environment and changes in physical and chemical properties of sorghum have been evaluated. An extrusion cell built for use with the Instron permits measurement of the texture of cooked sorghum in order to determine optimum cooking time. Other tests measure water absorption, increase in cooked kernel weight, density, flotation in sodium nitrate, kernel hardness and other properties which relate to tortilla quality. Intermediate kernel hardness is best because hard kernels require a longer cooking time.

An alkali test has been developed to select white kernels of sorghum with the least color. Several kernels of sorghum are placed in standard alkali for 2 hours and the color of the kernel and solution is subjectively rated on a 1-4 basis in comparison with standard samples. The test has been used in screening the food grain population to select for grain with white pericarp. Its value must still be determined, but it is much better than visual evaluation of the grain. The real significance is its simplicity.

The criollo sorghums native to Central America are not desirable for tortillas because they have purple or red plant color and spotted pericarps. Sorghum for tortillas can be improved by developing photosensitive, tall sorghums with tan plant color and white pericarp with low levels of color precursors. Our findings have been incorporated into the breeding and selection program in Honduras, and are being evaluated in Mexico.

Decorticated or pearled sorghum can be used in various foods, including tortillas. Decortication reduces the level of pigment precursors in sorghum; thus, decorticated white sorghum can produce tortillas with color similar to white maize tortillas. Even sorghums with a red pericarp can be decorticated and used in mixtures with maize to produce acceptable tortillas. Advantages of pearled sorghum are reduced cooking times, little or no washing of the nixtamal and little or no dry matter losses. The bran removed during pearling can be fed to livestock. Small village decorticators could be produced locally in Central America. Disadvantages of pearling are the cost and availability of mills and the need to change cooking and handling procedures, although these would be slight. In field tests, the use of pearled sorghum in blends with maize was acceptable when the pearled sorghum was added after the corn had been cooked. Sticky masa and hard centers in the sorghum can be avoided by steeping the grain to enable hydration prior to cooking.

In Mexico, whole and pearled sorghum has been used alone or in maize blends in cooking trials conducted in commercial tortilla manufacturing plants. It was found that both pearled and whole white sorghum could be blended with maize successfully to produce tortillas. Modifications in cooking times were needed, and sorghum affected color, masa handling properties and texture of the tortillas. Since sorghum is the second leading cereal produced in Mexico, its potential value as a substitute for maize in tortillas is being recognized. The development of white food types of sorghum is significant since the maize supply is inadequate. White sorghum makes better tortillas than the soft yellow maize used in many areas of Mexico.

Thick Porridge

Village milling and cooking evaluations in Mali and Upper Volta, done cooperatively with ICRISAT, show that milling properties, texture and keeping quality are critical to sorghum food acceptability. The poor "taste" of Tô from some sorghums is really related to undesirable texture. Tô is eaten with a sauce that tends to mask differences in taste among sorghum cultivars. Lack of sticky texture of fresh and stored Tô is a major criteria. Stickiness can be measured with a penetrometer or a double pan balance. Both methods use relatively unsophisticated, inexpensive equipment.

International Sorghum Food Quality Trials (IFQT)

These trials, developed in collaboration with ICRISAT, evaluated the food quality of traditional foods and were carried out in Africa and Mexico. The trials provided background information for much of the work reported in the 1981 Sorghum Grain Food Quality Symposium, and stimulated informal collaborative efforts among national programs in Mexico, Mali, Upper Volta, Tanzania, Botswana, Ethiopia, Sudan and India. The International Cereal Chemistry Symposim on Sorghum and Millet Food Quality in June 1984 was an update of work stimulated by the IFQT and subsequent workshops.

Several methods for predicting sorghum food quality were evaluated and revised based upon the IFQT. For example, small test mills were preferred for use in evaluating sorghum milling properties. Information on structure and genetics of sorghum kernel characteristics was summarized and illustrated with color photos. This was the first effort to make such information available to sorghum workers.

Tortillas

Procedures for evaluating sorghum tortillas have been standardized and applied to samples representing different germplasm types. Tortilla color is the most important factor in the acceptance of sorghum. Sorghums with colored pericarp are undesirable for tortilla production. Variation among the white sorghums is great. Color of sorghum tortillas is affected by the sorghum genotype, the cooking procedure and the environment in which the sorghum matures. Weathered sorghum gives off-color tortillas.

Modified traditional processes can be used to produce acceptable tortillas from sorghums and sorghum-maize blends. Commercial and traditional procedures for preparing maize tortillas in Mexico and sorghum tortillas in Honduras were documented. Sorghum requires less alkali and shorter cooking and steeping times than maize. Dry matter losses during optimum cooking and steeping of maize and sorghum are similar. The cooking time of sorghum varieties varies, depending upon kernel texture (hardness), water absorption and other unidentified factors.

Table 3. Grain Characteristics, Average Manual Decortication Time, and Endosperm Recovery of Sorghums with Contrasting Pericarp Thickness.

Grain Type	1,000-Kernel weight (g)	Endosperm texture (vitreousness)	Hardness (breaking strength, kg)[a]	Pericarp thickness	Average decortication time (min)[a]	Endosperm recovery (%)[a]
Nio-Fionto (very thick pericarp)	43.8	3	8.7[a]	Very thick	11.0[a]	66.3[a]
Malian Guineense (thick pericarp)	21.8	2	8.9[a]	Thick	19.4[b]	71.7[a]
Malian Guineense (thin pericarp)	21.3	2	9.4[a]	Thin	26.4[c]	68.6[a]
Voltaic Guineense (thick pericarp)	20.1	2	09.1[a]	Thick	20.0[b]	—
Voltaic Guineense (thin pericarp)	20.6	2	9.4[a]	Thin	29.0[d]	—

[a] Values within the same column followed by different letters are significantly different at P = .05, according to Duncan's Multiple Range Test.

Some sorghum lines do not make acceptable Tô. For example, S-940, an advanced line from Upper Volta, produces unacceptable Tô. Thus, it was not released as a commercial cultivar.

We have exchanged samples and procedures for evaluating Tô quality with Mali and Upper Volta.

Lab procedures for Tô production have been standardized. Selection in the field, based on visual kernel characteristics, is an effective way of selecting for sorghum quality in preliminary trials. The genetics of kernel charcteristics have been illustrated with color slides and photomicrographs. Milling properties can be determined by milling 10 g of sorghum in a small laboratory mill. Then the decorticated grain can be used to measure Tô texture (softness) and stickiness. Amylose content and some gel consistence tests were not highly correlated with Tô texture and acceptability. The specific heat and gelatinization temperatures of sorghum starches from the IFQT were not related to Tô quality. Particle size, variety, environment, pH and storage conditions do affect Tô properties. Significant interaction occurs between variety and pH; a variety that produces excellent acid Tô may produce poor alkali Tô. Native sorghum varieties are generally more tolerant to pH changes than introduced cultivars.

Village milling trials conducted in Mali found that sorghums with a thick pericarp were dehulled by hand pounding in two-thirds the time required to dehull thin pericarp sorghums. We milled sublots of the same samples using several laboratory mills and confirmed the Malian observations. In addition, light and scanning electron microscopy demonstrated that the thick pericarps had a greater number of starch granules in the mesocarp. Both environment and variety of sorghum greatly affect milling properties. Weathered grain or grain that matures under drought stress has poor milling properties and produces Tô with poor texture.

Sorghum kernels with thick pericarp and hard endosperm are required to produce acceptable Tô. The laboratory procedures are being used to select for Tô quality in early generations. Thus, village dehulling and cooking trials need to be done only on advanced sorghum lines. This reduces costs, saves time and ensures that sorghum with acceptable Tô quality will be the end result of the breeding program. Since thick porridges are major foods in nearly all sorghum and millet producing areas, that is most significant.

Processing of Sorghum

The combination of better sorghum varieties with processing techniques which improve food quality should lead to a better acceptance of sorghum as human food. Sorghum has been pearled and processed using a dry heating procedure (micronizing), and extruded using a high temperature, high pressure procedure. Ground, micronized and extruded sorghum appears useful as a substitute for part of the maize in instant dry masa flours. Up to 30 percent of ground, micronized sorghum from a commercial, red sorghum hybrid was acceptable in tortillas; larger quantities of a white sorghum could be used. Extruded sorghum products could be used in snacks and breakfast cereals and as a base for atoles and other processed products.

The dry milling properties of sorghum are important, because the finer the particle size the better the quality of composite flours made with sorghum and other grains. Sorghum can be substituted for up to 50 percent of the wheat flour in baked products without affecting acceptability. The exact amount depends on the baked product, the type of sorghum flour, the strength of the wheat flour and the baking procedure. The ability to secure adequate supplies of good quality sorghum flour is a major problem in many sorghum producing countries. More work is needed in this area.

Nutritional Value of Sorghum

The effect of lime treatment on nutrient digestibilities of maize, sorghum and pearled sorghum (10 percent of initial weight removed) was determined with growing pigs and rats in *in vitro* tests. The digestibilities were determined at the end of the small intestine and over the total digestive tract of pigs. Dry matter, gross energy and protein digestibilities were much higher for the maize and pearled sorghum than for the whole sorghum. Pearling decreased the levels of lysine and other essential amino acids; but the dry matter, protein and gross energy digestibilities were improved by pearling. The alkali decreased the lysine digestibility at the terminal ileum by five percentage points for sorghum and maize. The reduction in lysine digestibility in the lime-treated groups accounted for the differences in nitrogen (N) retention/N intake and N retention/N absorption. The major findings were that the nutritional value of sorghum tortillas and related lime-cooked products were quite comparable with similar maize foods. Sorghum can be substituted for part or all of the maize without adversely affecting the nutritional level for consumers. Sorghum, in general, has about 95 percent of the nutritional value of maize for livestock; that figure is true for tortillas and lime-cooked foods was well. Pearled sorghum has nutrient digestibilities equal to or better than maize, but the lysine content is decreased so it has lower nutritional value. The improved digestibility means that pearled sorghum products would be useful in foods.

A pronase assay was developed to serve as an index of *in vitro* protein digestibility. The *in vitro* digestibility of more than 400 sorghums taken from segregating populations and sister lines was measured. Results indicated that waxy sorghums had much better starch digestibilitiy and slightly better protein digestibility than nonwaxy sorghums. However, the waxy sorghums generally had lower kernel weights.

In vitro protein digestibility tests ranked sorghums with red and white pericarps without a testa highest, those with a testa (B_1-B_2-ss) slightly lower, and those with a testa and spreader (B_1-B_2-S-) lowest. Considerable variability existed within each group. For example, some sorghums with a testa have values equal to those without a testa. The *in vitro* assay suggests that the digestibility of white, nonwaxy sorghum lines is not very great. The waxy sorghums have better digestibility but lower grain yields and are susceptible to molds.

Structure and Composition of Sorghum

We have developed methods for extracting, separating and partially identifying the phenols of sorghums. These phenols exist in the sorghum pericarp, testa, aleurone layers and in the cell walls of the starchy endosperm. Some phenolic compounds inhibit the germination of microbial spores and may affect insect and disease resistance. Disease-resistant sorghum varieties contain both a greater variety and larger amounts of the phenols than susceptible varieties.

Our laboratory has confirmed that sorghums can be divided into three groups based on genotype. The Type I, II, and III sorghums are genotypically: $b_1b_1B_2$-ss, $b_1b_1b_2b_2$ -ss, $b_1b_1B_2$-ss (Type I); B-$_1B_2$-ss (Type II); and B_1B_2-S- (Type III). Whenever B_1-B_2- are both dominant a pigmented testa is present in the sorghum kernel, which means that condensed tannins are present. Dominant S- in the presence of B_1-B_2- produces higher levels of condensed tannins with different solubilities.

The detailed morphology of the sorghum kernel has been documented with light, scanning and flourescence micorscopy. Structural changes have been related to sorghum genotypes, which has enabled breeders to select for certain kernel types in the field. For example, the thick, starchy mesocarp is present when a homozygous, recessive Z- gene (zz) is present. Pericarp thickness and certain other characteristics can be determined with a pocket knife.

The amylose composition of sorghum starches does not vary as much as the amylose content of rice starches. Many tests useful for evaluating rice quality are not practical for sorghum quality evaluations. Basic aspects of starch properties, such as interaction with protein and other components of the sorghum kernel, have been investigated; but no clear cut information has been obtained. This complex problem must be resolved to develop more effecitve, practical testing and selection methods.

Detailed chemical, physical, physiochemical and structural evaluation of sorghums identified as having differences in "quality" has helped us make great progress toward understanding the factors affecting sorghum food quality. Since such information was scarce, scientists can now more easily make field evaluations for food quality selection.

Structure of Pearl Millet

The kernels of pearl millet genotypes from Mali, Niger and Upper Volta have been partially evaluated for structure and composition of phenols. The millet kernel structure is similar to that of sorghum, with some significant differences. The millet epicarp is much thicker with larger, blocky cells containing thicker cell walls. In the tan and brown millet kernels tested, orange and brown pigments were present in the epicarp and mesocarp; no pigments were observed in the pericarp of blue-grey millets. All millet kernels had pigmented testa. The blue-grey millet kernels appeared to have a discontinuous, pigmented testa. The size, shape and arrangement of the germ in millet kernels affects processing properties. Very little information is available on the variation in kernel characteristics and genetics of millet. The phenol content of pearl millet grains ranged from 0.13 to 0.30 mg/100 mg in an array of grain samples. No condensed tannins were found in the grain. Additional research on the factors affecting the visual appearance and color of millet grain is required.

Significance of Research Findings

This project, in collaboration with others, has clearly documented that sorghum food quality is critical in developing new sorghum cultivars. The study of traditional food processing methods and quality attributes of food products has increased awareness of what constitutes sorghum quality. Some simple selection techniques have been devised to use in breeding for food quality, and the groundwork has been laid for future progress. A major achievement is the bringing together

Crossing block parents with sources of good food quality, grain mold, and weathering resistance, and other yield limiting factors

	F_1	Hybrids
Crop season	F_2	Select for absence of testa, colorless thin pericarp, appropriate endosperm texture, medium size and round shape, tan colored plant, grain mold resistance and other good agronomic characters including straw colored glumes in the field.
Off season	F_3	Select for the desired grain and glume characters in the field. Select for a light color reaction of grains with KOH in the lab. Evaluate % water absorption of grain.
Crop season	F_4	Select for grain mold resistance in field. Evaluate hardness and milling quality with small grain samples in lab. Evaluate gel viscosity.
Off season	F_5	Evaluate milling quality, flour particle size and gel viscosity.
Crop season	F_6	Multilocational tests in the field. Carry out laboratory taste panel studies on the selected entries for the appropriate food system.
Off season	F_7	Carry out laboratory taste panel studies on the food product.
Crop season	F_8	Advanced yield tests—carry out consumer tests on few selected entries.

Figure 1. A scheme for selecting for food quality in a breeding program. This was proposed by Sansan Da as part of the research on his Ph.D. program.

of sorghum breeders, food scientists and cereal chemists to cooperate in this effort.

Our work has sparked interest in the use of sorghum for food in Mexico. A few years ago, almost all Mexican scientists were unaware of sorghum use as a human food. To put sorghum in tortillas was preposterous. Now, research in this area is underway. INTSORMIL/ICRISAT-CIMMYT activities have played a major role in encouraging this development.

LDC Collaboration

We have interacted with a large number of scientists from around the world to develop information on sorghum and millet quality. In addition to Honduras and Mexico, we have collaborative research in Mali, Upper Volta, India, Tanzania, Niger, Nigeria, Argentina, Denmark and Canada.

Training and Technical Assistance

A set of slides and detailed explanations that illustrate the structure and genetics of sorghum kernel characteristics has been created for use by sorghum workers. Traditional food products from sorghum and millet have been documented with slides. These are important training tools.

Project members participated in the International Symposium on Sorghum Food Quality, Sorghum in the '80s, the Sorghum Food Quality Workshop for Mexico and Central America, and several other workshops and seminars.

Twenty graduate students from LDCs and the U.S. have completed research in this project. We currently have 16 graduate students in the program. Several students from LDCs have returned home to make significant contributions to international sorghum improvement.

Implications for Future Research

We will continue to collect samples of grain with good and poor food quality characteristics. These will be subjected to detailed physical, biochemical, physiochemical, microscopical and processing tests in our laboratory. Results will be shared with other investigators in specific countries (Mali, Honduras and Mexico).

We also will continue seeking ways to convert sorghum and millet into attractive, storable processed foods appealing to urban consumers. The use of extrusion and dry heat processes to produce instant nixtamalized sorghum and maize flours will be extended to trials in Mexico by collaborative research with the University of Sonora.

The use of pearled red and white sorghum and whole white sorghum in commercial tortillerias in Mexico will be evaluated. These trials are important to ensure that our information does apply to the real world.

The Tô quality of sorghums from Mali will be compared to that of exotic sorghums to determine why the exotics produce poor quality Tô. The effects of kernel properties on head bugs, mold and grain quality also will be determined.

Nontannin phenols may play an important role in sorghum deterioration and resistance to molds. Studying the genetics of pericarp, testa, glume and other kernel characteristics in relation to total phenol content and specific kinds of phenols is a long-term effort that can lead to development of new, more efficient techniques for selecting mold-resistant sorghums with better food quality.

Samples of millet from Mali wil be evaluated for use in Tô production. Fundamental factors affecting keeping quality, stickiness and milling properties will be studied in our laboratory. The samples also will be examined for basic structure and composition.

Selected Publications

Akingbala, J.O., J.M. Faubion and L.W. Rooney. 1981. A laboratory procedure for the preparation of ogi, a Nigerian fermented food. *J. Food Sci.* 46(5):1532-1536.

Akingbala, J.O., J.M. Faubion and L.W. Rooney. 1981. Physical, chemical and organoleptic evaluation of ogi from sorghum of differing kernel characteristics. *J. Food Sci.*, 46(5):1532-1536.

Bedolla, S., M. Gonzalez de Palacios, L.W. Rooney, K.C. Diehl and M.N. Khan. 1983. The cooking characteristics of sorghum and corn for tortillas preparation using several cooking methods. *Cereal Chem.* 60(4):263-268.

Blakely, M.E., L.W. Rooney, R.D. Sullins and F.R. Miller. 1979. Microscopy of the pericarp and the testa of different genotypes of sorghum. *Crop Sci.* 19:837.

Choto, C.E., M.M. Morad and L.W. Rooney. 1984. Alkaline processing of sorghum-maize blends for tortilla production. *Cereal Chem.* 61.

Creelman, R.A., L.W. Rooney and F.R. Miller. 1982. "Sorghum." *In:* Y. Pomeranz and L. Munck (eds.) *Cereals: A Renewable Resource, Theory and Practice.* American Association of Cereal Chemists. Minneapolis, Minnesota. p. 395-426.

Doherty, C.A., J.M. Faubion, M.M. Morad and L.W. Rooney. 1983. Alcohol production from sorghum. Progress Report. Tx. Agr. Exp. Sta. College Station, Texas.

Doherty, C., J.M. Faubion and L.W. Rooney. 1982. Semi-automated determination of phytate in sorghum and sorghum products. 59:373-377.

Earp, C.F., C.A. Doherty, R.G. Fulcher and L.W. Rooney. 1983. B-Glucans in the caryopsis of *Sorghum Bicolor* (L.) Moench. *Food Microstructure.* 2:183-188.

Earp, C.F., C.A. Doherty and L.W. Rooney. 1983. Fluorescence microsopy of the pericarp, aleurone layer and endosperm cell walls of three sorghum cultivars. *Cereal Chem.* 60:408-410.

Earp, C.F. and L.W. Rooney. 1982. Scanning electron microscopy of the pericarp and testa of several sorghum varieties. *Foods Microstructure.* 1:125-134.

Earp, C., J.O. Akingbala, S.H. Ring and L.W. Rooney. 1981. Evaluation of several methods to determine tannins in sorghum with varying kernel characteristics. *Cereal Chem.* 58(3):234-238.

Glueck, J.A. and L.W. Rooney. 1979. Chemistry and structure of grain in relation to mold resistance. Proceedings of the International Workshop on Sorghum Diseases, ICRISAT, Hyderabad, India. p. 119-140.

Hahn, D.H., L.W. Rooney and C.F. Earp. 1984. Tannins and phenols of sorghum. *Cereal Foods World.*

Hahn, D., L.W. Rooney and J.M. Faubion. 1983. Sorghum phenolic acids, their HPLC separation and their relation to fungal resistance. *Cereal Chem.* 60(4):255-259.

Hahn D.H., J.M. Faubion, S.H. Ring, C.A. Doherty and L.W. Rooney. 1982. Semi-automated *in vitro* analysis of sorghum protein availability via pronase hydrolysis. *Cereal Chem.* 59(2):132-136.

Johnson, B.A., L.W. Rooney and M.N. Khan. 1980. Tortilla making characteristics of micronized sorghum and corn flours. *J. Food Sci.* 45(3):671-674.

Khan, M.N., L.W. Rooney, D.T. Rosenow and F.R. Miller. 1980. Sorghums with improved tortilla making characteristics. *J. Food Sci.* 45(3):720-722, 725.

Lichtenwalner, R.E., G.I. Glover and C.C. Shaw. 1979. Protease activity of water and acid-reconstituted grain sorghum. *Agri. & Food Chem.* 27(2):359-362.

Lichtenwalner, R.E., J.A. Glueck, L.W. Rooney and L. Reyes. 1979. Nutritive value of weathered grain for ruminants. *J. An. Sci.* 49:183-186.

Morad, M.M., C.A. Doherty and L.W. Rooney. 1984. Effect of sorghum variety on baking properties of U.S. conventional bread, Egyptian Pita "Balady" bread and cookies. *J. Food Sci.* 49(4):1070-1074.

Morad, M.M., C.A. Doherty and L.W. Rooney. 1984. Utilization of dried distiller grain from sorghum in baked food systems. *Cereal Chem.* 61(5).

Morad, M.M., C.A. Doherty, J.M. Faubion and L.W. Rooney. 1983. Utilization of dried distillers grain from sorghum in baked food systems. Progress Report. Tx. Agr. Exp. Sta. College Station, Texas.

Murty, D.S., L.W. Rooney, H.D. Patil and L.R. House. 1982. A Report on the International Sorghum Food Quality Trials (I.S.F.Q.T.). ICRISAT. Patancheru, India.

Rooney, L.W. and V. Guiragossian. 1983. Proceedings of the grain quality workshop for Latin America. INTSORMIL-INIA-ICRISAT-CIMMYT. Mexico City, Mexico.

Rooney, LW., J.M. Faubion and C.F. Earp. 1983. Scanning electron microscopy of cereal grains. *In:* D.B. Bechtel (ed.) *New Frontiers in Food Microstructure.* The American Association of Cereal Chemists, Inc. St. Paul, Minnesota. pp. 201-240.

Rooney, L.W. and D.S. Murty. 1982. Evaluation of sorghum food quality. *In: Sorghum in the Eighties.* Proceedings of the International Symposium on Sorghum. ICRISAT. Patancheru, India. pp. 571-580.

Rooney, L.W. and D.S. Murty (eds.) 1982. Proceedings of the International Symposium on Sorghum Grain Quality, ICRISAT, Patancheru, India. 407 pp.

Rooney, L.W., C.F. Earp and M.N. Khan. 1982. Sorghum and Millets. *In:* I.A. Wolff (ed.). *Handbook of Agriculture Processing and Utilization II, Part I, Plant Products.* Chemical Rubber Co., Cleveland, Ohio. pp. 123-137.

Rooney, L.W., M.E. Blakely, F.R. Miller and D.T. Rosenow. 1980. Factors affecting the polyphenols of sorghum and their development and location in the sorghum kernel. *In:* J. Hulse (ed.) *Polyphenols of Cereal and Legumes.* IDRC-1453. Ottawa, Ontario, Canada. pp. 25-35.

Rooney, L.W., C.F. Earp and M.N. Khan. 1980. Have you had your injera (sorghum) today? Tex. Agr. Prog. 26(2):15-16.

Rooney, L.W., M.N. Khan and C.F. Earp. 1980. The technology of sorghum products. *In:* G. Inglett (ed.). *Recent Progress in Cereal Chemistry: Cereals for Food and Beverages.* Academic Press, Inc., New York, New York.

Rooney, L.W. and A.W. Kirleis. 1980. Technologie Post-Recite des sorghos et des mils au Mali et en Haute Volta (Translated into French). International Crops Research Institute for Semi-Arid Tropics. West African Cooperative Program, Dakar, Senegal.

Rooney, L.W. 1980. Sorghum for food: opportunities, problems and potential. Proceedings of the 31st Annual Corn and Sorghum Research Conference. Am. Seed Trade Association.

Rusnak, B.A., C. Chou and L.W. Rooney. 1980. Effect of micronizing on kernel characteristics of sorghum varieties with different endosperm type. *J. Food Sci.* 45(6):1529-1532.

Scheuring, J.F., S. Sidibe, L.W. Rooney and C.F. Earp. 1982. Sorghum pericarp thickness and its relation to decortication in a wooden mortar and pestle. *Cereal Chem.* 59:86-89.

Scheuring, J.F. and L.W. Rooney. 1979. A staining procedure to determine the extent of bran removal in pearled sorghum. *Cereal Chem.* 56(6):545-548.

Seitz, L.M., H.E. Mohr, R. Burroughs and J.A. Glueck. 1983. Preharvest fungal invasion of sorghum grain. *Cereal Chem.* 60:127-130.

Teetes, G.L., W. Chantrasorn, J.W. Johnson, T.A. Granovsky and L.W. Rooney. 1981. Maize weevil: a search for resistance in converted exotic sorghum kernels. Tex. Agr. Exp. Sta., Texas A&M University. College Station, Texas. B-1371.

Enhancement of High Tannin Sorghum Utilization: Characterization, Metabolism, and Detoxification of Sorghum Tannins and Other Polyphenols

Larry Butler and John Rogler
Purdue University

Sorghum, unlike other cereals, produces relatively large amounts of phenolic compounds, including the condensed tannins (Table 1). We have not detected any tannin in millet. In the field, these polyphenols protect the sorghum seed against predatory birds, weathering and preharvest germination; they may protect the vegetative tissue of the plant against fungal pathogens or other environmental challenges (Table 2). In contrast to these beneficial effects in the field, sorghum polyphenols have several undesirable effects in the diet. Their tendency to develop unappetizing colors and their astringency diminish the palatability of the food. They can form complexes with dietary proteins and with digestive enzymes, interfering with the processes of digestion and absorption. Some are absorbed into the body where they apparently alter metabolism and inhibit growth. Sorghums which have no tannins and have relatively low levels of other polyphenols are valuable human foods in those areas of India, Africa, and Central America where they are available, but these nutritionally superior sorghums cannot be produced in many areas because of their vulnerability to pests and environmental conditions. Nutritionally inferior sorghums, rich in polyphenols and more resistant to these constraints, may be eaten as a last resort when better sorghums, or other crops, are no longer available.

The overall goal of this research is to eliminate from sorghum grain the antinutritional characteristics for which the polyphenols are responsible, while maintaining or enhancing the agronomic advantages which the polyphenols confer. There is real hope that this difficult goal can be reached.

The polyphenols of sorghum comprise a large group of structurally related compounds, most of which have not been assigned a definite chemical structure. We are finding that these polyphenols have many types of biological activities not previously reported. Although we have not yet been able to assign most of these biological activities to individual chemically characterized components, we have found that, at least in some cases, the components which have desirable biological activities (such as bird repellancy) are present at different times in the development of the sorghum seed from those components which interfere with digestion and are therefore undesirable. Different polyphenol components are therefore responsible for these beneficial and harmful effects, and with appropriate chemical assays to guide the breeder, it should be possible to selectively breed out the harmful components.

Research Accomplishments

Polyphenol Chemistry

We have devised several new assays and modified old assays in order to quantitate specific groups of sorghum polyphenols and to elucidate their chemical properties. The technique we developed for determining the number of flavan-3-ol units in tannin molecules, for example, has provided valuable chemical correlations with their observed biological effects. Tannins from mature sorghum seeds have from 3 to 15 or more flavanol-3-ol units; the larger molecules (MW more than 4000) have properties considerably different from the shorter tannins. Studying the polyphenols in sorghum leaves, we showed that tannins are absent, but we discovered apiforol, an unusual flavanoid not previously reported from any plant. Apiforol, a monomeric flavan-4-ol, is present in relatively large amounts in leaf and seed tissue of about one-third of the sorghum lines we examined. In addition, we are identifying the phenolic pigments which are responsible for the varied colors of the grain, and which develop intensively in vegetative tissue as a response to stress or injury. The main pigments found in sorghum are rarely found in other plants. These pigments and tannins seem to be alternate end products

Table 1. Phenolic Materials in Sorghum.

Material	Class	Precursor
Tyrosine	Amino acid	Phenylalanine
Phenylpropanoids	Hydroxylated cinnamic acids	Phe, Tyr
Flavanoids	Includes glycosylated and esterified forms	Phenylpropanoids
Anthocyanidins/ Anthocyanins	Flavanoid pigments	Flavanoids
Condensed tannins	Flavan-3-ol oligomers	Flavanoids
Lignin	Phenylpropanoid polymers	Phenylpropanoids

Table 2. Biological Effects of Sorghum Phenols.

In the field	
	Repel predatory birds
	Reduce weathering
	Reduce preharvest germination
	Color the seed
	Contribute astringency
In the diet	
	Reduce weight gains
	Reduce feed efficiency
	Form undesirable colors
	Reduce palatability
	Cause developmental abnormalities in chicks' legs
	Arrest development of young hamsters
	Induce secretion of salivary tannin-binding proteins
In the test tube	
	Selectively bind and precipitate proteins
	Inhibit protein digestion
	Inhibit most enzymes
	Inhibit germination of spores of fungal pathogens
	Antibiotic against gram-positive bacteria

of flavanoid metabolism in sorghum. When we discover how flavanoid metabolism is regulated between these alternate pathways we may be able to enhance the pathway which would promote resistance to fungal pathogens or other forms of stress.

Tannins are difficult to purify because of their tendency to irreversibly absorb to chromatographic media, as well as to proteins in the tissue from which they are extracted. We have modified the conventional tannin purification procedure using Sephadex LH-20 to minimize contamination by protein, and we supply INTSORMIL colleagues and others with standard samples of purified tannins which are not otherwise available. We have used continuous counter-current chromatography (a new technique never before applied to polyphenols) and HPLC (high performance liquid chromatography) to separate "purified" tannin into a series of about 10 components, and to separate crude sorghum polyphenols into characteristic patterns of components different and recognizable for each sorghum line.

Group II sorghums contain a type of tannin that does not extract in solvents that effectively extract polyphenols from conventional bird-resistant, high-tannin sorghums (Group III). Despite hopeful claims that Group II sorghums are agronomically equivalent and nutritionally superior to Group III sorghums, we find that tannins purified from the two groups are indistinguishable, and that Group II sorghums are not bird-resistant (Figure 1). Preliminary results suggest that the two sorghum types are nutritionally equivalent when compared at the same tannin level.

Polyphenols in the Diet

The antinutritional effects of dietary tannins, effects such as diminished weight gain and feed efficiency, have been considered to be due to their well-known tendency to bind to proteins, in this case dietary or digestive proteins. We have shown that protein binding by sorghum tannins has several features not previously recognized when tannins were considered to be nonspecific protein-binding agents. We found that tannins are unexpectedly specific; sorghum tannins can bind and precipitate one particular protein out of a 100-fold excess of other proteins. The characteristics of a protein which make it strongly bind to tannins are a relatively open (rather than compact) structure, large size, and high proline content. These observations brought attention to a heterogeneous group of proteins which contain high levels of proline (Table 3). The unusually high affinity of these proteins for condensed tannins such as those found in sorghum suggested a possible tannin-binding function. Tannin binding by collagen, for example, was the original basis for leathermaking.

With our collaborators, we observed that tannin in the diet of rats, mice and (presumably) humans rapidly induces hypertrophy of the parotid glands. Within 3 days these glands enlarge three-fold and secrete into the saliva an unique set of proline-rich (44 percent proline) tanning-binding proteins not detectable in the saliva of control animals consuming diets low in polyphenols. Hamsters do not respond this way; they are much more sensitive to dietary tannin. Blocking this protective response by injecting rats with synthetic hormones likewise renders them more vulnerable to dietary tannin.

Not all the effects of dietary polyphenols are understandable on the basis of protein binding in the digestive tract. High levels of polyphenols in hamster diets can result in death far too rapidly to be accounted for by interference with digestion. Dietary tannins cause

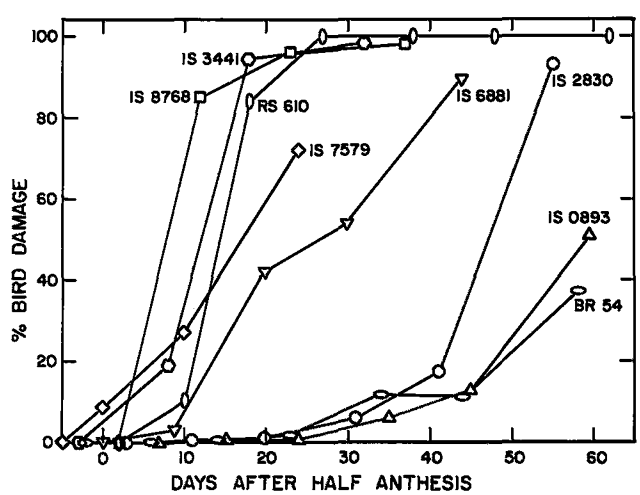


Figure 1. Comparison of bird-resistance of several sorghums. Data was obtained in the 1981 season at the Purdue Southwest Agriculture Center near Vincennes, Indiana. Triplicate replications were randomly located throughout the plot; data presented are the average for the three locations. RS 610 is a low-tannin type (Group I); IS 3441 and IS 8768 are Group II; and IS 0893, IS 2830, IS 6881, and IS 7579 are Group III.

Table 3. Classes of Proline-rich Proteins.

Seed prolamines
Plant cell walls
Collagen
Salivary proteins

developmental abnormalities in the legs of chicks. These effects suggest some absorption of dietary polyphenols out of the digestive tract into the body. We have begun feeding rats tannins which we have labelled with radioactive iodine so that we can readily determine their metabolic fate in the digestive tract. Our preliminary results do indicate that a certain proportion of dietary tannin is absorbed into bodily tissue, where it may have profound metabolic affects.

We have shown that soaking high-tannin sorghum seed overnight in a dilute solution of ammonia detoxifies the polyphenols so that they are detectable either by chemical assays or by their antinutritional effects. This technique is suitable for sorghum which is being processed into animal feed. In some cultures sorghum is soaked or germinated in aqueous alkali extracted from wood ash; this procedure partially detoxifies the tannins. We seek a less technological solution to the sorghum problem.

Non-tannin Phenolics

In addition to apiforol, there appear to be other flavanoids and possibly phenylpropanoids, too small to be classified as tannins, which are at least partially responsible for the biological activities previously attributed to tannin. Analyzing the phenolic materials present at the milk and dough stages of sorghum seed development, when the bird-resistant trait is most evident, we do not find tannins such as we find in mature grain. We find large amounts, in "high-tannin" bird-resistant lines, of flavanoid precursors of tannins, too small to precipitate protein and inhibit their digestion. Only at the end of the development process when the seed dries do the small precursors polymerize into genuine tannins characteristic of mature seeds. Premature arrest of seed development by cutting off the head and slowly drying it similarly results in the polymerization of precursors into tannin. We have also observed *in vitro* polymerization of partially purified fractions of precursors into tannin-like polymers; the process seems to be a free-radical dependent reaction. Our collaborator, Roger Bullard at the Denver Wildlife Center, has compared our crude preparations of the small precursors with purified polymeric tannins from mature seeds as repellants of *Quelea quelea*, the African weaver finch, which is said to be the world's most destructive bird. The data suggest that on an equal weight basis, the small non-tannin precursors are more repellant than are the tannins formed from them.

With our collaborators, we find that in addition to bird repellancy and resistance to weathering, the small non-tannin phenolics include components which inhibit the germination of washed spores of *Colletotrichum graminicola*, the fungus which causes anthracnose on sorghum, and components which have antibiotic activity against gram positive bacteria. Moreover, the small non-tannin phenolics are more effective in rat diets than are purified tannins at inducing production of proline-rich, tannin-binding salivary proteins.

Biosynthesis of Sorghum Tannins and Other Polyphenols

We have established 14 lines of sorghum growing as undifferentiated callus tissue on Petrie dishes; three lines have also been established in suspension culture. All cell lines examined produce polyphenols in culture; high-tannin lines tend to produce massive amounts which are toxic to the cells. Stress conditions such as dessication, aging and non-optimal levels of several media components lead to enhanced synthesis of phenols and pigments.

We find sub-cellular, membrane-bound organelles, which we call "inclusion bodies," within all sorghum cells growing in tissue culture. In the intact high-tannin sorghum plant we do not find tannin or inclusion bodies in vegetative tissue; similar inclusion bodies have previously been reported in the testa layer of developing seeds of high-tannin sorghums. Inclusion bodies in callus cells are rich in pigments and phenolics, and appear to be the site of polyphenol synthesis and accumulation. They tend to increase in size, number, and intensity of pigmentation as the cells age.

We have observed previously unreported extracellular globules of phenolic materials associated with root hairs of sorghum. In pigmentation, stability, general composition, and size these globules resemble the intracellular inclusion bodies of callus cells. These globules can be washed off of roots and obtained in rather pure form.

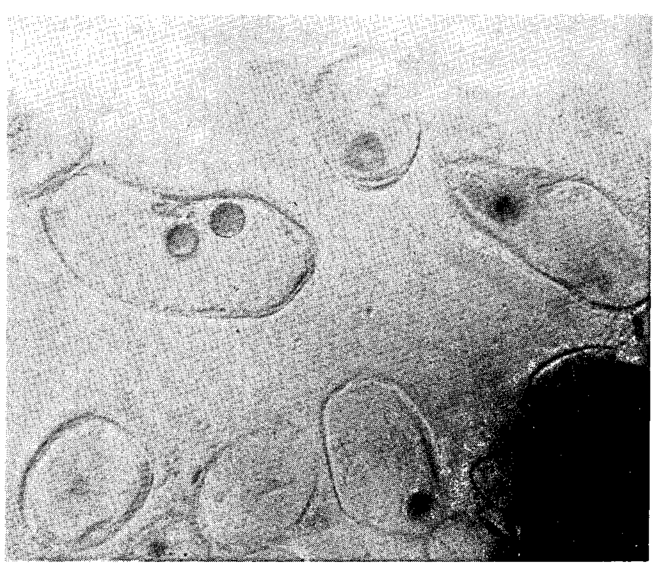


Figure 2. Undifferentiated cells of sorghum IS 8768 grown as callus tissue. Each cell contains at least one inclusion body. This preparation is not stained; inclusion bodies stain intensely with reagents which stain phenols.

Significance of Research Findings

Polyphenol Chemistry

Plant polyphenols have long been ignored or avoided if possible, because they often have complex structures difficult to characterize and they tend to bind to everything, making their purification a challenge. But only when we develop more and more specific assays, when we resolve and characterize individual components, and especially when we can associate particular polyphenol components with unique biological activities, can we understand and begin to deliberately and logically utilize this class of compounds to obtain desirable new plant characteristics. Examples of this correlation of chemical structures and biological activities are cited in the following sections.

Our studies on chemistry of the polyphenols of the Group II sorghums, which require different conditions for extraction from the seed from those of Group III (conventional high-tannin types), are complementary to those of Drs. Rooney and Miller at Texas A&M. They have determined the kernel characteristics of these types, and their inheritance patterns. Our studies, although not yet complete, do no support the notion that Group II sorghums are nutritionally superior to Group III sorghums.

Polyphenols in the Diet

Instead of the non-specific, protein-binding agents they were formerly assumed to be, we have shown that tannins can be highly selective in the proteins they bind. This high degree of selectivity suggests specific roles for tannin-protein interactions, even the likelihood of specific proteins whose biological function is to bind and thus inactivate tannins. Our discovery of the positive influence of proline on the affinity of proteins for tannin explains such diverse reports as the high proline content of a protein sludge obtained from beer by addition of tannin as a clarifying agent, and the low apparent digestibility of proline, compared to all other amino acids, in high-tannin diets. We suggest that the germinating sorghum seed protects itself from tannin inhibition of crucial metabolic enzymes by sacrificing a portion of its proline-rich, but metabolically inert, prolamine proteins (kafirins) to complex with and inactivate the tannin. In agreement with this suggestion, we have shown that in high-tannin sorghum, some of the kafirins are complexed with tannin and are indigestible by pepsin. The kafirins are virtually devoid of lysine, so that loss of this nutritionally poor protein fraction by complexing with tannin results in an improved nutritional value for the remaining proteins. There are other effects of dietary polyphenols, however, which negate this potential benefit. In diets low in protein, such as often occur in LDCs, especially when specific nutritionally poor tannin-binding proteins are absent, dietary tannin may have a relatively great harmful effect.

Probably the best examples of proteins whose function is to bind tannins are the proline-rich, tannin-binding salivary proteins induced by dietary tannin. This defense mechanism can be induced by non-tannin phenolics; it may be possible, by identifying and assaying for the inducer, to guide the breeders to develop sorghum lines relatively rich in the inducer. These lines would have the characteristic of heightening the consumers protective response to tannin in the diet.

Our studies, with those of our collaborators, clearly indicate that the biological effects of dietary polyphenols are not limited to inhibition of digestion and/or absorption. Moreover, our preliminary results with feeding radioactivity-labelled polyphenols suggest than some of these are absorbed out of the digestive tract into the body, where they may have profound metabolic effects such as we see on hamsters and chicks. We can no longer assume that protein binding in the gut is the sole (or major) antinutritional effect of dietary polyphenols. The other antinutritional effects must be elucidated in order to overcome them.

Our procedure for chemical detoxification of sorghum polyphenols (it elminates all of them, not just tannins) by soaking in dilute ammonia solution is similar to (but more effective than) traditional wet ash treatments reported from Uganda and Honduras. This process is no more technological, and less wasteful, than the special decortication mills being introduced by IDRC to overcome the tannin problem by removing the pericarp and testa from the grain. Ammoniation does, however, darken the grain and make it less attractive as a foodstuff. A more permanent genetic solution to the tannin problem is needed.

Non-tannin Phenolics

The occurence of the unusual flavan-4-ol we found in both seeds and leaves of some sorghum lines appears to be strongly correlated with resistance to weathering, at least in studies with our ICRISAT collaborators on lines they identified as resistant or susceptible to weathering. Our assay for flavan-4-ols is quite simple; it provides a convenient chemical assay for predicting weathering resistance for use by breeders. We are hopeful that further studies of the role of flavan-4-ols in weathering resistance will reveal the molecular mechanism of the resistance and lead to new, more efficient strategies for improving the resistance. Flavan-4-ols do not appear to be correlated significantly with bird resistance.

Many other non-tannin phenolics present are yet to be characterized for their biological activity. Some of these are apparently very active as bird repellants. These observations are enormously significant, for they indicate that the polymeric tannins, theoretically at least, can be elminated without loss of the agronomic benefits of the non-tannin phenolics, benefits formerly invariably assigned to "tannins." One obvious strategy is the identification and/or development of sorghum cultivars rich in the beneficial phenolic precursor of tannin, but which are incapable of polymerizing them into the protein-binding tannins. Our first survey has identified one cultivar which has tannin of about half the length of other cultivars examined; this line may be the prototype of the "short-tannin" sorghums, with superior nutritional value. This cultivar, IS 3150, is strongly bird-resistant. It was originally collected in South Africa, and was provided by our ICRISAT collaborators.

Perhaps our most significant finding is that these non-tannin phenolic materials exhibit more intense, and more varied, biological activities than do the true tannins. The protein-binding capability of the tannins is likely to be relatively less important than the other activities associated with the non-tannin phenolics. We can no longer focus on protein binding as the sole mode of action of these materials. We have observed, in hamsters on high-tannin sorghum diets, complete cessation of growth and development, with specific effects on the reproductive tract (shrinkage of the testes). It is imperative that these effects of high-tannin sorghum be examined carefully to determine if such effects are possible in human diets in the LDCs. Musing on the possibility that high-tannin sorghums contain an antifertility agent, we have speculated on the possible correlation of population increases in Africa with the diminished utilization of sorghum as it has been partially replaced by maize in human diets.

Biosynthesis of Sorghum Tannins and Other Polyphenolics

The non-tannin phenolics which have intense biological activities seem to be flavanoids, including metabolic precursors of tannins. Synthesis of tannins appears to be a stress-related phenomenon. In intact plants, tannins are found only in the testa layer (subcoat) of the seed; these cells disintegrate during seed development and tannin biosynthesis. Due to the limited amount of tissue available, tannin biosynthesis is very difficult to study in the intact plant. Fortunately, in tissue culture all the cells are capable of making polyphenols, and they appear to be made in prepackaged subcellular organelles, so isolation and characterization of the flavanoid biosynthetic enzymes should be possible. Application of genetic engineering techniques would then be feasible (using tissue culture as a source of protoplasts to be transformed by the appropriate DNA) to obtain plants with altered or synthetic genes for uniquely desirable traits. Our present use of tissue culture is also directed toward selection procedures whereby cell lines incapable of forming tannins from their precursors may be developed to improve the nutritional value of the grain.

At this time, our LDC colleagues are not equipped to maintain sorghum in tissue culture. There is some interest in establishing sorghum tissue cultures at ICRISAT; Dr. Jambunathan just spent a year in our laboratory learning tissue culture and other techniques.

LDC Collaboration

Researchers in this project are collaborating with scientists in Niger, Philippines, India (ICRISAT) and Guatemala who are also studying the polyphenols of sorghum.

Training and Technical Assistance

Dr. R. Jambunathan, Program Head of Grain Quality and Biochemistry at ICRISAT, spent a sabbatical year (July 1983-June 1984) in our laboratory, working on the relationship between sorghum polyphenols and resistance to grain weathering, and learning sorghum tissue culture techniques.

Dr. M. Oumarou, Director of the National Cereals Quality Laboratory, Kolo, Niger, spent 2 weeks in our laboratory in June 1984 learning polyphenol assays. With help from Purdue's Niger project, we are providing equipment and supplies to fully establish this cereals laboratory.

Implications for Future Research

We will continue to attempt to eliminate the antinutritional effects of sorghum polyphenols while maintaining their benefits, particularly by developing cultivars which make non-tannin precursors but cannot polymerize them to tannins. Sorghums of this type will be especially important for use in areas where only high-tannin sorghums can presently be produced, and should have a positive nutritional impact in these areas.

Recognition that it is the non-tannin phenolics which are largely repsonsible for the agronomic benefits of "high-tannin" sorghums, and that these phenolics exhibit a wide range of biological activities, will cause increased emphasis on this class of materials in our research. In particular, we must be concerned about their absorption from the digestive tract, and their effects once absorbed into the body. Other aspects of these non-tannin phenolics to be investigated with INTSORMIL and LDC collaborators include their effects on the color of the food, on resistance to preharvest germination of the seed, and on resistance to fungal pathogens.

These results represent a significant shift in our understanding of the effects of tannins in the plant and in the diet. These new ideas must be clearly communicated to our colleagues, both in the LDCs and in INTSORMIL. We must be prepared to aid our colleagues in learning the necessary techniques for assaying the specific polyphenol components to be manipulated by the breeders.

Selected Publications

Asquith, A., C. Izuno and L.G. Butler. 1983. Characterization of the Condensed Tannin (Iroanthocyanidin) from a Group II Sorghum. *J. Agr. Food Chem.* 31:1299-1303.

Bressani, R., L.G. Elias, A. Wolsak, A.E. Hagerman and L.G. Butler. 1983. The Tannin Content of Red Colored Common Bean Cultivars Determined by Various Methods and Its Relation to Their Protein Quality. *J. Food Science.* 48:1000-1003.

Butler, L.G. 1982. The degree of polymerization of sorghum tannin during seed development and maturation. *J. Agric. Food Chem.* 30:1090-1094.

Butler, L.G., M.L. Price and J.R. Brotherton. 1982. The vanillin assay for proanthocyanidins (condensed tannins): modification of the solvent for estimation of the degree of polymerization. *J. Agr. Food Chem.* 31:41-45.

Hagerman, A.E. and L.G. Butler. 1981. The specificity of proanthocyanidin-protein interactions. *J. Biol. Chem.* 256:4494-4497.

Hagerman, A.E. and L.G. Butler. 1980. Condensed tannin purification and characterization of tannin-associated proteins. *J. Agr. Food Chem.* 28:947-952.

Hagerman, A.E. and L.G. Butler. 1980. Determination of protein in tannin-protein precipitates. *J. Agr. Food Chem.* 28:944-947.

Hagerman, A.E. and L.G. Butler. 1978. Protein precipitation method for the quantitative determination of tannins. *J. Agr. Food Chem.* 26:809-812.

Mehansho, H., A.E. Hagerman, L.S. Clements, L.G. Butler, J. Rogler and D.M. Carlson. 1983. Studies on environmental effects on gene expression: modulation of proline-rich protein biosynthesis in rat parotid glands by high tannin sorghums. *PNAS (US).* 80:3948-3952.

Oberthur, E., R.L. Nicholson and L.G. Butler. 1983. Presence of polyphenolic materials, including condensed tannins, in sorghum callus. *J. Agr. Food Chem.* 31:660-662.

Price, M.L., A.E. Hagerman and L.G. Butler. 1980. Tannin in sorghum grain: effect of cooking on chemical assays and on antinutritional properties in rats. *Nutrition Reports International.* 21:761-767.

Price, M.L., A.E. Hagerman and L.G. Butler. 1980. Tannin content of cowpeas, chick peas, pigeon peas, and mung beans. *J. Agr. Food Chem.* 28:459-461.

Price, M.L., A.M. Stromberg and L.G. Butler. 1979. Tannin content as a function of grain maturity and drying conditions in several varieties of *Sorghum bicolor* (L.) Moench. *J. Agr. Food Chem.* 27:1270-1274.

Price, M.L., L.G. Butler, J.C. Rogler and W.R. Featherston. 1979. Overcoming the nutritionally harmful effects of tannin in sorghum grain by treatment with inexpensive chemicals. *J. Agr. Food Chem.* 27:441-445.

Price, M.L., S. Van Scoyoc and L.G. Butler. 1978. A critical evaluation of the vanillin reaction as an assay for tannin in sorghum grain. *J. Agr. Food Chem.* 26:1214-1218.

Price, M.L., L.G. Butler, W.R. Featherson and J.C. Rogler. 1978. Detoxification of high tannin sorghum grain. *Nutrition Reports International.* 17:229-236.

Price, M.L. and L.G. Butler. 1977. Rapid visual estimation and spectrophotometric determination of tannin content of sorghum grain. *J. Agr. Food Chem.* 25:1268-1273.

Watterson, J.J. and L.G. Butler. 1983. The occurrence of an unusual leucoanthocyanidin and absence of proanthocyanidins in sorghum leaves. *J. Agr. Food Chem.* 31:41-45.

Enhancement of High Tannin Sorghum Utilization: Biological Effects of Dietary Tannins

John C. Rogler and L.G. Butler

Purdue University

Tannins impart certain agronomic benefits to sorghum grain, particularly protection from birds. Thus, it is important in many parts of the world to grow high-tannin sorghum to maximize yields. However, the biological effects of tannins are detrimental to animals. The major thrust of this project is to identify these biological effects and to develop methods to detoxify tannin in sorghum grains. These results should be applicable to condensed tannins from other sources, such as beans, cassava leaf, etc.

Research Accomplishments

Effects of Dietary Tannins and Procedures for Detoxification

An isonitrogenous dietary substitution of high-tannin sorghum (HTS) for low-tannin sorghum (LTS) depressed growth rate and feed efficiency in rats, mice, hamsters, chicks and Coturnix quail. Tannins also reduced digestibility in these species, particularly protein digestibility. In addition, feeding HTS to young chicks increased the incidence of the leg abnormality known as "bow-leg." The effect appears to be manifested in a change in the organic matrix of bone, since there is no effect on bone ash or the mineral content of the ash. Dietary tannins also had adverse effects in adult animals, as evidenced by lower egg production and feed efficiency and greater weight loss in hens fed HTS as compared with LTS.

Tannin content of HTS increases during the growth period to a maximum at about 30 days past half-anthesis, and then decreases as the grain matures. Experiments were conducted with LTS and HTS harvested in the immature and mature stages (30 days versus 60 days past half-anthesis). HTS harvested at 30 days had approximately 65 percent more tannin (vanillin assay) than HTS harvested at 60 days. Stage of maturity had no effect on the biological value of LTS, but HTS had a much lower biological value in the immature than in the mature stage. These results indicate that the higher concentration of tannin in dried immature HTS does not represent a form of tannin that is less toxic to the chick and rat.

With chicks fed HTS-soybean meal diets, methionine supplementation is a very effective means of overcoming the growth depressing effect of tannin (Table 1). It also is effective in overcoming the detrimental effects of HTS on egg production in hens fed sorghum-soybean meal diet. However, although methionine supplementation improves feed efficiency, it does not completely correct the tannin effect.

It is interesting to note that HTS depresses growth rate by approximately the same degree in a sorghum-crystalline amino acid diet as in a sorghum-soybean meal diet (Table 1). In this instance, methionine supplementation was ineffective in correcting the growth depression. Both types of diets contained similar amino acid compositions. Also, methionine supplementation did not overcome the growth depression in rats fed a diet supplemented with lysine, but containing HTS as the sole source of protein.

Table 1. Influence of Supplemental Methionine in Sorghum-Soybean Meal and Sorghum-Amino Acid Diets on Chick Performance.[1]

	Diets				
	SBM[2]		AA[3]		
Sorghum	– Met[4]	+ Met[5]	– Met	+ Met	$\bar{x}$
LTS[6]	235	261	247	234	244
HTS[7]	161	291	139	139	182
$\bar{x}$	198	276	193	186	

[1]Three-week weight gains (g).
[2]Soybean meal.
[3]Crystalline amino acids equivalent to soybean meal.
[4]No supplemental methionine.
[5]Methionine added at the .15% level.
[6]RS610.
[7]BR54.

Other methods which have proved successful in detoxifying tannins in HTS include hot alkali extraction, ammoniation of whole seed, soaking whole seed in a solution of potassium carbonate, increasing dietary protein and adding 1 percent polyvinylpyrollidone to the diet.

Effect of HTS on the Gastrointestinal Tract

More than 400 slides were prepared on various sections of the gastrointestinal tracts of hens, chicks and rats fed HTS. No gross histopathological lesions were observed in animals fed HTS as compared with those fed LTS. In addition, fecal glucosamine and sialic acid, as measures of mucin excretion, were determined in rats fed HTS. Although the concentrations of these compounds in the feces (mg/g feces) were reduced by HTS, the total amounts of these compounds (mg/rat/day) and the amount excreted based on food intake (mg/g intake) were increased slightly by HTS. This probably results from the increased amount of feces excreted in rats fed HTS rather than an effect of tannin per se. These results suggest that the condensed tannins of sorghum have little or no effect on the integrity of the gastrointestinal tract, and are thus in direct contrast to research with relatively high levels of dietary hydrolyzabe tannin (tannic acid) in which gross histological lesions and a large increase in mucin excretion were observed. Apparently it is dangerous to try to extrapolate results obtained with hydrolyzable tannins to condensed tannins.

Protein Digestibility and the Tannin Effect

As previously mentioned, HTS was as detrimental to growth rate in a sorghum-crystalline amino acid diet as in a sorghum-soybean meal diet. If the tannin effect were mediated entirely via reduced protein digestibility, it would be expected that a diet containing crystalline amino acids would perform better since a portion of the protein would not require digestion. Other evidence was provided by the fact that methionine supplementation of a sorghum-soybean meal diet overcame the adverse effects of HTS on growth rate of chicks, but had absolutely no influence on the reduced digestibility caused by tannin. Furthermore, although ammoniation corrected the growth depression of HTS, it only increased protein solubilization of HTS in pepsin slightly (5.09 versus 6.99), which was still much lower than LTS (9.22 versus 9.07).

Based on these observations, experiments were conducted to compare increasing dietary nitrogen as intact protein (isolated soybean protein) versus increasing dietary nitrogen as crystalline amino acids in the same concentrations contained in the intact protein. The diets contained either LTS or HTS with supplemented nitrogen provided as described. The results showed that essentially all of the growth depression produced by HTS in chicks and rats could be overcome by increasing dietary nitrogen as intact protein, whereas increasing the nitrogen as crystalline amino acids did not correct the tannin effect. This was demonstrated even more

Table 2. Effects of Providing Supplemental Nitrogen as Intact Protein (Gelatin) or Amino Acids on the Growth Rate of Hamsters.

	Nitrogen Source			
Sorghum	None[2]	Gelatin[3]	AA[4]	$\bar{x}$
LTS[5]	+ 23	+ 29	+ 28	+ 27
HTS[6]	– 10	+ 23	– 3	+ 3
$\bar{x}$	+ 6	+ 26	+ 12	

[1]Three-week weight gains (g).
[2]Only sorghum protein.
[3]Substitution of 4% gelatin for corn starch.
[4]Crystalline amino acids in the same concentration as 4% gelatin.
[5]RS610.
[6]Savanna.

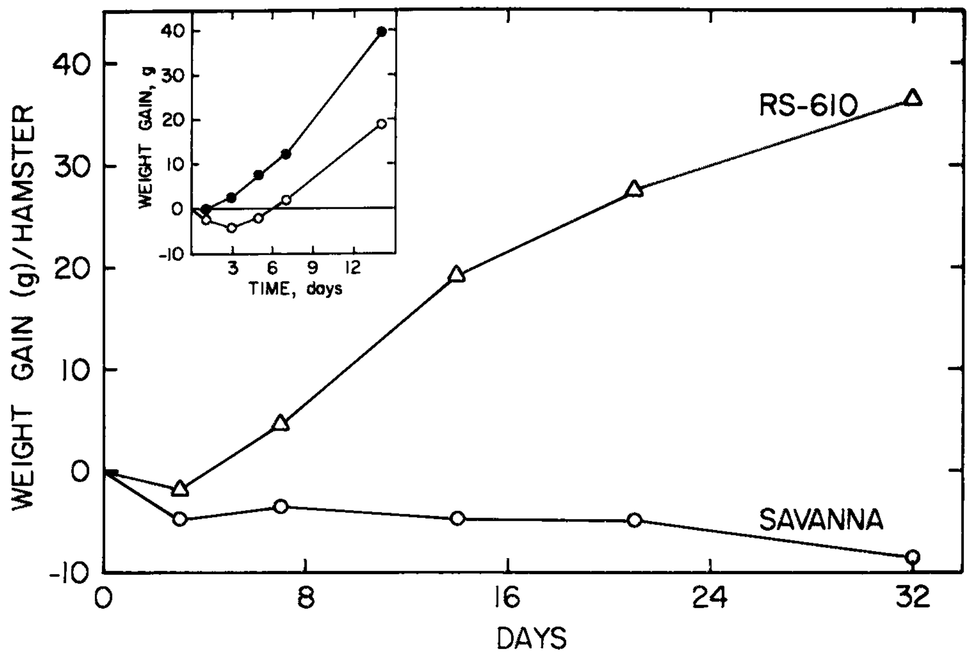


Fig. 1. Effects of LTS (RS610) and HTS (Savanna) on growth rate of hamsters. For comparison, the effects of the grains on the growth rate of rats is in the insert.

dramatically in hamsters, which are very sensitive to tannins (Fig. 1), by supplementing a HTS diet with gelatin or crystalline amino acids in the same concentrations as gelatin. This protein has a high affinity for tannin, but has a very low nutritional value. Gelatin supplementation had only a slight effect in the LTS diet, but overcame almost all of the growth depression in the HTS diet (Table 2). In contrast, supplementation with crystalline amino acids had essentially no effect in improving growth of hamsters fed HTS. These results suggest that protein digestibility may explain only a small part of the tannin effect, and that increased dietary protein binds tannin rather than providing additional amino acids. In this respect, protein functions in a manner similar to polyvinylpyrollidone, which complexes tannins and thereby overcomes the detrimental effects of tannins in HTS.

Effects of Tannins on the Salivary Glands

We demonstrated that tannins have a high affinity for proteins rich in the amino acid proline (PRP). Since PRP are synthesized by the salivary glands and secreted into the oral cavity, it was decided to feed HTS to rats, mice and hamsters to determine what effect tannin might have on these glands and their products. It was found that the parotid gland of the rat increased in size after only one day on the HTS diet, and reached a plateau after 3 days on HTS (Fig.2). The amount of PRP in the parotid gland followed a similar trend (Fig. 2). Similar results were observed in the mouse. However, no effects of HTS on hypertrophy of the parotid gland or PRP synthesis were noted in the hamster. Since tannins appear to be more toxic to the hamster than the rat (Fig. 1), the increased production of PRP by the parotid gland of the rat and mouse could be regarded as a pro-

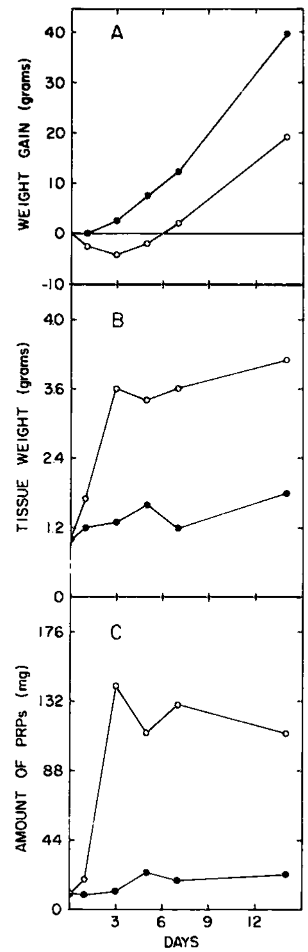


Fig. 2. Effects of tannin content of sorghum grain on growth weight, parotid gland weight and parotid gland PRP in rats. LTS, ●—●; HTS O—O.

tective mechanism to allow better utilization of HTS.

Treatments which are effective in protecting the animal against growth depression with HTS also are effective in preventing the parotid gland hypertrophy and PRP synthesis. These include ammoniation and supplemental dietary gelatin.

Absorption of Condensed Tannins

Assays for tannins by conventional methods in the urine of rats or blood of chicks fed HTS were unsuccessful. However, the assay procedure was admittedly insensitive and non-specific. Therefore, other methods were investigated in an attempt to determine whether or not condensed tannins are absorbed. The first procedure involved determining the activity of an enzyme (UDP-glucuronyltransferase (UDPG)) in liver microsomal membranes that is known to detoxify phenolic compounds. This seemed logical since condensed tannins are phenolic compounds and if they are absorbed enzyme activity should be enhanced. Chicks fed HTS showed a large increase in the activity of this enzyme in the liver microsomal membrane fraction which could not be accounted for by reduced protein digestibility. In contrast, the activity of UDPG in rat liver microsomes was not affected by HTS. These results suggest that either there is a species difference in absorption of tannins, or a difference in the ability of absorbed tannins to activate this enzyme.

The second and more direct approach involved the oral administration of radioactively-labelled tannin. Purified tannins were labelled with iodine-125. The ^{125}I-tannin was then mixed in a LTS diet and fed to rats following a 48-hour fast. The rats were killed at various hours post-dosing and the activity in feces, urine, liver, kidney and serum determined. As expected, most of the activity occurred in the feces, but activity was also observed in the serum, kidney and liver (Table 3). To make sure that the activity was not due to free ^{125}I as a result of deiodination, the activity in the liver and kidney was fractionated into free ^{125}I and ^{125}I-tannin. Approximately 60 percent of the radioactivity in both organs was in the form of free ^{125}I and the remaining 40 percent was in the form of ^{125}I-tannin as determined by precipitation with silver nitrate and polyvinylpyrollidone, respectively. In a longer-range experiment where fecal and urinary ^{125}I excretion was followed over 6 days post-dosing, peak excretion occurred 48 hours post-dosing in both feces and urine. At the end of 6 days post-dosing, accumulative excretion of the administered dose appearing in the feces and urine was 61 percent and 20 percent, respectively. Even if only 40 percent of the activity is still in the form of ^{125}I-tannin, this represents a sizeable absorption of condensed tannins, which have always been considered too large for absorption.

Thus, from the results with labelled tannins and the response in acitivty of UDPG in liver of chicks fed HTS, it would appear we should adjust our thinking toward a possible absorption of sorghum tannins. This would open up a whole new realm of possibilities.

Table 3. Radioactivity in various tissues following oral dosing of rats with ^{125}I-tannin.

Hours[1]	Liver[2]	Kidney[2]	Serum[3]	Feces[4]
6	4143	2129	3550	244,683
12	4659	1735	4540	207,527
24	5459	2223	5317	474,043

[1]Hours post-dosing.
[2]Cpm for entire organ.
[3]Cpm/ml of serum.
[4]Cpm voided in feces at specified time.

Significance of Research Findings

We consider all of the research findings significant since they contribute to a better understanding of the biological effects of dietary tannins. Also, significant advances have been made in procedures to overcome these effects.

Examples include the finding that protein digestibility, which had long been considered as the sole or primary cause of the detrimental effects of tannin, probably contributes only a small portion of the effect. Furthermore, some researchers had suggested that condensed tannins might disrupt the integrity of the gastrointestinal tract in the same way as hydrolyzable tannins, which might account for some of the adverse effects of condensed tannins. Our results essentially dispelled this theory.

The observation that tannins produce hypertrophy of the parotid gland and an increased synthesis of PRP had not been reported previously. In this regard, tannins behave in a manner similar to a beta-agonist (isoproterenol), except that the drug has a similar effect on the submandibular gland whereas HTS has no effect on this gland.

Research on the possible absorption of condensed tannins from the intestinal tract had not received attention because it was generally agreed that the molecules are too large to be absorbed. Our research, particularly with ^{125}I-labelled tannins, suggests that these compounds are absorbed to some extent. This indicates the possibility of previously unconsidered biological effects of tannins. These might include enzyme activity in various tissues and reactions with various proteins in the body, particularly collagen in bone and cartilage and elastin in blood vessels, since these proteins are relatively rich in proline. The bone anomalies in chicks fed HTS could be related to absorbed tannins. In addition, a tannin-elastin complex could reduce the elasticity of blood vessels. All of these effects could hold implications for humans as well as animals.

Sorghum is a staple in the diet of many people in Africa; however a considerable amount is also used for animal feed. In some cases (e.g. Nigeria) there is an effort to establish relatively large commercial poultry operations and feed mills. In other countries (the Philippines, Mexico, Argentina, Brazil and the U.S.), essentially all of the sorghum is used for animal feed. Even in Central America it has been reported that most of the sorghum produced goes into animal feed.

From our work we can confidently recommend the supplementation of methionine or its hydroxy analogue in HTS diets used for poultry feeds. Although feed efficiency may not be maximal, excellent growth and egg production can be obtained by methionine supplementation of a sorghum-soybean meal diet, and most poultry rations contain soybean meal as the supplemental source of protein. Why similar supplementation of sorghum crystalline amino acid is ineffective is not known, but this is not of practical importance.

Other methods of detoxification (e.g. ammoniation, alkali), although effective, are more involved and probably would not be used for treatment of HTS for animal feed. However, these methods might be feasible for detoxification of HTS for human consumption.

LDC Collaboration

We have consulted with several scientists in Brazil who are researching the effects of HTS in animal feed, and presented seminars on this subject at an EMBRAPA station. It is likely that a collaborative project with Brazil will be established. We have also exchanged information with faculty members of the University of the Philippines.

Training and Technical Assistance

Two Master's degree students, one of them from Argentina, and one Ph.D. student have completed research in this project. Another Master's degree student is currently working with us.

Implications for Future Research

Our research on the biological effects of sorghum tannins and means of overcoming these effects will continue along similar lines, particularly where there are gaps in our knowledge. Many of the observations have been quite dramatic, but we need more information on the mode of action of these compounds. Much of our work has tended to refute long established concepts concerning how tannins exert their detrimental effects. Now we need to develop new concepts to take their place.

We will do further work on the effects of HTS on bone anomalies in chicks. Research is needed to determine why methionine supplementation of a poultry ration corrects the growth depression in a sorghum-soybean meal diet, but not in a sorghum-crystalline amino acid diet. Research on the effects of tannins on the parotid gland and synthesis of PRP in rats and mice, and the lack of effect in the hamster, will be continued. This will be expanded to include the effects of HTS on the salivary glands of the chick, although this is more difficult due to the diffuse nature of these glands throughout the oral cavity in this species, and will be limited to histological evaluations of the glands.

An area that needs further investigation is the absorption of tannins from the digestive tract. This will involve an expansion of the work with ^{125}I-tannin and will include examination of other tissues in the body to see which tissues demonstrate the greatest accumulation of the labelled material. Because of the affinity of tannins for PRP, the bones, cartilage, blood vessels and salivary glands will be checked for radioactivity. Fractionation of the activity will be continued to make sure that the label is still in the form of ^{125}I-tannin.

Another avenue that may be investigated involves genetic selection for resistance to tannin toxicity. This work would be done with Coturnix quail in cooperation with Dr. V.A. Garwood of the USDA.

In addition to the work on the biological effects of tannins, attempts will be made to find new, simple and inexpensive ways of detoxifying tannins in HTS. One which will receive immediate attention involves merely wetting the seed (25 percent water plus mold inhibitor) and the storing it in sealed containers for various periods of time. The grains will then be dried, ground and tested in diets for chicks, rats and hamsters.

Selected Publications

Armstrong, W.D., W.R. Featherston and J.C. Rogler. 1974. Effects of bird resistant sorghum grain and various commercial tannins on chick performance. *Poultry Sci.* 53:2137-2142.

Armstrong, W.D., J.C. Rogler and W.R. Featherston. 1974. *In vitro* Studies of the Protein Digestibility of Sorghum Grains. *Poultry Sci.* 53:2224-2227.

Armstrong, W.D., J.C. Rogler and W.R. Featherston. 1973. Effect of tannin extraction on the performance of chicks fed bird-resistant sorghum grain diets. *Poultry Sci.* 53:714-720.

Armstrong, W.D., W.R. Featherston and J.C. Rogler. 1973. Influence of methionine and other dietary additions on the performance of chicks fed bird-resistant sorghum grain diets. *Poultry Sci.* 52:1592-2599.

Elkin, R.G., W.R. Featherston and J.C. Rogler. 1978. Investigations of leg abnormalities in chicks consuming high tannin sorghum grain diets. *Poultry Sci.* 57:757-762.

Elkin, R.G., J.C. Rogler and W.R. Featherston. 1978. Influence of sorghum grain tannin on methionine utilization in chicks. *Poultry Sci.* 57:704-710.

Featherston, W.R., J.C. Rogler and R.K. Giles. 1978. Studies on the utilization by chicks of sorghum grains with varying tannin contents. Proceedings of the XVI World's Poultry Congress. 7:1085-1093.

Featherston, W.R. and J.C. Rogler. 1975. Influence of tannins on the utilization of sorghum grain by rats and chicks. *Nutr. Rep. Int.* 11:491-497.

Mehansho, H., A. Hagerman, S. Clements, L.G. Butler, J.C. Rogler and D.M. Carlson. 1983. Studies on environmental effects on gene expression: modulation of proline-rich protein biosynthesis in rat parotid glands by high tannin sorghums. *Proc. Nat. Acad. of Sci.* 80:3948-3952.

Price, M.L., L.G. Butler, W.R. Featherston and J.C. Rogler. 1978. Detoxification of high tannin sorghum grain. *Nutr. Rep. Int.* 17:229-236.

Rogler, J.C. and D.R. Sell. 1984. Effects of stage of maturity on the tannin content and nutritional quality of low and high tannin sorghum. *Nutr. Rep. Int.* 29:1281-1287.

Rogler, J.C., W.R. Featherston, R.G. Elkin and R.K. Giles. 1978. Effects of high tannin sorghum, tannic acid, catechin and sorghum tannin extract on the performance of young chicks. Proceedings of the XVI World's Poultry Congress. 7:1094-1103.

Rostagno, H.S., J.C. Rogler and W.R. Featherston. 1973. Studies on the nutritional value of sorghum with varying tannin content for chicks. II. Amino Acid Digestibility Studies. *Poultry Sci.* 52:772-778.

Rostagno, H.S., W.R. Featherston and J.C. Rogler. 1973. Studies on the nutritional value of sorghum with varying tannin content for chicks. I. Growth Studies. *Poultry Sci.* 52:765-772.

Sell, D.R. and J.C. Rogler. 1984. Effects of sorghum tannins and methionine supplementation on the performance of laying hens. *Poultry Sci.* 63:109-116.

Sell, D.R., J.C. Rogler and W.R. Featherston. 1983. The effects of sorghum tannin and protein level on the performance of laying hens maintained in two temperature enivronments. *Poultry Sci.* 652:2420-2428.

Sell, D.R. and J.C. Rogler. 1983. Effects of sorghum tannins and dietary protein on the activity of liver UDP-Glucuronyltransferase. Proc. Soc. Exptl. Biol. and Med. 174:93-101.

Nutritional Quality of Pearl Millet

J.M. Faubion, R. Carl Hoseney and C.F. Klopfenstein

Kansas State University

In spite of its importance in the diets of many people in Africa and India, the nutritional quality of pearl millet and factors affecting its quality are not well understood. As a consequence, a major research goal of this project has been the investigation of the nutritional quality of pearl millet varieties in both unprocessed and processed food forms. Pearl millet is processed into a great many traditional foods. The main varieties desired for food production differ depending on the food made and the geographic region. For breeding programs to be most effective, it would be valuable to understand the causes of differences in food quality found in various pearl millet varieties. Thus, two additonal research objectives have been 1) to investigate chemical and microscopic differences in the distribution and nature of important kernel components; and 2) to determine kernel characteristics and factors responsible for differences in quality of traditional foods produced from millet. A related and equally important problem in the utilization of pearl millet for food is the fact that ground millet, as traditonally produced, develops unacceptable odors after brief storage. This limits large scale production and distribution of millet flour. The study of compounds responsible for that odor and the mechanism of their generation was our final research objective.

Research Accomplishments

Using fat acidity and peroxide values (Fig. 1), we demonstrated that ground millet meal, when stored, rapidly becomes rancid. The same sort of deterioration occurs in stored whole millet, but at a much slower rate. The fact that total fatty acid content does not change over storage time suggests that little, if any, classical oxidative degredation of fatty acids occurs. This was confirmed by our finding that hexanal, a major product of oxidative racidity, is not generated during the first 15 days of storage. Thus, we can conclude that the odors which develop in stored millet are not the result of the classical oxidative rancidity process. Further investigation has revealed that the odor-producing phenomenon is apparently enzyme mediated and centered on the bound lipid fraction of the kernel.

Using the unleavened, steam-puffed bread, roti, as a test system, a laboratory production method was developed and optimized. The term "dough" applied to the millet meal-water mixture may be misleading since this research showed that the roti dough is essentially a powder-water system in which "inert" millet particles are held together by the cohesive capillary forces of interparticle water. We found that all millet varieties tested could produce acceptable roti if a) the particle size of the starting meal was fine enough and b) the water was added in the correct amounts.

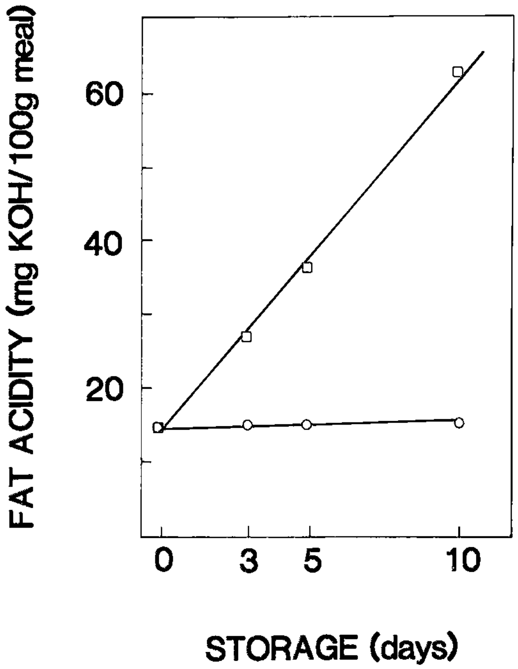


Fig. 1. Fat acidity of millet meal (Serere 3A) and whole millet grain (Serere 3A) stored at 25°C in polyethylene bags; 0 = whole grain, □ = ground grain.

Thus it can be seen that the way in which, and the extent to which, millet endosperm reduces in particle size is important in the ultimate quality of roti. This obviously relates to the physical hardness of the endosperm. Other researchers have demonstrated that the factor(s) responsible for millet endosperm hardness are extractable (by aqueous t-butyl alcohol), and are different than the factors responsible for hardness in sorghum endosperm. These findings have allowed us to address other questions relating to the differences in digestibility of sorghum and millet.

Until now, little was known of the relative amounts and composition of the anatomical parts of the pearl millet kernel. This information is necessary to accurately evaluate the effects or efficiency of milling procedures, and the subsequent biochemical effects of such procedures. We have demonstrated that pearl millet can have either a thick or thin pericarp; obviously this affects the way millets can best be processed.

Other studies have dealt with the vitamin B content of pearl millet, and how it is affected by genetic and environment.

Our animal feeding experiments have demonstrated that diets high in pearl millet are goitrogenic. Rats fed pearl millet develop thyroid histological changes similar to those that occur in human colloid goiter, even when they are generously supplemented with iodine. Serum thyroxine levels are higher and triiodothyronine levels lower than those in control (sorghum-fed) rats, which suggests that some component of dietary pearl millet might interfere with the peripheral deiodination of thyroxine. The goitrogenic property of pearl millet is associated with both the bran and endosperm fractions of the grain and is slightly water soluble. Dietary iodine supplementation does not diminish the histological changes of hormone pattern distortion, nor does fermentation of the grain. However, autoclave heating of the grain does lessen its goitrogenic properties.

Some known goitrogens, such as thiourea, propylthiouracil, methimazole and other thioamides, contain nucleophilic sulfur atoms which are known to be the site of metabolic oxidative attacks by a microsomal enzyme (dimethylaniline monooxygenase). While thioamides, thiocarbamates, thiols, sulfides, and disulfides are among the better substrates for this enzyme, some nucleophilic organic nitrogen compounds (tertiary and secondary amines) are also attacked.

By spectrophotometrically measuring the oxygenatable substrate-dependent oxidation of NADPH, we determined that an aqueous buffer extract of pearl millet contained a substrate for the monooxygenase. When a double-blank system was used (one blank had no microsomes, only extract + ocytlamine; the other had no extract, only microsomes + ocytlamine), the decreasing absorbance made it apparent that NADPH was disappearing from the system. This indicates that the enzyme had indeed found a nucleophilic sulfur or nitrogen-containing substrate in the pearl millet extract. This enzyme assay procedure shows promise as an *in vitro* method for detecting and measuring the pearl millet goitrogen.

Table 1. Proportion of Anatomical Parts of Pearl Millet Kernel.

	Kernel		Endosperm		Germ		Bran	
Size	Weight mg	S.D.[a]	%	S.D.[a]	%	S.D.[a]	%	S.D.[a]
Large	18.94	2.40	76.21	1.70	16.62	1.56	7.17	0.89
Medium	13.74	1.77	75.08		17.40	1.80	7.52	1.15
Small	10.39	0.88	73.89	2.05	15.47	1.41	10.64	1.50

[a]S.D. = Standard Deviation

Researchers in Senegal have developed a pearl millet weanling food which we have tested for protein quality, digestibility and goitrogenicity in weanling rats. While animal feeding studies cannot be directly transposed to human nutrition, our findings strongly indicate that the pearl millet weanling food is a highly nutritious, highly digestible food, although it does have some goitrogenic characteristics. Rats fed the pearl millet weanling food gained weight at a rate equal to, or greater than, those fed the reference casein diet (Fig. 2). The pearl millet weanling food has a protein efficiency ratio equivalent to that of casein, and protein and carbohydrate digestibilities were the same for both diets. Serum concentrations of thyroxine, triiodothyrionine and thyroid stimulating hormone were not significantly different for rats fed pearl millet weanling food or casein, but thyroid colloid follicles in millet-fed animals were somewhat enlarged.

All of our animal feeding studies have shown pearl millet to be a more nutritious feed than grain sorghum, especially during the early weeks (Fig. 2). We have also shown that after 3 to 4 weeks animals fed unsupplemented pearl millet diets abruptly stop growing. Our latest experiment indicates that supplementing pearl millet with calcium carbonate alone promotes continued moderate weight gain after the critical third week (Fig. 2).

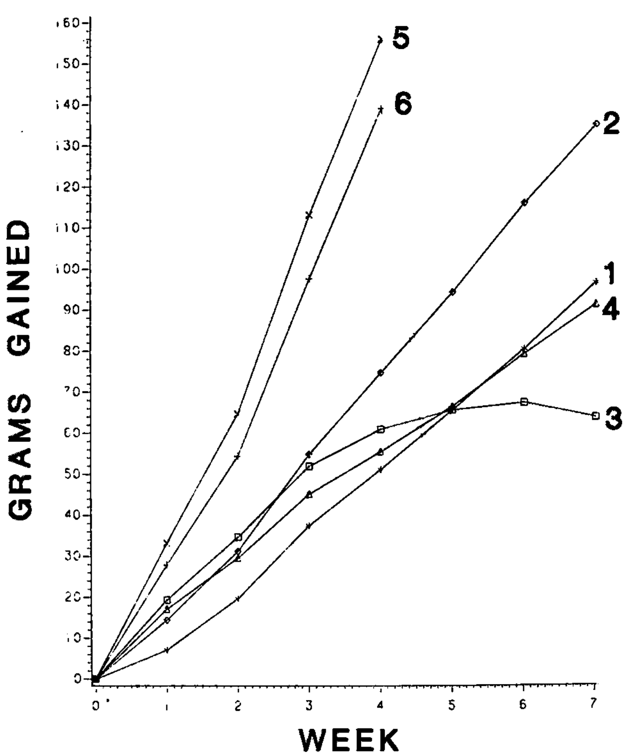


Fig. 2. Weight gain curves. 1 = sorghum diet, 2 = pearl millet diet, 3 = unsupplemented pearl millet, 4 = pearl millet + calcium carbohydrate, 5 = pearl millet weanling food PER diet, 6 = casein PER diet.

Significance of Research Findings

We have published our findings on the proportions and chemical composition of the hand-dissected anatomical parts of pearl millet. This information was not available before, and is essential if we are going to evaluate how good a job of milling we are doing. This information is also helpful in determining the nutritional significance of various milling operations.

We have detailed which B vitamins in millet are affected by genetics and which by environment. Surprisingly, cooking was found not to affect the vitamin level. The level of phytic acid was also determined.

By producing millet roti in the laboratory we found that all millets will produce good roti if the meal is ground sufficiently fine and the correct amount of water is used. Roti doughs were found to be essentially an inert material-water system. The water forms the continuous phase in the dough and provides the cohesive forces that hold the dough together.

Thus, to produce good roti one must grind millet to a fine particle size. The particle size depends upon the hardness of the grain and, of course, the type of mill used. In most coarse grains, including millet, the hardness of the grain is of great importance in producing any product. We found that the factor responsible for millet hardness could be extracted with aqueous t-butyl alcohol. This would appear to be a basic finding. Interestingly, grain sorghum has a different chemical entity responsible for hardness than does millet. We feel this may partially account for the difference in digestibility between pearl millet and grain sorghum.

The World Health Organization has reported that in some areas of Africa endemic goiter is a major public health problem. Insufficient dietary iodine is probably the most important cause of the problem, but the presence of goitrogenic substances in staple foods is also a significant factor. As reports from Sudan have suggested and our animal feeding studies have confirmed, pearl millet contains a goitrogen. More work is required to identify, characterize and measure it.

A major nutritional problem in developing countries has been the lack of a nutritious, digestible food for young children who are being weaned from their mothers' milk. Traditional grain-based foods are poorly utilized by this age group, whose relative nutritional requirements are very high. The pearl millet weanling food developed in Senegal appears to be an excellent candidate for filling this nutritional gap.

We have fairly well established that pearl millet diets fully supplemented with vitamins, minerals and amino acids are nutritious, but many people do not have access to complete dietary supplements. Recently, we have shown that feeding pearl millet supplemented with only calcium carbonate was equivalent to feeding a totally vitamin and mineral supplemented grain sorghum diet. We need to further define the limiting nutrients and use that information as a basis for improving the nutritional quality of pearl millet diets.

LDC Collaboration

We are collaborating with the Food Research Institute of Sudan, and with the Institut de Technologie Alimentaire in Senegal.

Training and Technical Assistance

We have supervised the research of seven graduate students from Sudan, Algeria, India, Venezuela, Mexico and the U.S.

Selected Publications

Abdelrahman, A. and R.C. Hoseney. 1984. Basis for hardness in pearl millet, sorghum and corn. *Cereal Chem.* 61:232.

Abdelrahman, A., R.C. Hoseney and E. Varriano-Marston. 1984. Proportion and composition of hand-dissected parts of pearl millet. *J. Cereal Sci.* 2:127.

Kaced, I., R.C. Hoseney and E. Varriano-Marston. 1984. Factors contributing to the development of rancidity in ground pearl millet during storage. *Cereal Chem.* 61:187.

Klopfenstein, C., R.C. Hoseney and H. Leipold. 1983. Further studies on the goitrogenic effects of pearl millet diets. *Nutr. Rep. Int.* 28:1137.

Olewnik, M., R.C. Hoseney and E. Varriano-Marston. 1984. A procedure to produce pearl millet rotis. *Cereal Chem.* 61:28.

Simwemba, C., R.C. Hoseney, E. Varriano-Marston and K. Zeleznak. 1984. Certain B vitamin and phytic acid contents of pearl millet. *J. Agric. Food Chem.* 32:31.

Varriano-Marston, E. and R.C. Hoseney. 1983. Barriers to increased utilization of pearl millet in developing countries. *Cereal Foods World.* 28:392.

Chemical and Physical Aspects of Food and Nutritional Quality of Sorghum

Allen W. Kirleis and John D. Axtell

Purdue University

The consumption of sorghum as a staple food in the semi-arid tropics is so diverse that no single criterion of quality can be applied to all sorghum foods. This has slowed the progress of plant breeders in developing high yielding sorghum varieties and hybrids with acceptable food quality. Specific research objectives of this project are to:

- determine how sorghum is processed, prepared into food and consumed in the semi-arid tropics;
- devise standard laboratory procedures for preparing traditional village foods made with sorghum, and use them to develop simple screening tests for use in breeding programs to predict grain food quality;
- determine what components in sorghum are related to the functional characteristics that constitute food quality;
- identify, develop and evaluate sorghum lines or mutants with improved nutritional quality and superior food grain quality, using both chemical and biological methods; and
- train LDC personnel in cereal chemistry.

Research Accomplishments

Grain Hardness

Sorghum grain hardness is related to storage characteristics, milling quality and food use properties. It is a useful characteristic for evaluating the food quality of agronomically improved sorghum lines. In a breeding program, several hundred lines must be screened and only limited amounts of grain are available for hardness tests. Thus, a hardness measurement method for a crop improvement program must be rapid, sensitive enough to be useful, and require only small amounts of grain.

In our work, grain hardness was defined as the ratio of corneous endosperm area to total endosperm area in cross-sectioned sorghum kernels. Five different procedures for measuring grain hardness were compared to the reference hardness method. All methods ranked the sorghum cultivars examined in an order similar to the reference method. A method based on kernel density, the percent floaters procedure, was by far the most rapid, required only small grain samples, and provided the degree of sensitivity needed for screening breeders' samples. In addition, the procedure does not require any expensive equipment, which makes it easily adaptable to LDC laboratory facilities. A modified floaters procedure is presently used by sorghum breeders developing grain with improved food quality at the ICRISAT Center.

Cagampang and Kirleis (1984a) examined the relationship of sorghum grain hardness to selected physical and chemical measurements of food quality. Grain hardness was significantly related to porridge and cooked whole grain texture. Hard grains produce a firmer porridge and require more energy to compress after cooking than softer grains. Two chemical parameters, water-soluble and kafirin protein, were found to be associated with grain hardness negatively and positively, respectively. These observations indicate that the protein components are important to traditional African porridge preparations.

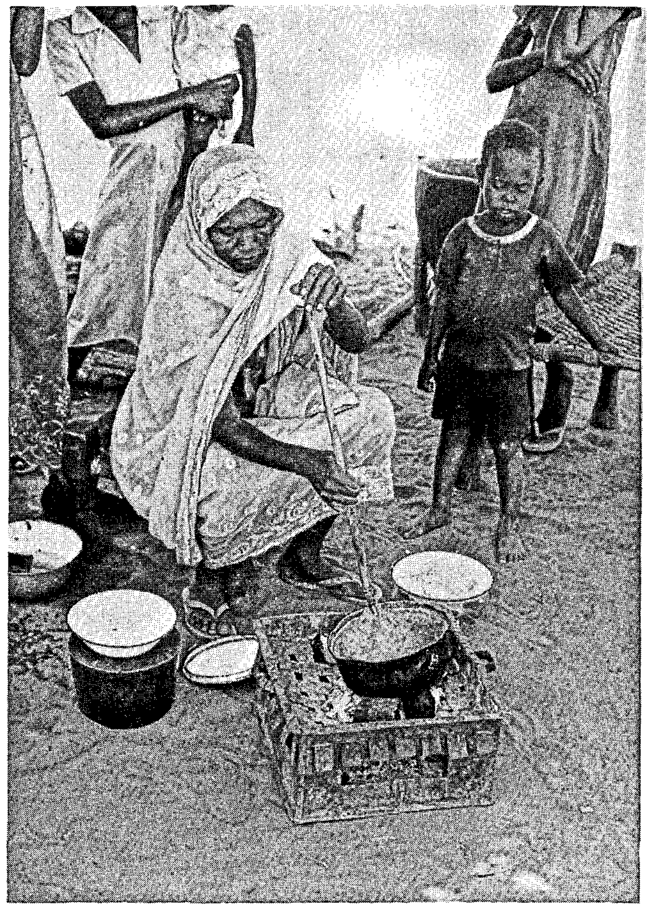
Starch and Protein Components

Since the ratio of corneous to floury endosperm of sorghum grain influences porridge texture, and as starch is the major constituent of sorghum endosperm, a study was undertaken to characterize the properties of starch isolated from the floury and corneous endosperm. Results showed that corneous endosperm starches have smaller granule size, higher gelatinization temperature, and higher intrinsic viscosity compared with the starches from floury endosperm. These properties, in addition to the lower degree of acid degradation observed, suggest that smaller granule corneous starch has a more crystalline structure and contains larger molecular components than the floury starch granules. This means that corneous endosperm starch could undergo a greater degree of retrogradation upon cooling; this would result in a stiffer alkali porridge. These results agree with our previous finding that harder grain sorghums produce stiffer gels than softer grain sorghums, and indicate that both starch and protein endosperm components influence food acceptance or quality.

Kafirin is the principal seed storage protein in sorghum, accounting for 37 to 50 percent of the total grain protein. Sorghum kafirin protein exists in two forms: aqueous alcohol-soluble kafirin (K-I); and cross-linked kafirin (K-II) which can be extracted in aqueous alcohol containing a reducing agent.

Like zein, its counterpart in maize, K-I is thought to be stored in membrane-bound vesicles called protein bodies. The origin of the K-II protein is not clear. This is important to an understanding of food quality, as previous work has shown that kafirin protein content is related to grain hardness and porridge texture.

Immature seeds were chosen for the kafirin localization study. Seed sections prepared for transmission electron microscopy suggested that sorghum protein bodies originate from the rough endoplasmic reticulum. We also isolated protein bodies, extracted kafirins and compared the isolated proteins electrophoretically. These

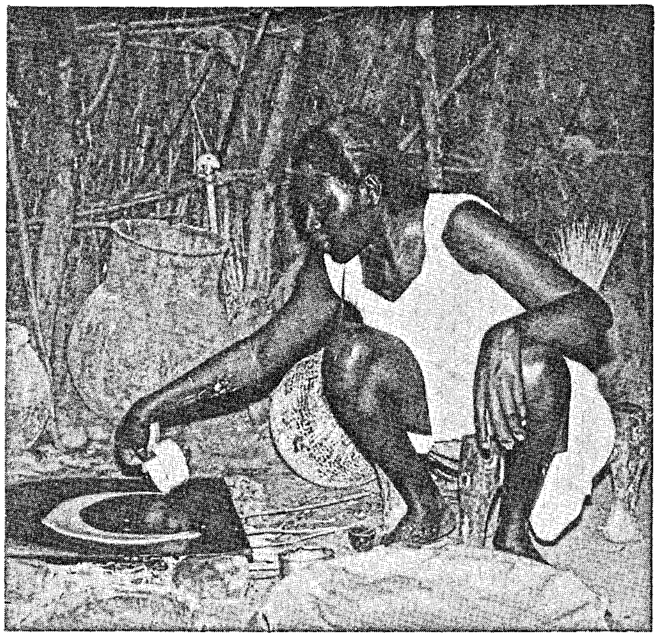


proteins were compared to proteins extracted from flour from mature and immature seeds. Our results confirm, by amino acid analysis, acid urea polyacrylamide gel electrophoresis, polyacrylamide gel electrophoresis in the presence of sodium dodecyl sulfate, and transmission electron microscopy, that protein bodies in sorghum endosperm contain kafirin.

Mature seeds were chosen for evaluation by scanning electron microscopy to illustrate the localization of cross-linked kafirin. Seed sections were treated sequentially with -amylase, aqueous alcohol, and aqueous alcohol with a reducing agent to remove starch grains, protein bodies and protein matrix. Results suggest that the protein matrix includes cross-linked kafirin as a component protein.

A study was conducted to separate K-I proteins into individual components and to establish the N-terminal amino acid sequence of several of the K-I components. Reversed phase high performance liquid chromatography was used to separate K-I into five groups. From these five groups, six individual K-I proteins were isolated and subjected to N-terminal amino acid sequence analysis. A comparison of the N-terminal sequences of these individual K-I proteins shows that there are three distinct types of sequence, two of which have highly conserved Ile-Pro-Gln and Pro-Pro sequences. One component exhibited 66 percent homology within the first 30 amino acid residues to a zein sequence.

A single low-molecular-weight component of K-I was unique when compared to other K-I components.



These women in El Obeid, Sudan are preparing aseda (left), a thick sorghum porridge, and kisra (above), a pancake-like fermented sorghum bread.

Although the amino acid composition of this component was consistent with that of prolamins (i.e. unusually high quantities of glutamyl and prolyl residues, and large amounts of non-polar amino acids), it was unusual because it contained so much methionine. A protein with an apparent molecular weight of 20,500, it had 15 residues of methionine.

Sorghum Protein Digestibility

Human feeding studies with children have shown that rice, maize and wheat proteins are much more digestible after cooking than sorghum protein (66 to 81 percent compared with 40 percent). A porcin pepsin *in vitro* protein digestibility assay shows these same digestibility differences. With the pepsin *in vitro* assay, we found that uncooked sorghum proteins have a high digestibility (78 to 100 percent), which is reduced to 45 to 55 percent after cooking. A traditional Sudanese fermented sorghum food (nasha) and a heat extruded sorghum food preparation had pepsin digestibility values of 70 to 86 percent. In contrast, thick porridges made in our laboratory from the same flours gave pepsin values of only 44 to 56 percent. The high *in vitro* protein digestibility values for nasha and heat extruded foods have been confirmed with children. Therefore, the cooking procedure used to prepare sorghum foods affects protein digestibility.

In order to understand more about the low protein digestibility of cooked sorghum proteins, the *in vitro* pepsin assays of uncooked and cooked fractionated proteins were examined. It was found that the low digestibility of sorghum proteins caused by cooking was due primarily to the indigestibility of the alkali-soluble glutelin fractions. Whether this is due to the character of the sorghum proteins themselves or to an interaction with a carbohydrate or lipid component of the grain is the subject of continued research.

Food Quality Evaluation

We have been working collaboratively since 1981 with the Agricultural Research Corporation and ICRISAT in Sudan on a "Sorghum Food Quality Assessment" program. The objective of the work is to define the grain parameters of sorghum for making kisra (a staple Sudanese food). The project is designed so that entries from the ICRISAT food grain nursery are evaluated for milling and kisra quality by Dr. Bitt Badi, and the physical and chemical grain characteristics are determined in our laboratory. Analytical data are then compared to kisra quality results in order to define grain properties related to food quality. Due to problems related to reaching a satisfactory agreement with ARC, results from this work have only provided some preliminary information about grain quality.

Significance of Research Findings

A significant aspect of these research findings is that they deal directly with identifying the physical and chemical properties of sorghum which provide the desired food and nutritional quality for human food.

Defining the relationship between grain characteristics and the food making properties of sorghum has provided a much better understanding of the factors that affect the food quality of the grain. Using this information, we have developed techniques for measuring grain hardness and food texture which can be used in a breeding program when screening for food quality. These methods will help LDC national programs to develop sorghums with acceptable food quality. In addition, our work on food quality has stimulated sorghum breeders and cereal scientists in Sudan to work on improving the food quality of improved sorghum lines.

Detailed studies on the kafirin protein fraction in sorghum have provided useful information about food quality and nutritional value of the grain. The amount of kafirin protein in the endosperm is associated with grain hardness. This indicates that the food quality as well as the amount of flour derived from a decorticated sorghum depend on the kafirin content of the endosperm. Secondly, a single purified component of kafirin was found to contain a very high amount of the essential amino acid methionine. By increasing the content of this kafirin component through gene amplification or by other means, the protein quality of the grain could be improved.

Detailed studies of the molecular changes occurring in processed sorghum proteins will help us understand the effects of cooking on protein digestibility.

Finally, in many parts of the world sorghum grain is still regarded as inferior to wheat, rice and maize. We have learned a great deal about the reason for this, and now have the research base, working with LDC scientists, to improve the situation.

LDC Collaboration

Our collaborative research is with the Food Research Centre of Sudan, the Cereal Quality Laboratory of Niger and ICRISAT in Mali and India.

Training and Technical Assistance

Five graduate and post doctoral students from the Philippines, Niger and the U.S. have participated in this project. In addition, we have trained three laboratory technicians from Iraq, Sudan and Niger.

Implications for Future Research

The goals of our project are by nature long-term. Therefore, many of our past activities will be continued to increase our knowledge about the chemical and physical aspects of the grain which influence sorghum food and nutritional quality. Our focus on the role of starch, protein and other minor grain components, and the interaction of these components resulting from food preparation, are critical to defining product quality differences between cultivars possessing similar grain color. As we improve our understanding of the function of grain components in traditional food systems we will continue to modify and develop new techniques that can be useful in breeding programs for evaluating the food quality of sorghum.

Areas of major focus in the future will be:

- Continued efforts to characterize the starch and protein components from sorghum, and to identify the chemical and functional properties of these components that influence product texture and keeping quality.
- Continued work with the Food Research Centre in Sudan to identify the grain characteristics leading to good kisra and injera (East African fermented sorghum foods) quality. We need to study the microbial composition of the "starter" cultures and the changes that occur during fermentation related to protein digestibility and food quality of kisra and injera.
- Examination of the factors which lead to improved protein digestibility in traditional and processed sorghum foods.
- Identification of the specific phenolic compounds responsible for undesirable colors of otherwise acceptable food quality sorghum cultivars.
- Development of methods for detecting the onset of weathering in sorghum.

Selected Publications

Axtell, J.D., A.W. Kirleis, M.M. Hassen, N. D'Croz-Mason, E.T. Mertz and L. Munck. 1981. Digestibility of sorghum proteins. Proceedings of the National Acad. Sci. 78:1333-1353.

Cagampang, G.B., A.W. Kirleis and J.S. Marks. 1984. Application of small sample back extrusion test for measuing texture of cooked sorghum grain. *J. Food Sci.* 49:278-280.

Cagampang, G.B. and A.W. Kirleis. 1984a. Relationship of sorghum grain hardness to selected physical and chemical measurements of grain quality. *Cereal Chem.* 61:100-105.

Cagampang, G.B. and A.W. Kirleis, 1984b. Some properties of sorghum starches from the floury and corneous endosperm fractions. Starke/Starch. (in press).

Cagampang, G.B., J.E. Griffith and A.W. Kirleis. 1982. Modified adhesion test for measuring stickiness of sorghum porridges. *Cereal Chem.* 59:234-235.

Kirleis, A.W., K.D. Crosby and T.L. Housley. 1984. A method for quantitatively measuring vitreous endosperm area in sectioned sorghum grain. *Cereal Chem.* 61. (in press).

Kirleis, A.W. and K.D. Crosby. 1981. Sorghum hardness; comparison of methods for its evaluation. Proceedings of the International Sorghum Grain Quality Symposium. ICRISAT. Hyderabad, India. p. 231-241.

Kirleis, A.W. 1981. Grain hardness: Its relationship to milling and food quality. *Agron. Abst.* p. 133.

Mertz, E.T., M.M. Hassen, C. Cairns-Whittern, A.W. Kirleis, L. Tu and J.D. Axtell. 1984. Pepsin digestibility of proteins in sorghum and other cereals. Proceedings of the National Acad. Sci. 81:1-2.

Summers, K.A., A.W. Kirleis and N.C. Nielsen. 1983. Characterization of sorghum prolamins. *Plant Physiology.* 72:30.

Summers, K.S. and A.W. Kirleis. 1982. Localization of kafirin and cross-linked kafirin in sorghum seeds. *Cereal Foods World.* 27:467.

Improving Nutritional Quality and Food Grain Quality of Sorghum

John D. Axtell
Purdue University

The focus of this research project is to identify the limitations of nutritional quality in sorghum grain and to develop germplasm with improved grain quality and grain yield for use in LDCs.

The levels of the major nutrients in sorghum are just as high as in the cereals considered more nutritious. However, the protein and energy availability is limited in some sorghum genotypes by the presence of polyphenolic compounds (tannins) located primarily in the testa layer of the grain. Also, the protein quality of an all-sorghum diet is limited by the low lysine content of the grain, which relfects the high prolamine content of the endosperm. There are also specific dietary limitations in the utilization of cooked and baked sorghum products for food, due to factors such as the high gelatinization temperature of the starch and the high viscosity of the cooked products, which can lead to problems of acceptability and digestion. To cope with these problems, local food preparation techniques, often dependent on specific local varieties, have been developed.

Research Accomplishments

Protein Quality

Two genetic mutants, one naturally occurring and one induced, have been identified that increase the lysine content of the sorghum endosperm and improve protein quality of the grain. Following is a brief review of the origin of these mutants, and recent results of experiments on the relationship between improved protein quality and total grain production in sorghum.

Ethiopian High-Lysine Gene

About 10,000 entries in the World Sorghum Collection were screened by cross-sectioning seeds from each entry to identify those with floury endosperm phenotypes, and then evaluating grain samples from those selected entries for protein and lysine concentration. Sixty-two floury endosperm lines were identified, of which two (IS-11167 an IS-11758) had a significantly higher lysine content than normal sorghum. These lines contain approximately 15 to 17 percent protein in comparison with normal checks averaging about 12 percent protein. The lysine content of the Ethiopian high-lysine selection is approximately 3.1 percent (expressed as percent of protein) and 0.50 percent (expressed as percent of sample) in comparison with normal sorghum values of 2.0 and 0.26 percent, respectively. The nutritional quality of the Ethiopian high-lysine grain is also significantly higher than normal sorghums in isonitrogenous rat feeding experiments. It has been established that the concentration of alcohol-soluble proteins is significantly reduced in high-lysine endosperm, relative to values present in normal sorghum endosperm.

On a trip to Ethiopia in 1973 we determined that the two lines previously identified were being cultivated by farmers in Wollo Province in the central highlands. Farmers grow these varieties in mixed plantings of sorghum varieties. We collected many varieties similar to the original high-lysine variety, in addition to an equivalent number of normal varieties for comparative purposes. The protein and lysine contents of grain from high-lysine and normal varieites grown under actual field conditions in Ethiopia were evaluated. The mean lysine concentration, expressed as percent of protein, was 2.88 for the high-lysine entires and 2.17 for the normal sorghum varieties grown in the same environment. Protein values were 15.7 and 11.4 percent, respectively. It seems likely that the high-lysine gene has been present in Ethiopia for a long time, since there is a great diversity in panicle morphology, maturity and plant height among the high-lysine genotypes collected. The farmers roast the heads of the high-lysine varieties in the late dough stage and eat the grain in mixtures with grain from normal sorghum varieties prepared in a similar way. Although the yield of high-lysine varieties is approximately 72 pecent of normal check varieties, farmers grow them because the high-lysine grain has superior flavor and improved palatability when roasted.

There is good opportunity to utilize these high-lysine varieties in African countries as high-protein, special-purpose sorghum varieties. The protein concentration is increased by about 30 percent, along with the significant increase in protein quality. We propose that these Ethiopian high-lysine varieties should be utilized in rural areas as special-purpose sorghums for people who have a high protein requirement. It should be possible for farmers to produce an adequate quantity of high-lysine sorghum grain on small sections of their farms for use as a weaning food and a supplement for pregnant women and nursing mothers. It may also be possible to develop a marketing system whereby these grains receive a market premium when sold in the cities.

Chemically Induced High-Lysine Mutant

Chemical mutagenesis was used to induce a second high-lysine gene mutation in sorghum. The parent line used for the mutagen treatment was a photoperiod insensitive, three-dwarf sorghum line with relatively broad agronomic adaptability. The parent line also had a colorless pericarp and a translucent (vitreous) endosperm so that progeny from the mutagen treatments could be screened for opaque mutant kernels over a light box.

Selfed seed was treated with diethyl sulphate (DES) by soaking in a solution containing 1 ml DES per 1,000 mil of distilled water for 3 hours. The M_1 plants were grown in Lafayette, Indiana during 1972, and each head was bagged to ensure self-fertilization. M_2 plants were then grown in Puerto Rico during the winter of 1972-73 and each M_2 head was again bagged to ensure self-fertilization. Approximately 23,000 bagged M_2 heads bearing M_3 seeds were harvested in the spring of 1973 in Puerto Rico and shipped to Lafayette for evaluation.

Seed from each head was threshed and examined for opaque kernel segregates over a light box. A total of 445 putative opaque mutants were identified and seed from each segregating head was separated into vitreous and opaque classes. Both classes of seed from each putative mutant head were then analyzed for protein and lysine concentration. Of the 445 mutants, only 33 were identified as having an increase in lysine concentration greater than 50 percent. Plants from each of these 33 opaque and normal sib seed lots were grown in paired rows to evaluate them for any morphological changes associated with the change in endosperm phenotype. In most of the opaque mutants either plant or seed development was drastically affected. Only one of these 33 (P-721) was found to produce normally appearing plants and seeds. The P-721 opaque mutant produced an increase of about 60 percent in lysine concentration. The mutant is controlled by a single gene that is simply inherited as a partially dominant factor. The nutritional quality of P-721 grain is significantly higher in monogastric feeding experiments than normal sib counterpart grain.

The effect of the P-721 mutant on grain yield potential was estimated by examining the mean seed weight per head of P-721 opaque and normal sib heads at periods ranging from 10 to 59 days after pollination in a space-planted population. These data indicate no difference in dry matter accumulation until approximately 31 days after pollination. After 31 days, dry matter accumulation in the P-721 opaque line levels off, whereas dry matter in the normal sib line continues to accumulate for an additional week, plateauing at 38 days after pollination. Seed weights of the normal and opaque lines are similar at 31 days after pollination, but diverge at 38 days after pollination. At maturity, kernel weight for the opaque line is reduced by 11 to 14 percent relative to its normal counterpart. No reduction in seed number was observed, so the difference between the lines can largely be accounted for by reduced kernel density. The reduction in kernel weight is in relative agreement with preliminary data from a 1977 four-replicate yield trial in which P-721 opaque showed a 9.4 percent yield reduction as compared to its normal sib line.

The next phase of this sorghum improvement program involved the making of hundreds of crosses of the P-721 opaque mutant with high-yielding entries from the World Sorghum Collection, with elite lines from the Purdue/AID sorghum breeding materials, and with individual plants selected from genetically heterogeneous random mating populations. Emphasis was put on incorporating the P-721 opaque gene into many and diverse genetic backgrounds to enhance the probability for identifying a genetic background which was optimal for expression of the P-721 gene. The pedigree breeding procedure was used in handling progenies from these crosses. Early generation selections were evaluated for agronomic desirability and yield potential at Lafayette, Indiana, and for tropical adaptability in Puerto Rico. All segregating lines which lacked promising agronomic potential were discarded without attention to chemical evaluation because the major objective was to derive high-yielding, agronomically desirable sorghum lines in which the P-721 gene had survived. Some 197 homozygous opaque F_6 lines survived, and after a final screening against lodging, stalk rot, and foliar diseases in Puerto Rico, Van Scoyoc tested the best 158 lines, 11 elite normal cultivars from international trials, and RS 671 for yield. Several of the elite normal lines (the P-954 series) have yielded very well in Africa.

Yields of the 158 P-721 lines and the 11 elite normal lines were divided into three classes: 22 with low yield; 111 with intermediate yield; and 36 with high yield. All check lines were in the high-yield class. Among entries that yielded above 8.0 t/ha, the 12 opaque lines and the 7 vitreous controls gave mean yields of 8.5 t/ha. Among entries yielding above 7.6 t/ha, the mean for 24 opaque endosperm lines was only slightly less than that for the 12 checks (8.1 versus 8.2 t/ha, respectively). These data indicate that line swith the P-721 opaque gene can yield as well as the best normal sorghum cultivars if the gene occurs in the proper genetic background. Earlier, Christensen, by studying a subset of the P-721 lines in F_5 breeding lines, also showed that the P-721 opaque gene, when placed in an appropriate genetic background, would not reduce grain yield potential. Because seed weight was reduced about 15 percent by the P-721 opaque gene, we speculate that selection for grain yield in P-721 lines must have resulted in an increase in the number of seeds per panicle and/or the number of panicles per unit area in order to have maintained a good yield level. It is likely that variations in sorghum panicle morphology compensate for reduced seed weight by increasing seed numbers per panicle.

Acceptance of high-lysine sorghum cultivars will be limited by problems associated with the opaque kernel phenotype. Ejeta was successful in identifying several lines with vitreous endosperm and high lysine content. Subsequently, these proved to be stable for vitreous endosperm phenotype and high lysine concentration. Also, seed treatments of P-721 opaque, high-lysine sorghum lines with DES resulted in mutants with vitreous endosperm and high lysine concentration. In general, the lines with modified vitreous endosperm from both sources had higher kernel weight and lower percentages of protein and lysine. Also, the most vitreous types had the highest test weight.

A replicated yield trial of 35 opaque lines and 11 normal lines at two locations in Indiana has recently been completed. The mean grain yield of the top three P-721 opaque lines is similar to that of the top three normal checks in the trial. The dye-binding capacity (DBC) of the high yielding P-721 derived lines is intermediate between the checks and that of the original P-721 opaque line.

Future studies with regard to the food-making characteristics of the high-lysine lines will reveal new possibilities and drawbacks. We can anticipate that the milling quality of the more vitreous high-lysine lines previously discussed will be better then P-721 opaque, which has poor milling quality due to its softness.

Sorghum Digestibility

In 1980, four Purdue cultivars of sorghum (two high lysine and two normal) were sent to Dr. George Graham at Johns Hopkins University to be tested in 6- to 27-month-old children in a hospital metabolic unit in Lima, Peru. Dr. Graham had previously determined the digestibility and nitrogen retention of wheat, maize and rice in children of this age group. Sorghum had an unusually low digestibility (and nitrogen retention) when fed as a cooked grain porridge (46 pecent digestibility compared with 81, 73 and 66 percent in wheat, maize and rice, respectively). When the same sorghum cultivars were fed to rats, at Purdue and in Guatemala, the digestibility was 80 to 85 percent. Fortunately, a simple *in vitro* pepsin method used in previous studies on high-tannin sorghum at Purdue gave values on sorghum and other major cereals that agreed with the values obtained in children. This method was therefore employed to study the effect of processing on the digestibility of sorghum cultivars.

Effect of Temperature on Digestion

Using the pepsin method, it was found (Table 1) that both whole kernel and dehulled sorghum had high digestibility in the form of an uncooked, thin porridge (78 to 93 percent). Upon cooking for 20 minutes, the digestibility dropped to a range of 37 to 57 percent. This also was found with uncooked and cooked Sudanese varieties (Davar, Tetran and Mayo, Table 2). Uncooked gruels ranged from 73 to 100 percent digestible and cooked from 44 to 56 percent. However, when these varieties were fermented and pan fried in the native Sudanese fashion, the kisra thin bread and the abrey flakes had higher digestibilities, ranging from 65 to 86 percent. In contrast to sorghum, gruels of wheat, maize and rice do not show this drop in digestibility on cooking.

Digestibility of Cooked Cereals and Processed Sorghum and Millets

The pepsin method was modified and used to determine the digestibility of other major cereals, as well as processed sorghum and millet. Table 3 shows that the digestibility of cooked gruels of wheat, maize and rice are 20 to 25 percent higher than either normal (P-721N and Dabar) or high-lysine (P-721) sorghum. Decortication of Purdue normal cultivar 954062 did not improve digestibility. However, extrusion at 350°C and low moisture increased the digestibility to 79 percent. This increase was confirmed by MacLean *et al.* in Peruvian children.

Cooked pearl millet gruels are more digestible than cooked sorghum gruels, but still about 10 percent below other major cereals. Fermentation and conversion into the Sudanese baby food nasha increased the digestibility of both millet and sorghum. The increase in sorghum was confirmed by Graham and co-workers in Peruvian children. They obtained values equal to those of wheat flour (about 80 percent digestibility) for the sorghum nasha supplied to them by the Purdue INTSORMIL group.

Table 1. Effect of Temperature on Digestion of Sorghum Proteins by Pepsin.

	Whole kernel*		Dehulled kernel*	
Variety	Uncooked	Cooked	Uncooked	Cooked
IS-11758 high-lysine	88.6	45.3	78.2	41.4
954063 normal	88.9	50.6	81.7	37.1
P-721 opaque	93.0	56.7	85.7	43.0
P-721 normal	92.9	46.4	81.1	40.7

*Percent solubilized by pepsin. Average of duplicate values.

Table 2. Effect of Fermentation and Temperature on Digestion of Sorghum Proteins by Pepsin.

Variety	Protein %*	Uncooked	Laboratory cooked	Kisra	Abrey
Dabar	8.7	100.0	55.7	65.4	86.2
Tetran	9.0	91.4	46.7	76.0	-
Mayo	9.1	73.1	43.6	-	71.1

*Protein contents of Dabar kisra, Dabar abrey, Tetran kisra and Mayo abrey were 11.4, 12.4, 10.4 and 8.7 percent, respectively.
Percent of protein solubilized by pepsin. Average of duplicate values.

Effect of Processing on Digestibility of Sorghum

The studies on pepsin digestibility of sorghums have confirmed Graham's work in children. Cooked sorghum gruels have significantly lower digestibilities than cooked gruels of other major cereals. Native methods of processing sorghum, such as fermentation, raise digestibility to that of other major cereals. Extrusion of sorghum flour at low moisture and high temperature also improves digestibility markedly. In all native cultures where sorghum is consumed, however, sorghum is processed in some manner other than simple boiling. For example, in the Andra Pradesh province of India, sorghum is prepared in twelve different ways. Using alternately all twelve of these preparations in a sorghum-black gram diet supplying 200 g of sorghum and 40 g of black gram per day to six preschool children 5 to 6 years of age, Pushpamma *et al.* obtained an average digestibility of 87 percent for the sorghum-legume combination. Whether other cultures have achieved this level of improved digestibility with their special methods of processing sorghum is not known, and will be explored at Purdue during the next 3 years.

Table 3. Pepsin Digestibility of Cooked Major Cereals.

Cereal	Protein digestibility* %	SD
Wheat	85.5	1.73
Maize	85.3	1.26
Rice	83.8	0.96
Sorghum P721N	59.0	2.45
Sorghum P721O	63.2	1.30
Millet, pearl	74.8	2.06
Millet nasha	85.5	0.58
Sorghum, Dabar	59.8	1.50
Sorghum nasha	65.5	1.29
Sorghum, decorticated 954062	56.8	2.22
Sorghum, decorticated/ extruded 954062	79.0	0.00

*Mean of four analyses.

Nature of the Heat-Sensitive Proteins in Sorghum

Maize proteins were compared with sorghum proteins using the Landry-Moureaux frationation method. Both raw and cooked gruels of whole maize flour and whole sorghum flour were digested with pepsin, and the pepsin-indigestible residue fractionated into six protein fractions. Table 4 shows the protein profiles of the pepsin-indigestible residues from sorghum and maize. These data show that sorghum proteins appear to polymerize to a greater extent than do maize proteins, with an accumulation in sorghum of the indigestible glutelin II and non-extractable protein fractions which are nearly three times that found in maize. Native processing methods apparently reduce this polymerization in those cases where normal digestibilities are found for the processed sorghum.

Significance of Research Findings

As a result of this research, several contributions of improved germplasm have been made to LDCs.

- A Purdue/INTSORMIL variety released locally as ICA-Nataima is the most widely grown sorghum cultivar in Colombia. ICA-Nataima is also grown extensively in Peru and Bolivia.
- Purdue/Texas A&M germplasm selected from BC_1 and BC_2 cycles of the Texas/USDA sorghum conversion program are widely used by ICRISAT in India and other LDCs.
- New A and B lines with good food grain quality have been released and at least one has excellent potential in East Africa.
- Three lines have been released and are widely used in Pakistan; three have also been released recently in Kenya.
- A Purdue/INTSORMIL Striga-tolerant line has been identified in Sudan, and will be used extensively in future Striga tolerance breeding programs.
- An excellent drought-tolerant line has been identified in Sudan and is being used at several stations for development of drought-tolerant sorghum varieties.
- Several high-lysine sorghum varieties derived from crosses between P-721 opaque and elite sorghum varieties have been developed. Significant progress in yield and kernel modification have been made, but none are yet good enough for release.
- Several food grain sorghum populations have been developed and released to LDC cooperators.

Training and Technical Assistance

Nine students from LDCs and six from the U.S. have contributed to the research of this project and received graduate training from it. Future training activities will focus on outstanding students from principal countries collaborating with INTSORMIL.

Table 4. Protein Profile of the Pepsin-indigestible Residue.

	Sorghum		Maize	
	raw	cooked	raw	cooked
	%	%	%	%
Albumin/Globulin	1.3*	2.5	2.8	2.9
Prolamine I	1.3	3.2	1.5	1.8
Prolamine II	0.0	0.0	0.0	0.0
Glutelin I	5.4	5.8	5.0	4.9
Glutelin II	6.6	10.7	4.4	4.2
Non-extractable	4.7	13.0	4.8	4.3
% Indigestible Protein	19.3	35.2	18.5	18.1

*Percent of total nitrogen.

Implications for Future Research

Studies of the nutritional value of sorghum grain for human nutrition are only beginning. Data accumulated so far are not adequate because too little work has been done with the locally produced food products. The more information we have on the nutritional quality of sorghum, the more appropriately we can use this grain in the future, both for feed and food.

Protein quality research needs to be continued to determine what level of success is achievable without sacrificing grain yield or food grain quality. Here a distinction needs to be drawn between plant breeding research objectives and plant breeding objectives. Protein quality improvement in sorghum remains a research objective at this time and is not a goal for most developing country sorghum breeders to pursue. We remain convinced, however, that in the near future we will be able to offer methods for genetic improvement of protein quality in sorghum without sacrificing either grain yield or food grain quality. A very substantial research effort on the molecular genetics of seed storage proteins is in progress throughout the world. Based on the knowledge and techniques gleaned from these studies, we are confident that we will learn how to manipulate plant genes to design endosperm proteins to better meet human nutritional needs.

A great deal of research is needed to resolve the often conflicting results on human digestibility of sorghum proteins. It is imperative that the human nutritional evaluation be conducted in consort with cereal chemists and food scientists who can duplicate local village procedures used in sorghum food preparations. It is also important to develop centers for nutritional studies in LDCs so that the response of children to their own traditional foods can be measured.

The complementarity of other foods in the diets of people using sorghum as the staple cereal must also be considered in the overall nutritional evaluation. Recently in Egypt, we noted that fenugreek, a small-seeded grain legume, was frequently mixed as a ground flour with sorghum flour. The fenugreek flour added elasticity to the sorghum dough, much as gluten protein does in wheat dough. The fenugreek also added significantly to the protein quality of the Egyptian sorghum bread, since our analysis showed it to contain 28 percent protein and 6 percent lysine (expressed as percent of protein). If this lysine from the fenugreek is physiologically available, it also improves the utilization of the sorghum proteins. Experiments are in progress to test this point. Certainly many other legumes are regularly used as complements to sorghum as well as other cereal diets, but we know relatively little about their effect on protein and carbohydrate utilization. Much research is needed in this area.

The high *in vitro* protein digestibility of the fermented Sudanese kisra and abrey strongly suggest that local food preparation methods have evolved which improve the nutritional quality of the sorghum grain. These results are confirmed *in vivo* in rats, but we suspect that this result may represent only the tip of the iceberg with regard to the interaction between village processing of sorghum and the nutritional value of the prepared foods. Again, a great deal of research is needed, including nutritional studies on humans.

The ultimate objective of research on nutrition and utilization in sorghum is to enhance the acceptability of sorghum grain as a human food, and to increase the versatility of this cereal which offers so much potential to people living in the semi-arid regions of the world. We have gained much knowledge about sorghum quality during the past 5 years, and in our opinion the momentum for such studies is increasing. Research is the key to understanding, and understanding is the key to further progress in the '80s.

Selected Publications

Axtell, J.D., A.W. Kirleis, M.M Hassen, N.D. Mason and E.T. Mertz. 1981. Digestibility of sorghum proteins. Proceedings of the National Acad. Sci. USA 78(3):1333-1335

Axtell, J.D., G. Ejeta and L. Munck. 1981. Sorghum nutritional quality. *In: Sorghum in the Eighties.* ICRISAT. Hyderabad, India.

Axtell, J.D., S.W. VanScoyoc, P.J. Christensen and G. Ejeta. 1979. Current status of protein quality improvement in grain sorghum. Proceedings of the International Symposium on Seed Protein Improvement in Creals and Grain Legumes. Vol. II. International Atomic Energy Agency, Vienna.

Bittinger, T.S., R.P. Antrell and J.D. Axtell. 1981. Allelism tests of brown midrib mutants of sorghum. *J. of Heredity.* 72:147-148.

Bittinger, T.S., R.B. Cantrell, J.D. Axtell amd W.E. Nyquist. 1981. Analysis of quantitative traits in PP9 random mating sorghum population. *Crop Sci.* 21(5):664-669.

Bucholtz, D.L., R.P. Cantrell, J.D. Axtell and V.L. Lechtenberg. 1980. Lignin biochemistry of normal and brown midrib mutant sorghum. *Food Chem.* 28:1239-1241.

Bucholtz, D.L., R.P. Cantrell, V.L. Lechtenberg and J.D. Axtell. 1979. Biochemistry of lignin in brown-midrib mutant and normal sorghum. *Agron. Abst.* 1979, p. 85.

Chibber, B.A.K., E.T. Mertz and J.D. Axtell. 1980. *In vitro* digestibility of high-tannin sorghum at different stages of dehulling. *J. Agr. Food Chem.* (18):160-161.

Eggum, B.O., L. Monowar, K.E. Bach Knudsen, L. Munck and J.D. Axtell. 1983. Nutritional quality of sorghum and sorghum foods from Sudan. *J. of Cereal Sci.* 1:127-137.

Eggum, B., K.E. Bach Knudsen, L. Munck and J.D. Axtell. 1981. Sorghum and millet milling technology: nutritional quality of locally prepared sorghum foods in Tanzania. Proceedings of the International Sorghum Grain Quality Symposium. ICRISAT, Hyderabad, India.

Ejeta, G. and J.D. Axtell. 1984. Quantitative inheritance and correlations of agronomic and quality traits of sorghum. *Crop Sci.* (submitted).

Ejeta, G. and J.D. Axtell. 1984. Modified endosperm, high lysine sorghum lines form diverse sorghum populations. *Crop Sci.* (submitted).

Fritz, J.O., R.P. Cantrell, V.L. Lechtenberg, J.D. Axtell and J.M. Hertel. 1981. Brown midrib mutants in sudangrass and grain sorghum. *Crop Sci.* 21:(5)706-709.

Fritz, J.O., R.P. Cantrell, V.L. Lechtenberg, J.D. Axtell and J.M. Hertel. 1979. Fiber composition and IVDMD of three Bmr mutants in grain and grass type sorghums. *Agron. Abst.* p. 128.

Ibrahim, O. and J.D. Axtell. 1984. Quantitative inheritance and correlations of agronomic and quality traits of sorghum. *Crop Sci.* (submitted).

Keaschall, J., R. Cantrell and J. Axtell. 1982. Variation in agronomic traits of B-lines developed from random-mating sorghum populations. *Agron. Abst.*

Maxon, E.J., J.D. Axtell and H.L. Warren. 1980. The inheritance of resistance to *Colletotrichum graminicola* in grain sorghum, *Sorghum bicolor. Agron. Abst.*

Mertz, E.T., M.M. Hassen, C. Cairns-Whittern, A.W. Kirleis, L. Tu and J.D. Axtell. 1984. Pepsin digestibility of protein in sorghum and other major cereals. Proceedings of the National Acad. of Sci. USA 81:1-2.

Munck, L., K.E. Bach Knudsen, J.D. Axtell and S. Mukuru. 1981. Sorghum and millet milling technology; quality of locally milled flour in Tanzania. Proceedings of the International Sorghum Grain Quality Symposium. ICRISAT, Hyderabad, India.

Munck, L., K.E. Bach Knudsen and J.D. Axtell. 1981. Industrial milling of sorghum in the 80s. *In: Sorghum in the Eighties.* ICRISAT, Hyderabad, India.

Prest, T.J., R.P. Cantrell and J.D. Axtell. 1983. Heritability of lodging resistance and its association with other agronomic traits in a diverse sorghum population. *Crop Sci.* 23:217-221.

VanScoyoc, S.W. and J.D. Axtell. 1981. Dry weight, amino acid and protein fraction changes in developing grain of P-721-Opaque sorghum. *Agron. Abst.*

Woodruff, B.J., R.P. Cantrell, J.D. Axtell and L.G. Butler. 1982. Inheritance of tannin quantity in sorghum. *J. of Heredity* 73:214-218.

The social and economic environments that affect small farm production are important areas of research.

SOCIOECONOMICS

The INTSORMIL program has always recognized that new technology alone is not enough to solve the food problems of less developed countries. Social, cultural, economic and political factors must also be addressed if basic human needs are to be met. It is for these reasons that INTSORMIL includes a significant amount of socioeconomic research.

Executive Summary

Research on the socioeconomic constraints to the increased production and utilization of sorghum and millet involves two principal areas. The first includes the "micro" aspects that affect production, distribution and consumption of these two grain crops. The second involves the more "macro" aspects of the production environment as a whole. In both cases, the goal of this research is to contribute knowledge that will help INTSORMIL improve the production, marketing and consumption of grain sorghum and pearl millet, thus enhancing the welfare of farmers and their families.

Micro Socioeconomic Research

Diagnostic farming systems research is an important part of the socioeconomics discipline. These diagnostic studies, which have been carried out in Sudan and Honduras and are beginning in Mexico and the Dominican Republic, have several major goals. The first is to describe for each region the major constraints to agricultural production, and to identify alternative practices, techniques, activities and policies that would promote effective rural development. The second goal is to determine the interactions among sociocultural, physical and biological factors. Some of the most important matters that have been investigated are the social milieu in which farm decisions are made, the economic environments of farms (e.g., relationships with markets), the attitudes of farmers, the use of different crops for consumption and exchange, and the institutions and policies that affect farming. The third goal is to provide a baseline against which to measure potential changes deriving from INTSORMIL research.

These diagnostic studies have greatly assisted in defining research needs in areas such as agronomy, breeding and entomology. Research in Honduras, for example, documented the important role of sorghum in human nutrition. This fact, along with the agronomic constraints identified, led to the decision to focus breeding efforts on a) improving varieties, b) retaining photoperiod sensitivity, c) improving crystalline structure of the grain to help reduce post-harvest storage losses, and d) improving food characteristics necessary for making good tortillas. Research in Sudan identified stand establishment and insect and bird resistance as the most important research needs.

A second kind of micro research determines how innovations in agricultural technology are transfered from researchers to farmers, as well as among farmers. INTSORMIL agricultural research has progressed to the point that such studies are now becoming feasible. INTSORMIL sociologists are beginning such a study in Sudan.

Finally, micro research deals with the effects of government-set prices for inputs and agricultural products on farmers' decisions.

Macro Socioeconomic Research

The first type of macro research describes recent trends in the worldwide production, consumption and trade of sorghum and millet. This work allows comparisons with other cereals and enables us to relate changes in sorghum and millet production to changes in the world grain economy.

The second type of macro research involves studies of agricultural research systems. This is designed to identify the internal dynamics of national and international research systems, as well as to relate these to the social, economic and political context in which they operate. As an example of the results of this research, recommendations to the Sudanese Agricultural Research Corporation included the need to design a coherent national agricultural research policy, improve communications among stations, and incorporate farming systems research and on-farm testing into the research program.

Another goal has been to relate the studies of small communities to regional, national and international ecological and economic processes. Thus, research in Sudan has viewed sorghum and millet cultivation within the context of increasing desertification. The main problem facing agriculture in that country is to develop alternative technologies that will benefit farm families in the short-run while combatting the trend toward desertification. In Honduras, sorghum production is considered within the context of large-scale deforestation which is being carried out to create pasture for cattle production. While sorghum is an important crop for small farmers, its production is increasingly hampered by ecological, social and political forces. In Mexico, sorghum is not grown for human consumption but as feed for the rapidly growing poultry and hog industries. It is important to understand this kind of overall agricultural environment when planning specific research programs.

INTSORMIL socioeconomic research has focused on two of the three major social systems involved in agriculture—farming systems and research systems. This work will continue, and will be expanded to include the third social system—the extension system—as INTSORMIL agricultural research produces technologies that can be disseminated.

Sociocultural Constraints to the Produciton and Consumption of Grain Sorghum and Pearl Millet in Less Developed Countries

C. Milton Coughenour

University of Kentucky

Many of the constraints to both production and consumption of grain sorghum and pearl millet are not agronomic but sociocultural in nature. Four groups of constraints may be identified; they correspond to the farming system, marketing system, research system and extension system in any given country. Farming system constraints include limitations on available labor at peak periods of use, as well as other constraints built into the farm household in its role as a unit of both production and consumption. Farming systems are also complicated in that many producers have substantial off-farm commitments. Marketing systems also may place constraints on production through, for example, government-set prices that are below production costs, as well as through poorly developed infrastructure. Research systems form an essential part of any improved production and consumption system. Constraints at this level involve inadequate facilities, poor scientific communication, and difficulties in establishing dialogue with farmers. Finally, extension systems may not do a good job of disseminating knowledge and teaching improved practices because of poor organization or poor training of agents.

In an attempt to identify the sociocultural constraints to production and consumption, investigators in this project have engaged in five discrete, though interrelated, sub-projects in three countries. Each sub-project is reported separately below.

The International Sorghum Research System

Lawrence Busch and William Lacy

University of Kentucky

It has been argued that technical innovations are "induced" by the relative scarcity of the three factors of production: land, labor and capital. Hence in the U.S., where labor has been scarce, research has tended to focus upon substituting capital for labor in agricultural production. In Europe, and to a much greater extent in Japan and Taiwan, land has been the scarce factor. There, research has emphasized the use of capital to enhance land.

Such differences in research were apparent as early as the 1830's. In the U.S. research was directed toward mechanization; in Europe it was directed toward the development of agricultural chemicals. Biological research was conducted in both the U.S. and Europe, but to different ends. In the U.S., biological research sought crop "improvements" that permitted mechanical harvesting (e.g., evenness of stands). In Europe research emphasized such properties as the fertilizer response of plants. In recent years, and particularly since the end of World War II, the European chemical and American mechanical traditions have been brought together.

One result of this melding of research approaches has been a very significant increase in the capital intensity of agriculture. As Lewontin has argued, productivity has been increased by substituting manufactured inputs for those produced on the farm. As a result, in most developed countries, the value of agricultural products has been increased far more by off-farm processes than by on-farm processes. Put another way, the entry of capital into agriculture has aided the process of capital accumulation by shifting part of that process off the farm and into the industries that manufacture agricultural inputs and process food. Agricultural research has been in the vanguard of this movement.

In the developed countries this process proceeded largely unhindered, and most of the displaced labor was employed in other sectors of the economy. In LDCs, however, the situation has been quite different. There, capital-intensive systems have been introduced into areas where other, traditional production systems were operative and where non-agricultural employment opportunities were scarce. As a result, in most LDCs today, two or more production systems exist side by side and the ranks of the unemployed and underemployed have greatly increased in urban and rural areas.

Research decisions are made by members of a scientific community in accordance with the values of that community and the larger society. Although these decisions are technical (i.e., they involve esoteric procedures not immediately understood by the lay public), they are also value choices. However, while science may, and frequently does, incorporate ideologies of the larger society into its practice, it remains an activity fundamentally aimed at changing the material world. In fact, it is this very capacity to develop concrete products and processes out of theory that provides modern science with its awesome power.

Grain sorghum is a case in point. Although sorghum is an important crop in numerous climatically similar locations, its use varies widely from place to place. In Africa and Asia sorghum has long been grown for food, fuel, fodder, and even building materials. As a food it takes many forms, from *kisra* (a thin pancake-like unleavened bread), to *ogi* (a smooth, creamy, uncrusted, thin porridge), to a variety of fermented beverages. The long stalks contribute significantly to the fuel supply in areas where wood is scarce. The stalks also provide fodder for the draft animals of Asia, and also are used to reinforce mud walls and as a substitute for timbers in roof construction. In Asia and Africa sorghum is grown primarily by small landholders and cultivated with draft animals (in Asia) or by hand (in Africa). Little is traded in international markets. Even in major producing areas, people in large cities are often nourished by imported wheat flour rather than locally produced sorghum.

The situation is quite different in the Americas. Sorghum is not a native crop, but was introduced as a source of feed grain. The cultivars grown are dwarfs. This permits an even, low stand that is resistant to lodging and amenable to large scale mechanical cultivation and harvesting. Additionally, in dwarfs the plants' energy is directed into grain production instead of stalk growth. The production of grain sorghum as a feed crop in North America has been so successful that it is displacing maize in many areas at a fairly substantial rate. U.S. sorghum exports, which consist of 31 percent of the crop, account for about 50 percent of the world market. Clearly, American sorghum producers are oriented toward capital-intensive production for the world market.

Sorghum production and yield figures indicate that in the U.S., Mexico and Argentina—where sorghum is grown for feed—production and yields are significantly higher than in other countries. Moreover, yields in the Sahel countries, where accurate data are lacking, are likely to be at or below the levels for Nigeria.

The major efforts in sorghum research occured and continue to occur in the temperate zones. Since most sorghum produced in this zone is used for feed, sorghum research has focused upon this use for the crop. In 1977, approximately 500 scientific journal articles on sorghum were published, compared to more than 1,000 on barley and more than 3,000 on wheat. The research problems addressed in these papers are generally applicable to the needs of producers in the more developed temperate zone.

Until World War I, sorghum improvement in the U.S. was achieved largely through selection of mutations and natural crosses. Deliberate hybridization first occured in 1914. One successful early hybrid was Beaver, which had the advantages of erect heads together with short stalks, making it suitable for combining. Hybrid production was given an enormous boost by the discovery of male-sterile plants, thus making commercial production of hybrid seed possible. However, the most successful cultivars were not adopted because of the increased yield they provided, but because they could be harvested mechanically.

Development of high-yielding sorghum strains in the U.S. was assisted by the absence of many insects and diseases which affect sorghum in its native environment. Of particular importance was the absence of *Striga* (witchweed), an extremely difficult-to-control parasitic weed common in Africa and Asia. For years American breeders could work with varieties which exhibited little pest and disease resistance but produced higher yields. In fact, prior to the 1950's, sorghum researchers paid little attention to pests and diseases. Recently, the situation has begun to change as insect problems have increased and greater use of pesticides has been required.

In addition, since breeders did not have to be concerned with food quality, they were able to work with a wider range of varieties, including those considered, for reasons of texture and color, unacceptable for human consumption. As a result, efforts toward grain quality improvement have been minimal.

Finally, U.S. farmers had at their disposal the infrastructure, credit system, and manufactured inputs that allowed them to outproduce their African and Asian counterparts. Thus, the development of cultivars suitable for mechanical cultivation, and which require significant amounts of manufactured inputs, is the focus of much U.S. sorghum research. In contrast, research on grain quality, food preparation, and the role of sorghum in human nutrition is of recent vintage. Furthermore, socioeconomic studies of sorghum farming systems are just now being conducted.

In short, sorghum production and utilization differs markedly in North America, Asia and Africa. Within LDCs the varieties cultivated, the agricultural practices employed and the use of the grain differs from region to region. In North America, large areas employ essentially the same monocultural and uniform farming system. This sharp distinction in modes of sorghum production is implicit in many of the issues addressed by research scientists.

Research Accomplishments

Scientific communities are "invisible colleges." As a result, research conducted in any one location is intimately linked to that conducted at many other locations. Moreover, when researchers from various geographical areas gather, they usually do so in disciplinary meetings. At these meetings the context within which disciplinary work takes place is usually taken for granted. Yet, for our research, it is necessary to examine the assumptions of the work and the implicit values inherent in the various approaches. Fortunately, there are occasions when scientists from different disciplines concerned with the same commodity do meet. In the case of sorghum research, once every decade leading scientists assemble to present papers on current research findings and to propose research directions for the next decade. We attended and participated in the symposium on "Sorghum in the '80s" and the related "International Symposium on Sorghum Grain Quality" in Hyderabad, India in November 1981. Hyderabad is the location of the International Crops Research Institute for the Semiarid Tropics (ICRISAT), the international agricultural research center with primary responsibility for grain sorghum. Fifty-seven persons attended the grain quality conference, while about 200 persons attended the symposium on "Sorghum in the '80s." Participants included plant breeders, entomologists, pathologists, food scientists, nutritionists, economists, and two sociologists. The ten days of paper presentations proved to be an excellent opportunity to observe and participate.

The very structure of the meetings revealed certain aspects of sorghum research. First, the symposium on grain quality was organized separately from that on sorghum. Moreover, while most participants in the grain quality symposium stayed on for "Sorghum in the '80s," few production scientists participating in the latter symposium attended the former. While food scientists and nutritionists sought knowledge about breeding, cultural practices, physiology and pathology, few persons in those fields felt compelled to learn about food preparation and nutrition. In addition, the internal organization of the two symposia revealed other questions of priority. One physician who had been engaged in infant feeding studies using sorghum, and who seriously questioned its food value, had difficulty getting a place on the grain quality program. A small group apparently felt that their objective was to promote sorghum as a food in addition to studying its food uses. Similarly, at the week-long "Sorghum in the '80s," sessions on food quality and socioeconomic considerations remained in the background. They are not a major part of the context within which research is conducted.

Participants at "Sorghum in the '80s" appeared to work infrequently in interdisciplinary teams or to consider more than a very small number of breeding goals. Two incidents clearly illustrate this point. For example, resistance to a major insect pest was achieved only by decreasing resistance to a minor insect pest. This had the effect of turning a previously unimportant problem into a serious one. In another example, a breeder reported a new pest-resistant variety that was red in color. A nutritionist pointed out that such sorghum was bitter in taste, and possibly toxic due to high tannin content. The breeder replied that this pointed to the need for better milling technologies. This, of course merely passed the problem on to another discipline. While these examples are admittedly extreme, they serve to illustrate the disciplinary "blinders" frequently present at the symposium and characteristic of much sorghum research. These "blinders" make value conflicts invisible by confining particular goals to particular disciplinary communities. In addition, they can cause a significant waste of scarce research resources. However, a fortunate outcome of multi-disciplinary symposia may be the exposure of such implicit conflicts and contradictions.

Within the developed countries, research goal conflicts have relatively little short-term effect upon farmers because of the uniformity of sorghum production. This uniformity consists not only of monocultural fields but also of relatively uniform land tenure arrangements, marketing systems and feed usage. Certain issues simply do not reach research agenda because they have no social or economic significance within the current production system or because they are unrelated to capital accumulation. For example, the percentage of protein and protein quality may be important to the livestock farmer, but as long as these factors remain outside the market they will not be a major consideration in most U.S. breeing programs.

Still another value issue concerns a fundamental contradiction upon which the plant breeding discipline is built: Breeders desire an extremely diverse germplasm pool from which to select; yet, at the same time, they consider themselves successful when farmers have widely adopted a cultivar they have developed, thereby reducing the diversity available in the field. This is inherent in the concept of selection.

Over the last several decades, the number of breeders in the world has increased, and a small number of new cultivars of major crops have gained widespread acceptance. As farmers have rapidly adopted these improved cultivars, vulnerability to insects and pathogens may acutally have been increased. At the same time, the pool of genetic material available for breeding has diminished.

Breeders and international agencies have responded to this by establishing germplasm banks in various locations around the world. Ironically, this may actually contribute to the problem. The practice of submitting selections to the international germplasm banks also makes free exchange of the "best" material fairly easy. For example, more than 59 percent of the improved rice varieties grown in Asia had as a parent "Cina," a line used initially at the International Rice Research Institute. In short, the very presence of the germplasm banks has exacerbated the tendency toward increasing uniformity at the same time that breeders attempt to maintain diversity.

The existence of germplasm banks also has raised the issue of breeding goals to the institutional level. For example, the sorghum germplasm bank at ICRISAT contains approximately 20,000 entries. As the entries are received, information about them is collected as well. Presumably, other scientists are then able to request particular entries from the collection based upon the breeding goals they have adopted. The problem lies in the system of "descriptors" that must be used to define the material. The system currently in use contains a maximum of about 125 descriptors for each cultivar entered. These are grouped into seven categories:

1. Accession Identifier
2. Field Collection Data
3. Taxonomic and Morphological Evaluation Data
4. Agronomic Evaluation Data
5. Pest Resistance Evaluation Data
6. Disease Resistance Evaluation Data
7. Others

Only one descriptor set deals with grain quality, and it is limited to a normal-waxy-sugary trichotomy and a notation of high protein, lysine, and/or tannin. No information on storability, food quality or cropping practices is included. Curiously, the ethnic group living in the area where the germplasm was collected is duly recorded.

In short, breeding goals not only differ widely but are often conflicting. These conflicts are not always apparent because they rarely reach the level of scientific discussion. They appear to stem from a combination of three interrelated phenomena:

1. Sorghum is grown in many different production systems and for different uses.
2. Scientists work in disciplinary groups with narrow agendas and are often isolated from their colleagues in other disciplines, as well as from potential client groups.
3. Plant breeders are limited in the number of characters for which they can simultaneously breed, and therefore must make tradeoffs. Additionally, plant breeding is based on the concept of selection, a concept that demands diversity at the same time as it seeks uniformity.

These potential conflicts reflect broader problems of value. For example, the distribution of the benefits of research may not be just. Tradeoffs between nutrition and yield are also tradeoffs between health and abundance. The demand for high productivity must be weighed against the long-term consequences of an energy-intensive agriculture. The advance of disciplinary knowledge must not take precedence over the integrated knowlege valued by farmers and the ideal of the ultimate unity of science. These and other value issues permeate the goals and practices of sorghum researchers.

Significance of Research Findings

In this research we have shown that the technical choices made by sorghum scientists are, in fact, also value choices. To the extent that such choices are seen by scientists as merely technical decisions, enclosed by the vocational world of the scientist, science becomes an ideology. Such decisions are made to appear "natural," rather than as subject to social, economic and political exigencies. Thus, they may serve to justify or even exacerbate previously existing and often inequitable social relations. They may also conceal the wide-ranging implications and consequences of those decisions.

To the extent that disciplinary organizations conceal the values inherent in technical decisions, they contribute to the development of science as an ideology. By placing disciplinary concerns above all others, by insulating scientists from others who have different goals, the discipline may give scientists the false impression that that which is not problematic to the discipline is not problematic at all.

At the same time, however, by revealing the value assumptions of technical decisions we demonstrate that science is a force for material change. Science is *not* neutral with respect to the changes it constructs or encourages, but an active advocate for a particular position. This occurs as a consequence of the trade-offs that scientists must make if they are to conduct a research program.

What, then, can be done to ensure that the products of sorghum research are appropriate for the varying socioeconomic conditions and production systems of lesser developed countries? The following suggestions are offered:

1. The recent development of the farming system approach promises to bring some of these issues to open dialogue among scientists, farmers and others. If taken seriously, this approach can help ensure that the products of research are relevant to, and therefore adopted by, the users. On the other hand, it may be reduced to simply the new "buzzword" of the '80s.

2. Better methods need to be developed for assessing research goals before research begins. While there are always unexpected consequences from research, scientists rarely embark upon a project without knowing with a high level of probability some of its desired outcomes as well as the implicit tradeoffs. Those probable outcomes could, thus, be evaluated before research gets underway rather than after the fact.

3. To date, most sorghum research has been compartmentalized into numerous disciplines. Despite multidisciplinary commodity research programs, this compartmentalization still persists. Scientists in each discipline in a commodity program generally continue to pursue specific disciplinary research problems. In addition, those commodity research programs providing a multidisciplinary and in some instances an interdisciplinary approach still compartmentalize research along commodity lines. Truly interdisciplinary research will require that scientists in various disciplines be more aware of the full range of technical and value questions, that natural scientists begin to appreciate the socioeconomic questions raised by social scientists, and that social scientists better understand the technical questions raised by natural scientists. Unfortunately, university and research service reward structures tend to discourage this type of interaction.

4. We should strongly caution, however, against attempting to find technical solutions to the problem of breeding goals. For example, one might collect field data on the relevant constraints before the research is conducted, and then conduct a multiple regression analysis to estimate the effects of various pathogens on yields. This certainly appears a reasonable approach. However, this approach assumes that each pathogen is independent, that yield should be the sole indicator of success, and that economic value should be the sole arbitor in decision-making. Clearly, the products of the breeding program will be determined by the set of goals one wishes to optimize. Moreover, it is important to remember that breeding goals—or any other research goals—are "intermediate" goals and not ends in themselves. Ultimately, these goals must be related to ends such as full stomachs, good societies, and decent levels of living.

These suggestions can only mark a beginning. There are few examples upon which to build. The provision of a safe, secure, adequate food supply accessible to all will require a great deal more attention to the value implications of research than has been given in the past.

Millet and Sorghum in a Sudan Farming and Marketing System

Edward Reeves and Timothy Frankenberger

University of Kentucky

Research Accomplishments

A comprehensive study was made of the farming systems in 15 villages within 50 kilometers of El Obeid, capital of the Kordofan region (Fig. 1). The El Obeid area receives an average of 347 mm of rainfall annually, most of it from July through October. The amount of rainfall varies greatly from one year to the next, and within a single season the pattern of its distribution is quite irregular. This climate make consistently successful farming extremely difficult to achieve, given the rudimentary labor-intensive technology that farmers are able to apply. El Obeid lies in the transitional zone between the clayey sand soils to the south and the goz soils (stabilized sand dunes) to the north. These two soil types have different cropping patterns and livestock rearing practices. Both types of soil have low fertility. Fallowing is the principal means for restoring soil fertility. The *Acacia senegal* tree native to the region gives farmers an income from fallow land through collection of the gum arabic it produces.

The rural population is dispersed in villages that vary in size from five or six households to 1,000 or more. The number of villagers occupying a village varies with the season. The population is greatest during the rainy, cropping season and lowest during the dry season. The average household numbers between seven and eight members. The nuclear family residence seems to be preferred, but extended families, matrifocal families, and other household arrangements are fairly common. The household is the basic unit of consumption, but agricultural production is typically in the hands of more than one decision-maker in the household. A common pattern is for husband and wife to manage separate farms. Unmarried sons and daughters who are old enough are also given land to manage, if it is available. Besides farming, virtually every household has members who work in secondary occupations, usually on a seasonal basis. The survey of households revealed that nearly two-thirds of the members were productive in some way during a part of the year. The usefulness of children as producers and income earners is well understood by parents.

The average amount of cultivated land managed by a household head is 18 makhammas (1 hectare = 1.39

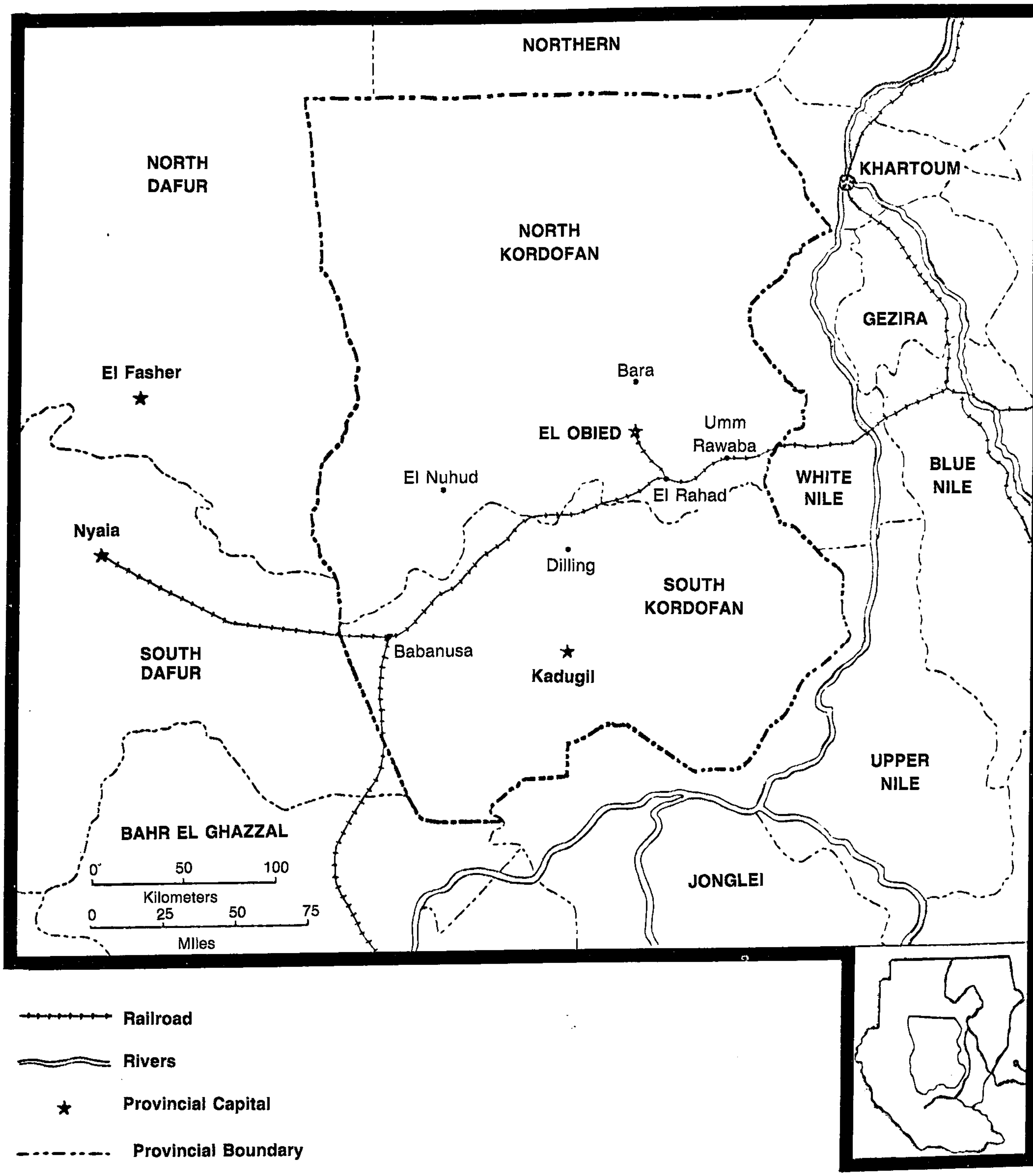


Figure 1. Map of Central Sudan.

makhammas). Most farmers cultivate more than half of their total land, thus the decline in soil fertility in the region may be a result of insufficient fallowing. One-third of all cultivated lands are rented rather than owned by farm managers. Most of the rented land is leased by better-off farmers from farmers who are poorer than the average. Since labor is the key constraint to land cultivation and poorer farmers cannot afford to hire labor, rent from idle land is an important source of supplemental income.

The four most common crops are millet, sorghum, sesame and groundnuts. The cereals are primarily subsistance crops, though surpluses are sold to other farmers and at local markets. Millet is the preferred staple of the rural diet, and the stalks of the millet plant are ubiquitously used as a building material. Thirty-eight percent of the cultivated lands are cultivated in millet, while 95 percent of the households grow it. Sorghum is not nearly as important a crop, although about three-quarters of the farmers do grow some sorghum. Local varieties (milo type, red and white) are frequently seen intercropped (in the same hole) with sesame. White sorghum is preferred for making bread and porridges. Red sorghum is used to make beer. Sorghum is also an important animal fodder, and both the grain and the stover are used for this purpose.

Forty-eight percent of the cultivated land is planted in sesame, while 93 percent of the farmers grow sesame in their fields. Sesame is often intercropped with sorghum, cowpeas, watermelon or karkadee. Some farmers sow varieties of sesame which mature at different rates in order to avoid the labor bottlenecks that occur during the busy harvest season. Since sesame is threshed by hand, it must have the characteristic of shattering easily. Sesame is the bread-and-butter crop. Most of it is sold at regional markets and is destined for processing into oil which is consumed in the urban centers. Market prices of sesame tend to be stable and predictable. Ten percent of the cultivated land was planted in groundnuts during the 1980-81 season. Barbiton variety is grown exclusively and seed quality is said to be very poor. Groundnuts are grown primarily for the export market where large price fluctuations have occurred in recent years. Price instability makes this a high-risk crop for farmers.

Besides these four major crops, a variety of less important crops is grown. Roselle is usually sold for cash or traded in kind. Cowpeas and okra are intended for domestic consumption but may also be sold or traded. Watermelon is grown as a water source and fodder for livestock during the dry season. It is also consumed domestically and sold in local markets. These minor crops are frequently interplanted with sesame and sorghum.

The cropping cycle begins with land clearing from January to April (Table 1). Then, between April and August all four major crops are planted. Millet is planted earliest because the locally preferred variety is long-maturing. If the early plantings germinate well because of early rains, the crop will mature before the season in which insects and birds usually attack the immature candles. If the early plantings of millet fail to come up the farmer replants within a month's time. Or, he may change to a shorter maturing crop like sesame or sorghum. Regular plantings of sesame, groundnuts and sorghum generally occur in June and early July. These crops, too, may have to be replanted if rains are insufficient for germination or if sandstorms kill the seedlings.

According to the area's farmers, the ideal is to weed every crop at least twice. Although financially secure farmers can afford to hire labor for a third and even a fourth weeding of groundnuts, poor farmers are forced by their need for cash to hire their labor to other farmers and thereby neglect an adequate weeding of their own lands.

Harvesting operations are spread over the period of late August to January, with most activity occurring in October and November. All threshing operations are accomplished by hand.

Next to the vagaries of the climate, labor is the most important constraint on the cropping system. For many farmers the cost of hiring agricultural laborers is the largest input expenditure. Looking at returns to labor by crop, it was calculated that the rate of return was highest for millet, followed by groundnuts, sesame and sorghum. Sesame's popularity among farmers, in spite of its lower rate of return than either millet or groundnuts, can be attributed to risk avoidance. Millet is a greater risk than sesame because of its higher susceptibility to pests; unstable prices and higher labor costs limit the planting of groundnuts.

Animals play an important role in this farming system. The availability of drinking water and pasture during the dry season are the main constraints on livestock raising. Crop residues and commercial sorghum are an important source of fodder for working animals, but herd animals subsist largely on the pasture that lies beyond the village's cultivated lands. Most farm families own a donkey and several goats. Better-off families are able to invest in sheep and cattle. The largest herd of cattle we recorded was 60, but the average herd size is only six. Similiarly, the largest herd of sheep was 120 but the average herd is also about six.

Nearly every farm household supplements its income through off-farm activities. These include dry-season migration for wage jobs, charcoal manufacturing, water-hauling, tailoring, carpentry, metalworking, itinerant marketing, and the operation of such capital-intensive enterprises as a village shop, bakery, flour mill, oil press, cistern or truck. Monetary gifts from relatives living elsewhere is another important source of income for about one-fourth of the farm households.

Farming in this region is not subsistence-oriented. Farm households purchase foodstuffs at village shops each day, or several times per week at least. These goods are paid for either in cash or in kind. In the latter case a crop is usually offered to the merchant as payment, the price of the crop having been determined by the schedule of prices prevailing among all crop buyers in the village. To obtain a cash income from agriculture, farmers may sell their crops (primarily sesame, groundnuts, roselle and gum arabic) to a variety of buyers, including the shopkeeper, the urban crop merchant's agent who buys at rural crop markets, and jobbers who are prepared to haul the purchase immediately to the urban market.

To gain a general overview of marketing in the study area, observations were made in four heterogeneous villages which are marketing centers. Government records for crop auction and livestock sales were copied down for two villages with large market places. Through this study we identified a number of important marketing institutions, including the village shop, weekly markets, the government administered crop market,

Table 1

SEASONAL CYCLE

Seasonal Variables		Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb
1. Season		Şeef (hot, dry)		Rushaash (early rains)		Khariif (rain)		Darat (harvest)		Shita (cool, dry)			
2. Temperature C°	Minimum	17.1	20.5	23.2	23.6	22.5	21.6	21.4	21.1	17.0	13.4	18.1	13.3
	Maximum	39.4	41.3	42.2	40.2	36.8	38.8	36.9	38.6	36.6	35.0	35.2	36.1
3. Rainfall mm.		1.5	1.5	22.4	19.4	100.7	133.9	49.9	16.3	1.5	0	0	0
4. Wind Patterns		Northerly Winds		High Winds (Habuub)		Southerly Monsoon				Northerly Winds			
5. Access to Water		Difficult Expensive			Readily Available From Rain Pools					Available From Hafiirs, Shallow Wells, Govt and Private Deep Wells			
6. Food Consumption		More Sorghum Eaten Than Millet, Less Meat			More Millet Milk & Milk Products, Vegetable, From Farm & Market			Mariisa (beer) & Meat, Fariik (immature millet & sorghum)		Millet & Meat Mariisa (sorghum beer)			
7. Gum Production		Collecting Gum From Young Trees, Sometimes From Old Ones							Tapping Old Trees		Tapping Young Trees & Collecting Gum From Old Trees		
8. Cropping Cycle	Millet	Land Clearing	1st Planting 2nd Planting				Cutting					Land Clearing	
					1st Weeding		2nd Weeding		Threshing				
	Sorghum	Land Clearing		1st Planting 2nd Planting			Cutting					Land Clearing	
					1st Weeding		2nd Weeding		Threshing				
	Sesame	Land Clearing		1st Planting 2nd Planting			Cutting					Land Clearing	
					1st Weeding		2nd Weeding		Threshing				
	Groundnuts	Land Clearing		1st Planting				Pulling				Land Clearing	
					1st Weeding		2nd Weeding		Threshing				
9. Farm Labor		Land Clearing	Planting Before Rains (rimeel) After Rains (nadaaya)										
				Weeding: ← 1st Weeding			2nd Weeding →					Land Clearing Begins →	
							← Cutting and Threshing →						
10. Crop Marketing		Farmers Sell off all Remaining Cash Crops (a) To Buy Feterita (b) To Buy Animals (c) To Pay for Land Cleaning, Planting & Weeding				Crop Marketing Generally Dormant; Local Sale of Seed for Planting		Sale of Early Maturing Crops to Merchants to Pay for Commodities at Shops		Continued Selling of Crop at Shops to Buy Consumption Goods; Increasing Sales of Cash Crops in Large Quantities at Rural Markets			
11. Livestock Marketing		Sale of Weak and Dying Animals, Particularly Goats				Period of the Greatist Number of Sales, for all Livestock, by Farmers and Nomads. Farmers Use Earnings from Sales to Finance Hiring of Farm Labor and to Pay for Household Expenses, Nomads Sell off Weak Animals and Buy Better Quality Livestock					Horse Sales (for hauling water and crops); Sale of Other Livestock Generally Dormant		
12. Transportation		Loose Shifting Sand Makes Travel Difficult				Roads Often Impassable Due to Rains					Crop Trucks Travel Frequently from Villages to Urban Markets		
13. Off Farm Income Sources		Migration for Wage Labor Off-Farm Occupation in Village									Migration for Wage-Labor, Off-Farm Occupation in the Village		
14. House Construction		Building and Maintenance of Houses and Compounds									Building and Maintenance of Houses and Compounds		
15. School Schedule	a) Primary	In Session	Vacation			In Session			Vacation	In Session			
	b) Intermediate	In Session	Vacation			In Session			Vacation	In Session			
	c) Secondary	In Session	Vacation			In Session			Vacation	In Session			

and the government administered livestock market.

Smuggling—that is, the illegal conveyance of certain crops, particularly sesame, from the farm to crop buying agencies in El Obeid without full assessment of taxes—is believed to be a widespread practice. Farmers as well as crop merchants benefit from it.

Millet, the subsistence crop, is supplemented by the importation to the region of sorghum (feterita type) grown principally on the mechanized farms at Habila, South Kordofan. Only the wealthier households are able to realize the ideal of eating from their own millet stores throughout the year. This is because only they have enough cash to purchase the labor to cultivate a large field of millet. They may also buy millet from farmers who are in need of cash. Most families buy feterita at least during the dry season in order to save their millet for rainy season consumption. A prevailing belief is that feterita is an undesirable food for the rainy season. During this period of hard physical labor, only millet can provide the required nutrition. Information from the sample of 40 households suggests that the typical farm family supports itself on its own millet for only about 4 months in the year. The rest of the time it buys feterita.

A preliminary analysis of crop marketing channels revealed a number of incentives and constraints for the participants. For example, farmers who produce little or who lack equity are usually unable to hold their crops off the market until the post-harvest rise in prices occurs. They have to begin selling their crops immediately after the harvest to pay for their consumption bill. Better-off farmers, on the other hand, may be able to store their crops for several months in anticipation of a rise in prices.

From government records of livestock sales it is possible to gauge the dramatic effect which the seasonal presence of nomads has on the larger rural markets. The relationship between nomad and farmer, who are frequently in conflict over access to forage and water, is complementary when it comes to livestock marketing. The farmers sell livestock during the rainy season in order to pay for farm inputs, while the nomads cull their herds of weak and unproductive animals and purchase breeding stock.

*Millet Cropping Patterns**

Thirty-eight percent of the total cultivated land is planted in millet. Several types of millet are grown. The local names for these are dukhun baladi or dimbi, dukhun HireeHri, and Eish bornu. Dukhun baladi or dimbi is a late-maturing variety (90 to 110 days) characterized by long slender candles and small seeds. Dukhun HireeHri is an early-maturing variety (70 to 80 days) with candles which are shorter and thicker than baladi candles. Eish bornu is an intermediate-maturing variety (80 to 90 days) characterized by very long candles ranging from greenish yellow to dark brown in color.

**Data presented in this section and in the following section are based on an intensive study of cropping patterns (1981-82) in three villages—El-Kharta, Umm Ramad, and El-Geifil.*

From Table 2 it is apparant that baladi/dimbi is the most common type grown, followed by HireeHri and Eish Bornu. To get a better idea of the importance of each of these millets, we calculated the amount of land planted in each type. Table 3 presents the amount of land and percentage planted to each type of millet.

Table 2. Distribution of Farmers by Type of Millet Produced.

Type of millet	Percentage[1]
baladi/dimbi	66
HireeHri	32
Eish Bornu	8

[1]Some farmers grew more than one type of millet, so the percentages add up to more than 100.

Table 3. Amount of Land and Percentage Planted in Each Type of Millet.

Type of millet	Percentage[1]
baladi/dimbi	49
HireeHri	44
Eish bornu	7
	100

[1]Some farmers grew more than one type of millet, so the percentages add up to more than 100.

These findings are similar to the ones presented above, in that dukhun baladi is the most important in area cultivated. However, dukhun HireeHri also is found on a significant percentage of land, due to the large tracts of this variety grown by the larger farmers in El Kharta.

The villages tend to differ in the types of millet grown. In El Kharta the dominant variety grown is HireeHri. Seventy-six percent of all land cultivated in millet is in HireeHri, and 67 percent of all farmers interviewed grow this crop. El Kharta is north of El Obeid where the rainfall is lower, and HireeHri produces better there than the other varieties, according to farmers.

In contrast, El Geifil grows more baladi than HireeHri. Eighty-six percent of the land cultivated in millet is in baladi, and all farmers interviewed plant some of this type. Although El Geifil receives slightly more rainfall than El Kharta, we do not believe it is sufficient to account for this difference. The dominance of baladi is due partly to the shortage of HireeHri seeds in El Geifil, and the long tradition of growing baladi.

In Umm Ramad, baladi is also the dominant type. Sixty-four percent of the land cultivated in millet is in baladi, and 79 percent of the farmers surveyed plant it. A higher rainfall here could definitely explain this pattern, since Umm Ramad is south of El Obeid. Higher rainfall also could explain the appearance of another millet variety called Eish bornu. Twenty-seven percent of all the millet planted is of this type.

The extent of millet cultivation demonstrates the crop's importance in the farming system and as a main source of food for farm households. Moreover, millet stalks are the main construction material for houses and other structures. In fact, the importance of millet stalks as a building material might ensure that millet will never be totally displaced by other crops, unless another, equally economical building material was introduced.

Sorghum Cropping Patterns

Another important subsistence crop in the area is sorghum. Although it is not as extensively grown as millet, seventy-five percent of the farmers plant some sorghum. Sorghum is grown in separate stands as well as intercropped with other food crops. Forty-three percent of the farmers plant sorghum in separate stands. Unfortunately, we could not estimate what proportion of the total land cultivated is in sorghum since so much is intercropped with sesame or other crops. However, the importance of this crop is demonstrated by the extent to which farmers plant it.

Farmers in the area grow several different types of sorghum. The local names for these types are quite numerous; however, they can be grouped under three basic categories. These are mareeg/zunaari baladi, mareeg/zunaari HireeHri, and najaad/feterita. As for distinguishing characteristics, mareeg/zunaari varieties tend to have curved necks and large seeds which may be either red, black or white. There is essentially no difference in shape or color between the baladi type and the HireeHri type of mareeg/zunaari. The major difference is the maturation period. HireeHri matures much earlier (70 to 80 days) than baladi (90 to 120 days). Also, baladi tends to produce more heads per plant than HireeHri. In contrast, najadd/feterita varieties are usually straight-necked with small seeds. The types of najaad/feterita grown in this area usually have white or red seeds. These types are usually intermediate in maturation (90 to 100 days).

Table 4. Distribution of Farmers by Type of Sorghum Produced.

Type of Sorghum	Frequency	Percentage[1]
mareeg/zunaari baladi	19	63
mareeg/zunaari HireeHri	13	43
najaad/feterita	2	7

[1]Some farmers planted more than one type of sorghum, so the percentages add up to more than 100.

Mareeg/zunaari baladi is the most common type of sorghum grown in the area, followed by mareeg/zunaari HireeHri and najaad/feterita (Table 4). To determine if farmers who plant sorghum in separate stands grow different types from those who intercrop it, we compared the sorghum varieties grown by each. Table 5 presents the frequencies and percentages of farmers who grow the various types of sorghum, and compares those who grow it in separate stands with those who intercrop.

Table 5. Frequency Distribution of Farmers, Comparing Those Who Planted Sorghum in Separate Stands with Those Who Intercropped.

	Separate stands		Intercropped[1]	
Type of sorghum	Frequency	%	Frequency	%
mareeg/zunaari	7	54	12	63
mareeg/zunaari HireeHri	5	39	9	47
najaad/feterita	1	8	1	5

[1]Some farmers intercropped more than one type of sorghum, so the percentages add up to more than 100.

Mareeg/zunaari baladi is the most commonly grown sorghum by farmers who grow it in separate stands as well as by those who intercrop. Likewise, mareeg/zunaari HireeHri is the second most common type regardless of planting strategy. In other words, no real difference exists between these farmers regarding types of sorghums grown. Only a few farmers in the sample, all in El Kharta, plant more than one type of sorghum. All of them intercrop sorghum with another crop.

Sorghum cultivation patterns differ in important ways in the three villages. In El Kharta 93 percent of the farmers grow sorghum, and all of them intercrop it with sesame. No farmer surveyed grows sorghum in a separate stand. Only the mareeg/zunaari varieties are grown in this village. Mareeg/zunaari varieties seem to be better suited to the environmental conditions found at El Kharta, such as low rainfall and sandy soils (goz). The early-maturing HireeHri and late-maturing baladi types are grown in equal amounts.

In El Geifil only 40 percent of the farmers grow sorghum, and three-fourths of these intercrop it with sesame. Very few grow it in a separate stand. The mareeg/zunaari varieties are the main types grown, although one farmer grows a najaad/feterita type. The major reason for the failure of other farmers in El Geifil to grow sorghum is the difficulty in obtaining seeds. Several farmers indicated that they would have planted sorghum if the seeds had been available.

In Umm Ramad, 80 percent of the farmers grow sorghum and all of these plant it in separate stands. Sorghum is usually planted separately in this southern village because the higher level of rainfall and clayey soils favor sorghum production. Twenty percent of all the land cultivated in Umm Ramad is in separate stand of sorghum, a much higher proportion than in the other two villages. Mareeg/zunaari varieties are the main types of sorghum grown, with baladi planted more extensively than HireeHri. One farmer grows a type of najaad/feterita. In addition, two farmers also intercrop sorghum with groundnuts; however, intercropping sorghum is not a common pattern here.

Sorghum is important in the farming systems of this area because of the multiple functions it serves. First, it is a food source for farmers, often a substitute or supplement for millet, and therefore is considered the second most important subsistence crop grown in this area. Second, the stover is a livestock feed. The moisture and sugar content of the stalks also give refreshment to farm laborers at harvest time. This is especially true in villages where water is in short supply. In fact, many farmers in villages to the north of El Obeid said that this is one of the main reasons why they plant sorghum in their sesame fields. Third, sorghum is used to manufacture the local beer called mariisa. This beer is the main source of food for at least one meal during the day, especially during the harvest season. The extent to which mariisa is consumed varies from one village to the next. In two of the villages under study mariisa is consumed by most of the farmers, while in the other village very few people drink it. The strictness with which Islamic values are upheld appears to account for this difference. Fourth, sorghum is intercropped with sesame to serve as a wind break for sesame plants. Wind damage is a serious problem in sesame production and farmers have found that sorghum in sesame fields aid in resisting wind erosion.

Significance of Research Findings

Our research identified a number of farming system constraints. Following is a summary of these and possible strategies for alleviating them.

Natural Constraints

These include wind erosion, pests and diseases, low soil fertility and inadequate rainfall.

To prevent soil erosion farmers can improve intercropping practices, limit early land clearing and planting, adopt mulching practices, and establish shelter belts.

Pest and disease damage could be alleviated if research developed a way of eradicating santa *(Crytocamenta* spp.); developed high yielding, bird-resistant millet varieties; and promoted the use of seed dressings.

Soil fertility might be raised by developing optimum rotation and intercropping systems, taking into account farmers' labor and seed limitations; adding *Acacia senegal* and cowpeas in rotation systems; encouraging the continuation of minimal tillage techniques; and promoting mulching.

To combat inadequate rainfall, researchers should introduce improved, early-maturing, drought-resistant varieties of present crops as well as new drought-resistant crops; investigate the optimal planting period for each crop while keeping in mind labor constraints; promote mulching and the planting of shelter belts to conserve soil moisture; and investigate the benefits of placing water catchments around plants.

Input Constraints

The major problems in this area are access to labor and seeds, the use of chemicals, and availability of drinking water.

Introduction of early-maturing varieties would allow poor farmers to resolve the conflict between the need to work in their own fields during the second weeding period and the need to earn cash by selling their labor. Credit programs could provide farmers with funds for hiring additional labor. Cultivation with animal-pulled plows and conservation tillage practices would also help.

The availability of seeds of early-maturing varieties should be increased. Village merchants might be used as the primary distributors of improved varieties.

The use of herbicides and fertilizers does not seem economically feasible for small farmers in the El Obeid area. The program of distributing seed dressing should be expanded, perhaps using local merchants as distributors. Research should look for a substitute for the DDT which is used excessively on stored food crops, and introduce an alternative to using salt on millet and sorghum threshing floors to prevent termite damage.

The scarcity of drinking water is an important constraint on crop production, since farmers are reluctant to cultivate in areas where there is not a reliable water supply. Care must be taken, however, to ensure that increased access to water, through the excavation of reservoirs or the digging of wells, does not lead to growth of livestock populations in excess of available pasture. Careful regional planning is required to ensure the optimal distribution of watering points.

Other Constraints

These include credit, crop auction procedures, pricing policy of gum arabic, and limited knowledge of farmers.

The Sudan Agricultural Bank, in its program to make loans to small, traditional farmers, should consider raising the interest rate to a level in excess of the annual rate of inflation plus the amount needed to reimburse the cost of administering the program. An alternative to this might be to make loans to farmers on the basis of valuables left as collateral.

At government administered crop markets, the assignment of farmers' crops to lots and the order in which buyers may bid should both be randomized.

The difference between the farm price for gum arabic and the international price is more than 100 percent. The government of Sudan must find a way to increase the farmers' share of the income from gum marketing. Otherwise, the area in which *Acacia senegal* grows will continue to decrease. Also, a program is needed to teach farmers better ways to propagate and care for the trees.

To increase the knowledge of illiterate farmers, there should be a low-cost system for disseminating farming and marketing information. This might be accomplished via radio programming, since radios are common in the villages.

Agricultural Research in Sudan

William B. Lacy and Lawrence Busch

University of Kentucky

Unlike the situation in many other states of sub-saharan Africa, agricultural research in Sudan dates back to the turn of the century. Research was begun in 1902 to meet the demand of the Lancashire cotton industry. In the beginning, the focus of research was almost exclusively on cotton, and particularly upon the proposed irrigated area between the two Niles that would eventually become known as the Gezira scheme.

After World War II, concern for nutritional deficiencies forced attention toward food crops. Experimental work on mechanized grain production in Sudan began in 1945. Research on food crops started in 1952, and focused on rain-fed agriculture.

In 1967 a semi-autonomous Agricultural Research Corporation (ARC) was created. In 1977 already existing research functions in the areas of food processing, forestry, fisheries, range management and wildlife were incorporated into the ARC. More recently, with the establishment of the Western Sudan Agricultural Research Project, major progress has been made toward the improvement of rain-fed agriculture and livestock production in the west and the integration of social and economic scientists into the organization. Today, the ARC conducts research in all broadly defined areas of agriculture, with the exception of livestock research.

The Agricultural Situation

Sub-saharan Africa is one area of the world in which food production has not kept pace with population growth over the last decade. Sudan is no exception. Total agricultural production has remained constant over the last decade while total food production has increased slightly. However, due to population increases, per capita agricultural and food production have both declined considerably.

Concomitantly, the Sudanese economy has fallen into serious difficulties largely as a result of increased oil prices. Given the enormous size of Sudan and the great distances between ports of entry and producing areas, transport costs have risen enormously over the last decade. In addition, balance of payments problems have led to deferred maintenance of the railroads and endemic fuel shortages.

The Agricultural Research Corporation has itself suffered significantly as a result of the general economic situation. Fuel for ARC vehicles is often unavailable, making travel to outlying fields difficult if not impossible. Foreign exchange for journal subscriptions, scientific equipment, and spare parts for existing equipment is often unavailable. At the same time, significant numbers of newly-trained scientists have been returning from overseas, putting more pressure on an already over-extended research system. Finally, salaries have not kept pace with inflation. These circumstances have weakened the effectiveness of the ARC and led many researchers to consider professional opportunities outside Sudan.

Agricultural Scientists and Support Staff

The growth in Sudan's agricultural research system has been substantial since its modest beginning in 1902. Early research stations and laboratories were staffed initially by British scientists and were devoted almost exclusively to export crops. By 1950 Sudan's agricultural research system included 55 scientist-years. By 1980 there were 212 scientist-years committed to agricultural research in Sudan.

The Agricultural Research Corporation accounts for approximately two-thirds of Sudan's agricultural research scientist-years. This is likely to increase if the ARC retains most of the scientists currently working in the system and incorporates most of the ARC assistant scientists and scientists currently being trained abroad. A recent report of the ARC estimated that the scientific staff consisted of 164 scientists and 139 assistant scientists (including 85 abroad for training). In addition, there were 625 technical assistants, 400 clerical and support staff, and nearly 4,000 laborers.

In our 1982 sample of Sudan researchers, scientists reported an average of 2.3 technicians, 7.8 laborers, and 1.1 other persons working under their direction, but technicians and field staff are often shared by large groups of scientists. In addition, declining budgets and demands of production schemes have made it extraordinarily difficult for the ARC to compete for farm labor during the peak planting and harvesting times. As a result, many scientists reported that experimental plots were not harvested on time or at all. This is clearly a waste of both money and trained scientific personnel.

Growth in Sudan's expenditures for agricultural research has also been substantial. In 1961, ARC expenditures in U.S. dollars were $1.2 million. By 1971, expenditures had increased another 60 percent to U.S. $4.5 million. Sudan's growth rate of research expenditures between 1970 and 1980 was 8 percent per annum.

A recent ARC report emphasized that the initial investment in human resources and equipment will be wasted unless there is compound investment in scientific training and a complete rehabilitation of the agricultural research system. The rehabilitation costs are estimated to require about a 60 percent increase in the total annual budget.

Demographic Characteristics

Sex

Generally, women remain underrepresented. In the ARC's list of research scientists in October 1979, there were four women scientists among 123 (3.3 percent) and 2 women assistant scientists among 38 (5.2 percent). Five of these six women were in research stations recently transferred to the ARC (Food Research Center, Forestry, and Wildlife). Women were a slightly larger percentage of the scientists and assistant scientists on study courses, but 50 percent of the women were studying at the University of Khartoum while less than 5 percent of the men were receiving training in Sudan. In our survey, five of the interviewed scientists were women. There were no women in the sample of Sudanese agricultural scientists studying in the U.S.

Age

The average age of scientists in our sample was 39 years, with an age range of 29 to 52. Not surprisingly, the average age of our sample of Sudanese scientists studying in the U.S. was about 5 years younger than the scientists on site (34.4).

Family Background

The occupations of fathers of scientists was used as an indicator of family origin. Our sample reflects very diverse family experiences (Table 1.). Given the large percentage of the population of Sudan that remains on the farm and the nature of the research in the ARC, it is surprising that such a small percentage of scientists comes from a farm background.

Of the total 162 scientific staff, 81 had received Ph.D.s. This percentage is even higher (65 percent) if one excludes the assistant scientists. Most of the education at the master's level and nearly all at the Ph.D. level was received at universities in Great Britian and the U.S. Indeed, 96 percent of the Ph.D. degrees awarded to Sudanese scientists were received at institutions in those two countries.

Table 1. Father's Occupation When Scientist Was 16 Years Old.

	Scientist's Responses	
Father's occupation	Frequency	Percent
Farmer-owner	19	26.7
Business-merchant	14	19.7
Government	12	16.9
Skilled labor	9	12.7
Laborer	5	7.0
Farmer-tenant	5	7.0
Education	3	4.2
Other	3	4.2
Religious leader	1	1.4
	71	100

Advanced training in some disciplines, however, is more likely to take place in a specific country. For example, Ph.D. degrees in entomology and in food science generally have been obtained in Great Britian. Ph.D. training in horticulture is primarily in U.S. institutions.

One of the strongest dimensions of the ARC is its community of well-trained scientists. In addition, there appears to be a positive ratio of technicians-to-scientists relative to other third world countries. However, a number of additional issues should be addressed regarding human resources for agricultural research in Sudan.

As noted, Sudan's agricultural scientific manpower, although not optimal, has certainly reached a critical mass in numbers of staff. As levels of training of staff improve, management will become a main determinant of their effectiveness. The agricultural research community must compete for funds in the overall budget. Therefore, some scientific personnel should receive training in research management. These managers must be able to demonstrate to policy makers, where appropriate, that agricultural research funds will be effective in achieving national objectives and priorities. In addition, they must maintain effective contact with their own scientists and staff.

The issue of recurrent funding needs and its relationship to scientific staff is another important theme. Most recurrent expenditures appear to be for salaries for current staff. With inflation and increasing numbers of scientists returning from training, a continual erosion of operating budgets appears likely. This not only leads to a high degree of inefficiency in the use of trained scientists, but also contributes to high levels of frustration among the scientists themselves. To some extent foreign donors contribute to this plight, since a number are hesitant to finance recurrent expenditures or even impose an absolute sanction on such support. Ironically, gains from capital investment depend on the effective use and retention of trained human resources. In short, training and staff development should be matched to the provision of recurrent funds and capital investment.

Finally, the training of scientists and technicians should be congruent with the overall needs and priorities of Sudan. The share of human resources devoted to export and/or cash crops, as opposed to food crops for national consumption, should be analyzed, as should the balance among various disciplines. The Western Sudan Agricultural Research Project, for example, appears to be filling gaps in the relatively weak areas of pasture management, animal husbandry, social sciences and economics. But these projects are still inadequate.

The Current Situation

This description of the current situation in the Agricultural Research Corporation (ARC) is based primarily on the responses and perceptions of our 1982 sample of scientists in the system.

Research Orientation

Scientists in the ARC are strongly oriented toward applied research. They were asked how they would categorize their research over the last 5 years in terms of basic science, applied science and development. ARC scientists classify 83 percent of their research as being applied, 12.7 percent of their research as basic, and the remainder as development. Given the kinds of resources available to ARC scientists and the research needs of Sudan, this appears to be an appropriate division of effort.

Research Sites

Researchers were also asked where their research took place. On average, scientists reported that 55.9 percent of their research took place in experiment station fields, while 32.9 percent of their research took place in the laboratory. Only 3.2 percent of research was conducted in farmers' fields. The low percentage of research taking place in farmers' fields reflects the lack of adequate transportation and the relatively weak institutional ties that would permit on-farm experiments. In addition, scientists whose research required greenhouse work strongly voiced their frustration over the lack of such facilities.

Resources: Adequacy and Importance

Various resources are necessary to the research process. These range from transportation to opportunities for advancement. Scientists rated the adequacy of resources available to them at the ARC on a scale from 1 (very adequate) to 5 (very inadequate). Then they rated each item regarding its importance for the success of their work (Table 2).

The availability of experimental land was seen as the most adequate resource, followed by personal freedom to determine research problems. On the other hand, equipment and tools to use in research and financial support were seen as the most inadequate research resources. Transportation, availability and quality of trained technical help, and opportunities for advanced education were also seen as inadequate.

While the perceived adequacy of resources differed significantly, scientists viewed most of those resources as very important to their work. Scientists saw financial support and operating supplies and materials as the two most important resources in their work, but ranked all resources as important. Futhermore, the discrepancy between adequacy and importance is quite large for many of the resources.

Sudanese students presently enrolled in Ph.D. programs in the U.S. also rated the various resources available to them at their host institutions in terms of adequacy and importance for their work. Scientific literature, personal freedom to incorporate new materials and techniques, personal freedom to determine

Table 2. Sudanese Agricultural Scientists' Ratings of Adequacy and Importance of Resource Facilities.

Resource	Adequacy of resources[a]	Importance of resources[b]	Difference between importance and adequacy
Operating supplies and materials	3.6	1.2	– 2.4
Availability of experimental land	1.7	1.5	– .2
Equipment and tools to use in research	4.0	1.3	– 2.7
Transportation	3.8	1.3	– 2.5
Availability and quality of labor	3.3	1.4	– 1.9
Financial support	4.1	1.1	– 3.0
Scientific literature	3.0	1.3	– 1.7
Availability and quality of trained technical help	3.7	1.4	– 2.3
Personal freedom to incorporate new materials and techniques into your research	2.1	1.6	– .5
Personal freedom to determine research problems	1.9	1.6	– .3
Contact with other scientists	2.7	1.4	– 1.3
Opportunities for your advanced education	3.7	1.5	– 2.2
Opportunities to gain scientific recognition	3.2	1.4	– 1.8
Opportunities for professional advancement	3.2	1.5	– 1.7
Opportunities for training for people who work under you	3.7	1.5	– 2.2
Average mean score	3.3	1.4	– 1.9

[a] Mean score of 71 scientists—1 very adequate; 5 very inadequate
[b] Mean score of 71 scientists—1 very important; 5 very unimportant

research problems, and transportation were the most adequate answers, but there was virtually no difference between this group of variables and the remaining resources. The range was from 1.4 to 2.2 and thus all were considered to be adequate to very adequate. The only inadequate rating given was given to availability and quality of labor resources. All resources were considered to be very important.

Not surprisingly, the Sudanese students, all of whom are enrolled in major land-grant and agricultural schools in the U.S., considered their institutional resources to be significantly more adequate than did the ARC scientists on-site in Sudan. The students rated every resource, with the exception of availability of experimental land, more adequate than did the Sudanese scientists.

These findings are generally consistent with those found among Asian rice breeders, U.S. scientists, and sorghum scientists. Sudanese scientists and scientists from other LDCs agree with scientists from the U.S. and other developed countries as to what is important with respect to resources, but are laboring under considerably less adequate conditions in the conduct of research.

Extramural Support and Collaboration

It is to the credit of scientists at the ARC that they have not used the current fiscal problems as an excuse for abandoning a meaningful research program. Our study reveals that 50 percent of researchers have received financial support from organizations other than their employer during the last 5 years. Support has ranged from the provision of small pieces of equipment or subscription to scientific journals to the provision of entire laboratories and research stations. Despite the large numbers of highly-trained scientists employed by the ARC, however, many aid agencies continue to see financial support largely in terms of providing training for additional scientists or supplying expatriate scientists. Sudanese scientists and administrators rightly resent this and feel that aid could be better spent to provide adequate equipment and resources for the existing system. If the support does not improve, about one-third of the Sudanese scientists expressed their intent to seek work in other countries where more adequate resources, support, and salaries are provided.

Most research within the ARC is conducted by groups of scientists rather than by individuals. In fact, 73.8 percent of ARC scientists report working with other professionals within ARC, with university faculty, and with scientists in other branches of the government.

Career Advancement

All organizations should have a reward system that 1) provides a career ladder (or internal labor market) for employees; 2) provides monetary and/or nonmonetary incentives to employees; and 3) encourages employees to support the goals of the organization.

The products of research institutions may be either abstract (e.g., farm management practices) or concrete (e.g., improved seeds). Unlike manufactured goods, research products may take years to produce. Most importantly, the products of research are both heterogeneous and somewhat unpredictable. Occasionally, research projects may fail to come to fruition through no fault of the scientist.

This poses difficult problems for the research administrator. A reward system must take into account the enormous diversity of research products as well as the differing frequency of production across disciplines. In addition, it must take into account the relevance of research products to the various clients of the research system. Finally, it must include some way of avoiding measures of scientific productivity and/or effectiveness that can be manipulated by the scientist.

Scientists in the ARC were asked what criteria they felt were important for advancement within their organization (Table 3). Publications were seen as the single most important criterion for advancement. Scientists further qualified this to mean largely the writing of annual reports. Years of service was seen as the second most important criterion, while actual evaluation of research projects ranked third. Only one out of six scientists identified problem solving or meaningful research as a criterion for promotion.

Table 3. Criteria for Advancement.

	Scientists' Responses	
Criteria	Number	Percent[a]
Publications	42	59.2
Years of service	19	26.7
Evaluation of research/projects	16	22.5
Problem solving	12	16.9
Meaningful research	11	15.5
Education	7	9.9
Administrative work	6	8.5
Fieldwork	3	4.2
Projects	3	4.2
Reputation	2	2.8
Willingness to go to distant stations	1	1.4
Personal ties	1	1.4

[a]Does not equal 100 percent because the scientists were requested to give up to three criteria.

These perceptions indicate serious discontinuity between the goals of the ARC and the system used to reward scientists. As with U.S. scientists, there is little guarantee that publications will benefit clients. Clearly, years of service with ARC is likely to be unrelated to any client needs. On the other hand, few scientists saw field work or problem solving as important in career advancement. Thus, it appears that while the ARC does use objective criteria for advancement of scientists, these criteria do not have the effect of encouraging scientists to produce results that are useful to potential client groups. With relatively little effort and no additional expenditure, it might be possible to change the reward system in order to better direct research towards the needs of farmers and other clients.

Scientists' Future Career Plans

Sudan's proximity to the various oil-producing countries of the Middle East, as well as the common language it shares with those countries, puts it in a particularly difficult situation with regard to maintaining an adequate supply of trained scientists. Salaries for doctoral scientists in Saudi Arabia and other Arab countries often surpass those of ARC scientists by a factor of 5 to 10. Since no salary adjustments are likely to be possible in the foreseeable future, it is necessary to assess the future career plans of scientific staff in order to predict the staffing problems which the ARC may encounter over the next decade.

When asked what type of work they would like to be doing in 10 years, 82 percent of ARC scientists saw research as their first choice. An additional 11 percent saw teaching as their choice, while 5 percent wished to enter administrative positions in agriculture and 2 percent wished to enter an extension role. These data reflect the strong commitment to research that we encountered in the interview process.

Scientists were also asked in what type of organization they would prefer to be working in 10 years. We found that 35 percent desired to work for a government research organization such as the ARC, while 40 percent preferred to work for a non-profit international research organization. In addition, 6 percent preferred to work at an agricultural college, 5 percent for a private corporation, and 2 percent for the extension service. At first glance these data suggest that the ARC might be in danger of losing more than half of its scientific staff. However, this is rather unlikely. It should be noted that job openings in non-profit, international organizations would be unlikely to accomodate more than a few persons. Few scientists expressed a strong interest in moving to other types of organizations.

Informal Communication

Informal communication plays a particularly important role in the life of ARC scientists. Forty-five percent of ARC scientists report conversing with their colleagues daily over scientific issues. However, this high level of informal communication may be an attempt to compensate for the relatively limited opportunities to meet with colleagues at other stations or in other nations, as well as the weak formal communication ties.

Table 4. Scientists' Frequency of Communication with Colleagues Regarding Scientific Issues.

	Scientists' responses	
Communication frequency	Number	Percent
Daily	24	45.3
Weekly	11	20.8
Monthly	11	20.8
Less than once a month	3	5.7
Other	4	7.5
Total	53	100

Only 19 of the scientists interviewed reported that they usually attended scientific meetings. Tight budgets have forced the ARC to restrict domestic scientific travel, while the lack of foreign exchange has made overseas travel nearly impossible.

Formal Communication

On the average, Sudan scientists subscribed to approximately 0.7 journals. There were very few duplications in the list of journals. Subscriptions tended to be specific to discipline and personal interests. One reason for the low level of subscriptions to scientific journals was the difficulty of obtaining the necessary foreign exchange. Many felt the required bureaucratic approvals did not warrant the effort. Despite the limited number of journal subscriptions, more than 50 scientists did report that they read journals regularly.

The other side of the scientific communication process is the publication activity of individual scientists. Among ARC scientists the most common publication is the report. ARC scientists published an average of less than one journal article over the last 3 years. Other types of scientific publications were relatively rare among ARC scientists. While publication activity is considered to be the primary criterion for advancement, and thus an important activity for the ARC scientists, the actual productivity is relatively low.

In sum, scientific communication in the ARC is restricted in several important ways. Scientists' access to journals is limited by the difficulty of obtaining subscriptions, the small numbers of journals in libraries, and the lack of transportation to libraries. Access to colleagues in other stations, institutions or nations is also limited due to restricted travel opportunities and minimal telephone services. Effective agricultural research policy must address the importance of the scientific communication system, its integral relationship with the goals and products of agricultural research, and the potential conflicts in the present system.

Research Goals

Agricultural research is, by definition, a goal-oriented activity. However, the particular goals of a research program may differ markedly from program to program, discipline to discipline, and scientist to scientist. In addition, scientists' perceptions of research goals may differ significantly from those of administrators. In order to assess the relative importance of various research goals for scientists in the ARC, a list of 10 common research goals was utilized. Scientists were asked to rank each of these 10 goals on a scale from 1 (of no importance) to 5 (of highest importance) in terms of their own research. Mean scores range from a high of 4.5 for increasing agricultural productivity to a low of 2.6 for improving marketing efficiency. Only one goal ranked below the mid-point on the 5-point scale (Table 5). This suggests that, unlike their counterparts in the U.S., ARC scientists take a broad view of research goals in their own work. In fact, these scores may understate the differences, given the narrower range of disciplines present in the ARC.

Beneficiaries

ARC scientists define their principal goal as being to increase agricultural productivity. It seems apparent that in order to pursue this mission scientists must understand clients' needs. Researchers were asked who they perceived as the main audience for their research. Nearly 50 percent of the scientists listed farmers as the audience for their research, followed by industry (24.2 percent), and extension/government (16.1 percent) (Table 6). This appears consistent with the scientists' goal of increasing agricultural productivity.

Table 6. Agricultural Scientists' Perceived Beneficiaries of Agricultural Research.

	Scientists' Responses	
Beneficiaries	Number	Percent
Farmers	29	46.8
Industry	15	24.2
Extension/ government	10	16.1
General public	4	6.5
Students/universities	3	4.8
Projects	1	1.6
Total	62	100

Information Diffusion

We asked the scientists how their audiences received the information. There were five major methods, the most popular being reports and publications. Ironically, the World Bank reports that adult literacy in Sudan in 1975 was only 20 percent. Consequently, in most instances these reports could not be used by farmers even if they were the intended recipients of these publications. The second most popular choice was information dissemination through extension. Given the serious difficulties that have befallen the Sudanese economy and the resultant scarcity of staff and fuel for extension vehicles, this method of information diffusion must be highly problematic. It is difficult to assess the efficiency of information dissemination through meetings and other personal methods. However, given the diverse ecological conditions and the great distances that many farmers would have to travel to research stations, it is highly unlikely that a large amount of information is diffused in these ways.

Significance of Research Findings

In light of the study, a series of recommendations were made to the ARC. These recommendations focused upon eliminating constraints to the successful operation of the organization. Among the recommendations were the following:

1. A policy committee should be created. It would be made up of appointed national coordinators, station directors and chaired by the deputy director for programs. The committee should determine the appropriate directions for applied research. This committee could be assisted by an advisory council representing various parties interested in agricultural research (e.g., the regional ministries of agriculture, farmer organizations, etc.).

2. There are three fundamental ways in which agricultural research systems can be organized: by discipline, by commodity, and by farming system. In order to maximize the effectiveness of an agricultural research program, all three of these approaches must be considered.

3. While the need for research on experiment stations should not be ignored, the ARC should give serious consideration to the use of the Farming Systems Research (FSR) approach at all stations.

4. Since Sudan is a large country with multiple ecological zones, agricultural scientists in the ARC have been widely dispersed to meet local socio-economic situations, special environments, or particular commodity needs. The ARC itself has been organized into regional stations, commodity stations, specialized centers and testing sites. As a consequence, a number of stations lack sufficient staff and funding for effective research. The ARC needs to review the overall organization regularly to determine whether and where to consolidate human resources most effectively.

5. Although the ARC has a relatively large and varied scientific staff, it has a serious shortage of well-trained technicians. There are at least two reasons. First, it is difficult to attract technicians graduating from technical schools or to retain them due to limited career opportunities within the ARC. Second, since technicians graduate from 3-year post-secondary programs, they feel nearly as well-qualified as assistant scientists who have bachelor's degrees. These factors, coupled with relatively low salaries, encourage a high turnover among technicians. The recommendation of one scientist to establish a technical secondary school to train agricultural technicians for the ARC appears to be a promising complement to the current on-the-job training. In addition, a career ladder and opportunities for further training for technicians should be established.

6. Foreign governments and private organizations occasionally make funds available for agricultural research on both a programmatic and individual project basis. The ARC should identify which such sources might be regular, inform appropriate administrators and scientists, and assist in the procurement of these funds.

7. A small research fund should be established within the ARC to be allocated competitively. These monies would complement the station formula funding and those funds available from the National Council for Research, and could be used either to support important immediate national objectives or promising but underfunded long-term needs.

8. Currently, each scientist conducts separate discipline-oriented field experiments. The feasibility of doing interdisciplinary field research on these experimental plots should be explored. This could reduce overall costs, lessen problems of labor shortages at key periods

in the research, promote inderdisciplinary research, and contribute to research results which are applicable across interdisciplinary lines.

9. A radio communication system linking the research stations would be a relatively inexpensive, yet effective, way to improve communication.

10. Research results are often buried in annual reports. The revival of the *Sudan Journal of Agricultural Research* should be a high priority.

11. Foreign aid agencies could facilitate contact with other African researchers by translating key publications from francophone Africa into English or Arabic, and by promoting cross-national contact within Africa.

12. The effectiveness of the ARC in reaching farmers needs to be improved. A first step might be: a) to strengthen the link between the ARC and the extension service, perhaps through assignment of an extension staff member to every ARC station (or section); b) to create positions for "agricultural development specialists" or "farming system research specialists;" and c) to conduct more research on farmers' fields.

The current situation in the ARC combines opportunity with the frustration of inadequate resources. The staff is generally well-trained and highly committed, but the facilities, supplies and other research resources are inadequate. If all efforts fail to improve the fiscal situation of the ARC, serious consideration should be given to reducing the scientific staff through attrition and closing selected facilites. This last resort would make it possible for the ARC to provide minimum levels of support to the remaining scientists, and would enable those scientists to conduct a limited, small scale program.

The above recommendation is neither an optimal nor even an acceptable strategy under most circumstances. Therefore, our final recommendation is to the Sudanese government and to other potential funding agencies. It is not enough to provide funds for the training of new scientists and technicians. Budgetary support for operational costs other than salaries must be provided. Training and staff development should be matched to the provision of recurrent funds and capital investment. Consequently, infusion of adequate funding and resources for current operations, as well as for institutional development in the ARC, should be a high priority of the Sudanese government and other agencies interested in agricultural development in the Sudan.

Farming Systems Research in Southern Honduras

Billie DeWalt and Susan Duda

University of Kentucky

The objective of our work in Central America has been to understand the socioeconomic constraints to the production, distribution and consumption of sorghum. Research has focused on southern Honduras.

Sorghum was intorduced into Central America shortly after 1800. Since that time, it has become an important crop along the Pacific coast. In Guatemala, El Salvador, Nicaragua and Honduras the grain is usually intercropped with maize and sometimes with beans.

Sorghum is grown as both an animal feed and a food grain. In southern Honduras sorghum is used as an animal feed in years when the maize crop is good. When the maize crop fails, as often happens, sorghum is used as a substitute in the making of tortillas, the staple food of the region.

Although the amount of land sown in sorghum has been increasing, yields have been falling (Table 1). The result has been a relatively stable amount of production in the country. The demand for sorghum as an animal feed has been increasing, so that in recent years Honduras has become a net importer of the grain.

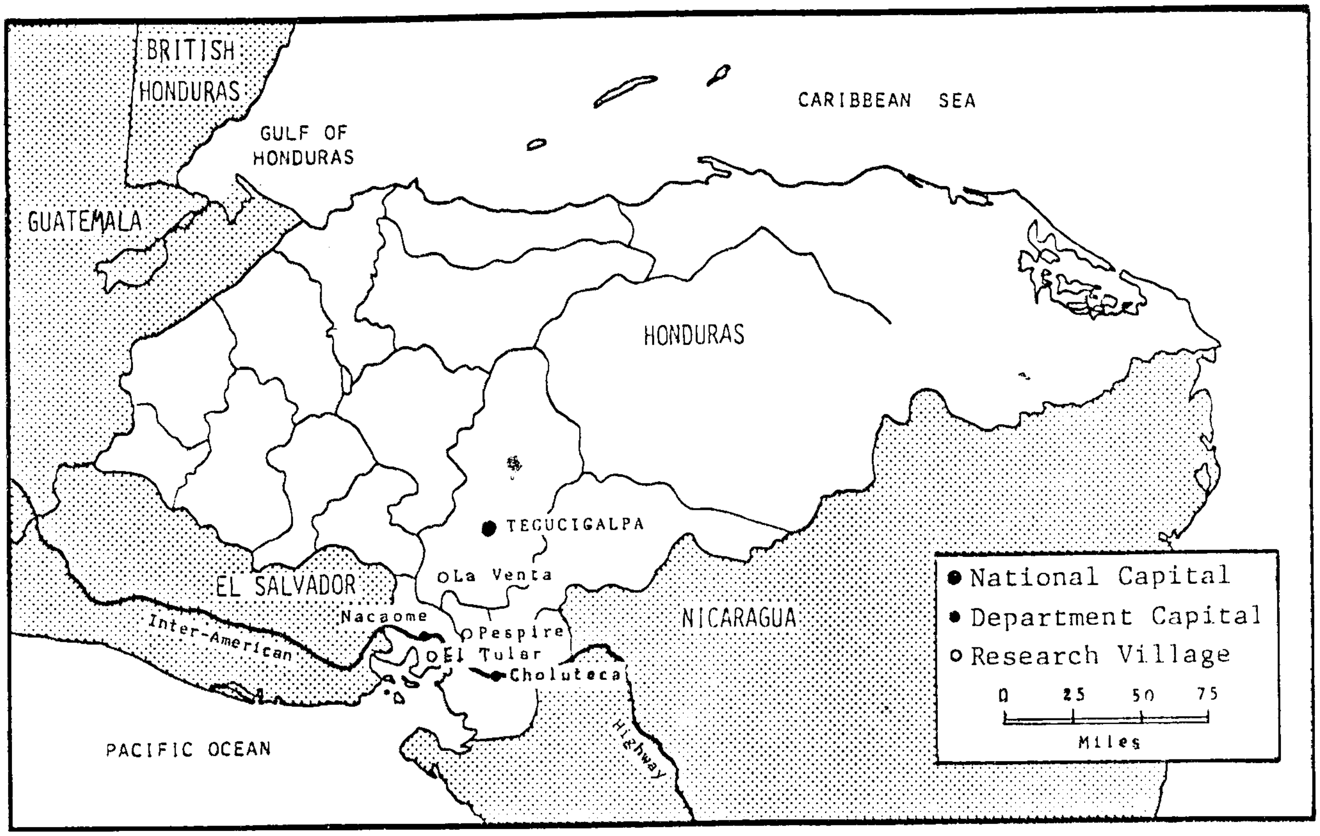
In 1981, 1982 and 1983 INTSORMIL and the Honduran Institute of Anthropology and History undertook collaborative research in the southern region. The goals of this scientific research included the following:

- To identify the types of farming systems in which sorghum is included;
- To identify the principal constraints to increased production of sorghum'
- To suggest how new varieties and/or technologies might be most easily and beneficially introduced into the region; and
- To collect baseline data on nutrition, health and family economics to use as indicators in future evaluations of development in the region.

From 1981 to 1983, diagnostic farming systems research was conducted both in the lowlands and highlands of southern Honduras. The personnel involved, all from the University of Kentucky, were Dr. Billie R. DeWalt of the Department of Anthropology and Dr. Kathleen DeWalt of the Department of Behavioral Science (Medical School) as co-directors; and Elizabeth Adelski, Susan Duda, Miriam Fordham and Karen Thompson, graduate students in Anthropology.

Seven communities in three *municipios* (roughly equivalent to a U.S. county) within the Nacaome River

Map 1. INTSORMIL Research Sites in Honduras.



watershed were studied. These included the *asentamiento* (a land reform community) of Santa Erlinda in the coastal lowlands; the communities of Cacautare, El Naranjito, El Corinto, Esquimay, and San Antonio de Padua in the highland *municipio* of Pespire; and the community of La Canada in the *municipio* of La Venta (Map 1). These communities were chosen because they have different cropping systems at altitudes ranging from near sea level to about 1000 meters.

Problems and Prospects

While the political crisis occurring in Central America is most visible to the world, there is a related socioeconomic crisis in the southern region of Honduras that has more potentially devastating human and ecological consequences. The crisis is caused by a combination of the region's unfavorable climate, relative scarcity of good agricultural land, unequal landholdings, high population density, high unempolyment, and low per capita income.

The climate of the region is best characterized by an expression commonly heard in Tegucigalpa (the national capital): "Going to Choluteca (the most important southern city) is good practice for going to hell!" Maximum temperatures frequently reach around 40°C during the hottest months of March and April, while minimum temperatures along the coast rarely fall below 16°C. Temperatures are more moderate in the hills and mountains, but even there hot, muggy conditions prevail. Rainfall is seasonal and quite variable. Little or no rain falls from December to April. The rainy season, from May to November, may produce as little as 500 mm per year or as much as 2500 mm. It is almost always, however, marked by a *canicula*—a dry period of 2 or more weeks. Figure 1 gives some idea of the variability in rainfall throughout the year and also clearly shows the canicula. Even in the years of "average" rainfall serious difficulties may arise. In 1982, for example, heavy rainfall caused floods and landslides at the beginning of the rainy season, a drought occurred during June, July and August, and damaging rains returned in September. It was a disastrous crop year in spite of "average" rainfall. The heat, variable rainfall, and the canicula impose severe ecological constraints on agriculture in the region.

The topography also is difficult for agriculture. There is only a small coastal plain with relatively flat, good land. About three-quarters of the land is in hills and mountains with slopes of from 15 to 60 percent common.

Data from the 1952, 1965 and 1974 agricultural censuses show an increasing polarization of landholdings into very small and relatively large farms. The large landholdings are concentrated along the coastal lowlands and are devoted to cash crops such as sugar cane, cotton, melons and, increasingly, cattle. The small landholdings are in mountainous areas where farmers plant the basic grain crops of maize, sorghum and beans. By 1974, 68 percent of all farms in southern Honduras were less than 5 hectares in size. This is about the minimum amount of land necessary to maintain a farm family in highland environments. In addition to the many landholders with minimal land, there are many rural families who do not have any access to land. As larger farmers invest more heavily in machinery and switch to less labor-intensive crops, these landless farmers find it more and more difficult to find employment.

In 1980 the region contained nearly half a million people, with some rural areas having a population density of 160 people per square kilometer. Agricultural unemployment was estimated at 62.2 percent and per capita income at $118, making this one of the poorest regions in all of Latin America. A 1980 nutritional survey in the region indicated that 52.9 percent of children up to 5 years of age had some form of nutritional deficiency, 23.9 percent had severe nutritional deficiency, and 1 percent bordered on death due to malnutrition.

In summary, the climate, topography, high population density, unequal landholdings, competitive allocation of subsistence and commercial crops, and high rates of unemployment all contribute to widespread regional poverty. It is within this context that we must view the importance of sorghum cropping systems in the region.

We should note that, while our research focused on southern Honduras, we believe many of the same patterns exist in other regions along the Pacific coast of Central America in which sorghum is grown.

Field Research

Despite the fact that southern Honduras has widespread economic, social and nutritional problems, the region is, nevertheless, ecologically diverse. In order to obtain information about the regional farming, cropping and nutritional systems associated with this ecological diversity, we chose seven communities from various ecological zones for intensive research (Map 1). They included Santa Erlinda, a lowland community located at near sea level; the foothill communities of Cacautare, El Naranjito, El Corinto and Esquimay, all at elevations of less than 400 meters; and the highland communities of La Canada and San Antonio de Padua, at more than 400 meters.

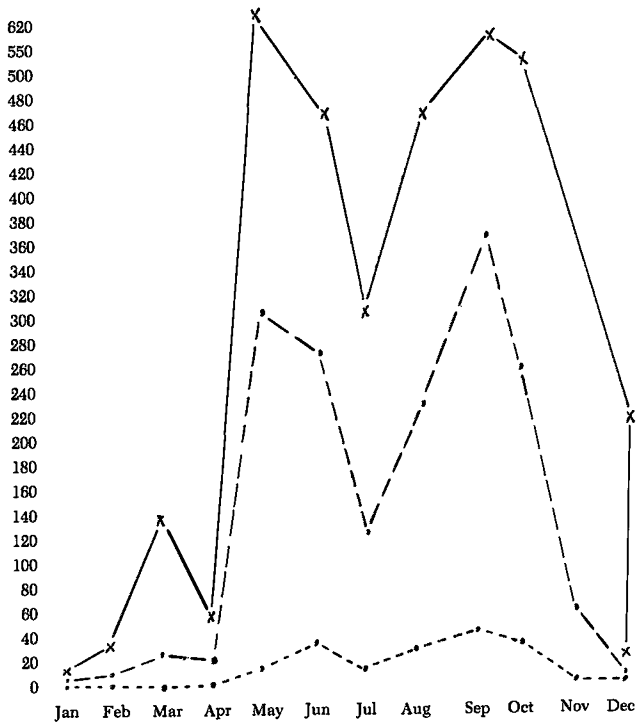
A combination of ethnographic and survey research was used in all communities. Agricultural and nutri-

Table 1. Production and Demand of Corn and Sorghum.

Year	Area cultivated (hectares)	Production metric tons	Yield metric tons per hectare	Internal demand	Production minus demand
			Corn		
1965-66	278.655	236.325	0.84	md	md
1966-67	279.685	334.681	1.19	md	md
1967-68	280.400	335.655	1.19	md	md
1968-69	281.115	336.631	1.19	md	md
1969-70	281.831	337.610	1.19	md	md
1970-71	282.546	338.591	1.19	319.700	+ 18.891
1971-72	283.261	339.576	1.19	360.100	− 20.524
1972-73	283.977	340.563	1.19	377.400	− 36.837
1973-74	287.011	342.561	1.19	389.600	− 47.039
1974-75	286.284	343.557	1.20	408.900	− 65.343
1975-76	330.532	358.129	1.08	429.900	− 71.771
1976-77	380.705	388.566	1.02	452.700	− 64.134
1977-78	430.878	419.002	0.97	478.300	− 59.298
			Sorghum		
1965-66	60.130	44.102	0.73	md	md
1966-67	26.654	39.674	1.49	md	md
1967-68	31.276	41.267	1.32	md	md
1968-69	32.904	42.860	1.30	md	md
1969-70	34.530	44.454	1.29	md	md
1970-71	36.155	46.047	1.27	43.000	+ 3.047
1971-72	37.780	47.640	1.26	45.100	+ 2.540
1972-73	39.405	49.234	1.25	47.200	+ 2.034
1973-74	52.802	40.624	0.77	48.700	− 8.076
1974-75	42.655	52.420	1.23	50.500	+ 1.920
1975-76	55.605	52.271	0.94	52.200	+ 0.071
1976-77	60.702	43.753	0.72	54.200	− 10.447
1977-78	65.799	35.236	0.54	56.700	− 21.464

Source: Secretaria de Recursos Naturales, "Los Granos Basicos en Su Aspecto Economico," Tegucigalpa, Honduras, January 1980.

Figure 1. Minimum, average, and maximum monthly rainfall totals for Pespire, Southern Honduras.



Note: While Hargreaves computed probabilities, the data he included for many months and several years in Pespire were quite obviously wrong due to the unreliability of the station. I have used the data for those years and months that appear to be correct in compiling this figure. The data reported here are consistent with the figures from the Choluteca station.

Source: George Hargreaves, *Monthly Precipitation Probabilities for Moisture Availability for Honduras*, Utah State University Report, 1980, pp. 82-83.

tional surveys were administered to male and female household heads twice in each community—once during the rainy season and again during the dry season. In this way, we hoped to obtain information on seasonal variation in agricultural practices an diet. We combined this survey approach with ethnographic techniques; researchers lived in the communities, observed and participated in community/agricultural activities, and interviewed many people.

Cropping Systems

Although sown primarily in the southern region, sorghum occupies the third largest amount of crop land in Honduras after maize and beans. We should note, however, that approximately 90 percent of the sorghum grown in Honduras is intercropped to minimize risk. Farmers in the region expect to lose much of the maize harvest in about one out of every two years. During the years in which drought reduces maize yields, the drought-tolerant sorghum can be counted on to produce a harvest. In good years, the quicker maturing maize (45 to 50 days) is harvested during the *canicula* (early July). At this point the sorghum begins to grow more quickly and produces its harvest in late November or early December.

Lowland Cropping

In 1982 cropping systems in the agrarian reform community of Santa Erlinda included a mixture of cash crops and food crops. The 41 members of the *asentamiento* had just been granted their land early in the year. They had sown a large amount of land in cotton in early July, but much of this was lost to drought. In early November the community sowed watermelons to take advantage of the residual moisture in the soil. The major crops sown, however, were maize and sorghum. Community leaders explained that because they had received their land so late in the year, and had to rent all of the machinery to plow the land, they had planted much more maize and sorghum than they would in the future. They had also planted all of the land communally. In the future, they expected to allocate 2 or 3 hectares to each of the members to produce maize and sorghum for subsistence. The cash crops would continue to be cultivated communally. We found that this same pattern was true of other *asentamientos* in the region that had obtained their land earlier than Santa Erlinda.

When sorghum is grown in the lowlands it is almost always intercropped with maize. After the land is plowed and harrowed, the maize is sown in furrows approximately 90 cm to 1 meter apart. This may be done with a mechanical seeder on a tractor or with a team of animals that opens up a furrow into which maize seed is dropped and covered manually. Either immediately afterward or a week or two later, sorghum is sown in between the rows of maize. This operation is almost always done with a team of animals and manual planting.

Foothill Cropping Systems

Cropping systems in the foothills communities of Cacautare, El Naranjito, El Corinto and Esquimay are considerably more complicated. Figure 2 shows the most common cropping cycle used in these communities. A field in secondary growth forest enters the cropping cycle through one of three slash and mulch systems used after the *canicula*. In all three systems the basic method used is to sow either maize or sorghum first, then chop down the forest cover, leaving the vegetation on the field as a kind of mulch. The maize or sorghum has to grow in the interstices of the dead and decaying vegetation.

The first of these, called *socolar*, is used for planting corn in the *postrera*, or second growing season. With this method the understory of fallow land is cut and removed, after which the farmers plant corn using a digging stick. When the corn has grown a few inches the larger trees are felled and left in the field. The corn must then find its way through the cut vegetation.

The second slash and mulch system is used to plant sorghum, and is called the *maicillera*. This system can only be used when it is raining because the sorghum seed is broadcast on the fallow land. The vegetation is then cut and left to serve as a mulch for the sorghum. The third system, *guatera*, is a variant of the second. Sorghum is broadcast later in the season and is sown more densely. Farmers are interested in using this

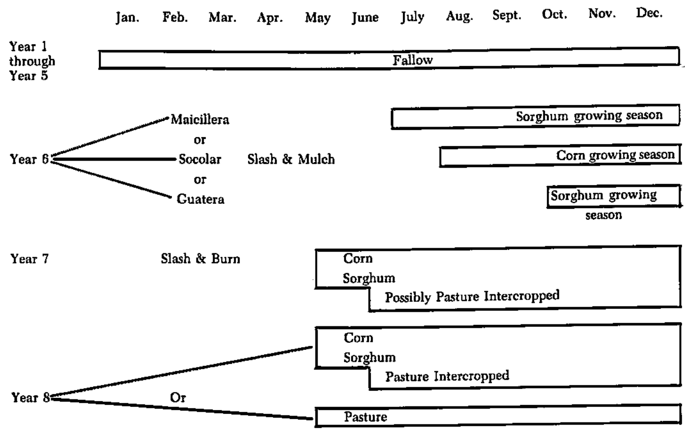


Figure 2. Fallow and alternative cropping cycles from Pespire.

sorghum for the fodder value of the stalk and leaves rather than for grain.

Farmers report that the slash and mulch system allows them to obtain an extra harvest from a piece of land. If they cut the forest down and burn the land for sowing in the first season, the land can only be used for 2 years. With slash and mulch, there is not as great a need to burn because insect pests are not as prevalent in the second harvest season and the mulch from the dead vegetation keeps weed growth down.

The second and third year that a field is in cultivation, preparation is with the more common slash and burn method. The field is burned in late March or April, then maize and sorghum are planted. The two grains usually are planted in the same hole—3 to 5 grains of maize and 12 to 15 grains of sorghum. Farmers with more available manpower may wait a week or two until the maize has germinated and then plant sorghum in between the hills of maize. Production costs of one manzana of intercropped corn/sorghum are given in Table 2. Much land in the region is being converted into pasture and this is often the end product of the cropping cycle. In the past, after three cropping seasons land would be left fallow for 5 to 8 years.

Farmers recognize that burning their fields increases erosion, but report that they have serious insect and weed problems if they do not burn. In addition, many of the trees and shrubs that grow in their fields have sharp spines; it is easier and safer to burn them than to haul them away.

From an agronomic point of view, this system of intercropping corn and sorghum seems odd because corn and sorghum compete for the same soil nutrients. However, from the farmer's point of view, the system makes a great deal of sense. The corn that is planted has to be a rapidly-maturing variety that will finish its growth before the onset of the dry season. Corn yields are low largely because they mature in such a short time (60 to 70 days), but they do sustain the farmer for a few months while he waits for the main harvest in December and January. The sorghum plants remain stunted while the corn is growing, but after the corn is harvested the sorghum grows rapidly and is harvested in December.

This farming system is a compromise between the clear cultural preference for corn, the staple of the peasant diet, and the need for the less desirable but climatically better adapted sorghum. When corn is not available, sorghum is substituted in the making of *tortillas.* The advantage of sorghum is that it is much more drought-tolerant than corn. Its function as a risk-averting crop is best illustrated by its performance in 1982. Corn yields from the *primera* (first sowing) were low because the *canicula* started a little earlier than usual. Most of the grain crop was just maturing when the rains stopped. The long duration of the *canicula* meant that farmers were not able to sow their second crop of corn until quite late—about mid-September. And because the rains only lasted a month, the corn from the second planting did not mature and was completely lost. Meanwhile, the sorghum tolerated the heavy rains in May and September, the drought in July and August, and the early end of the rains in October, so that the harvest was normal.

A second advantage of sorghum is that it can serve several purposes. It is used as a substitute for corn in making *tortillas* for human consumption; it is fed to the pigs and chickens that are raised in most peasant households; and it also finds a ready national market as animal feed. As with corn, the stubble left in the field is grazed by cattle.

Pasture grasses are sown along with the corn and sorghum during the third year of cultivating a field. At the end of the growing season, when the corn and sorghum have been harvested, the farmers are left with pasture. In the past, the typical pattern was for the farmers to graze animals on the pastures for a year or two and then allow natural succession processes to occur. The fields progressed from cultivation, to 2 years in grass, then another 3 or 4 years in fallow during which secondary forest would begin to grow. Many of the wealthier farmers, however, are now more interested in raising cattle than growing crops. Consequently, they weed their pastures and burn them once a year. These fields become permanent pastures.

In 1981 our research showed that larger landowners hire landless people to help convert forest into pasture. They rent their land to landless individuals for a year or two. The tenant clears the land, fixes the fences, and in the last year of cultivating grain crops sows *jaragua* grass in the field. This is a cheap way for landowners to create pasture for their animals. The process has been occurring all along the southern coast of Honduras, where the amont of land in pasture increased by approximately 50 percent between 1952 and 1974. In the municipality of Pespire, the increase in pasture land was more than 300 percent.

Highland Cropping Systems

In communities at elevations above about 400 meters (San Antonio de Padua and La Canada) beans enter the cropping systems, which become quite complex. There, either a slash and burn or a slash and mulch system after the *canicula* may be used to start the cultivation cycle. Maize and beans may be intercropped, beans may be planted alone, or, less commonly, sorghum may be planted alone. In the second and third years of cultivation, maize and sorghum are either intercropped as in the foothill communities, or beans, maize, and sorghum are intercropped. When intercropped, beans are sown up to a week after the corn or sorghum.

Table 2. Production Costs for One Manzana of Corn and Sorghum Planted with Digging Stick.

Activity	Date	Number of man-days	Cost (in lempiras)*
Fence repair	February, March	2	8
Land clearing	April	3-8	12-32
Making firebreaks	April	2-3	8-12
Burning	April	4-6	16-24
Sowing corn & sorghum	April, May	2-4	8-16
(Sowing corn)	(April, May)	(2)	(8)
(Sowing sorghum)	(April, May)	(2-3)	(8-12)
Herbicide application	June	1-2	4-8
(First weeding)		(20-28)	(80-112)
Harvest corn	July, August	3-4	12-16
Transport corn	July, August	1-2	4-8
Shelling corn	August	3-5	12-20
Second weeding	August, September	7-15	28-60
Bird scaring (4/6 hrs/day)	December	12-15	48-60
Harvest sorghum	December, January	4-8	16-32
Transport harvest	December, January	3-6	12-24
Threshing & winnowing	January, February	3-5	12-20
	TOTALS:	48-75	200-340

Other possible inputs	
10-20 pounds of corn seed	L. 2.40-4.80
5-10 pounds of sorghum seed	.80-1.60
1 quart of herbicide (Hedonal 720)	5.00
950 grams of insecticide (Dipterex)	5.00

RANGE OF TOTAL COST OF INPUTS (lempiras): 208.20 - 356.40

Value of production	Market price (lempiras)	Retail price (lempiras)
3 *cargas* (600 pounds) of corn	55-93	100-144
8 *cargas* (1600 pounds) of sorghum	112-168	209-256
Haulm (crop residues)	50-100	50-100
RANGE OF TOTAL VALUE OF PRODUCTION (lempiras):	217-361	359-500

*Two lempiras are equal to one U.S. dollar.

Figures 3, 4 and 5 show the cropping systems used in La Canada, and can be contrasted with Figure 6, which illustrates the most common cropping system practiced in San Antonio de Padua. In La Canada a variety of cropping systems are currently practiced. The first (Figure 3), an 8-year cycle in which 5 years of fallow are followed by 3 years of cropping, is very similar to the foothill system summarized in Figure 2, with the addition of beans. The most common fallow cropping cycle in La Canada, however, is the 5-year cycle shown in Figure 4. In this cycle, 3 years of fallow are followed by 2 years of cropping, the first in the *postrera*, the se-

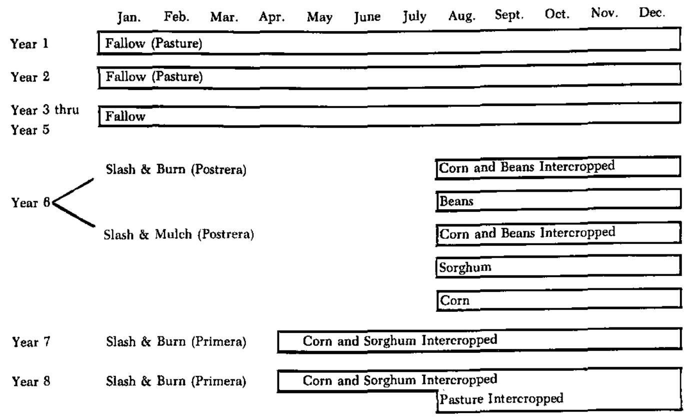


Figure 3. Eight-year fallow and alternative cropping cycles—La Canada, November 1982.

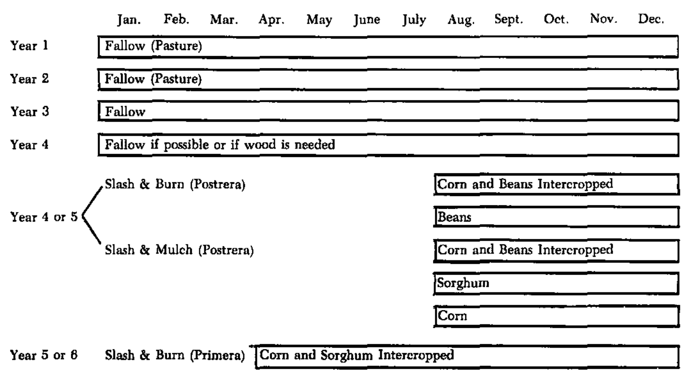


Figure 4. Five- or six-year fallow and alternative cropping cycles—La Canada, November, 1982.

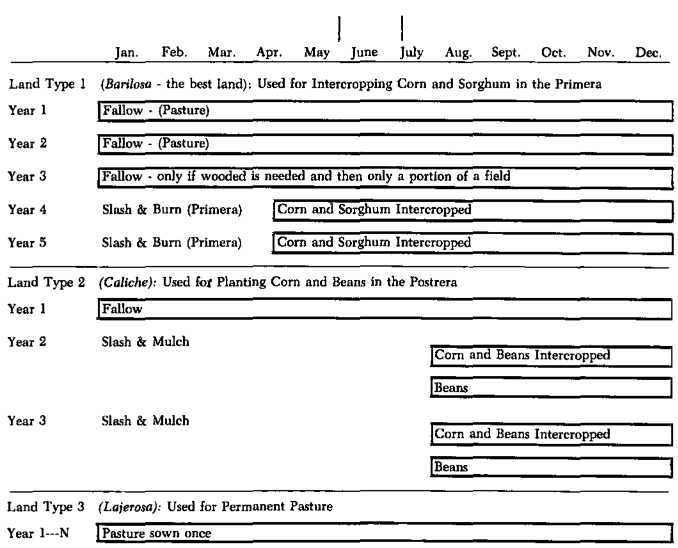


Figure 5. Fallow and alternative cropping cycles dependent on land type—La Canada, November, 1982.

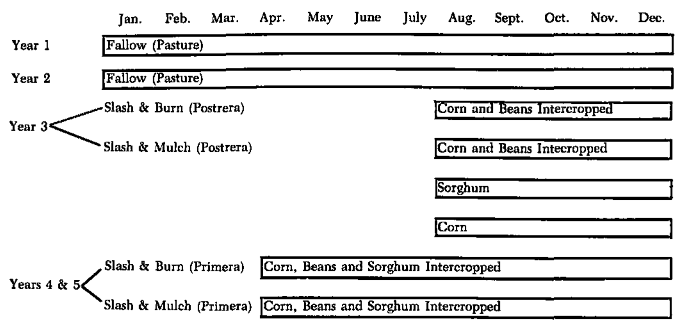


Figure 6. Five-year fallow and alternative cropping cycles—San Antonio de Padua, 1983.

cond in the *primera.* This cycle is being practiced even though most farmers believe that the longer fallowing cycle results in better agricultural yields. A variation of the shortened fallow cycle is shown in Figure 5. This system includes not only a shorter fallowing cycle of 1 to 2 or 3 years, but also more specialized use of the land. In this last system, different types of land are used for different crops: the best land for corn and sorghum; and more arid, sandy land for beans or intercropped beans and corn; and whatever land is left for pasture. This last appears to be the newest system. The individuals who use it report that they have tried it only for the last 3 to 4 years.

A shown in Figure 6, there is much less variation in the cropping systems practiced in San Antonio de Padua. Here a 5-year fallow/cropping cycle is most common. Land enters the cropping cycle in the *postrera* when maize and beans are intercropped using either a slash and burn or slash and mulch system. That is followed by 2 years of cropping during which maize, sorghum, and beans are intercropped in the *primera.* An interesting difference in San Antonio is that both slash and burn and slash and mulch systems are used at this time. Half the farmers in San Antonio report that they do not burn their fields. This change began during the mid-1970s when the government began urging farmers to stop burning in order to inhibit erosion. The farmers of San Antonio reported that around that time they had noticed increased erosion in their fields, which they associated with the shortening of the fallow cycle from 5 or 6 years to 2 or 3 years which had occurred a few years earlier.

Yields in San Antonio and La Canada are similar. In 1981 and 1982, the yields of intercropped corn and sorghum ranged from .20 MT/ha to .90 MT/ha (sorghum was 55 percent to 80 percent of the yield), and bean yields ranged from .07 MT/ha to .39 MT/ha.

The regional pattern of cropping systems is complex and dynamic. However, general trends include more intensive use of the land, shortening of the fallow cycle, the presence of both slash and burn and slash and mulch systems, and in the community of La Canada, the specialization of land use tending slightly toward monocropping.

Constraints

The principal constraints to increasing the production and utilization of sorghum in southern Honduras are of two types. First are the technological/ecological constraints that may be addressed by agricultural scientists. The second are socioeconomic constraints that cannot be solved scientifically.

In terms of the technological/ecological constraints, the hillside cultivators are especially affected by problems of declining soil fertility. Population increase and the increasing amounts of land being devoted to pasture for livestock mean that less land is available for subsistence crops. This has resulted in shortening the fallowing cycles which causes lower soil fertility, increased soil erosion, and declining yields. In Esquimay, older farmers maintain and statistical data support the belief that yields have decreased more than 25 percent over the last 20 years.

Insect pests are also a problem for farmers. The most damaging are the grain weevils *(C. granaria)* that eat stored maize and sorghum. Termites, ants, birds and rodents often eat the seed before it germinates in the field. Stem borers cause some damage, as does the fall armyworm. The midge *(Contarinia sorghicola)* also seems to be an increasing problem.

Birds cause a lot of grain loss in sorghum. Several species of doves and other birds migrate to Central America during the season when sorghum matures. Farmers try to station someone in the fields to scare away the birds during the hours when they feed. Losses to any one farmer are not ususally great, but the total amount of grain lost is substantial.

Socioeconomic constraints in the region are perhaps more important than technological constraints in the long run. Although the Honduran government has undertaken an agrarian reform program that has made some progress in redistributing land, the overall trend in southern Honduras is toward increased concentration of landholdings and a significant shift of land resources to livestock pasture.

The 1952, 1965, and 1974 Censuses of Agriculture indicated a reduction in the total area planted in basic food grains and a corresponding decrease in total production.

Table 3. Area, Production, and Yield for Major Crops in Southern Honduras for the Years 1980, 1981, 1982.

Crop		Area harvested (ha.)	Production (tm.)	Yields (tm./ha.)
Corn	1980	26,627	20,720	.75
	1981	31,260	20,319	.65
	1982	34,695	19.082	.55
Sorghum	1980	16,682	12,178	.73
	1981	20,857	16,686	.80
	1982	21,480	11,599	.54
Beans	1980	2,461	738	.30
	1981	1,925	577	.30
	1982	3,374	977	.27

Source: CSPE/OEA, 1982, p. 126.

In the *municipio* of La Venta alone, between 1952 and 1974 the amount of land in maize decreased 25 percent, the amount in beans 59 percent, and the amount in sorghum 23 percent. Cash crops such as cotton, sugar cane, and sesame, which formerly provided labor opportunities, are also declining. The result is that small farmers and landless individuals are having an increasingly difficult time earning a living.

In order to increase the availability of basic foods, the current Honduran National Development Plan has as an immediate goal increasing basic grain production. Data presented in Table 2 for the years 1980, 1981, and 1982 seem to indicate this major effort at increasing production. During the period, corn and sorghum had a 32 percent increase in hectares planted and beans 37 percent. However, this resulted not in greater but in smaller total yields. Two reasons for this may be bad weather and the planting of these food crops in increasingly marginal land.

New Varieties and Technologies

Our research suggests that sorghum as a monocultigen does have some prospects in the coastal lowlands where inputs such as machinery, fertilizer and sometimes irrigation can be used. High-yielding hybrids might be grown along with or in place of the existing cash crops of cotton, sugar cane, melons and rice. A few larger farmers were already experimenting with some hybrid sorghums.

By far the greatest research need, however, is for varieties of sorghum that can improve yields within the maize intercropping system in which it is currently grown. Research should be focused on improving the existing *criollo* varieties. Reducing plant height (existing varieties are often 3 to 4 meters tall) may increase yields. Some of the existing varieties have a crystalline seed that provides some resistance to granary weevils and also has good quality for making tortillas. These characteristics should be enhanced if possible. It may be that the photosensitivity of existing varieties should also be kept because this assures that the sorghums mature after the end of the rainy season, thus minimizing crop loss due to excessive moisture.

Improved varieties can be passed on from farmer to farmer and grown year after year. This is important in a country such as Honduras where the seed multiplication and distribution system is extraordinarily underdeveloped. Farmers are also quite used to experimenting with and adopting new varieties. Our data show that they are all aware of several native varieties and that most are using different varieties than they used several years ago.

We were impressed by the overall level of receptivity of these farmers to new technology. In addition to using new varieties of seed, more than two-thirds of the farmers we interviewed in the *municipio* of Pespire had begun using herbicides to control weeds. Many had joined grain storage cooperatives as a means of reducing post-harvest losses.

Farming Systems Research in Mexico

Billie R. DeWalt

University of Kentucky

The aim of this project is to understand the socioeconomics of production, distribution and consumption of sorghum in Mexico. Because sorghum production has been such an economic and technological success in Mexico, the Mexican experience may be emulated in other LDCs in Central America and the Caribbean.

INTSORMIL's collaborative agreements with the Instituto Nacional de Investigacion Agricolas (INIA) and with the Universidad Autonoma Metropolitana (UAM) call for research that will:

1. determine the agroecological constraints on the production of sorghum and alternative cultigens;
2. determine the linkages between the microeconomics of sorghum production and the macroeconomic situation in Mexico; and
3. determine the nutritional implications of switching from semi-subsistence maize farming to cash cropping of sorghum.

This collaborative research began in June 1984.

Research Accomplishments

Because the research in Mexico has just begun, results are limited to a background paper which documents the phenomenal growth of sorghum production during the past quater century (see DeWalt 1984).

Statistics on grain sorghum were not collected in Mexico prior to 1958 due to the insignificance of the crop. Since that time, sorghum has become the third largest crop in terms of hectares sown (after maize and beans), as well as in terms of crop value (after maize and cotton). Between 1958 and 1980 the number of hectares sown in sorghum increased by almost 1300 percent and total production increased by 2772 percent. More than 1.5 million hectares were sown in sorghum in 1980 (Table 1.), with yields averaging about 3 metric tons per hectare. The high rate of growth of sorghum production has been made possible by the rapid adoption of U.S hybrid seeds.

Despite the incredible growth of domestic production, Mexico found it necessary to import more than 2.25 million tons of sorghum in 1981, making it the second largest importer (after Japan) of sorghum from the U.S. Mexico was the sixth largest sorghum producing country in the world in 1980-81, and only the U.S. and the People's Republic of China used more of the grain.

The sorghum grown in Mexico is destined for industrial uses, principally in manufacturing animal feed. Sorghum comprises 74 percent of the raw material used in balanced animal feed.

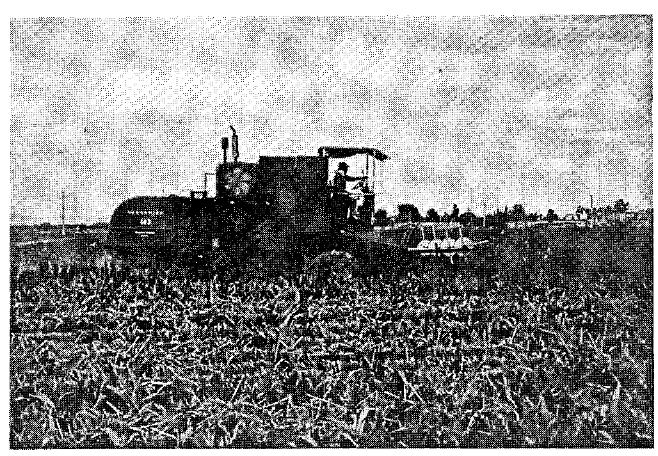
Because sorghum has replaced both maize and wheat in many parts of Mexico, there is much debate within the country about the wisdom of substituting a feed crop for food crops. As Figure 1 shows, approximately one-third of all grains in Mexico are now used for animal feed. In 1960 less than 5 percent of grain use in Mexico was by animals. For farmers, however, the issue is one of economics. Sorghum is generally less costly and less risky to produce than either maize or wheat. With high yields, increasing demand, and less risk, farmers have found sorghum to be a remunerative crop.

The economic, social and nutritional issues that arise in determining the future role of sorghum in Mexican agriculture are many and varied. These issues are not isolated from the technology involved in sorghum production, but are intimately linked with it. For example, the vastly increased amount of land devoted to sorghum is largely because of the great success that has been achieved with hybrids and with improved cultivation techniques.

As Mexico struggles with an agricultural crisis that has caused it to import large quantities of grains, it is clear that the socioeconomic and nutritional issues surrounding sorghum cultivation will be of paramount importance. For example, because it is more productive than maize there is considerable interest in using sorghum for tortillas. The use of sorghum for human consumption will have to compete with the use of sorghum as an animal feed.

Training and Technical Assistance

Eleven students who are finishing their *licensiado* and *ingeniero* degrees at the Universidad Autonoma Metropolitana have been trained in farming systems research methods and are carrying out the field research. These students are receving credit for their "social service" requirement because of their participation in the joint INTSORMIL/UAM research.



Sorghum production in Mexico uses U.S. hybrids and is highly mechanized.

Table 1. Grain Sorghum: Harvested Area, Yield, Production, Foreign Trade and Consumption in Mexico, 1958-1980.

Years	Average Area Harvested (hectares)	Average Yield (kgs./ha.)	Average Production (tons)	Average Net Imports (tons)**	Average per capita Consumption (kgs.)
1958-59	113,393	1478	167,567	5,133	5.036
1960-64	164,964	2090	344,713	51,596	10.268
1965-69	655,302	2568	1,682,627	-100,645	34.586
1970-74	1,071,206	2734	2,928,789	125,408	55.947
1975-79	1,334,221	3114	4,132,952	717,301	76.144
1980	1,578,629	3018	4,812,427	2,251,886	101.869
1981***	1,767,258	3562	6,295,667	--	--

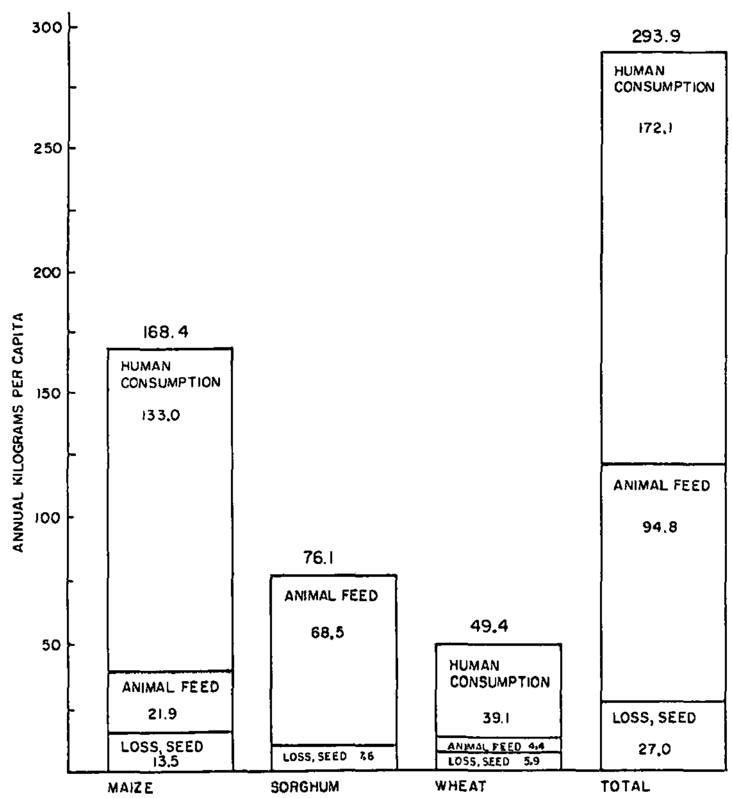
*Source: Secretaria de Agricultura y Recursos Hidraulicos, "Consumos Aparentes de Productos Agricolas 1925-80", Econotecnia Agricoa Vol. V, No. 9, 1981, pp. 58-9. Sorghum statistics have only been collected since 1958.

**This reflects the total imports minus the total exports. A negative number in this column indicates that the country exported more than it imported during that period.

***Preliminary estimate from Boletin Interno 1982.

Figure 1.

PER CAPITA ANNUAL APPARENT CONSUMPTION OF MAIZE, SORGHUM, AND WHEAT IN MEXICO, (1975-79 AVERAGES)



Two students from U.S. universities are also attached to the research effort, although both are receiving funds from other sources. One is an undergraduate major in anthropology at the University of Massachusetts; the other is a Master's degree student in political science from the University of Kentucky. The latter is expected to write a Master's thesis about the role of women in agriculture in the San Luis Potosi region. Finally, Elizabeth Adelski will finish her field research in the Guasave region and will return to the U.S. to write her Ph.D. dissertation.

Implications for Future Research

UAM and INTSORMIL will cooperate during 1984-85 in socioeconomic research on sorghum in Mexico. Eleven students from the UAM (nine agronomists and two economists) were trained in farming systems research methods in June 1984. From July to November they conducted field research in four regions of Mexico, under the supervision of faculty from the University of Kentucky and the UAM. The four regions—Abasolo, Tamaulipas; Cerritos, San Luis Potosi; Axochiapan, Morelos; Apatzingan, Michoacan—are all areas in which *ejidatarios* (small farmers who received land under Mexico's agrarian reform program) have switched from maize cultivation to sorghum. Maize cultivation was largely for subsistence and used manual labor and animal traction; sorghum production is mechanized and is for the market. The data from these communities will be compatible with that collected in 1983 by Elizabeth Adelski in Guasave, Sinaloa. From these five studies it will be possible to determine what socioeconomic and nutritional impacts the adoption of sorghum cultivation has had on these communities of farmers.

Selected Publications

DeWalt, Billie R. 1984. Mexico's second green revolution: food for feed. *Mexican Studies* (in press).

DeWalt, Billie R. and David Barkin. 1984. El sorgo y la crisis alimentaria mexicana. Paper presented in the workshop, "Sorgo y Mijo en Sistemas de Produccion en America Latina." CIMMYT.

Converted exotic sorghums such as these contribute to genetic diversity.

APPENDICES

Appendix I. INTSORMIL Projects By Discipline, July 1, 1979-June 30, 1984.

		U.S. Institution	Collaborative Host Country	Beginning Date
KSU 2	Identify and Evaluate Physiological and Developmental Processes Adversely Affected by Environmental Stresses.	Kansas State	Sudan, India	79-80
KSU 6	Seedling Vigor, Stand Establishment, Plant Growth and Development, Water Use, Drought Resistance and Herbicide Susceptibility of Pearl Millet.	Kansas State	Nigeria, Sudan, Botswana, ICRISAT	80-81
MSU 1	Seed Factors Influencing Germination, Emergence and Stand Establishment.	Miss. State	Upper Volta	79-80
UN 1	Physiological Methods of Selecting for Drought Resistance in Sorghums. (Restructured in Year 4, 1982-83, as part of UN 16.)	Nebraska	Mali, Zimbabwe, ICRISAT, Australia, Philippines, Mexico, Egypt, Sudan	79-80
UN 2	Grain Sorghum and Millet Response to Temperature Stress. (Restructured in Year 4, 1882-83, as part of UN 16.)	Nebraska	Mali, Zimbabwe, ICRISAT, Australia, Philippines, Mexico, Egypt, Sudan	79-80
UN 3	Grain Fill Period in Sorghum. (Discontinued after 80-81.)	Nebraska	Botswana, Brazil, Dominican Republic, Mali, Morocco, Pakistan, Philippines, Senegal, Sudan, Tanzania	79-80
UN 4	Adaptation and Yield Stability in Grain Sorghum. (Restructured in Year 4, 1982-83, as part of UN 15.)	Nebraska	Botswana, Brazil, Dominican Republic, Mali, Morocco, Pakistan, Philippines, Senegal, Sudan, Tanzania	79-80
UN 5	Mineral Element Efficiencies and Tolerances in Sorghum and Millet. (Restructured in Year 4, 1982-83, as part of UN 14.)	Nebraska	Brazil, ICRISAT	79-80
UN 6	Nitrogen Uptake in Sorghum/Millet. (Restructured in Year 4, 1982-83, as part of UN 14.)	Nebraska	ICRISAT	79-80
UN 8	Agricultural Climatology of Sorghum and Millets.	Nebraska	Dominican Republic, Mexico, Tanzania, Philippines	79-80
TAM 4	Efficient Nutrient Use (Restructured in Year 3, 1981-82 as TX 23.)	Texas A&M	Mali, Botswana, Brazil, Guatemala, Australia	79-80
TX 23	Breeding for Insect Resistance and Efficient Nutrient Use.	Texas A&M	Mali, Botswana, Guatemala, Brazil, Egypt	81-82
UN 13	Agronomy and Cropping Systems.	Nebraska	Philippines, Botswana, Tanzania, Sudan, Mexico, Dominican Republic, Egypt	82-83
UN 16	Water and Temperature Effects on Sorghum and Millet as Related to Production and Breeding.	Nebraska	Sudan, Egypt, Botswana, Dominican Republic, Mali, Mexico, Zimbabwe, Australia, ICRISAT, Philippines, Colombia	82-83
KSU 7	Water Use Efficiency, Inter-Cropping with Legumes, Tillage of Sorghum Millet in Botswana.	Kansas State	Botswana	83-84
UN 22	Improve Sorghum Production/Utilization in Dominican Republic.	Nebraska	Dominican Republic	83-84
KS1-1	Agronomic Activities in North Kordofan, Western Sudan. (Formerly a part of KSU 1.)	Kansas State	Sudan	83-84
UN 21	Sorghum Production in the Philippines. (Includes all disciplines.)	Nebraska	Philippines	82-83
Plant Breeding				
KSU 2	Expansion of the Pearl Millet Breeding Program at Fort Hays Branch Agric. Experiment Sta. and Organization and Development of a Pearl Millet Breeding Program at Kansas State University.	Kansas State	India, Sudan, Nigeria, Mali, Mauratania, Ghana, Niger, Honduras, Dominican Republic, Mexico, Philippines	79-80
AZ 1	Evaluation and Development of Sorghum Germplasm for Arid Land Agriculture.	Arizona	Yemen, Sudan, Egypt, Mexico, Colombia	79-80

		U.S. Institution	Collaborative Host Country	Beginning Date
MSU 2	Sorghum Host-Plant Resistance and Genotype Evaluation (Project funded 79-80, 80-81, 81-82, then restructured in Year 4, 82-83, into three projects, MSU 4, 5, 6.)	Mississippi	Honduras	79-80
UN 7	Recurrent Selection in Sorghum. (Restructured in Year 4, 82-83, as part of UN 15.)	Nebraska	Botswana, Brazil, Dominican Republic, Mali, Morocco, Pakistan, Philippines, Senegal, Sudan, Tanzania	79-80
PRF 3	Chemical and Physical Aspects of Food and Nutritional Quality of Sorghum.	Purdue	Sudan, Niger, India, Mali, Egypt, Brazil, Colombia, Mexico	79-80
TAM 1	Plant Breeding and Genetics. (Restructured in Year 3, 81-82, as part of TX 21.)	Texas A&M	Mexico, Guatemala, El Salvador, Honduras, Brazil, Chile, Venezuela, Egypt, Yemen, Upper Volta, Mali, Tanzania, Sudan, Ethiopia, China, India	79-80
TAM 2	Plant Breeding and Genetics. (Restructured in Year 3, 81-82, as part of TX 22.)	Texas A&M	India, Upper Volta, Mexico, Sudan, Egypt	79-80
TAM 3	Breeding for Insect Resistance. (Restructured in Year 3, 81-82, as part of TX 22.)	Texas A&M	Egypt, Brazil, Mexico	79-80
TAM 5	Plant Breeding and Improvement-Other Environmental Stress. (Restructured in Year 3, 81-82, as part of TX 21.)	Texas A&M	Egypt, Sudan, Upper Volta, Mali, Mexico, India	79-80
TAM 6	Reproductive Systems. (Restructured in Year 3, 81-82, as part of TX 22.)	Texas A&M	India, Australia	79-80
TAM 16	Meteorological Adaptation. (Identification of Grain Sorghum Cultivars Adapted to Suboptimal Moisture Conditions.) (Restructured in Year 3, 81-82, as part of TX 22.)	Texas A&M	Mali, Upper Volta	79-80
TX 21	Breeding for Productivity in Sorghum.	Texas A&M	Tanzania, Sudan, Mali, Upper Volta, Ethiopia, Kenya, Zambia, Costa Rica, Dominican Republic, Guatemala, Jamaica, Haiti, Argentina, Mexico, Philippines, China, India, Niger, Egypt, Venezuela, Brazil	81-82
TX 22	Breeding for Disease and Drought Resistance and Increased Genetic Diversity.	Texas A&M	Honduras, Sudan, Mali, Niger, Tanzania, Mexico, Brazil, Venezuela, Upper Volta, Argentina, Australia, Zambia	81-82
MSU-4	Sorghum Host-Plant Resistance and Genotype Evaluation.	Miss. State	Mexico, Honduras, Peru, Colombia, Brazil, Venezuela, Panama	81-82
MSU-11	Adaptation of Sorghum to Highly Acid Tropical Soils.	Miss. State	Colombia, Peru, Honduras, Mexico, Brazil, Venezuela, Panama	82-83
TAM 31	Honduras.	Texas A&M		82-83
UN 15	Plant Breeding.	Nebraska	Botswana, Pakistan, Sudan, Senegal, Tanzania, Dominican Republic, Morocco, Philippines, Brazil, Mali	82-83
PRF 7	Strengthening Outreach Work in Sorghum Production and Utilization.	Purdue	Sudan, Niger, India, Mali, Egypt, Brazil, Colombia, Mexico, Ethiopia, Kenya	83-84
PRF 9	Niger Country Coordinated Research.	Purdue	Niger, India, Mali	83-84
TAM 32	Tanzania.	Texas A&M	Tanzania	
Entomology				
KSU 4	Storage and Preservation of Pearl Millet and Sorghum. (Terminated at end of Year 5.)	Kansas State	Sudan, Honduras, ICRISAT	79-80
TAM 11	Development and Evaluation of Systems for Controlling Insect Pests of Sorghum by Integration of Resistant Varieties, Cultural Manipulation and Biological Control. (Restructured in Year 3, 81-82, as part of TX 25.)	Texas A&M	India, Guatemala, Mexico, Brazil, Honduras, Australia	79-80

		U.S. Institution	Collaborative Host Country	Beginning Date
TAM 12	Same title as TAM 11. (81-82, Year 3, TX 25.)	Texas A&M	See TX 25	79-80
TAM 13	Same title as TAM 11. (Discontinued after 80-81.)	Texas A&M	See TX 25	79-80
TAM 14	Same title as TAM 11. (Discontinued after 80-81.)	Texas A&M		79-80
TX 25	Development and Evaluation of Systems for Controlling Pests of Sorghum by Integration of Resistant Varieties, Cultural Manipulation and Biological Control.	Texas A&M	Honduras, Nicaragua, El Salvador, Guatemala, Uruguay, Ethiopia, Senegal, Niger, Botswana, India, Sir Lanka, Brazil, Argentina, Mexico,Kenya, Mali	81-82
MSU 5	Biological Investigations and Management of the Fall Armyworm and Stem Borers on Sorghum.	Miss. State	Colombia, Brazil, Honduras, Mexico	82-83
Pathology				
UN 9	Toxins in Resistance Screening. (Terminated June 30, 1981.)	Nebraska		
PRF 2	Studies on the Mechanisms of Disease Resistance and Susceptibility using Pathotoxins and Screening for Improved Resistance to Fungal Pathogens. (Discontinued after 81-82.)	Purdue	Egypt	79-80
TAM 7	Identification, Evaluation and Implementation of Effective Systems for Controlling Disease or Pathogens in Sorghum/Millet. (Restructured in Year 3, 81-82, as part of TX 24.)	Texas A&M	Uruguay, Sudan, Tanzania, Philippines, Honduras, India, Uganda, Brazil, Argentina, Colombia, Mexico	79-80
TAM 8	Same title as TAM 7 Cultural Control. (Restructured in Year 3, 81-82, as part of TX 24.)	Texas A&M	Uruguay, Sudan, Tanzania, Philippines, Honduras, India, Uganda, Brazil, Argentina, Colombia, Mexico	79-80
TAM 9	Plant Pathology Diagnostic Systems. (Restructured in Year 3, 81-82, as part of TX 24.)	Texas A&M	Philippines, Venezuela, Australia, Argentina	79-80
TAM 10	Modes of Resistance. (Nature of Resistance to Diseases.) (Restructured in Year 3, 81-82, as part of TX 24.)	Texas A&M	Egypt	79-80
UN 10	Identification of Genes Controlling the Reaction of Sorghum to MDMV.	Nebraska	Philippines, Colombia, Nigeria, Iraq	81-82
TX 24	Sorghum and Millet Pathology.	Texas A&M	Uruguay, Sudan, Tanzania, Philippines, Honduras, India, Uganda, Brazil, Argentina, Colombia, Mexico	81-82
MSU 6	Sorghum Disease Resistance Evaluation and Pathology Investigations.	Miss. State	Brazil, India, Mexico	82-83
PRF 6	Studies on Mechanisms of Disease Resistance and Susceptibility and Screening for Improved Resistance to Fungal Pathogens with Emphasis on *Colletotricum Graminicola* (Anthracnose).	Purdue	Egypt, Sudan	82-83
Food Quality and Utilization				
FAM 1	Development and LDC Field Testing of Culturally Acceptable Recipes Utilizing Grain Sorghum and Pearl Millet. (Terminated after 81-82.)	Florida A&M	Haiti	79-80
MSU 3	An Interdisciplinary Approach to Nutrition Improvement of People Consuming Grain Sorghum and Pearl Millet as the Staple Food.	Miss. State	Honduras, Sudan	79-80
PRF 4	Enhancement of High Tannin Sorghum Utilization.	Purdue	Philippines, Niger, Brazil	79-80

		U.S. Institution	Collaborative Host Country	Beginning Date
TAM 15	Food Quality. (Restructured in Year 3, 81-82, as TX 26.)	Texas A&M	Mali, Upper Volta, India, Mexico	79-80
KSU 5	Nutritional Quality of Pearl Millet. (Terminated June 30, 1984.)	Kansas State	Senegal, Sudan, ICRISAT	80-81
TX 26	Food and Nutritional Quality of Sorghum.	Texas A&M	Mali, Upper Volta, India, Honduras, Mexico, Nigeria, Argentina, Denmark	81-82
UN 14	Mineral Element Uptake, Use, Efficiency, and Tolerance in Sorghum and Millet.	Nebraska	Botswana, Colombia, Egypt, India, Mali, Brazil, Sudan, Philippines, Mexico	82-83
Socioeconomics				
KSU 3	A Farming Systems Approach to Sorghum and Millet Production in Rajasthan, India. (Terminated during Year 4, 82-83.)	Kansas State	India	79-80
UK 1	Sociocultural Constraints in the Production and Consumption of GS/PM in Less Developed Countries.	Kentucky	Sudan, Honduras, Mexico	79-80
PRF 1	Socioeconomic Constraints to Sorghum and Millet Production and Utilization: Risk, Government Policy, Consumer Preference and the Marketing System. (Terminated June 30, 1983.)	Purdue	Upper Volta	79-80
PRF 5	Pricing, Policy and International Trade Constraints on Sorghum and Millet Production and Utilization in Developing Countries.	Purdue	Upper Volta, Sudan, Niger	81-82
UK 2	Sudan/Honduras. (Formerly a part of UK 1.)	Kentucky	Sudan, Honduras, Mexico	82-83
UN 17	An Economic Analysis of the Potential for the Production and Marketing of Grain Sorghum in the Philippines.	Nebraska	Philippines	82-83

Appendix II. INTSORMIL U.S. and Host Country Principal Investigators, July 1979-July 1984.

U.S. Principal Investigators	Project	Host Country Collaboration
University of Arizona		
Vicki Marcarian A.K. Dobrenz R.L. Voight O.J. Webster	Evaluation and Development of Sorghum Germplasm for Arid Land Agriculture. (AZ 1)	N. Seetherama, ICRISAT D. Markarian, Yemen Senegal, Sudan, Egypt, Mexico, Colombia
Florida A&M		
Hetty Deane Banatte	Development and LDC Field Testing of Culturally Acceptable Recipes Utilizing Grain Sorghum/Pearl Millet. (FAM 1)	Haiti
Kansas State University		
W.D. Stegmeier T.L. Harvey F.L. Barnett Babrak Khaleeq	Expansion of the Pearl Millet Breeding Program at Fort Hays Branch Agricultural Experiment Station and Organization and Development of a Pearl Millet Breeding Program at Kansas State University. (KSU 1)	Dr. Oumar Niangado, Mali India, Sudan, Nigeria, Mali, Mauratania, Ghana, Niger, Honduras, Dominican Republic, Mexico, Philippines
Tareke Berhe	Agronomic Activities in North Kordofan, Western Sudan. (KSU 1-1)	Bakheit Musa, El Obeid, Sudan Abulgassim Abudick, El Obeid, Sudan
E.T. Kanemasu	Identify and Evaluate Physiological and Developmental Processes Adversely Affected by Envrionmental Stresses. (KSU 2)	N. Seetherama, ICRISAT Dr. Phool Singh, India, Sudan
Barry H. Michie Janet Benson David Norman Jim Converse T. Robert Harris Warren Prawl	A Farming Systems Approach to Sorghum and Millet Production in Rajasthan, India. (KSU 3)	India
Robert B. Mills John R. Pedersen	Storage and Preservation of Pearl Millet and Sorghum. (KSU 4)	Dr. M.H. Shazali, Sudan Dr. Klaus Leuschner, ICRISAT Honduras
J.M. Faubion R. Carl Hoseney Carol Klopfenstein E. Varriano-Marston Kathleen Zeleznak	Nutritional Quality of Pearl Millet. (KSU 5)	Dr. Sitt Badi, Sudan Dr. Lila Manawar, Sudan Dr. M. Hamdy, Senegal Dr. Jambunathan, ICRISAT
R.L. Vanderlip E.T. Kanemasu W.D. Stegmeir F.L. Barnett Merle D. Witt	Seedling Vigor, Stand Establishment, Plant Growth and Development, Water Use, Drought Resistance and Herbicide Susceptibility of Pearl Millet. (KSU 6)	Dr. David Andrews, ICRISAT Dr. Francis Bidinger, ICRISAT Dr. M.U.K. Sivakumar, ICRISAT Dr. S.M. Virmani, ICRISAT Dr. P.N. Egharevba, Nigeria Sudan, Botswana.
L.V. Withee Douglas Carter Wayne Youngquist R.L. Vanderlip W.D. Stegmeier	Water Use Efficiency, Intercropping with Legumes, Tillage of Sorghum/Millet in Botswana. (KSU 7)	Botswana
University of Kentucky		
C. Milton Coughenour Lawrence Busch William B. Lacy Billie DeWalt Kathleen DeWalt Edward B. Reeves	Sociocultural Constraints in the Production and Consumption of GS/PM in Less Developed Countries. (UK 1 and UK 2)	Sudan, Honduras, Mexico

U.S. Principal Investigators	Project	Host Country Collaboration
Mississippi State University		
J.C. Delouche C.H. Andrews H.C. Potts C.E. Vaughn	Seed Factors Influencing Germination Emergence and Stand Establishment. (MSU 1)	Upper Volta
Lynn Gourley Norman C. Merwine Jacques C. Denis Larry E. Trevathan Stanley B. King Natale Zummo Henry H. Pitre	Sorghum Host-Plant Resistance and Genotype Evaluation. (MSU 2)	Honduras
Mary Futrell Lois Kilgore John Saunders Louis Bluhm Eunice McCulloch	An Interdisciplinary Approach to Nutrition Improvement of People Consuming Grain Sorghum and Pearl Millet as the Staple Food. (MSU 3)	Honduras, Sudan
Lynn Gourley Norman C. Merwine	Sorghum Host-Plant Resistance and Genotype Evaluation. (MSU 4)	Dr. Fernando Arboleda, Colombia Dr. Eric Owen, Colombia Mr. Cesar Ruiz, Colombia Dr. Dale Bandy, Peru Dr. Manuel Villavicencio, Peru Dr. Louis Alberto Narro Leon, Peru Dr. Oscar Agreda Turriate, Peru Dr. Alberto Betancourt, Mexico Dr. Vartan Guiragossian, Mexico Dr. Robert Schaffert, Brazil Dr. Renato Borgonova, Brazil Dr. Gilson Pitta, Brazil Dr. Hector Mena, Venezuela Dr. Oscar de Cordova, Venezuela Dr. Gaspar Silvera, Panama Honduras
Henry N. Pitre B.R. Wiseman	Biological Investigations and Management of the Fall Armyworm and Stem Borers on Sorghum. (MSU 5)	Colombia, Brazil, Honduras, Mexico
Natale Zummo Larry E. Trevathan Lynn Gourley Stanley B. King	Sorghum Disease Resistance Evaluation and Pathology Investigations. (MSU 6)	Dr. Robert Schaffert, Brazil Dr. Lewis Mughogho, India Dr. A. Betancourt, Mexico
Lynn M. Gourley	Adaptation of Sorghum to Highly Acid Tropical Soils. (MSU 11)	Individuals contacted are same as in MSU 4.
University of Nebraska		
C.Y. Sullivan J.D. Eastin D.G. Watts ICRISAT W.M. Ross C.A. Francis	Physiological Methods of Selecting for Drought Resistance in Sorghums. (UN 1)	John Scheuring, Mali S. Muchena, Zimbabwe J. Peacock, Australia Lee House, Australia R. Henzell, Australia J. O'Toole, Philippines S. Yoshida, Philippines R. Maiti, Mexico Fayed Bishay, Egypt Botswana, Colombia, Sudan
J.D. Eastin C.Y. Sullivan C.A. Francis M.D. Clegg A.K. Dobrenz	Grain Sorghum and Millet Response to Temperature Stress. (UN 2.)	Individuals contacted are the same as in UN 1.

U.S. Principal Investigators	Project	Host Country Collaboration
C.A Francis J.D. Eastin M.D. Clegg W.M. Ross	Grain Fill Period in Sorghum. (UN 3)	L. Mazhani, Botswana M. Lira, Brazil R. Perez, Dominican Republic U. Niangodo, Mali L. Oubaha, Morocco M. Saeed, Pakistan S. Dalmacio, Philippines A. Fofana, Senegal A. Ndoye, Senegal M. Abdelrahman, Sudan A. Mahamed, Sudan G. Mitawa, Tanzania R. Mushi, Tanzania
C.A. Francis W.M. Ross J.D. Eastin	Adaptation and Yield Stability in Grain Sorghum. (UN 4)	Individuals contacted are same as in UN 3.
R.B. Clark J.W. Maranville W.M. Ross R.A. Olson	Mineral Element Efficiencies and Tolerances in Sorghum and Millet. (UN 5)	G.E. deFranca, Brazil V. Balligar, Brazil R. Schaffert, Brazil A.M. Furlani, Brazil P. Furlani, Brazil Dr. Seetharma, ICRISAT Dr. Buford, ICRISAT Dr. Oswalt, ICRISAT Dr. Biddinger, ICRISAT
J.W. Maranville R.B. Clark C.A. Francis J.D. Eastin	Nitrogen Uptake in Sorghum/Millet. (UN 6)	David Andrews, ICRISAT
W.M. Ross C.O. Gardner C.A. Francis	Recurrent Selection in Sorghum. (UN 7)	Individuals contacted are the same as in UN 3.
R.E. Neild	Agricultural Climatology of Sorghum and Millets. (UN 8)	Eng. Rafael Perez Duverge, Dominican Republic Dr. Rodolfo Peregrina-Robles, Mexico Vartan Guiragossian, Mexico Compton Paul, Mexico Tanzania, Philippines
J.E. Partridge	Toxins in Resistance Screening. (UN 9)	
S.G. Jensen	Identification of Genes Controlling the Reaction of Sorghums to MDMV. (UN 10)	Philippines, Colombia, Nigeria, Iraq
M.D. Clegg C.A. Francis J.D. Eastin J.W. Maranville R.B. Clark C.Y. Sullivan W.M. Ross D.J. Andrews R.E. Neild	Agronomy and Cropping Systems. (UN 13)	L. Mazhani, Botswana D. Gollifer, Botswana Rafael Duverge Perez, Dominican Republic S. Mostafa, Egypt J.R. Santos A Soriano, Philippines G. Mitawa, Tanzania R. Mushi, Tanzania Sudan, Mexico
R.B. Clark J.W. Maranville W.M. Ross M.D. Clegg C.A. Francis J.D. Eastin C.Y. Sullivan R.E. Neild	Mineral Element Uptake, Use, Efficiency, and Tolerance in Sorghum an Millet. (UN 14)	Sam Dalmacio, Philippines R.K. Pandy, Philippines W. Herrera, Philippines Botswana, Colombia, Egypt, India, Mali, Philippines, Sudan, Brazil, Mexico

U.S. Principal Investigators	Project	Host Country Collaboration
W.M. Ross D.J. Andrews C.A. Francis C.O. Gardner J.D. Eastin M.D. Clegg J.W. Maranville R.B. Clark C.Y. Sullivan S.G. Jensen	Plant Breeding. (UN 15)	L. Mazhani, Botswana M. Lira, Brazil R. Perez, Dominican Republic U. Niangodo, Mali L. Oubaha, Morocco M. Saeed, Pakistan S. Dalmacio, Philippines A. Fofana, Senegal A. Ndoye, Senegal M. Abdelrahman, Sudan A. Mohamed, Sudan G. Mitawa, Tanzania R. Mushi, Tanzania
J.D. Eastin C.Y. Sullivan R.B. Clark D.J. Andrews M.D. Clegg J.W. Maranville C.A. Francis S.G. Jensen W.M. Ross	Water and Temperature Effects on Sorghum and Millet as Related to Production and Breeding. (UN 16)	John Scheuring, Mali S. Muchena, Zimbabwe J. Peacock, ICRISAT Lee House, ICRISAT R. Henzell, Australia J. O'Toole, Philippines S. Yoshida, Philippines R. Maita, Mexico Fayed Bishay, Egypt Botswana, Colombia, Sudan, Dominican Republic
Dale G. Anderson George Pfeiffer	Economic Analysis of the Potential for Marketing of Grain Sorghum in the Philippines. (UN 17)	Philippines
J.W. Maranville	Sorghum Production in the Phillipines. (UN 21)	Philippines
R.E. Neild	Improve Sorghum Production/Utilization in the Dominican Republic. (UN 22)	Dominican Republic
Purdue University		
W.H.M. Morris L.F Schrader M.G. Lang	Socioeconomic Constraints to Sorghum and Millet Production and Utilization: Risk, Government Policy, Consumer Preference and the Marketing System. (PRF 1)	Upper Volta
L.D. Dunkle H.L. Warren	Studies on the Mechanisms of Disease Resistance and Susceptibility using Pathotoxins and Screening for Improved Resistance to Fungal Pathogens. (PRF 2)	Egypt
John D. Axtell Allen W. Kirleis	Chemical and Physical Aspects of Food and Nutritional Quality of Sorghum. (PRF 3)	Mrs. Laila Monawar, Sudan Dr. Osman Ibrahim, Sudan Dr. Sit Bai, Sudan Dr. Moussa Saley, Niger Dr. R. Jambunathan, India Dr. Lee House, India Dr. Sam Mukuru, India Dr. Dallas Oswalt, India Dr. D.S. Murty, India Dr. V. Guiragossian, Mexico Dr. Ron Cantrell, Mexico Mali, Egypt, Brazil, Colombia
Larry G. Butler John Rogler	Enhancement of High Tannin Sorghum Utilization. (PRF 4)	Dr. M. Oumarou, Niger Dr. E. Luis, Philippines Dr. S. Dalmacio, Philippines Dr. G. Jham, Brazil Dr. G. de Moraes, Brazil
Robert L. Thompson Philip C. Abbott	Pricing, Policy and International Trade Constraints on Sorghum and Millet Production and Utilization in Developing Countries. (PRF 5)	Upper Volta, Sudan, Niger
Herman L. Warren	Studies on Mechanisms of Disease Resistance and Susceptibility and Screening for Improved Resistance to Fungal Pathogens with emphasis on *Colletotricum Graminicola* (Anthracnose). (PRF 6)	Egypt, Sudan

U.S. Principal Investigators	Project	Host Country Collaboration
Gebisa Ejeta	Breeding Sorghum Varieties and Hybrids with Improved Grain Quality, Drought Resistance and *Striga* Resistance in Collaboration with Colleagues in Africa. (PRF 7)	Dr. Moussa Saley, Niger Dr. Lee House, India Dr. Sam Mukuru, India Dr. R. Jambunathan, India Dr. John Scheuring, Mali Dr. Ahmed Hassan, Egypt Dr. Fakhry Fayed, Egypt Dr. Yilma Kebede, Ethiopia Dr. Brhane Gebrekidan, Kenya Dr. Robert Schaffert, Brazil Dr. Tuneo Sediyama, Brazil Dr. V. Guiragossian, Mexico Dr. Ron Cantrell, Mexico ARC, WSARP, NSA, Sudan
John D. Axtell Philip Abbott Gebisa Ejeta Thomas Housley	Niger Country Coordinated Research. (PRF 9)	Dr. Moussa Saley, Niger Dr. Issaka Magah, Niger Dr. Mousa Adamou, Niger Dr. Boutorou Qendeba, Niger Mr. Ly Samba, Niger Bruce Gulliver, India John Scheuring, Mali
Texas A&M University		
Fred Miller Page Morgan Richard Creelman J.W. Johnson Darrell Rosenow	Plant Breeding and Genetics. (TAM 1)	Dr. A. Betancourt, Mexico Dr. V. Guiragossian, Mexico Dr. Gebisa Ejeta, Sudan Dr. S.I. Salama, Egypt Dr. M. Riccelle, Venezuela Dr. J. Scheuring, Mali Dr. F. Alonzo, Guatemala Dr. B. Gebrekidan, Ethiopia Tanzania, El Salvador, Honduras, Brazil, Chile, Yemen, Upper Volta, Peoples Rep. of China
Darrell Rosenow	Plant Breeding and Improvement. (TAM 2)	Dr. Gebisa Ejeta, Sudan Dr. M.E. Oner, Sudan Mr. M.N. Kanani, Sudan S.I. Salama, Egypt Dr. V. Guiragossian, Mexico India, Upper Volta
Jerry W. Johnson George L. Teetes J.M. Phillips V. Riggs	Breeding for Insect Resistance. (TAM 3)	Dr. A.H. Shehata, Egypt Dr. R.A. Borgaonovi, Brazil J.M. Waquil, Brazil Dr. V. Guiragossian, Mexico
Arthur B. Onken Jerry W. Johnson	Efficient Nutrient Use. (TAM 4)	Mali, Botswana, Brazil, Guatemala, Australia
Page W. Morgan Wayne R. Jordan Lewis E. Clark Jerry W. Johnson Darrell T. Rosenow R.A. Frederiksen	Plant Breeding and Improvement—Other Environmental Stress. (TAM 5)	Dr. A.H. Shehata, Egypt Dr. Gebisa Ejeta, Sudan C.M. Pattanayak, Upper Volta J.F. Scheuring, Mali V. Guiragossian, Mexico L.R. House, India
Keith F. Schertz Roberta Smith	Reproductive Systems. (TAM 6)	Prasada Rao, ICRISAT Andrews, Australia U.R. Murty, India C.S. Reddy, India
R.A. Frederiksen J. Craig R. Toler G. Odvody	Identification, Evaluation and Implementation of Effective Systems for Controlling Disease or Pathogens in Sorghum/Millet. (TAM 7)	Uruguay, Sudan, Tanzania, Philippines, Honduras, India, Uganda, Brazil, Argentina, Colombia, Mexico

U.S. Principal Investigators	Project	Host Country Collaboration
Gary Odvody R.A. Frederiksen	Identification, Evaluation and Implementation of Effective Systems for Controlling Disease or Pathogens in Sorghum/Millet - Cultural Control. (TAM 8)	Uruguay, Sudan, Tanzania, Philippines, Honduras, India, Uganda, Brazil, Argentina, Colombia, Mexico
Robert W. Toler	Plant Pathology Diagnostic Systems. (TAM 9)	Dr. Roman Lastra, Venezuela Dr. Mauricio Riccelli, Venezuela Dr. Hector A. Mena, Venezuela Philippines, Australia, Argentina
J. Craig	Nature of Resistance to Disease. (TAM 10)	Egypt
George L. Teetes	Development and Evaluation of Systems for Controlling Insect Pests of Sorghum by Integration of Resistant Varieties, Cultural Manipulation and Biological Control. (TAM 11)	Drs. Davies & House, ICRISAT Jesus Vargas, Mexico Carlos Rossetto, Brazil Keith Andrews, Honduras Bob Page, Australia Bill Hare, Australia M.G. Jotwani, India Guatemala
Frank E. Gilstrap	Same Title as TAM 11. (TAM 12)	Same as TX 25.
George L. Teetes	Same Title as TAM 11. (TAM 13)	Same as TX 25
Kerry F. Harris	Same Title as TAM 11. (TAM 14)	
Lloyd W. Rooney	Food Quality. (TAM 15)	Dr. Andres Iruegas, Mexico Dr. V. Guiragossian, Mexico Dr. John Scheuring, Mali C.M. Pattanayak, Upper Volta India
Charles W. Wendt	Meteorological Adaptation. Identification of Grain Sorghum Cultivars Adapted to Suboptimal Mositure Conditions. (TAM 16)	Mali, Upper Volta
Fred Miller W.R. Jordan P.W. Morgan R. Creelman	Breeding for Productivity in Sorghum. (TX 21)	Mr. C. Mushi, Tanzania Mr. H. Saadan, Tanzania Dr. Abdel Latif, Sudan Mr. Lamine Traore, Mali Dr. Sansan Da, Upper Volta Dr. Yilma Kebede, Ethiopia Mr. Newton Ochanda, Kenya Mr. W. Chibasa, Zambia Mr. Marco Castro, Costa Rica Ing. Rafael Perez D., Dominican Rep. Ing. Leonal Pinto, Guatemala Ruby Roger, Jamaica Sixto Desir, Haiti Dr. John Clark, Niger Dr. Brhane Gebrekidan, Kenya Laura Giorda, Argentina Ing. G. Vega, Mexico Dr. S.C. Dalmacio, Philippines Mr. Qiao Kui-due, Peoples Republic of China Dr. N.G.P. Rao, India Dr. El-Hamid, Egypt Mr. M. Riccelli, Venezuela Dr. R. Schaffert, Brazil
D.T. Rosenow L.E. Clark K.F. Schertz C.W. Wendt Roberta H. Smith	Breeding for Disease Resistance and Drought Resistance and Increased Genetic Diversity. (TX 22)	Abdel Latif Nour, Sudan Oumar Niangado, Mali John Scheuring, Mali John Clark, Niger Moussa Adamou, Niger S. Da, Upper Volta Honduras, Tanzania, Zambia, Upper Volta, Mexico, Brazil, Venezuela, Argentina, Australia

U.S. Principal Investigators	Project	Host Country Collaboration
Gary C. Peterson Arthur B. Onken	Breeding for Insect Resistance and Efficient Nutrient Use. (TX 23)	Dr. Oumar Niangado, Mali Dr. John Schuering, Mali Mr. C.S. Manthe, Botswana Mr. Leonel Pinto, Guatemala Dr. Jairo Silva, Brazil Dr. Robert G. Henzell, Australia
		Egypt
R.A. Frederiksen Gary Odvody R.W. Toler Jeweus Craig Lucas Reyes	Sorghum and Millet Pathology. (TX 24)	Dr. V. Trucillo, Uruguay Dr. Omer Hilu, Sudan Dr. James Teri, Tanzania Dr. S. Dalmacio, Philippines J. Esele, India Dr. E. Teyssandier, Argentina Dr. N.G Fernandes, Brazil Laura Giorda, Argentina Dr. F. Llobet, Argentina Dr. L. Cabrales, Colombia Dr. A. Betancourt, Mexico Ing. Jesus N. Sanchez, Mexico
		Honduras, Uganda
George L. Teetes Frank E. Gilstrap	Development and Evaluation of Systems for Controlling Insect Pests of Sorghum by Integration of Resistant Varieties, Cultural Manipulation and Biological Control. (TX 25)	Keith Andrews, Honduras Maritza De Rodriguez, Nicaragua Rafael Reyes, El Salvador Leonel Pinto, Guatemala Vicente Trucillo, Uruguay Adugna Haile, Ethiopia R.T. Gahukar, Senegal K.V. Seshu Reddy, Kenya John Scheuring, Mali C.S. Manthe, Botswana B. Dayawathie, Sri Lanka Jairo Silva, Brazil Laura B. Almaraz, Argentina Rafael Bujanos, Mexico
		Niger, India
L.W. Rooney J.M. Faubion	Food and Nutritional Quality of Sorghum. (TX 26)	John Scheuring, Mali O. Niangado, Mali Dr. S. Da., Upper Volta Dr. D.S. Murty, India Ing. M.S. Lucero, Mexico Dr. O. Paredes-Lopez, Mexico Dr. Y.G. Navarro, Mexico Ing. Hector C. Gomez, Mexico Dr. J.O. Akingbala, Nigeria Ing. C. Domanski, Argentina Dr. L. Munck, Denmark
		Honduras
Dan Meckenstock	Honduras. (TX 31)	Rigoberto Nolasco, Honduras Juan Guevara, Honduras Edmundo Ramerez, Honduras Mauricio Garcia, Honduras Rigoberto Rodriguez, Honduras Rafael Martinez, Honduras Romero Troches, Honduras
John Mann	Tanzania. (TX 32)	

Appendix III. INTSORMIL Five-Year Budget Summary of Funds Allocated to Participating U.S. Institutions and U.S. Institutions Matching Funds 1979-1984.

Participating U.S. Institutions	Year 1 1979-80 INTSORMIL	Matching	Year 2 1980-81 INTSORMIL	Matching	Year 3 1981-82 INTSORMIL	Matching	Year 4 1982-83 INTSORMIL	Matching	Year 5 1983-84 INTSORMIL	Matching
Univ. of Arizona	$ 55,000	$ 18,333	$ 66,000	$ 22,000	$ 70,000	$ 23,333	$ 80,000	$ 26,667	$ 90,000	$ 30,000
Florida A&M Univ.[1]	17,400	5,800	27,680	9,227	29,000	9,667	—	—	—	—
Kansas State	196,000	65,333	339,000	113,000	365,000	121,667	400,000	133,333	340,000	113,333
Univ. of Kentucky	60,000	20,000	70,000	23,333	50,000	16,667	100,000	33,333	100,000	33,333
Mississippi State	268,000	89,333	307,000	102,333	255,000	85,000	300,000	100,000	265,000	88,333
Univ. of Nebraska	420,500	140,167	478,858	159,620	410,000	136,667	495,000	165,000	575,000	191,667
Purdue Univ.	271,607	90,536	400,393	133,464	435,000	145,000	450,000	150,000	470,000	156,667
Texas A&M Univ.	597,000	199,000	689,000	229,667	650,000	216,667	679,500	226,500	710,000	236,667
Total	$1,885,507	$628,502	$2,377,931	$792,644	$2,264,000	$754,668	$2,504,500	$834,833	$2,550,000	$850,000

[1]Florida A&M University became inactive in 1982-83.

Appendix IV. INTSORMIL Five-Year Budget Summary, 1979-1984.

	Year 1 1979-80	Year 2 1980-81	Year 3 1981-82	Year 4 1982-83	Year 5 1983-84	5-Year Total
LDC Host Country Agreements	$ 49,564	$ 175,000	$ 345,000	$ 560,000	$ 695,000	$ 1,824,564
Technical Assistance	24,500	87,500	40,000	45,000	40,000	237,000
Allocated to U.S. Institutions	1,885,507	2,377,931	2,264,000	2,504,500	2,550,000	11,581,938
Special Projects - Striga	—	—	—	40,000	40,000	80,000
Program Administration	200,000	200,000	200,000	300,000	320,000	1,220,000
Total Aid Grant	$2,159,571	$2,840,431	$2,849,000	$3,449,500	$3,645,000	$14,943,502
U.S. Institution Matching	628,502	792,644	754,668	834,833	850,000	3,860,647
Total	$2,788,073	$3,633,075	$3,603,668	$4,284,333	$4,495,000	$18,804,149

Appendix V. INTSORMIL Discipline and Special Project Coordinators, July 1979-July 1984.

Discipline	1979-80	1980-81	1981-82	1982-83	1983-84
Breeding/Genetics	Miller	Rosenow →	→	→	Miller
Agronomy/Physiology	Clegg	Eastin	Vanderlip/ Dobrenz	Kanemasu →	→
Entomology	Teetes →	→	→	→	→
Pathology	Frederiksen →	→	→	→	→
Socioeconomics	Busch →	→	→	→	B. DeWalt
Utilization and Quality	Rooney →	→	→	Kirleis	Axtell
Striga	—	—	—	Zummo →	→
Germplasm	—	—	—	Schertz →	→

Dr. Fred Miller, Texas A&M
Dr. Darrell Rosenow, Texas A&M
Dr. Max Clegg, University of Nebraska
Dr. Jerry Eastin, University of Nebraska
Dr. A.K. Dobrenz, University of Arizona
Dr. Richard Vanderlip, Kansas State University
Dr. Ed Kanemasu, Kansas State University
Dr. George Teetes, Texas A&M University
Dr. Richard Frederiksen, Texas A&M University
Dr. Larry Busch, University of Kentucky
Dr. Billie DeWalt, University of Kentucky
Dr. Lloyd Rooney, Texas A&M University
Dr. Allen Kirleis, Purdue University
Dr. John Axtell, Purdue University
Dr. Natale Zummo, Mississippi State University
Dr. Keith Schertz, Texas A&M University

Appendix VI. INTSORMIL Country Coordinators, July 1979-July 1984.

Country or Center	1979-80	1980-81	1981-82	1982-83	1983-84
Mexico and CIMMYT	—	Miller →	→	→	→
Honduras	—	—	Rosenow		
South America	—	—	—	Frederiksen →	→
Botswana	—	—	Vollmar →	→	→
Niger	—	—	Axtell →	→	→
Sudan	—	Frederiksen	Kirleis →	→	Vollmar/ Kirleis
Mali	—	—	Onken →	→	→
Egypt	—	Axtell	Eastin →	→	→
Tanzania	—	—	—	Miller →	→
Philippines/IRRI	—	—	Francis →	→	Maranville
ICRISAT, CIMMYT, IRRI, CIAT and Other Centers with Administration	Program Director →	→	→	→	→
CIAT/Colombia	—	—	Frederiksen →	→	Gourley
Caribbean	—	—	—	—	Futrell
Costa Rica	—	—	—	—	B. DeWalt
Burkina Faso (Upper Volta)	—	—	—	—	Abbott
Dominican Republic	—	—	—	—	Neild
India	Program Director →	→	→	→	→

Appendix VII. INTSORMIL External Evaluation Panel, July 1979-July 1984.

Name	Membership	Discipline	Affiliation
Dr. Bruce Maunder*	1980-	Sorghum Breeding	DeKalb-Pfizer, U.S.A.
Dr. John Monyo	1983-	Sorghum Breeding	FAO-Rome (from Tanzania)
Dr. Bobbie Renfro	1980-	Pathology	Rockefeller Foundation (Thailand)
Dr. Brhane Gebrekidan	1980-	Sorghum/Millet Breeding	SAFGRAD-ICRISAT Nairobi, Kenya (from Ethiopia)
Dr. Ricardo Bressani	1980-	Sorghum Utilization, Food Quality	Institute of Nutrition (INCAP) Guatemala
Dr. Uma Lele	1980-84	Socio-economics	World Bank (from India)
Dr. Hugh Doggett**	1980-82	Sorghum Breeding	IDRC, Canada
Dr. Ralph Cummings, Jr.***	1982	Socioeconomics	Rockefeller Foundation, U.S.A.

*Chairperson, 1983-
**Chairperson, 1980-82.
***Served only for 1982 EEP Program Review.

Appendix VIII. INTSORMIL Board of Directors, July 1979-July 1984.

1979-80	Institution
Dr. Dudley T. Smith, Chair	Texas A&M University
Dr. Rodney R. Foil	Mississippi State University
Dr. R.W. Kleis	University of Nebraska
Dr. Floyd Smith	Kansas State University
Dr. D. Woods Thomas	Purdue University
1980-81	
Dr. D. Woods Thomas, Chair	Purdue University
Dr. Floyd Smith	Kansas State University
Dr. Dudley T. Smith	Texas A&M Universtiy
Dr. L.W. Dewhirst	University of Arizona
Dr. R.W. Kleis	University of Nebraska
1981-82	
Dr. Floyd Smith, Chair	Kansas State University
Dr. Dudley T. Smith	Texas A&M University
Dr. R.W. Kleis	University of Nebraska
Dr. H . Dean Bunch	Mississippi State University
Dr. R.P. Upchurch	University of Arizona
1982-83	
Dr. R.P. Upchurch, Chair	University of Arizona
Dr. Herbert Massey	University of Kentucky
Dr. Dudley T. Smith	Texas A&M University
Dr. H. Dean Bunch	Mississippi State University
Dr. R.W. Kleis	University of Nebraska
1983-84	
Dr. H. Dean Bunch, Chair	Mississippi State University
Dr. George Ware	University of Arizona
Dr. D. Woods Thomas	Purdue University
Dr. Herbert Massey	University of Kentucky
Dr. R.W. Kleis	University of Nebraska

Appendix IX. INTSORMIL Technical Committee, July 1979-July 1984.

1979-80	Discipline	Institution
Dr. Jerry Eastin, Chair	Physiology	University of Nebraska
Dr. Richard Vanderlip	Physiology	Kansas State University
Dr. John Axtell	Breeding	Purdue University
Dr. Larry Busch	Socioeconomics	University of Kentucky
Dr. Mary Futrell	Utilization	Mississippi State University
Dr. Darrell T. Rosenow	Breeding	Texas A&M University
1980-81		
Dr. John Axtell, Chair	Breeding	Purdue University
Dr. Larry Busch	Socioeconomics	University of Kentucky
Dr. Mary Futrell	Utilization	Mississippi State University
Dr. Jerry Eastin	Physiology	University of Nebraska
Dr. George Teetes	Entomology	Texas A&M University
W.D. Stegmeier	Breeding	Kansas State University
1981-82		
Dr. George Teetes, Chair	Entomology	Texas A&M University
W.D. Stegmeier	Breeding	Kansas State University
Dr. Jerry Eastin	Physiology	Nebraska
Dr. Mary Futrell	Utilization	Mississippi State University
Dr. Billie DeWalt	Socioeconomics	University of Kentucky
Dr. Allen Kirleis	Utilization	Purdue University
1982-83		
Dr. George Teetes, Chair	Entomology	Texas A&M University
W.D. Stegmeier	Breeding	Kansas State University
Dr. Charles Francis	Agronomy/Breeding	University of Nebraska
Dr. Billie DeWalt	Socioeconomics	University of Kentucky
Dr. Allen Kirleis	Utilization	Purdue University
Dr. Vickie Marcarian	Breeding	University of Arizona
1983-84		
Dr. Billie DeWalt, Chair	Socioeconomics	University of Kentucky
Dr. Allen Kirleis	Utilization	Purdue University
Dr. Vicki Marcarian	Breeding	University of Arizona
Dr. Charles Francis	Agronomy/Breeding	University of Nebraska
Dr. Richard Frederiksen	Pathology	Texas A&M University
Dr. Ed Kanemasu	Physiology	Kansas State University

Appendix X. Foreign Student Training between 1979 and 1984 or in Progress.

Student	Home Country	Degree Sought
Agronomy/Physiology		
Project Title: Identify and Evaluate Physiological and Development Processes Adversely Affected by Environmental Stresses.		
J. Owonubi	Nigeria	Ph.D.
T. Mtui	Tanzania	M.S.
Piara Singh	India	Ph.D.
R. Lapital	Philippines	Ph.D.
F. Rachidi	Morocco	non-degree
Project Title: Seedling Vigor and Stand Establishment in Pearl Millet.		
William Ndahi	Nigeria	M.S.
Gallus Mwageni	Tanzania	M.S.
Harmut Stutzel	Germany	M.S.
Julius Okonkwo	Nigeria	Ph.D.
Elijah Modiakgotla	Botswana	M.S.
Patrick Egharevba	Nigeria	Post doc.
Project Title: Agronomy and Cropping Systems.		
L.P. Gakale	Botswana	M.S.
L.P. Gakale	Botswana	Ph.D.
G.M. Mitawa	Tanzania	M.S.
G.M. Mitawa	Tanzania	Ph.D.
M.S. Mostafa	Egypt	Ph.D.
P.E. Odo	Nigeria	Ph.D.
J.F. Santos	Philippines	Ph.D.
A.S. Soriano	Philippines	Ph.D.
Project Title: Mineral Element Uptake, Use, Efficiency and Tolerance in Sorghum and Millet.		
P.R. Furlani	Brazil	M.S.
Y. Yusuf	Nigeria	Ph.D.
G.E. deFranca	Brazil	Ph.D.
A.M.C. Furlani	Brazil	Ph.D.
P.R. Furlani	Brazil	Ph.D.
R. Magnavoca	Brazil	Ph.D.
L.C.M. Bernardo	Philippines	M.S.
P.E. Odo	Nigeria	M.S.
Project Title: Water and Temperature Effects on Sorghum and Millet as Related to Production and Breeding.		
V.B. Ogunlela	Nigeria	M.S.
J. Gomez	Mexico	Ph.D.
V.A. Gonzalez	Mexico	M.S.
Dennis Garrity	Philippines	Post doc.
Roberto Maurer	Mexico	M.S.
Baba K. Kaigama	Nigeria	M.S.
Arvind Dhopte	India	Ph.D.
Amare Retta	Ethiopia	Post doc.
Moussa Traore	Mali	Ph.D.
Fidel Patarroyo	Colombia	Ph.D.
Cecira R. DeMartinez	Colombia	Ph.D.
M. Livera	Mexico	Ph.D.
P. Verma	India	Ph.D.
M. Abdelrahman	Sudan	Ph.D.
Project Title: Seed Factors Influencing Germination, Emergence and Stand Establishment of Sorghum and Pearl Millet.		
R.M. Ali	Iraq	M.S.
R. Andriqueto	Brazil	Ph.D.
A.A. Aziz	Sudan	Ph.D.
C.P. Camargo	Brazil	Ph.D.
J.K. Kemei	Kenya	M.S.
A. Kpodar	Togo	M.S.
P. Matambo	Malawi	M.S.

Student	Home Country	Degree Sought
Plant Breeding		
Project Title: Breeding for Productivity in Sorghum.		
G.L. Thomas	Australia	Ph.D.
A. Betancourt-Vallejo	Mexico	Ph.D.
Abdalazim B. Abdalla	Sudan	Ph.D.
Y. Kebede	Ethiopia	Ph.D.
G. Valdez	Mexico	Ph.D.
Pao Ching-I	Taiwan	Ph.D.
G.J. Perez C.	Venezuela	M.S.
L. Traore	Mali	M.S.
B.L. McIntyre	Canada	M.S.
H.M. Saadan	Tanzania	M.S.
N.W. Ochanda	Kenya	M.S.
S. Balachondra	St. Lonica	M.S.
Anne M. Alegre	France	Ph.D.
Marcel Galiba	Senegal	Ph.D.
Francisco Gomez	Honduras	Ph.D.
Pedro Jasa	Uruguay	Ph.D.
German Perez	Venezuela	Ph.D.
Yan-Wan Yang	Taiwan	Ph.D.
J. Akuouo-Nyantaki	Ghana	M.S.
Colette Blanchet	Haiti	M.S.
S. Hilare	Haiti	M.S.
Daniel Kriechbaum	W. Germany	Special
Project Title: Breeding for Disease and Drought Resistance and Increased Genetic Diversity.		
Sharmala Bhaskaran	India	Post doc.
Newton Ochanda	Kenya	M.S.
Sebastine Onwika	Nigeria	M.S.
Sharzesh Paliwal	India	Technician
Abdullahi Wardere	Somalia	M.S.
Alberto Betancourt	Mexico	Ph.D.
Jose Armando Valdez	Mexico	Ph.D.
M.A. Pastor	Peru	Ph.D.
Sansan Da	Upper Volta	Ph.D.
Azim Abdalla	Sudan	Ph.D.
Yilma Kedebe	Ethiopia	Ph.D.
George Wall	El Salvador	Ph.D.
Francisco Gomez	Honduras	Ph.D.
Jose Sifuentes	Mexico	Ph.D.
Quinten Kubicek	Venezuela	Ph.D.
Marcel Galiba	Senegal	Ph.D.
Mamourou Diourte	Mali	M.S.
Geoffrey Thomas	Australia	Ph.D.
Project Title: Plant Breeding		
Mohammad Saeed	Pakistan	Ph.D.
A.B. Mohamed	Sudan	Ph.D.
Robert Mushi	Tanzania	Ph.D.
Catalino Flores	Philippines	Ph.D.
Louis Mazhani	Botswana	M.S.
Amadu Fofana	Senegal	M.S.
Mohammed Abdelrahman	Sudan	Ph.D.
Project Title: Sorghum Host Plant Resistance and Genotype Evaluation.		
R.C. Mabesa	Philippines	Ph.D.
A.A. Aziz	Sudan	M.S.
C.R. Bastos	Brazil	M.S.
C.R. Bastos	Brazil	Ph.D.
A.A. Aziz	Sudan	Ph.D.
J.A. Cuarezma	Nicaragua	Ph.D.
Project Title: Adaptation of Sorghum to Highly Acid Tropical Soils.		
Jorge A. Cuarezma	Nicaragua	Ph.D.
Ing. Agr. Manuel Coronado	Colombia	non-degree

Student	Home Country	Degree Sought
Project Title: Evaluation and Development of Sorghum/Millet Germplasm for Arid Land Agriculture.		
Sylvestor R. Boye-Goni	Ghana	Ph.D.
Charles F. Chigwe	Malawi	Ph.D.
Paul Bimpolo	Congo	M.S.
Abdul Agbary	Yemen	Ph.D.
Ibrahim Yassin	Sudan	Ph.D.
Mohamed Abbas	Sudan	M.S.
Moncel Ben Hammouda	Tunisia	M.S.
Ahmen Sh. H. Khalif	Somalia	M.S.
S. Mater	Yemen	M.S.
R. Matilo	Botswana	M.S.
Mohammed A. Saeed	Yemen	M.S.
Guimma Shawesh	Libya	M.S.
Entomology		
Project Title: Storage and Preservation of Pearl Millet and Sorghum.		
Yosif Seifelnasr	Sudan	Ph.D.
Alawia Fadelmula	Sudan	M.S.
Manuel Zeledon	Costa Rica	Ph.D.
Lawrence Wongo	Sudan	Ph.D.
Rafael Urrelo	Peru	Ph.D.
Anne Itto	Sudan	Ph.D.
Cletus Asanga	Cameroon	M.S.
Jose Espinal	Honduras	M.S.
Nour A.E. Sinada	Sudan	M.S.
Ampai Ungsunantwiwat	Thailand	Post doc.
Dansou Kossou	Benin	Post doc.
Project Title: Development and Evaluation of Systems for Controlling Insect Pests of Sorghum by Integration of Resistant Varieties, Cultural Manipulation and Biological Control.		
Warlarde Chantrasorn	Thailand	Ph.D.
Jose Waquil	Brazil	Ph.D.
Marta Becerra	Colombia	M.S.
Chris Manthe	Botswanna	Ph.D.
Bentara Dayawathie	Sri Lanka	Ph.D.
Ousmane Youm	Senegal	M.S.
Ousmane Youm	Senegal	Ph.D.
Ronaldo Sequeira	Nicaragua	M.S.
Ali Ali	Sudan	M.S.
Pathology		
Project Title: Sorghum and Millet Pathology.		
Quentin Kubicek	Venezuela	Ph.D.
Wolfgang Schuh	Germany	Ph.D.
Malojirao Pawar	India	Ph.D.
George Wall	El Salvador	Ph.D.
Baikabile Motalaote	Botswana	M.S.
Mamourou Diorte	Mali	M.S.
S. Shabani	Zaire	M.S.
S. Shabani	Zaire	Ph.D.
M. Pastor-Corrales	Peru	Ph.D.
M. Natural	Philippines	Ph.D.
George Wall	El Salvador	M.S.
Jose Sifuentes	Mexico	M.S.
Laura Giorda	Argentina	M.S.
Project Title: Sorghum Disease Resistance Evaluation and Pathogenicity Investigations.		
Jorge A. Cuarezma	Nicaragua	Ph.D.
Tobias Ochor	Kenya	M.S.
Julio Borbon	Dominican Republic	M.S.
Yacine Kouyate	Mali	Ph.D.
Victor Canez	Dominican Republic	M.S.
Jeannette Domingez	Dominican Republic	Training
Weerachai Sukolapong	Thailand	Training
Tin Soe	Burma	Training
Luis Cediera	Brazil	Training
Candido Bastos	Brazil	Training

Student	Home Country	Degree Sought
Food Quality and Utilization		
Project Title: Food and Nutritional Quality of Sorghum.		
S. Bedolla	Mexico	Ph.D.
J.O. Akingbala	Nigeria	Ph.D.
San San Da	Upper Volta	Ph.D.
H.M. Sadaan	Tanzania	M.S.
U. Akoma	Nigeria	M.S.
M. Gonzalez-Palacios	Mexico	M.S.
H. Almeida-Dominquez	Mexico	M.S.
C. Choto	El Salvador	M.S.
P. Leungchaikul	Thailand	M.S.
C. Domanski	Argentina	M.S.
C. Choto	El Salvador	Ph.D.
S. Serna-Saldivar	Mexico	Ph.D.
F. Gomez	Honduras	Ph.D.
F. Gomez-Gonzalez	Mexico	Ph.D.
N. Vivas-Rodriguez	Mexico	M.S.
E. Riba	Panama	M.S.
M. Galiba	Senegal	Ph.D.
C. Blanchette	Haiti	M.S.
Project Title: Farming Systems Research in Mexico.		
Oscar San German A	Mexico	Lic.
Hugo Ortiz M.	Mexico	Lic.
Rosalia Gonzalez R.	Mexico	Lic.
Silvia Delgadillo	Mexico	Lic.
Pedro Vargas G.	Mexico	Lic.
Marco Callegjas F.	Mexico	Lic.
Gloria Quintero B.	Mexico	Lic.
Valentin Niembro D.	Mexico	Lic.
Jose Colli	Mexico	Lic.
Uriel Sanchez M.	Mexico	Lic.
Bernal Gellida E.	Mexico	Lic.
Project Title: Chemical and Physical Aspects of Food and Nutritional Quality of Sorghum.		
G.B. Cagampang	Philippines	Ph.D.
L. Monawar	Sudan	Training
M. Oumarou	Niger	Training

Appendix XI. Workshops and Short Courses.

Name	Where	When	Attendance	Purpose
Project Title: Seedling Vigor and Stand Establishment in Pearl Millet.				
Sorghum in the '80s	ICRISAT	1984		Chairman of session
Agrimeteorology of Sorghum and Millet in the Semi-arid Tropics	ICRISAT	1982		Presented paper
Project Title: Mineral Element Uptake, Use, Efficiency and Tolerance in Sorghum and Millet.				
Consultative Meeting and Review of Sorghum Research and Development Program in the Philippines	Los Banos, Philippines	6/84	40	Represented INTSORMIL in planning PCARRD's future role in sorghum research
Sorghum in the '80s	India	11/81		Presented paper
Breeding of Sorghum	El Baton, Mexico	4/83		Presented paper
Strategy for control of stalk-root in sorghum	Bellagio, Italy	11/83		Presented paper
Evaluating sorghum for Al toxicity in tropical soils of Latin America	Cali, Colombia	4/84		Presented paper
Project Title: Water and Temperature Effects on Sorghum and Millet as Related to Production and Breeding.				
Sorghum in the '80s	Hyderabad, India	10/81		
Iowa State University Plant Stress Lecture Series	Iowa			
IRRI Potential Crop Productivity Symp.				
National Science Foundation Stress Workshop	Duke University			
INTSORMIL-ICRISAT Plant Breeding Workshop	CIMMYT			
Oklahoma International Drought Symposium	Oklahoma			
Project Title: Breeding for Productivity in Sorghum.				
Sorghum in the '80s	Hyderabad, India	11/81		Gave papers
Hybrid Sorghum Seed Workshop	Wad Medani, Sudan	11/83		Participated in study group
International Symposium on Sorghum Grain Quality	ICRISAT	10/81		Gave paper
Latin America Sorghum Quality Short Course	El Batan, Mexico	4/82		Gave paper
Sorghum Breeding Workshop for Latin America	CIMMYT	4/83		Gave paper
International Sorghum Entomology Workshop	College Station, Texas	7/84		Field discussion leader
Sorghum Downy Mildew Workshop	Corpus Christi, Texas	6/82		Gave paper
INTSORMIL Graduate Student Workshop and Tour	College Station, Texas	6/84		Led field tour
Sorghum Breeding Lecture on current strategies in germplasm improvement	Buenos Aires, Argentina	4/84		Lectured
Conference on chemical regulators of plants and insects	Monterrey, Mexico			Gave paper
Workshop on plant hormone research methods and symp. on hormonal regulations of the development of plants	Mexico City, Mexico	1981		Gave paper
South Texas Disease, Adaptation and Breeding Nursery		Annually		Discussion leader and field tour
Project Title: Breeding for Insect Resistance and Efficient Nutrient Use.				
Sorghum Breeding Workshop for Latin America	Mexico City, Mexico	4/83		Inform Latin America sorghum breeders of new techniques and germplasm available. Foster cooperation among sorghum breeders.
International Sorghum Entomology Workshop	College Station, Texas	7/84		Discuss state of sorghum entomology

Name	Where	When	Attendance	Purpose
Project Title: Plant Breeding				
Maize and Sorghum	Lima	1979		Presented paper
Farming Systems	Dakar	1981		Consulted with ministry and university people
Mexico/Multiple Crops	Saltillo	1981		Presented short course
Mexico/Genetics Conference	Saltillo	1982		Presented paper
Mexico/Breeding	CIMMYT	1983		Presented paper
Dominican Republic/Sorghum	Santa Domingo	1984		Presented paper
Mexico/Farming Systems	CIMMYT	1984		Presented paper
Philippines/Sorghum	Los Banos	1984		Presented paper
Project Title: Sorghum Host-Plant Resistance and Genotype Evaluation.				
Evaluating Sorghum for Tolerance to Al-Toxic Tropical Soils in Latin America	CIAT	5/84	50	Coordinated research and trained LDC scientist
Sorghum in the 80's	ICRISAT	11/81		International review of sorghum research
Plant Pathology	CIMMYT	6/82		Trained LDC scientists
Plant Breeding	CIMMYT	4/83		Trained LDC scientists
Farming Systems	CIMMYT	9/84		Trained LDC scientists
Project Title: Adaptation of Sorghum to Highly Acid Tropical Soils.				
Evaluating Sorghum for Tolerance to Al-Toxic Tropical Soils in Latin America	CIAT Colombia	5/84	50	Coordinated research and trained LDC scientists
Sorghum Breeding	CIMMYT	4/83		Presented paper
Project Title: Development and Evaluation of Systems for Controlling Insect Pests of Sorghum by Integration of Resistant Varieties, Cultural Manipulation and Biological Control.				
International Short Course in Host Plant Resistance	College Station, Texas	1979		
IX International Congress of Plant Protection	Washington, D.C.	1979		
Consortium for International Crop Protection	Berkeley, California	1980-1984		
Biennial Plant Resistance Workshop		1980 and 1982		
Sorghum Improvement Conference of North America		1980 and 1982		
Sorghum in the '80s	Hyderabad, India	1981		
Sorghum Breeding Workshop in Latin America	Mexico	1983		
Sorghum Insect Symposium and Field Tour	Corpus Christi, Texas	1983		
International study workshop on host plant resistance and its significance in pest management	Nairobi	6/84		
International Sorghum Entomology	College Station, Texas	6/84		
Project Title: Sorghum and Millet Pathology				
Sorghum Disease Short Course for Latin America	Mexico	3/81	52	Sorghum pathologist training
South Texas Sorghum Disease Conference	Corpus Christi, Texas	6/82	75	Review current status of sorghum disease control
South Texas Sorghum Insect and Disease Conference	Corpus Christi, Texas	7/83	75	Review current status of sorghum disease control
South Texas Graduate Training Field Days	Corpus Christi, Texas	6/84	75	Review current status of sorghum disease control
Sorghum Disease Short Course for Latin America	Mexico	3/81		Training of Latin American sorghum workers
Sorghum in the '80s	Hyderabad, India	10/81		Sorghum quality in India
Sorghum Breeding/Mexico	Mexico	3/83		Training of Latin American sorghum workers
Sorghum Quality	Mexico	3/82		
Stalk and Root Rots	Ballagio	11/83		Develop goals for future collaborative research

Name	Where	When	Attendance	Purpose
Project Title: Sorghum Disease Resistance Evaluation and Pathogenicity Investigations.				
Sorghum Disease Short Course for Latin America	Mexico	3/81	52	Train Latin American sorghum pathologists
Striga Workshop	Raleigh, North Carolina	8/82	27	Train workers in Striga control
Consultative group discussion on research needs and strategies for control of sorghum root and stalk rot diseases	Bellagio, Italy	12/83	28	Discuss research needs in sorghum root and stalk rots
Sorghum in the '80s	Hyderabad, India	11/81		Discuss sorghum outlook for this decade
Project Title: Food and Nutrition Quality of Sorghum.				
INTSORMIL Graduate Student/Faculty Sorghum Workshop and Field Day	College Station, Texas	6/84	40	Interaction opportunity between faculty and graduate students
International Symposium on Food Quality	Hyderabad, India	10/81		Combine and correlate research findings on sorghum to date and map out future research needs on an international basis
Sorghum Food Quality Workshop	El Batan, Mexico	4/82		Dissemination of available information on sorghum
Workshop on Processing of Sorghum and Millet	Vienna	6/84		Gave opening paper
Primer Seminario National Sobre Produccion y Utilizacion del Sorgo	Santa Domingo	2/84		Presented information on first national meeting on sorghum in the Dominican Republic
Taller Sobre Produccion y Calidad	Irapuato	9/83		First meeting in which all major Mexican sorghum research centers were represented
Plant Breeding, Methods and Approaches in Sorghum	El Batan, Mexico	4/83		Dissemination of information
Sorghum Production Genetics and Quality for Feed	Sonora, Mexico	3/83		Week of lectures to graduate students
Sorghum Diseases	El Batan, Mexico	4/82		Gave presentation to other scientists and industry researchers
Sorghum in the '80s	Hyderabad, India	10/81		Summation of current knowledge of sorghum and planning for future research needs
Sorghum Grain Quality and Improvement	Buenos Aires	1980		PROSORGO short course and seminar
Project Title: Chemical and Physical Aspects of Food and Nutritional Quality of Sorghum.				
International Symposium on Sorghum Grain Quality	India	11/81		Presented lecture
Sorghum in the '80s	India	11/81		
Sorghum Food Quality Workshop	Mexico	4/82		Presented lecture

Appendix XII. Travel and Technical Assistance.

Name	Where	When	Purpose	No. of days
Project Title: Identify and Evaluate Physiological and Development Processes Affected by Environmental Stresses.				
Kanemasu	Hyderabad, India	1978	Meetings	5
Kanemasu	Hyderabad, India	1982	Workshop	5
Kanemasu	Morocco	1983	Meetings	21
Project Title: Seedling Vigor and Stand Establishment in Pearl Millet.				
R.L. Vanderlip	India	1979	Pearl millet and cultural practices	21
R.L. Vanderlip	India	1981	Sorghum in the '80s	10
R.L. Vanderlip	Senegal	1981	SAFGRAD Farming Systems Conference	9
R.L. Vanderlip	Sudan	1982	Agreement for INTSORMIL Program	10
R.L. Vanderlip	India	1982	ICRISAT, INTSORMIL, WMO Agriclimatology Conference	10
Project Title: Agricultural Climatology of Sorghums and Millets.				
R.E. Neild	India	1982	International Symposium on Agrometeorology of Sorghum—invited paper	5
R.E. Neild	China	1982	Lectures at Beijing University and Nanjing University, People's Republic of China	11
R.E. Neild	Laguna	1984	Sorghum Research and Development in the Philippines—consultative meeting and revision by Philippine Council for Agriculture	2
Project Title: Agronomy and Cropping Systems.				
C.A. Francis	Mexico	1980	Establish contacts in Honduras, Guatemala, and attend sorghum workshop in Mexico	8
M.D. Clegg	Egypt	1980	Survey sorghum production and potential research needs and collaborative efforts with EMCIP	9
C.A. Francis	Senegal	1981	SAFGRAD Farming Systems Research Workshop	6
C.A. Francis	Philippines	1981	Develop collaborative plan with IRRI	5
M.D. Clegg	Egypt	1981	Memorandum of Agreement	17
M.D. Clegg	Botswana	1981	Crop Production Planning Program for sorghum/grain legume response	11
M.D. Clegg	India	1981	Present paper	6
C.A. Francis	Tanzania	1982	Explore potential INTSORMIL activities and evaluate constraints of sorghum and millet	16
M.D. Clegg	Kenya	1983	Review cropping systems for AID	11
M.D. Clegg	Botswana	1983	Evaluate progress in legume/soybean systems	
C.A. Francis	Dominican Republic	1983	Supervise field research and explore potential interest for collaborative research	6
C.A. Francis	Dominican Republic	1984	Attend workshop	8
Joann Logan	Dominican Republic	1984	Attend workshop	8
J.R.A. Santos	Philippines	1984	Participate in Sorghum Research and Development Progress Workshop	2
Project Title: Mineral Element Uptake, Use Efficiency and Tolerance in Sorghum and Millet.				
J.W. Maranville	Sudan	1980	To initiate INTSORMIL program	15
R.B. Clark	India, Philippines	1981	Sorghum in the '80s	31
R.B. Clark	West Germany	1982	Visit labs and scientists	14
J.W. Maranville	Philippines	1982, 1983	Sabbatical leave	350
J.W. Maranville	Thailand, India	1983	Consult at ICRISAT and Thailand program	14
R.B. Clark	Mexico, Honduras, Colombia, Brazil	1983	INTSORMIL/ICRISAT Workshop at CIMMYT	32
R.B. Clark	Italy, West Germany	1983	INTSORMIL/ICRISAT Workshop	15
J.W. Maranville	Italy, Egypt	1983	INTSORMIL/ICRISAT Workshop	13
R.B. Clark	Colombia	1984	INTSORMIL/ICRISAT Workshop	12
J.W. Maranville	Philippines	1984	Coordinate PICARD/INTSORMIL Workshop	14
Project Title: Water and Temperature Effects on Sorghum and Millet as Related to Production and Breeding.				
J.D. Eastin	India	1981	Sorghum in the '80s	
J.D. Eastin	Bellagio	1983	Bellagio Stalk Rot Conference	
J.D. Eastin	Mexico	1983	Breeding Workshop in Mexico	
J.D. Eastin	CIMMYT		Cooperation with V. Guiragossian, ICRISAT scientist at CIMMYT, on cool tolerance and drought tolerance	
Project Title: Seed Factors Influencing Germination, Emergence and Stand Establishment of Sorghum and Pearl Millet.				
G.A. Reusche	Upper Volta	1982	Seed use survey	28

Name	Where	When	Purpose	No. of days
Project Title: Breeding for Insect Resistance and Efficient Nutrient Use.				
A.B. Onken	Mali	1981	Memorandum of Understanding	8
A.B. Onken	Senegal	1982	Fact-finding relative to joint research	2
A.B. Onken	India	1982	ICRISAT review	11
A.B. Onken	India	1982	Discuss research plan and establish likages	13
A.B. Onken	Niger	1982	Discuss potential research and plans	7
A.B. Onken	Mali	1982	Discuss research plans	7
G.C. Peterson	Honduras	1982	Evaluate sorghum breeding germplasm	7
G.C. Peterson	Mexico	1983	Sorghum Breeding Workshop for Latin America	6
A.B. Onken	Mali	1984	Discuss work plan, research and planning	
Project Title: Plant Breeding.				
C.A. Francis	Peru	1979	Workshop	8
C.A. Francis	Colombia	1980	Consulting	10
C.A. Francis	Colombia	1981	Consulting	8
C.A. Francis	Senegal	1981	Workshop	6
C.A. Francis	Mexico	1981, 1983	Consulting, teaching	5-10
C.A. Francis	Mexico	1983, 1984	Workshops	5-10
C.A. Francis	Tanzania	1982	Thesis advisory	5
C.A. Francis	Morocco	1982, 1984	Administrative	10
C.A. Francis	Dominican Republic	1983	Thesis advisory	5
C.A. Francis	Dominican Republic	1984	Workshop	5
C.A. Francis	Tanzania	1984	Consulting	6
C.A. Francis	Kenya	1984	Consulting	4
C.A. Francis	Botswana	1984	Consulting	14
W.M. Ross	Mexico	1983	Workshop	7
W.M. Ross	Botswana	1984	Consulting	10
C.I. Flores	Philippines	1984	Workshop	8
Project Title: Sorghum Host-Plant Resistance and Genotype Evaluation.				
L.M. Gourley	Mexico	1980	INTSORMIL agreement	4
J.C. Denis	Senegal	1981	OAS meeting	10
L.M. Gourley	Colombia	1981	CIAT agreement	5
N. Zummo	Mexico	1981	Workshop	7
L.M. Gourley	India, Thailand, Japan	1981	Sorghum in the '80s	28
S.B. King	India, Thailand, Japan	1981	Sorghum in the '80s	28
H.N. Pitre	India, Thailand, Japan	1981	Sorghum in the '80s	18
L.M. Gourley	Colombia	1982	Nurseries	21
L.M. Gourley	Colombia, Brazil	1982	Nurseries	25
L.M. Gourley	Colombia	1982-84	Assigned	600
L.M. Gourley	Mexico, Honduras	1983	Workshop nurseries	12
L.M. Gourley	Brazil	1983	Brazil agreement	12
L.M. Gourley	Peru, Brazil	1984	Acid soil research coordination	17
Project Title: Adaptation of Sorghum to Highly Acid Tropical Soils.				
Lynn Gourley	Colombia	1982-84	Assigned	600
Lynn Gourley	Mexico	1983	Workshop	7
Lynn Gourley	Honduras	1983	Review breeding material	5
Lynn Gourley	Brazil	1983	Program coordination	12
Lynn Gourley	Peru	1984	Acid soil research coordination	14
Project Title: Storage and Preservation of Pearl Millet and Sorghum.				
R.B. Mills (with Dansou Kossou)	Senegal	1982	Study farm storage	12
D. Kossou	Benin	1981	Observe millet storage	21
Y. Seifelnasr	Sudan	1982	Observe farm and village millet storage in Western Sudan	21

Name	Where	When	Purpose	No. of days
Project Title: Development and Evaluation of Systems for Controlling Insect Pests of Sorghum by Integration of Resistant Varieties, Cutlural Manipulation and Biological Control.				
G.L. Teetes	Guatemala	1979	Evaluate and select in midge resistant sorghum nurseries	5
G.L. Teetes	Nepal	1979	Technical assistance relative to insecticide use	14
G.L. Teetes	India	1980	Sorghum in the '80s planning committee	8
G.L. Teetes	Honduras	1981	Collaborative research program development	5
G.L. Teetes	Trinidad	1981	Technical assistance, IPM instruction	10
G.L. Teetes	India	1983	Develop collaborative INTSORMIL/ICRISAT South Africa Regional Project	8
G.L. Teetes	Cameroon	1983	Technical assistance, IPM capabilities and training	33
G.L. Teetes	Kenya	1984	International Study Workshop on Host Plant Resistance in Pest Management	14
F.E. Gilstrap	Honduras	1981	Establish collaborative research program for student	2
F.E. Gilstrap	India	1981	Sorghum in the '80s	10
F.E. Gilstrap	Sir Lanka	1981	Review collaborative research program	4
R. Jones	Honduras	1982, 1983	Conduct collaborative research	330
G.L. Teetes	Honduras	1982	Review collaborative research program	2
F.E. Gilstrap	Honduras	1982	Reivew collaborative research program	4
F.E. Gilstrap	Niger	1983	Technical assistance, biological control of stemborers	9
G.L. Teetes	Niger	1983	Technical assistance, biological control of stemborers	22
G.L. Teetes	Niger	1984	Technical assistance, panicle-bug complex	7
G.L. Teetes	Mali	1984	Technical assistance, panicle-bug complex	6
Project Title: Sorghum and Millet Pathology.				
R. Toler	Mexico	1981	Sorghum disease workshop	9
P. Berger	Mexico	1983	Virus survey	5
R. Frederiksen	Mexico	1979	Collaborative research	5
R. Frederiksen	Sudan	1980	Memorandum of understanding	15
R. Frederiksen	Mexico	1981	Disease conference	8
R. Frederiksen	Mexico	1981	Collaborative research	5
R. Frederiksen	Egypt	1981	Review research	15
R. Frederiksen	India	1981	Sorghum in the '80s/Sorghum Quality Symposium	14
R. Frederiksen	Sudan	1981	Collaborative research	12
R. Frederiksen	Colombia	1982	CIAT collaboration	5
R. Frederiksen	Philippines	1983	Collaborative research	5
R. Frederiksen	Sudan	1983	Plan conference	5
R. Frederiksen	India	1983	Prepare joint conference collaborative research	14
R. Frederiksen	Italy	1983	Stalk Rot Conference	8
R. Frederiksen	Mexico	1983	Breeding conference	5
R. Frederiksen	Brazil	1983	Memorandum of understanding	5
R. Frederiksen	Brazil	1984	Collaborative research	7
R. Frederiksen	CIAT/Colombia	1984	Collaborative research	15
J. Craig	Mexico	1981	Disease workshop	8
J. Craig	India	1981	Symposium	9
G. Odvody	Mexico	1981	Disease workshop	8
G. Odvody	Italy	1983	Stalk Rot Conference	7
D. Collins	Honduras	1984	Set up micrologger	4
D. Collins	Mexico	1982	Set up micrologger	5
Project Title: Sorghum Disease Resistance Evaluation and Pathogenicity Investigations.				
N. Zummo	Mexico	1981	Sorghum disease workshop	9
N. Zummo	India	1981	Sorghum conference	10
N. Zummo	Thailand	1981	Sorghum research	5
N. Zummo	Mexico	1983	Sorghum disease workshop	8
N. Zummo	Gambia	1983	Sorghum and millet conference	7
N. Zummo	Niger	1983	Sorghum and millet disease survey	9
N. Zummo	Brazil	1983	Sorghum research	7
N. Zummo	Colombia	1983	Sorghum research	6
N. Zummo	Niger	1984	Sorghum and millet research	10
N. Zummo	Italy	1983	Sorghum Root and Stalk Rot Conference	9
L.E. Trevathan	Colombia	1983	Sorghum research	5
Jorge A. Cuarezma	Colombia	1983	Sorghum research	81

Name	Where	When	Purpose	No. of days
Project Title: Food and Nutrition Quality of Sorghum.				
L.W. Rooney	Washington, D.C.	1979	Conference	6
M.N. Khan	Washington, D.C.	1979	Conference, field evaluations	6
L.W. Rooney	Mali	1979	Research	10
L.W. Rooney	Scottsdale, Arizona	1980	Planning meeting, Poza Rico, ICRISAT-CIMMYT Workshop	4
L.W. Rooney	Mexico	1980	CIMMYT Workshop	5
M.N. Khan	Mexico	1980	Workshop	5
J.O. Akingbala	New Orleans, Louisiana	1980	Conference	5
M. Gonzalez	New Orleans, Louisiana		Conference	5
M.N. Khan	New Orleans, Louisiana	1980	Conference	5
L.W. Rooney	Lubbock, Texas	1980	Research, planning	5
M.N. Khan	Lubbock, Texas	1980	Research, planning	5
L.W. Rooney	San Antonio, Texas	1980	Conference	4
M.N. Khan	San Antonio, Texas	1980	Conference	4
L.W. Rooney	Halfway, Texas	1980	Research, planning	3
L.W. Rooney	West Lafayette, Louisisana	1980	Meetings, planning	5
L.W. Rooney	Argentina	1980	Meetings, planning	5
L.W. Rooney	Argentina	1980	Consultant, meeting	11
L.W. Rooney	Mexico	1981	Workshop, teaching	6
L.W. Rooney	Lubbock, Texas	1981	Research, planning	4
L.W. Rooney	India	1981	Management, meeting	60
J.W. Rooney	Denmark	1981	Workshop, research	21
D.H. Hahn	Houston, Texas	1981	Workshop	1
L.W. Rooney	Mali	1981	Research, planning	15
L.W. Rooney	Dominican Republic	1981	Workshop	7
S. Bedolla	Mexico	1981	Workshop	5
J.L. Akingbala	Denver, Colorado	1981	Conference	5
L.W. Rooney	Lubbock, Texas	1981	Research, planning	5
M.M. Morad	Fort Worth, Texas	1981	Conference	2
L.W. Rooney	San Antonio, Texas	1982	Meeting	1
L.W. Rooney	Kansas City, Kansas	1982	Meeting	3
L.W. Rooney	Mexico	1982	Workshop	5
S. Bedolla	Mexico	1982	Workshop	5
C.F. Earp	California	1982	Conference	6
C. McDonough	New York	1982	Technical training	3
M.M. Morad	Dallas, Texas	1982	Conference	1
L.W. Rooney	Lubbock, Texas	1982	Research, planning	1
L.W. Rooney	Lubbock, Texas	1982	Research, planning	2
L.W. Rooney	Dallas, Texas	1982	Research, planning	1
G. Fulcher	College Station, Texas	1982	Teaching, consulting	7
M.M. Morad	San Antonio, Texas	1982	Conference	5
C.E. Choto	San Antonio, Texas	1982	Conference	5
L.W. Rooney	San Antonio, Texas	1982	Conference	5
S. Bedolla	San Antonio, Texas, Juarez, Mexico	1982	Conference, tortilla trials	4
S. Bedolla	El Paso, Texas	1982	Data collection INTSORMIL	4
L.W. Rooney	Scottsdale, Arizona	1983	Planning, meeting	4
L.W. Rooney	West Africa	1983	Field trials, planning, research	21
L.W. Rooney	Honduras	1983	Food quality trial, data collection	7
L.W. Rooney	Brownsville, Texas	1983	Conference	3
D.H. Hahn	Brownsville, Texas	1983	Conference	3
L.W. Rooney	Mexico	1983	Management workshops	6
S. Bedolla	Mexico	1983	Sorghum breeding workshop	6
L.W. Rooney	Lubbock, Texas	1983	Data collection	2
L.W. Rooney	Denmark	1983	Sorghum food quality research	4
L.W. Rooney	Mexico	1983	Teaching, workshops	5
L.W. Rooney	Kansas City, Kansas	1983	Conference	7
M.M. Morad	New Orleans, Louisiana	1983	Food exposition	5
L.W. Rooney	New Orleans, Louisiana	1983	Conference	5
L.W. Rooney	Scottsdale, Arizona	1984	INTSORMIL planning meeting	4
Edgard Riba	Dominican Republic	1984	Food quality workshop	5
L.W. Rooney	Dominican Republic	1984	Food quality workshop	5
L.W. Rooney	Austria	1984	ICC conference and workshop	7
L.W. Rooney	West Lafayette, Louisiana	1984	INTSORMIL meetings, planning	3
C.E. Choto	Honduras	1984	Field trials and data collection	8
S. Serna-Saldivar	Mexico	1984	Short course and lecture, University of Sonora	8

Name	Where	When	Purpose	No. of days
Project Title: Chemical and Physical Aspects of Food and Nutritional Quality of Sorghum.				
Kirleis	Mali and Upper Volta	1979	Technical assistance	15
Kirleis	Sudan	1980	Begin work with Food Research Centre on food quality	10
Kirleis	Zambia	1981	Technical assistance	10
Kirleis	Sudan	1982	Establish agreement with ARC/Research, work with Food Research Center	17
Kirleis	Sudan	1983, 1984	Agreement with ARC/Acting Agriculture Country Coordinator	10

Research supported by grant AID/DSAN/XII/G-0149 from the Agency for International Development, Washington, D.C.

The Management Entity
University of Nebraska
Lincoln, Nebraska

Cover Photo: Millet harvest and threshing in Niger.