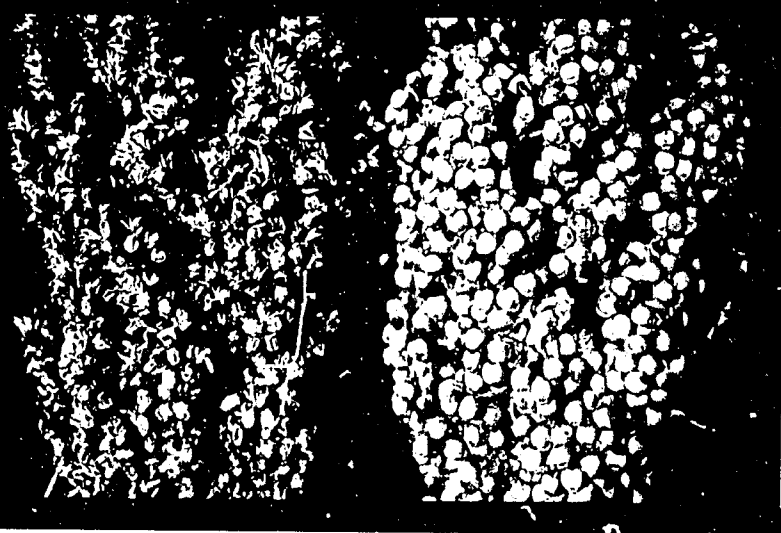
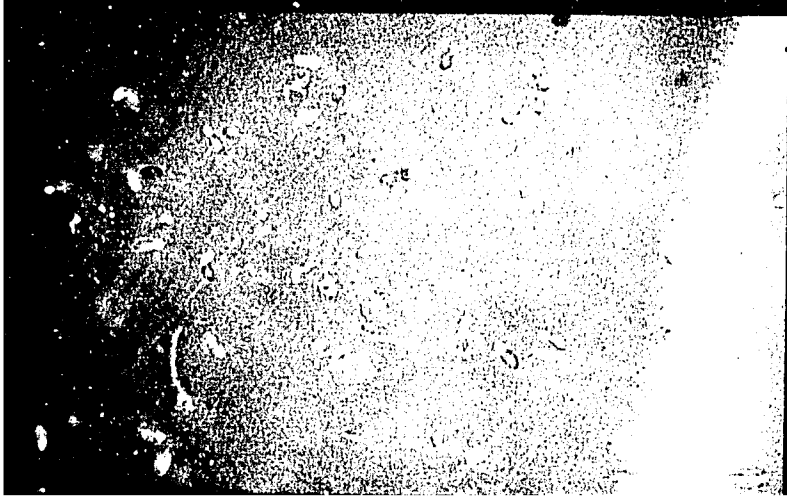
INTSORMIL



Annual Report 1993

SORGHUM/MILLET COLLABORATIVE RESEARCH SUPPORT PROGRAM (CRSP)



Fighting Hunger with Research ... a team effort

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Cover Photographs
(top to bottom)

1. Sorghum line exhibiting "stay green" character for drought tolerance on right and susceptible line on left. Charcoal rot resistance is associated with the "stay green" characteristic. (Photo courtesy of Dr. Darrell Rosenow)

2. Example of infested sorghum head by panicle feeding bugs on left and uninfested sorghum head on right at Samanko Research Station, Bamako, Mali. (Photo courtesy of Dr. George Teetes)

3. Dr. El Hilu Omer, Agriculture Research Corporation (ARC), Sudan, demonstrating inoculation technique on pearl millet to Mr. Issoufou Kolo, INRAN/Niger and Dr. Joseph Werder, former plant pathologist, ICRISAT Sahelian Center in Niger. (Photo courtesy of Dr. Richard Frederiksen)

4. Agar gel *Striga* seed germination assay of Sorghum line N13. N13 is a high *Striga* seed germination stimulant producer. (Photo courtesy of Dr. Larry Butler)

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INTSORMIL

Annual Report 1993

Fighting Hunger with Research . . . A Team Effort

Grain Sorghum/Pearl Millet Collaborative
Research Support Program (CRSP)

The Sorghum/Millet Collaborative Research Support Program (CRSP) is an initiative of the Agency for International Development, Grant No. DAN-1254-G-00-0021-00, Title XII and the Board for International Food and Agricultural Development and Economic Cooperation (BIFADEC), the participating U.S. Universities and other collaborating institutions.

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Kansas State University
Mississippi State University
University of Nebraska
Purdue University
Texas A&M University

INTSORMIL Institutions are affirmative action/equal opportunity institutions.

Contents

Introduction and Program Overview vi

1993 Project Reports 1

Sustainable Plant Protection Systems

Agroecology and Biotechnology in Stalk Rot Pathogens of Sorghum and Millet - L.E. Claflin and J.F. Leslie (KSU-108) 2

Low Input Ecologically Defined Management Strategies for Insect Pests on Sorghum - Henry N. Pitre (MSU-105) 10

Role of Polyphenols in Sustainable Production and Utilization of Sorghum and Millet - Larry G. Butler (PRF-104B and PRF-104C) 17

Disease Control Strategies for Sustainable Agricultural Systems - R.A. Frederiksen (TAM-124 and TAM-124B) 23

Integrated Insect Pest Management Strategies for Sustainable Agricultural Systems - George L. Teetes (TAM-125) 31

Biological Control Tactics for Sustainable Production of Sorghum and Millet - Frank E. Gilstrap (TAM-125B) 39

Development of Plant Disease Protection Systems for Millet and Sorghum in Semiarid Southern Africa - G.N. Odvody (TAM-128) 48

Sustainable Production Systems

Modelling Millet and Sorghum Establishment and Growth and Sustainable Crop Production - Richard L. Vanderlip (KSU-106) 56

Sustainable Production of Sorghum and Pearl Millet in Fragile, Tropical Acid Soils - Lynn M. Gourley and Guillermo Muñoz (MSU-111) 59

Economic and Sustainability Evaluation of New Technologies in Sorghum and Millet Production in INTSORMIL Priority Countries - John H. Sanders (PRF-105) 67

Resource Efficient Crop Production Systems - Max D. Clegg and Stephen C. Mason (UNL-113) 75

Nutrient Use Efficiency in Sorghum and Pearl Millet - Jerry W. Maranville (UNL-114) 82

Physiologically Derived Cultural and Genetic Enhancements of Water and Temperature Stress Induced Limitations - Jerry D. Eastin (UNL-116) 90

Mechanisms of Environmental Stress Resistance in Sorghum and Pearl Millet Relative to Sustainable Production Systems - C.Y. Sullivan (UNL-123) 97

Germplasm Enhancement and Conservation

Pearl Millet Germplasm Enhancement for Semiarid Regions - W.D. Stegmeier (KSU-101) 102

Breeding Sorghum for Tolerance to Infertile Acid Soils - Lynn M. Gourley (MSU-104) 109

Breeding Sorghum for Increased Nutritional Value - John D. Axtell (PRF-103) 116

Development and Enhancement of Sorghum Germplasm with Sustained Tolerance to Drought, Striga, and Grain Mold - Gebisa Ejeta (PRF-107 and PRF-107B) 122

The Enhancement of Sorghum Germplasm for Stability, Productivity, and Utilization - Fred Miller - (TAM-121) 129

Germplasm Enhancement for Resistance to Pathogens and Drought and Increased Genetic Diversity - Darrell T. Rosenow (TAM-122) 139

Germplasm Enhancement through Genetic Manipulation for Increasing Resistance to Insects and Improving Efficient Nutrient Use in Genotypes Adapted to Sustainable Production Systems - Gary C. Peterson and Arthur B. Onken (TAM-123) 149

Breeding Sorghum for Stability of Performance Using Tropical Germplasm - David J. Andrews (UNL-115) 166

Breeding Pearl Millet for Stability Performance Using Tropical Germplasm - David J. Andrews (UNL-118) 170

Crop Utilization and Marketing

Chemical and Physical Aspects of Food and Nutritional Quality of Sorghum - Bruce R. Hamaker (PRF-112) 180

Utilization and Quality of Sorghum and Millet - L.W. Rooney (TAM-126) 187

Host Country Program Enhancement

INTSORMIL Collaborative Sites **198**

Botswana - M.D. Clegg 199

Egypt - J.D. Eastin 202

Honduras - Dan Meckenstock, Francisco Gomez and Gary Peterson 205

Mali - Darrell Rosenow and Aboubacar Toure 216

Niger - John D. Axtell and Ouendeba Botorou 224

South America (Colombia/CIAT) - Guillermo Munoz 229

Sudan - Gebisa Ejeta 235

Training

Introduction 244

Year 13 Training Participants 246

Year 13 SADC/ICRISAT Training Participants 248

Appendices

INTSORMIL Buy-Ins 252

INTSORMIL Sponsored and Co-Sponsored Workshops 1979 - 1993 255

Acronyms 256

Introduction and Program Overview

The INTSORMIL program, initiated in 1979, is one of ten Collaborative Research Support Programs (CRSPs) established through USAID core funding to respond to the Title XII legislation mandate to"... improve the participation of these (the agriculturally related) universities in the United States' governmental efforts internationally to apply agricultural sciences more effectively to increasing world food production and provide... support to the application of science to solving developing countries' food and nutrition problems". The INTSORMIL program was designed to respond to the intent of the Title XII legislation by focusing on grain sorghum and pearl millet related issues in strategically selected regions of the world.

Sorghum and millet are important world foods crops in moisture stressed regions of the world. They are staple foods for millions in Africa which, in their area of adaptation, cannot be substituted by other cereals. Sorghum is also a major feed grain in the U.S.

In working with selected host countries where sorghum and millet are important crops, INTSORMIL has mobilized the institutional and technical expertise of eight land-grant universities to focus on the special constraints of sorghum and millet production, processing, utilization, and marketing in the collaborating host countries. The universities which are still active in the INTSORMIL CRSP are Kansas State University, Mississippi State University, University of Nebraska, Purdue University, and Texas A&M University. The prime sites actively collaborating with INTSORMIL are Botswana, Colombia, Honduras, Mali, Niger and Sudan. Several other countries such as Senegal, Burkina Faso, Egypt, Kenya, Zimbabwe and El Salvador are also collaborating at a lower level.

The primary approach for INTSORMIL to reach its goal is to foster and cultivate the collaborative research mode involving the partnership of U.S. and host country scientists. They develop and transfer appropriate scientific technologies and strategies for alleviating the dominant sorghum and millet production and utilization constraints of the participating host countries and the U.S. Building and strengthening the manpower and the institutional capacities of the host countries for implementing effective collaborative research programs continues to be an important and necessary part of the INTSORMIL CRSP. INTSORMIL is committed to increasing production while maintaining and enhancing the natural resource base of sorghum and millet production both in the host countries and the U.S.

INTSORMIL currently provides technical backstopping, conducts collaborative research, trains national staff and students, and contributes operational support to National Agricultural Research Systems (NARS) grain sorghum and pearl millet programs. The success of INTSORMIL ca attributed to five unique features.

- INTSORMIL capitalizes on over 90% of U.S. Uni sities grain sorghum and pearl millet research cap where most basic and strategic research is conduc This allows the unique opportunity to support complement applied field work conducted at N sites by adding an otherwise unknown dimensio the research.

- INTSORMIL is an integrated, interdisciplinary ganization encompassing breeding, agronomy, ph ology, insect and disease management, food qua and economics.

- INTSORMIL enhances the capacity of NARS to sc country and region-specific problems through laborative research, thus increasing NARS techni and institutional productivity.

- INTSORMIL activities are constraint and NA driven: identification and alleviation of priority p duction constraints are achieved in concert w NARS.

- The INTSORMIL strategy focuses on five techni thrusts, each aimed at increasing productivity a improving sustainability:

  * Germplasm Enhancement—the development of resource efficient cultivars.

  * Sustainable Production Systems—the establishment of environmentally safe and financially profitable production systems.

  * Sustainable Plant Protection Systems—the deve opment of environmentally sound and economical pest control systems.

  * Crop Utilization and Marketing —the development of shelf stable processed foods with good marketing potential as well as improving traditional food processing systems.

  * National Sorghum and Millet Research Program Enhancement —short and long term training for NARS staff, equipment procurement, and overall NARS operations support.

Administration and Management

The University of Nebraska (UNL) is the Management Entity (ME) for the Sorghum/Millet CRSP and is the primary grantee of USAID. UNL subgrants are made to the participating U.S. Universities for the research projects between individual U.S. scientists and their host country counterparts. Country project funds, managed by the ME and U.S. participating institutions, flow to the country program in support of the research activities at the host country level. The Board of Directors (BOD) of the CRSP serves as the top management/policy body for the CRSP. The Technical Committee (TC), Ecogeographic Zone Council (EZC), External Evaluation Panel (EEP) and USAID. personnel advise and guide the ME and the Board in areas of policy, technical aspects, collaborating host country coordination, budget management, and review.

Several major decisions and accomplishments were made by the ME, BOD, TC and EZC during the past year.

- INTSORMIL's Strategic Plan for the next decade was developed. In connection with the preparation of the Strategic Plan, Brhane Gebrekidan, Acting Associate INTSORMIL Program Director, visited all INTSORMIL host country (except Colombia) and domestic institutions whose inputs were incorporated into the Strategic Plan Document. Subsequently two documents were prepared:

  * INTSORMIL CRSP: A Strategic Plan for the Next Decade

  * Status Reports on Domestic and Host Country Institutions

- The INTSORMIL External Evaluation Panel (EEP) completed its review of the host country sites, Botswana (March 6-10, 1993), Honduras (November 30-December 4, 1992), Mali (October 11-16, 1993) and Niger (October 16-23, 1993). Sudan and Colombia were not reviewed because of USAID travel restrictions to those countries. The Program Director traveled with the EEP to facilitate the site reviews.

  All the domestic sites (Texas, Mississippi, Nebraska, Kansas, and Purdue) were also reviewed during the year. The ME office was kept busy throughout the year organizing these extensive reviews of overseas and domestic sites.

- The major publications organized and published by the ME office during the year included:

  * INTSORMIL: Fighting Hunger with Research... MAKING HEADWAY

  * INTSORMIL Annual Report 1992, INTSORMIL Publication No. 93-2.

  * Proceedings of the Workshop on Social Science Research and the CRSPs (INTSORMIL Publication No. 93-3).

  * INTSORMIL Annual Report 1992, Executive Summary (INTSORMIL Publication No. 93-4).

- The INTSORMIL BOD approved the inclusion of host country representatives on both the TC and EZC.

- The INTSORMIL BOD approved the annual budget which includes a 7.8% reduction in funds.

- The Program Director, at the invitation of the Africa Bureau, represented the CRSP Council at the Africa Bureau sponsored workshop on "Agricultural Technology Development and Transfer Collaborators Workshop".

- The Program Director travelled to El Salvador and Honduras to pursue opportunities for a potential training contract with CENTA in El Salvador under a World Bank loan project and to finalize arrangements for the termination of INTSORMIL's resident scientist posting in Honduras.

Training

Training of host country scientists contributes to the capability of each host country research program to stay abreast of environmental and ecological changes which alter the balance of sustainable production systems. The strengthening of host country research institutions contributes to their capability to predict and be prepared to combat environmental and ecological changes which affect sorghum and millet. A well balanced institution will have to be prepared to prioritize and blend its operational efforts to accomplish the task of conserving and efficiently utilizing its natural resources.

Since its initiation, INTSORMIL trained a total of 739 students of which 517 were from foreign countries and the remaining from the U.S. Out of the total number of foreign students trained, 284 were from Africa. Of the trained African students, 14% were female. About 83% of the total number of trainees obtained M.S. or Ph.D. degrees while the remaining 17% received Post Doc, B.S., or short term visiting scientist training. The distribution of the INTSORMIL trainees in the past fifteen years by gender and geographic origin is given below.

Distribution of trainees by country of origin and gender

Origin	Females	Males	Total	% Females
U.S.	79	143	222	36%
Foreign	103	414	517	20%
Africa	39	245	284	14%
Others	64	169	233	27%
Total	182	557	739	25%

The majority of the trainees over the past fifteen years have returned to their home countries and are serving there in various capacities. Comprehensive data on the current jobs and assignments of all former INTSORMIL trainees are not available. Many hold responsible administrative and research positions in the NARS. These former trainees are real assets in promoting and strengthening collaborative research in the host countries.

Benefits to Host Countries

The lasting benefits and advantages of the collaborative research philosophy initiated and pursued in this CRSP are its contributions to cementing a long term relationship between the U.S. and host country scientists and institutions involved.

Germplasm exchange, movement of seeds in both directions of the U.S. and host countries, has involved populations, cultivars, and lines carrying resistances to pests, diseases, *Striga*, drought, and soil acidity as well as elite materials which could be used as cultivars per se or used as parents in breeding programs. INTSORMIL funds have been made available to the collaborators in the NARS for essential research operation expenses, including labor and materials, and equipment. A wide range of equipment has been provided to the NARS scientists for implementing collaborative INTSORMIL projects.

Improved varieties and hybrids have been developed for production by farmers in different INTSORMIL countries. In Sudan, two high yielding sorghum varieties have been developed and released through ARC/INTSORMIL collaboration, Ingaz (=M90393 = Salvation Government) and Feterita Wad Ahmad (=Cr35:18). Ingaz is grown under irrigation in about 60,000 ha in the Gezira, and Feterita Wad Ahmad is targeted both for rainfed and irrigated conditions and is under large scale seed increase. A *Striga* resistant variety, SRN-39, has been identified as promising and released for production. In one area alone about 1200 ha of SRN-39 have been grown in 1992. The hybrid sorghum success story in Sudan traces to ICRISAT/INTSORMIL/ARC collaboration in which they developed, produced seed, and popularized the first hybrid sorghum, Hageen Dura-1 (=Tx623 x K1567), currently covering about 12% of the sorghum area in the Sudan Gezira Irrigation Scheme, the largest in the world under one management. The HD-1 success story has become famous and has been recounted in many circumstances.

In Niger, one sorghum hybrid (NAD-1 = Tx623 MR732) has been sufficiently tested and introduced to farmers and policy makers through a number of strategically located large scale demonstration plots. Policy makers in Niger have been impressed and farmers have been excited with the potentials of NAD-1. Reliable mechanisms for large scale seed production of NAD-1 have yet to be worked out. Among the varieties tested and released in Niger are SRN-39 and SEPON-82.

In pearl millet, the cytoplasmic-genetic male sterile 79 2068A is used extensively as a seed parent of hybrids grown in Northwest India. These same lines are being used widely in breeding programs by ICRISAT and the Indian national program to develop improved hybrid seed parents.

In Honduras, three food type high yielding sorghum cultivars have been tested and released. These are Tortillero (=CS3541 Sel.), Catracho (=ATx623 x Tortillero), and Sureño [(=SC423 x CS3541)E35-1]-2-2. Sureño, in particular, has widespread acceptance by Honduran farmers because of its superior grain quality, high yield potential, disease resistance, and dual purpose use for both forage and grain.

In Colombia, two sorghum lines, Sorghica Real 40 and Sorghica Real 60, have been released as acid soil tolerant cultivars suitable for the immense South American Llanos and Cerrados which are rendered unproductive by acid soils and high aluminum (Al) saturation. These cultivars should open up the vast acid soil affected areas for sorghum production.

In crop protection, a wide range of sources of resistance for insects, diseases, and *Striga* have been identified and crossed with locally adapted germplasm. Among the best of these are Malisor 84-7 and SRN-39 for head bug and *Striga* resistance, respectively. An effective screening method for head bug resistance has been developed in Mali. A reliable germplasm screening technique for sorghum long smut has been developed in Sudan and extended to other INTSORMIL countries in west Africa.

In agronomy and soil/crop management, a major INTSORMIL impact has been in understanding the soil/cropping system genotype interactions. Research in Mali has shown that small nitrogen additions are beneficial and necessary to sustaining sorghum grain yields. This information has been compiled and is being used by extension personnel in their discussions with farmers. In Botswana, the benefits of single element fertilizer have been determined and demonstrated to farmers. Water harvesting technology has been evaluated and appropriate recommendations have been extended to farmers. Additions of nitrogen have improved water use efficiency of both pearl millet and grain sorghum.

In food technology, the major achievement has been the establishment of well equipped and functioning sorghum and millet food technology and quality laboratories as in

Mali and Niger. In Sudan, the use of sorghum in composite flour (up to 50%) for wheat bread making has been investigated and its commercial viability and acceptability has been established. The newly released cultivars such as HD-1, Ingaz and SRN-39 have been evaluated for their kisra quality properties and have been found suitable.

In socioeconomics, the impacts of technologies generated by INTSORMIL, especially that of HD-1, have been assessed. The internal rates of return to the HD-1 breeding without any further extension of the absolute area in HD-1 were 23 to 31% for low and high fertilization, respectively. With the present rate of diffusion, the investment on this research would pay approximately $1 million of annual benefits. INTSORMIL's socioeconomic research has also shown that in Honduras the internal rate of return to the development of two new sorghum cultivars, Sureño and Catracho, which are in diffusion, is estimated at 32% or, on annuity basis, $0.7 million annually for the next 30 years. Thus, the new sorghum cultivars in Honduras have benefitted small farmers dependent on small-acreage hillside farms.

Benefits to the U.S.

The economic benefits of INTSORMIL research to U.S. agriculture has been hundreds of millions of dollars. Economic gains to the U.S. from research on developing the greenbug resistant (biotype E) sorghum alone was estimated at $389 million under the 1989 farm program provisions. Also, the economic benefits of research on developing food type varieties/hybrids was estimated as $183 million net welfare gain to the U.S. A wide range of sorghum and millet germplasm with high yield potential, improved grain quality, and resistance to pests and diseases have been introduced from the host countries through this CRSP. These materials have continuing potentials for generating millions of dollars of benefit to agriculture in the U.S. As a result of their involvement in this CRSP, a pool of U.S. scientists that is familiar with the global circumstances of sorghum and millet improvement, production, protection, utilization, and economics has been realized.

Sustainable Plant Protection Systems

Numerous pathotypes of sorghum downy mildew (SDM) from various regions of the world have been defined and sources of resistance to these pathotypes have been identified. Recently, host genes for resistance have been mapped and specific probes for identifying the presence of the SDM pathogen or several other downy mildew fungi have been described.

INTSORMIL PIs developed an International Anthracnose Virulence Nursery which is used to monitor the pathogen. This nursery is now managed in cooperation with ICRISAT. The system of networking includes the growing of several uniform nurseries in locations where sorghum/millet diseases are important such as the International Sorghum Anthracnose Virulence Nursery which is grown where anthracnose is endemic. Other nurseries include a uniform nursery for head smut, sorghum downy mildew, sorghum viruses, and grain mold. Growing of these nurseries permits a quick evaluation of pathotype differences among locations and the severity of the problem. INTSORMIL also evaluates and distributes elite sorghums in nurseries for evaluation of the multiple resistance of sorghum. These are international nurseries and represent a means of distributing elite germplasm from different breeding programs in INTSORMIL.

The identification of the "F" mating population as the major cause of *Fusarium* stalk rot in the U.S. and the provision of appropriate strains for breeders has greatly increased the screening reliability for resistance to this disease. Within a biological species there is limited genetic variability in material from the United States and somewhat more variability in material examined from LDCs. INTSORMIL PIs have developed VCG (Vegetative Compatibility Group) technology and protocols so that LDC scientists can make estimates of the genetic variability within their pathogen populations.

A collection of approximately 6,000 cultures of *Fusarium* based on world wide collections is maintained at Kansas State University. Many of these strains have been genetically characterized, and have known mycotoxin or pathogenicity profiles. Pharmaceutical companies are screening this unique collection for novel secondary metabolites for therapeutic value. This collection complements other major collections of *Fusarium* that are maintained in Pennsylvania, Australia, Germany, and the Republic of South Africa.

INTSORMIL PIs have developed a dot immunobinding assay (DIA) to distinguish different bacterial pathogens of sorghum and millet. The test is easy to perform, inexpensive, requires limited equipment and chemicals, and was designed with LDC laboratory conditions in mind. It has been shown that the causal agent of bacterial leaf streak is seedborne and can remain viable in the seed for more than two years.

An extensive phytopathogenic bacterial culture collection of over 600 species has been established in the laboratory at Kansas State University. This is the most comprehensive collection of plant pathogenic bacteria affecting grain sorghum and pearl millet in the world.

Insects cause more damage than pathogens, but pathogens become more severe as insect abundance and damage increases. Pathogens can occur without insects, but diseases may be significantly more serious when insects are present. The severity of pathogen infection is increased when rains continue late into the season, that is, when sorghum matures during wet conditions.

International collaborative research programs with NARS and ICRISAT scientists have resulted in the devel-

opment of sustainable insect management strategies and identification of sorghums resistant to sorghum midge, greenbug (biotypes C, E, and I), African sorghum head bugs, sugarcane aphid, and yellow sugarcane aphid. Mechanisms and inheritance of resistance have been determined, and genes conferring resistance have been introgressed into elite parental lines that have been evaluated alone and in hybrid combinations. Levels of resistance have been quantified, and economic injury levels established for most of them.

Research at Texas A&M University has employed a holistic approach to identify, evaluate, and deploy sorghum midge, greenbug, and yellow sugarcane aphid resistant sorghums as a component of IPM, and develop and validate sorghum plant and sorghum midge dynamics computer models. Significant advances were made in developing the technology to allow farmers to manage these sorghum insect pests.

Significant advances have been made in biological control and these advances contribute to improved IPM of sorghum and millet, and to improved concepts for using biological control in annual crops. For aphids attacking sorghum in the U.S., predators were demonstrated as key natural enemies for effective biological control of these pests. In the U.S., phytoseiid predators have been demonstrated as an effective alternative to pesticides for control of spider mites, and parasites were shown to be effective on the American sugarcane borer attacking sorghum.

Since the initiation of INTSORMIL, cooperation between sorghum breeding and sorghum entomology projects has resulted in the registration and release of 65 sorghum midge-resistant A- and R-lines (Tx2754-Tx2781, Tx2801-Tx2815, Tx2869-Tx2890). For greenbug, 33 sorghum lines resistant to biotype C (Tx2567-Tx2568, Tx2734-Tx2752, TAM Bk41-44), and 11 lines resistant to biotype E (Tx2783, Tx2859-Tx2868) were registered and released. Of these releases, ATx2752 and RTx2737 were extensively used in commercial sorghum hybrids for resistance to biotype C, and RTx2783 and its derivatives were extensively used for commercial hybrids resistant to biotype E.

The impact of insect resistant germplasm in sorghum production of the U.S. has been dramatic. For example, insecticide use on sorghum in Texas was at an all-time high at the initiation of this CRSP. In 1978, nearly 60% of the sorghum acreage in Texas was treated with insecticide, while in 1990 only about 24% of the acreage was treated. The savings gained from not using insecticide were $6,000,000 per year, and this does not consider the ecological or environmental benefits, or benefits from reduction in insect pest resurgence or secondary pest outbreaks. During this project, the economic benefit to Texas farmers has been at least $90,000,000.

INTSORMIL PIs at Purdue and their collaborators identified sorgoleone, a group of chemically reactive oily quinones exuded from the root hairs of sorghum, as the first natural germination stimulant identified from a *Striga* ho: Sorgoleone has other activities, including herbicidal a antibiotic, and is a powerful contact allergen. In the fiel *Striga* germination is not controlled by sorgoleone but by different set of compounds exuded by host roots. The: compounds are more stable and more water soluble th: sorgoleone.

The INTSORMIL PIs at Purdue consider each stage the *Striga* life cycle separately. They characterize the hos parasite interaction at each stage, particularly the chemic: signals exchanged. For each stage simple ways to dete ineffective interactions are sought. These screening metl ods are used to identify crop genotypes bearing the resi: tance conferring traits, and to map the traits on the sorghu genome.

INTSORMIL investigators in Niger did not find an significant interaction between N, P, K in *Striga* contro Nitrogen application did not reduce the amount of *Strig* infestation, but this may be explained by previous fertilize trials in the plots. Phosphorous application reduced th number of *Striga* at Kollo and increased it at Bengou Potassium had no effect on *Striga* at Kollo but increased i at Bengou.

Sustainable Production Systems

In the area of plant physiology, current water stres: research is centered on preanthesis stress mechanisms (me tabolic efficiency, heat shock protein development, etc.) an post anthesis stress research as it relates to improving see size. Improving seed size capacity is probably a valuabl preanthesis stress compensating factor. A workable preanthesis stress screening program based on yield component analyses to help identify the time of stress damages was developed. A stress resistant hybrid consumed only half the O_2 required to produce a gram of root dry matter as did a stress susceptible hybrid making the stress resistant hybrid twice as efficient in utilization of respiratory energy. It was shown that genotypes could be selected for tolerance of the photosynthetic mechanisms to stress. In this regard, heat tolerance of pearl millet was found to be higher than that of sorghums.

Research in the area of mineral stress, particularly nitrogen, has shown that certain genotypes cope with low soil nitrogen better than others by a rapid mobilization of that element to actively growing tissue which sustains whole plant photosynthesis and thus growth. Also, certain sorghum genotypes have higher photosynthesis rates at lower tissue nitrogen concentrations than others which allows continued growth at low nitrogen supply.

INTSORMIL research results have demonstrated 18 to 203% yield enhancement of pearl millet and grain sorghum yields by use of crop rotation with legumes, and a sizeable nitrogen equivalent contribution to cereals following legumes. Intercropping has shown land use efficiency increases

over sole crops, and also to enhance yields of succeeding crops. Obviously legume production, no matter the system, is important to producing optimal yield when nitrogen fertilizer is limiting and improved cultivars are available.

Foliar spraying of sorghums with abscisic acid (ABA) increased yields of some genotypes under drought stress, mainly due to increased seed numbers, while decreasing or having no effect on the yield of well watered plants. Seeds treated with ABA had increased germination, longer root growth, and better seedling tolerance to drought stress. The ABA treatment was more effective on stress susceptible genotypes.

Germplasm Enhancement and Conservation

INTSORMIL PIs have developed numerous germplasm lines resistant to biotype C and/or E greenbug which have been distributed to private seed companies for use in their breeding programs. Several lines have been extensively used directly in the production of hybrids and they include ATx2752, Tx2737, Tx2783, Tx2864, and Tx2862.

Germplasm resistant to sorghum midge, developed through INTSORMIL support, has served as the foundation for many similar breeding programs throughout the world. Lines used, or those that could be used, directly in sorghum hybrids include ATx2755, Tx2767, Tx2880, and Tx2882.

INTSORMIL PIs have cooperated in the release of three hundred fifty converted exotic sorghum lines. The releases were made in three groups: two hundred forty lines in 1986, fifty in 1992, and an additional sixty in 1992.

Results have consistently shown that grain yields at high and low fertility as well as yield responses to fertilizer are to some degree independent of one another. Therefore, it is incorrect to assume that selection of sorghums under adequate soil nutrient conditions will result in sorghums that perform well under nutrient stress. Sorghum performance at low nutrient levels, yield potential under good conditions and responsiveness to applied fertilizer appear to each be under separate genetic control.

The identification of Hageen Dura-1 in the Sudan was an impressive finding. The female ATx623 was used because of its wide adaptation and yield potential, as well as its drought resistance. A sister line ATx622 has been introduced in China and used in hybrids planted on tens of thousands ha.

Eight genes have been described which affect the food quality of sorghum grain; pericarp color, presence or absence of a pigmented testa, thickness of pericarp, nature of endosperm, and basic plant color. More than 14,500 sources of germplasm, inbred lines, and enhanced populations have been distributed to collaborators. These materials have been incorporated into national breeding programs, selected for release to farmers, and used in training programs.

One major dominant gene and one major recessive gene were found to control the ability to stay green under drought conditions. A consistent relationship has been shown between high nonstructural carbohydrates in the stem and charcoal rot resistance. Two-gene systems appear to control relative water content, osmotic potential, and heat tolerance. One INTSORMIL project, TAM-121, has developed and released 68 inbred parental stocks for use domestically and internationally since the INTSORMIL program was initiated. More than 10 countries are known to have released hybrids using materials developed in this project.

It is now known that genetic variability for tolerance to the tropical acid soil complex exists in the genus *Sorghum*. Tolerant varieties have been released and are producing economic grain yields for resource-poor farmers in marginal production areas using low-input technology. Information has been obtained concerning gene action and inheritance of tolerance to Al, Mn, and acid soils in general. Since tolerance to the acid soil complex appears to be dominant in sorghum, either tolerant pollinator or seed parent lines can be used to produce commercial cytoplasmic-genic hybrids in tropic or temperate zones. After screening nearly 6,000 sorghum genotypes, INTSORMIL PIs found that about 8% would tolerate 65% Al saturation and a few of these varieties would produce more than two tons of grain per hectare. Most of these highly tolerant genotypes were identified in the world collection as originating in acid soil areas in Nigeria, Uganda, and Kenya. The Colombian/ICA-INTSORMIL released Al-tolerant varieties, Sorghica Real 60 and Sorghica Real 40, have consistently produced high grain yields on acid soils in both cropping seasons during the year. Both cultivars have good yield stability in acid and fertile soils, and are photoperiod sensitive Caudatums.

The INTSORMIL/McKnight research group at Purdue, in collaboration with Pioneer Hybrid Seed Company, is the first to report the stable and heritable transformation of sorghum. This is a significant accomplishment which will allow new opportunities for sorghum improvement in the future. Transgenic sorghum plants have been obtained after microprojectile bombardment of immature embryos. The variety transformed is the drought resistant cultivar P-898012 which is well adapted to the African Sahel. This achievement will allow sorghum scientists to introduce new and useful genes into this important African sorghum variety, and could be the dawn of a new era for sorghum research.

A new drought tolerant sorghum hybrid designated NAD-1 has proven to be highly productive and well adapted in Niger. The grain quality is acceptable for local food preparations and the yields reported from demonstration plots in 1992 were approximately twice the yields of local varieties. Farmer interest has been very high since this is the first sorghum hybrid that has actually reached farmer fields and the head size and grain yield have been impressive to them. The 1992 trials, at over 100 farmer locations, was a critical test of the performance of this hybrid. It is important

now to develop a seed industry (either private or parastatal) in Niger that is adequate to produce and distribute hybrid sorghum seed.

In pearl millet, population improvement using mass-selection and S_1 progeny performance recurrent selection programs have resulted in improvements in tolerance to drought and low soil fertility, increased stand establishment capability, and excellent bird resistance in bristled populations. Good rates of progress have been made reducing lodging caused by poor root/soil attachment, nodal abscission layers, and charcoal stalk-rot. Improved stand establishment has been obtained by selecting rapidly emerging seedlings from planting depths of 100 mm in the greenhouse and 75 to 80 mm depths in the field. Selections surviving this type of screening emerge 0.5 to 2 days earlier than unselected lines when planted at normal depths and produce larger plants at 10 days after emergence.

Nearly all new accessions of millet entering the program are routinely screened for seedling tolerance to aphids. Approximately 75% of the accessions tested have moderate to high levels of resistance to greenbug, with most of the injured lines producing sufficient numbers of tolerant plants for effective selection.

Several superior seed parents have been obtained from the male-sterilization backcross program at Kansas. F_1 hybrids appear to have similar grain yield potentials when compared to sorghum hybrids of similar maturity. Three Kansas cytoplasmic-genetic male-sterile inbred lines and their maintainer lines have been used extensively for several years in the ICRISAT breeding program in India and have been released to public and private breeding programs in India for utilization in the production of hybrids. In the U.S., research continued on producing segregating populations for selection in West Africa, providing data on production of protogyny hybrids for use in low-resource agriculture and developing hybrid parent lines in the A_4 cytoplasmic male sterility system which has several major advantages over the A_1 system, and may also be useful for improving agriculture in developing countries.

Crop Utilization and Marketing

INTSORMIL PIs in Indiana originally addressed the tannins as antinutritional factors. They developed methods, now widely used by others, for assaying and characterizing these materials. They also developed a simple method for detoxifying and improving the nutritional value of high tannin sorghum. They are elucidating the biochemical mechanisms by which tannins exert their antinutritional effects. They are also characterizing the role of tannins and related materials in resistance to birds, molds and leaf diseases. Methods for polyphenol analysis, purification and characterization have been widely adopted and used by nutritionists and ecologists studying tannins in other crops and range plants.

Sorghum digestibility in humans was shown by nutritioı ists to be low compared to other cereal grains, and from th project we now have a clear concept of why the storag proteins, or kafirins, are difficult to digest. Presently, a hig molecular weight non-kafirin endosperm protein that ir versely correlates to reduced digestibility is being evaluate as a possible means of increasing digestibility throug breeding or genetic manipulation. INTSORMIL PIs hav identified a sorghum line in the World Collection (IS 2319 which has a significantly reduced cross-linked kafirin frac tion and shows very good digestibility results in rat feedin trials, whether cooked or uncooked. They believe this cross linked kafirin is responsible for many of the digestibilit problems in sorghum and are giving this activity a very hig priority.

Processing sorghum in certain ways was found to effec tively increase digestibility. A traditional fermented prod uct, Sudanese *nasha*, and high temperature, low moistur extruded gruel made from decorticated sorghum were foun to be highly digestible in children both in protein and energy New processed foods from sorghum in Sudan were evalu ated for nutritional quality and research was conducted tha will improve quality and help efforts to commercializ *kisra*, the staple Sudanese fermented flat bread.

It was found that high amounts of kafirin decrease th gelatinization potential of the starch granules thereby mak ing a thinner porridge. Porridge texture was found to be th most important attribute when different sorghum cultivar were evaluated using sensory panels in Niger. Laboratory tests for porridge quality were identified that best correlat to consumers in Niger. Grain hardness tests, which ar important indicators of end-use quality, were evaluated and suitable methods that are rapid and simple were put in place.

Simple methods to evaluate milling and porridge quality of sorghum have been developed and used to produce new cultivars. For example in Mali, Malisor 84-7 was developed specifically for improved thick porridge quality. Its tan plant color and hard endosperm provides excellent quality grain which has been found to have resistance to head bugs.

The chemistry, composition, structure and nutritional value of sorghum kernels has been related to genes that control pericarp thickness and color and the presence and absence of a pigmented testa. From this knowledge, several white, tan plant sorghum inbreds have been released to the seed industry and are being grown in the United States. These food hybrids have improved quality for use in livestock feed as well as ingredients in food systems.

Sorghum is used for malting and traditional beverage production in Africa. Malt quality is critically important and limits its use. Methods of determining malting potential of sorghum have been developed and used to show large differences exist among cultivars. Both genetic and environment significantly affect malting properties. Dorado, a white food type sorghum, had the best malting properties. Eco-

nomically, significant differences have been found. Malted sorghum has greatly modified kernel structure which improves its nutritional value significantly.

New prototype food products including noodles, ready-to-eat breakfast foods, weaning foods, granolas, instant porridges, baked products and others have been developed from 100% sorghum and millet for potential utilization in several countries. Products have been made with sophisticated techniques like extrusion and micronizing and also with simple, low-technology methods appropriate to targeted countries. The major constraint limiting their application is the lack of a consistent supply of good quality sorghum and millet grains at a price competitive with imported rice, corn and wheat products. Parboiled sorghum and millet has excellent potential in Mali. Malian sorghum breeders are developing photosensitive sorghums with tan plants to provide a consistent supply of grain for processing.

Sorghum has been used to produce tortilla chips, tortillas and related products from alkaline cooking. Several new cultivars with improved tortilla making quality have been or are near release in Central America because of collaborative work within the breeding programs. A simple test to evaluate tortilla potential of sorghums has been successfully utilized.

New waxy and heterowaxy sorghum cultivars and hybrids have been developed with unique properties for use in food systems. A white, tan waxy sorghum produced flakes for granola using micronizing. These JOWAR flakes have excellent potential for use in a wide variety of products. The same grains have excellent steam flaking properties and may have improved feed efficiency when fed to ruminants and swine.

The adverse effects of molds and weathering on sorghum quality significantly limit the use of sorghum for foods in many areas. Major progress to understand the factors affecting grain deterioration has been made. Work continues to secure mold resistant sorghum cultivars. Some of the new cultivars, i.e., Sureño, Malisor 84-7, have improved resistance to grain deterioration. New information on the role of antimicrobial proteins is being developed. Head bugs and molds are major constraints restricting sorghum improvement in West African countries.

The structure and processing properties of pearl millet has been evaluated. A white pearl millet grain had excellent acceptance when cooked like rice. The milling properties of millet were mainly affected by kernel size, shape and hardness. Parboiled millet did not develop the off-flavor that occurs in millet millet products.

Host Country Program Enhancement

Mali

The collaborative research on African sorghum head bugs in West Africa, especially Niger and Mali has quantified damage (yield and quality loss); identified resistant genotypes, including practical methodology to screen for resistance; and described bug species composition, biology, and population dynamics. Research in Mali confirmed the resistance of Malisor 84-7 to head bugs. Research on the sugarcane aphid was conducted in Botswana and Zimbabwe, sorghums resistant to this insect were identified, and the mechanisms and inheritance of resistance assessed.

Sorghums accumulating high amounts of proline had significantly greater heat and desiccation tolerance than those that accumulated less proline. Plants grown from seed produced in a stressful area in Mali had more seedling drought resistance than plants grown from seed of the same genotypes produced in a less stressful area. Local Malian sorghums acclimated to environmental stress to a greater degree than introduced genotypes. The evaluation of adaptation to stress in Mali showed that the local Malian sorghums were superior in a combination of several physiological characteristics that were identified as contributing to drought and high temperature resistance.

Research in Mali has shown that grain yields do not always increase with applied N when conditions are extremely dry. However, in the higher rainfall regimes, yield increases are obtained with N application and the local varieties such as Tiemarifing have consistently higher N use efficiency than the improved types such as Malisor 84-7. There appears to be a tremendous need for phosphorus in the sandier soils, and this may be the mineral element which is most limiting in many cases.

Sorghum-peanut intercropping increased the land use efficiency ratio (LER) by 4, 13, and 41% over sole crops at zero, 40 and 90 kg ha^{-1} N, while millet-cowpea intercrop increased the LER BY 29-33% at all N levels. Research in Mali has shown clear yield advantage to rotation of sorghum following peanut and millet following cowpea, and a smaller yield advantage following intercropping.

A food technology laboratory that works closely with the millet and sorghum improvement programs has been developed and equipped. The laboratory has applied several simple techniques developed at Texas A&M to evaluate sorghum and millet for thick porridge quality. Critically important factors like pericarp removal, grain deterioration by head bugs and molds, the effect of plant color and different cultivars on porridge quality were discovered and introduced into the sorghum improvement program.

The food technology laboratory has conducted many village and urban cooking and processing trials of sorghum, millet and legumes. A blend of three parts millet flour and

one part of cowpea flour was shown to work well as an inexpensive weaning food for young children. This technology has been successful in some areas of Mali. Parboiling trials showed the importance of grain with tan plant color to produce improved highly acceptable products. This has led to current objectives to produce an improved local photosensitive sorghum with tan plant color specifically for use in value added processing.

The Malian laboratory found that major constraints to millet quality were seed shape, size and texture. Globular kernels with medium size gave the highest milling yields. Parboiling pearl millet enhanced decortication yields significantly and improved the texture and acceptability while reducing the development of objectionable aromas. Parboiling is a simple technique that can be applied in villages using existing equipment.

The development of new cultivars for use in value-added processing should lead to increased economic activities in Mali.

Niger

In pearl millet, the diversity and diallel cross studies indicate clearly that knowledge of the degree of similarity or dissimilarity among landraces is not sufficient when choosing the best parent for crosses. The population crosses Ex-Bornu x P3Kolo gave the highest grain yield and a good level of heterosis even though the cluster analysis showed that the two cultivars had similarities for most of the traits measured.

An integrated sorghum and millet disease research program is in place. Emphasis has been on the biology and control of long smut. Initially, collaboration between workers in Sudan and Niger permitted the rapid transfer of specific technologies. Evaluation of resistance to long smut is an integral part of the Niger sorghum improvement program. Evaluation for resistance to head smut, Acremonium wilt, and anthracnose is also part of this program. Work on the control of downy mildew of pearl millet has been accelerated with the deployment of Apron® plus.

In Honduras and Niger INTSORMIL collaboration has resulted in development of sustainable biological control strategies for stem borers, and information on pest and natural enemy biologies has contributed to improved approaches to IPM. For whorlworms in Honduras, techniques were developed to manipulate key natural enemies; for stem borers in Honduras, an efficient natural enemy was imported, released in Honduras and established; for stem borers in Niger, natural enemies were demonstrated to occur in greater densities in natural vegetation than in millet, a suggestion that the substantial changes to cultivated millet is interfering with biological controls.

In Niger on the sandy dune soils, crusting is usually a less serious problem but the water rapidly infiltrates deeply into the soil so that the plant roots are not able to tap it. Moderate fertilization and higher plant densities have been shown to simultaneously increase soil fertility and water-use efficiency. The research in Niger showed that these crops can gain benefits from added N in either a wet or a dry year. If a legume/cereal rotation is used to obtain "fixed N", then some addition of P is needed to maximize yields. Pearl millet yields increased greatly following a cowpea intercrop or sole crop cowpea. These results demonstrate the importance of a cowpea legume crop and N fertilizer in improving millet yields under the stressful Nigerien conditions.

In the Sudanian zone, as in Burkina Faso, the combined introduction of tied ridges, fertilization, and a new animal traction implement has the economic potential to substantially increase sorghum yields. This higher input system is more sustainable than the deteriorating low input system generally practiced now. The impact of agricultural and household technologies on the welfare of women has been analyzed. With most types of household decision making both types of technologies have substantial positive impacts on female (and household) incomes. INTSORMIL has studied the economic factors influencing the shift from extensive, low input systems, where the principal innovation is animal traction, to intensive systems with purchased input use and improved cultivars. To increase yields profitably it is generally necessary to respond to both the water availability and the soil fertility constraints.

Sudan

The economic impacts of Hageen Dura 1, in the Sudan, show substantial returns to agricultural research and extension. The Hageen Dura 1 experience indicates the importance of the expansion of a private seed industry and a fertilizer distribution system to support the rapidly increasing demand for both inputs once a new hybrid is introduced. The extensive, low-input agriculture is not sustainable but leads to soil degradation and declining yields. The use of moderate levels of chemical fertilizer, an improved cultivar, and improved agronomic practices can raise yields and maintain them at 1.2 to 1.4 mt/ha. These are not outstanding sorghum yields internationally but they are a substantial improvement over present yields. These improved technologies were also highly profitable. The potential farmer demand for medium and longer season cultivars and the importance of reducing the cereal price collapse in good rainfall years both became obvious in country studies in Niger and Burkina. In Sudan Hageen Dura 1 diffusion was related to the functioning of the input markets, extension contacts, and farmers' taste preferences. Intensive technologies not only increase yields but are more sustainable systems than the extensive systems presently practiced. Many of these intensive systems are highly profitable and their water-retention features result in little increase in riskiness of the combined systems.

Forage legumes of clitoria (C)*Clitoria ternata* L. and phillipesara (P)*Phasulus trilobus Ait.* in a two-course rota-

tional system greatly increased sorghum yield over that of continuous sorghum. However, clitoria performed better than phillipesara as a previous crop.

Research in Sudan began with the control of charcoal rot, resistance to long smut and related smut diseases and, more recently, on control of anthracnose and downy mildew of pearl millet. Host resistance work for control of charcoal rot and long smut are included as a continuing program in Sudan. Transfer of the inoculation techniques to Niger and elsewhere represents the quality and maturity of the research on sorghum pathology in Sudan.

Botswana

Several cultivars with SC326-6 in their genetic background demonstrated good general adaptation to the SADC region and possessed excellent disease resistance needed in some areas of the region (leaf blight and anthracnose). Lines and advanced lines were evaluated and those with potential are being utilized as parental lines. A seed parent from Segaolane has been developed. Variability on both the female and male sides is being used to develop adapted hybrids for Botswana. The pearl millet breeding program has made selections from a Serere 6A population. An advanced improved line from this population is being tested for its potential as a new variety. Identification of resistance to the sugarcane aphid and identification of predators that will attack it have been found.

Pearl millet seed either screened for larger size or produced by partial removal of the head resulted in better establishment and in many cases improved yields. The exception was under extremely severe stress conditions in Botswana. Germination responses of both pearl millet and grain sorghum to temperature and soil moisture have been quantified. Interactive effects between seed quality and environmental conditions were variable. The grain sorghum growth model sorkam was validated, improved and utilized to develop a replant decision to allow for U.S. conditions.

Management practices on water runoff showed if additional water could be diverted to a site, better yields resulted. Practices associated with better water availability must be coupled with the proper plant population and pest control. In the event excess water occurs, the system must be designed to release water without erosion. The National Tillage Trials showed early tillage frequently improved soil water storage. This coupled with fertilizer (15 kg P ha^{-1}) generally increased yield. Due to low yield, addition of P was not economical where soil P was greater than 5 mg kg^{-1}. Nitrogen was not influential unless the rain was uniformly distributed over the season. However, manure/crop residues were effective in increasing water intake. Manure by itself was quite effective, but combined with residues, intake was even greater.

Honduras

Crop mortality factors were partitioned in sorghum-corn intercropping systems in Honduras; 65% mortality was due to insects. Pest species diversity and density levels were cataloged. Seed treatment with insecticide was required to prevent seed and seedling loss due to soil-inhabiting insects and millipedes. Parasites of armyworm species in the langosta complex were identified and their impact quantified. The international significance of a migratory pest species (fall armyworm) was elucidated in comparisons of insect biology, behavior and reaction to insecticides for insect populations from the U.S. and the Latin American Ecogeographic Zone.

Ecological approaches to insect pest management included cultural and biological control and host plant resistance. Honduran native landrace sorghums, "maicillo criollos" with antibiosis insect resistance were identified.

In Honduras the investment in the soil conservation technology made possible the introduction of an intensive technology system (yield increasing) including fertilization, better agronomic practices, and a new cultivar. Honduras farmers are growing Sureño, an improved maicillos, because the grain produces lighter colored tortillas.

Colombia

Since 1982, five cultivars, the result of collaboration between ICA, commercial companies, and INTSORMIL, have been released. These cultivars produce profitably in soils with as high as 60% Al saturation, opening up more than 200,000 ha of marginal land in Colombia alone. The two varieties released in 1990, Sorghica Real 40 (156-P5-Serere 1) and Sorghica Real 60 (MN-4508), are tolerant to soils with 40% and 60% Al saturation, respectively. ICA and the El Alcaraván Foundation, with INTSORMIL's support, released in 1993 two lines adapted to Arauca (Colombian Eastern Plains): IS-3071 (Icaraván 1) and IS-8577 (Icaraván 2). These lines have good agronomic characteristics.

Colombia is the only Latin American country where universities, the private sector (El Alcaraván), national research institutions (FENALCE and ICA), and an international center (CIAT) collaborate with INTSORMIL to accomplish research and training goals.

All mineral elements were affected by acid soils stresses, but silicon and calcium in plant tissue were most closely related to acid soil tolerance. An effective laboratory screening technique was devised to screen sorghum seedlings for acid soil tolerance. Studies on mycorrhizal (VAM) colonizations on sorghum showed that VAM associations on roots can assist in the extraction of phosphorus (P) from low P soils. However, the higher the inherent soil P level, the lower the VAM association which occurred.

Networking

Over the years, established networking activities have continued with ICRISAT, SADC/ICRISAT, SAFGRAD, ICRISAT Sahelian Center, ICRISAT West Africa Sorghum Improvement Program, EARSAM of ICRISAT, ICRISAT/CIMMYT, CLAIS of Central and South America, and CIAT. There has been excellent collaboration with each of these programs in co-sponsoring workshops and conferences, for coordination of research and long term training.

INTSORMIL is working with newly emerging networks, such as ROCAFREMI (INSAH) of West/Central Africa. INTSORMIL plans to strengthen linkages among the NARS it works with, as well as international and regional organizations and networks. INTSORMIL will continue to promote free exchange of germplasm, technical information, improved technology, and research techniques.

Future Directions

INTSORMIL will continue to jointly plan and execute collaborative research that benefits developing countries and the United States. These collaborative relationships are keys to INTSORMIL's success and will continue as fundamental approaches to meeting the INTSORMIL mission. In the future, INTSORMIL will target NARS collaborative ties that reflect regional needs for sorghum and/or millet production. These ties are envisioned to be in the sorghum and millet agroecological zones of western, eastern, and southern Africa, and Central America. By concentrating collaboration in selected sites, INTSORMIL optimizes its resources, builds a finite scientific capability on sorghum and millet, and creates technological and human capital that has a sustainable and global impact. INTSORMIL will use four specific strategies to maintain its current momentum, build on its record of success, and accomplish a new set of goals. These strategies are (1) sustainable research institutions and human capital development, (2) conservation of biodiversity and natural resources, (3) research systems development with focus on relevant technology generation, and (4) information and research networking.

Sustainable Plant Protection Systems

Agroecology and Biotechnology of Stalk Rot Pathogens of Sorghum and Millet

Project KSU-108

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Summary

KSU-108 was initiated in 1989 (year 10).The project has been dispersed over many sites and has not been tied to a particular INTSORMIL prime site, although a buy-in from the USAID mission in Cairo in 1991 has led to extensive work in Egypt. Research has been broadly focused in the core project with the limited funds provided used to provide supplies and technical assistance for work with most of the LDC sorghum samples that we examine, development of techniques that can be implemented under LDC conditions, and travel for collecting additional isolates.

Fusarium spp. are responsible for stalk rot and grain mold of sorghum as part of a stalk rot complex that is poorly understood. In sorghum, these fungi belong primarily to section *Liseola*, of which *F. moniliforme* is the most prominent. We have divided this complex group of fungi into six distinct biological species and have found that only two of these species are of importance on sorghum and that the overlap between maize and sorghum pathogens is very limited. The identification of the "F" mating population as the major cause of *Fusarium* stalk rot in the U.S. and the provision of appropriate strains for breeders has greatly increased the screening reliability for resistance to this disease. Within a biological species there is limited genetic variability in material from the United States and somewhat more variability in material examined from LDCs. We have developed VCG (Vegetative Compatibility Group) technology and protocols so that LDC scientists can make estimates of the genetic variability within their pathogen populations. In Egypt, Pokkah boeng, a sorghum disease that is also associated with these fungi, has been identified as a significant problem on the Giza 15 variety with losses of 5-15% common throughout the country.

With respect to bacterial diseases of sorghum and millet, there has been little work done outside of our program. We tested numerous sorghum accessions for susceptibility to three bacterial pathogens and found that 80B3039 was the most susceptible entry tested while several others were very resistant including SC414, Sureño, and B35-6. We also identified two bacterial diseases of pearl millet that occur in Niger, Nigeria, and Sudan, bacterial streak (*Xanthomonas campestris* pv. *pennamericanum*) and bacterial stripe (*Pseudomonas avenae*). We have shown that the causal agent of bacterial leaf streak is seedborne and can remain viable in seed for more than two years.

Bacterial pathogens are difficult to diagnose, particularly when disease symptoms alone are not definitive or when phytosanitary certificates are required for quarantine controls. We have developed a dot immunobinding assay (DIA) to distinguish different bacterial pathogens of sorghum and millet. The test is easy to perform, inexpensive, requires limited equipment and chemicals, and was designed with LDC laboratory conditions in mind. This assay is being improved through the development of monoclonal antibodies that increase the accuracy by reducing the background.

A long-term screening program for determining resistance to covered kernel smut of sorghum in various sorghum accessions has been successful. Cultivars SC414, Sureño, and B35-6 were shown to be immune.

Introduction

The main thrust of this project has been studies of stalk rot pathogens, both bacterial and fungal, with an emphasis on using biotechnology tools to develop rapid diagnostics and to understand the life history of these pathogens as a prelude to their control. Stalk rots account for an average loss of 4-8% of the sorghum crop in the U.S. per year. Losses in LDCs vary widely depending on the cultivar used and local environmental conditions. As the project developed, it acquired responsibility for all bacterial sorghum diseases, covered kernel smut, and additional *Fusarium* diseases such as pokkah boeng and grain mold.

In all of the diseases we have studied, except for covered kernel smut, the identity of the causal agent was not well-defined at the start of the project and efforts to control the disease or to breed for resistance remarkably unsuccessful. Based on symptomology, many of the causal agents were assumed to be the same as those that caused similar diseases in maize or other cultivated grasses. Prior to our program, these diseases were usually treated only in conjunction with numerous other diseases, and were subjected only to routine surveys of disease incidence and severity. The lack of success of traditional methods for developing resistant germplasm led us to study the basic biology of these pathogens, since it was obvious that additional information was required before a rational control program could be formulated.

With respect to *Fusarium* spp. associated with sorghum and millet, some of the most interesting current problems in *Fusarium* taxonomy are associated with isolates recovered from sorghum and millet in Africa. In the past few years, several new species have been named based on such collections, and from our work it appears that there are numerous species that still need to be described.

Over the course of this project, we have identified six different biological species (designated by the letters A-F) within what used to be a single species, *F. moniliforme*. One of these biological species (F) dominates on sorghum, while a second (D) is also present at a significant level. We have been working on different ways to easily distinguish these species and have developed one technique that requires standard tester strains that we have developed, routine culture media, and a suitable place to incubate microbial cultures. This technique has become the standard by which the isolates from this group of fungi are identified. Development of additional identification tools that are more rapid, but just as accurate, is in progress. Identification of the different mating populations is important because these isolates differ in their ability to synthesize mycotoxins, such as fumonisins and moniliformin, and in their host preference. We have been collaborating with other researchers worldwide on the synthesis of the fumonisin toxins to assess the risks posed by these toxins to consumers of different products known to be contaminated by these fungi.

We also have developed a technique for assessing genetic identity known as VCG typing and have been using this technique to assess genetic variability in a population. This technique has been used by researchers in Kenya and Egypt to measure variability within a population. We continue to develop new tools for measuring genetic variability within these pathogen populations to determine if there is sufficient recombination occurring within the population to account for the observed variability in toxin production and virulence.

From the research to date, it has become apparent that isolates of *F. moniliforme* are essentially endophytes of sorghum, with every plant being infected with one or more strains of this organism. We are now working to document the extent of colonization of individual plants under field conditions and will determine if isolates delivered with the seed are the predominant colonizers of the mature plant (as is the case for maize). We could then use modified strains delivered with the seed at planting time to reduce the incidence of stalk rot and toxin contamination of the grain.

With respect to bacterial diseases of sorghum and millet, the initial thrust was towards assistance in diagnoses of bacterial pathogens. Many LDC laboratories are poorly equipped and the personnel have little or no expertise in bacteriology. Updating these laboratories and training sufficient personnel was not economically feasible; therefore, we decided to develop diagnostic tests that were reliable, inexpensive and which could be conducted in LDC labora-

tories and interpreted by personnel with little expertise in bacteriology. A definitive diagnosis is required for many bacterial pathogens because of numerous quarantines against the import or export of sorghum seeds and feed grains that might be infested with seedborne plant pathogenic bacteria. Presently, LDC researchers are forced to evaluate germplasm in screening programs based solely on disease symptoms and without conclusively identifying the causal agent(s).

Our goal in this case was to develop diagnostic kits that utilize immunological procedures developed from biotechnological research such as the dot-immunobinding assay or western blots to satisfy this diagnostic void. The procedure is simple, inexpensive and requires only limited equipment such as a refrigerator. We have obtained polyclonal antisera of high quality and in sufficient quantity that we can address many of these problems. At this time we are developing monoclonal antisera of high quality that will be available to LDC scientists upon request. Periodically, we complete the diagnosis for the LDC researcher in our laboratory.

It has been difficult to convince some LDC scientists that the DIA diagnostic test is an acceptable alternative to conventional (and usually less-reliable) diagnostic procedures. Other LDC scientists are reluctant to request the antiserum and the modest amount of chemicals and supplies that are required. To date scientists from Argentina, India, Lesotho, Egypt, Nigeria and Bulgaria have successfully used the DIA diagnostic that we have developed. Undoubtedly the DIA procedure will gain wider acceptance as scientists become more aware of this biotechnological progress.

Objectives, Production, and Utilization Constraints

Objectives

Identify and characterize *Fusarium moniliforme* isolates to determine the mating type and vegetative compatibility groups. Evaluate this technique for characterizing other fungal pathogens of sorghum such as *Claviceps* spp. (ergot) and *Acremonium* wilt.

Characterize various strains of *Fusarium moniliforme* for mycotoxin (fumonisin) production.

Provide an antisera bank that will enable LDC scientists to diagnose bacterial diseases of pearl millet and sorghum.

Develop monoclonal antibodies against various bacterial pathogens of sorghum and pearl millet.

Develop a semiselective medium and cDNA probe for *Pseudomonas andropogonis*.

Monitor sorghum accessions from the Texas A&M University All Disease and Insect Nursery (ADIN) for genetic variability in resistance to covered kernel smut, rust and bacterial diseases of sorghum.

Constraints

It is imperative that causal agents of plant diseases be correctly identified. Most laboratory facilities in LDCs are without equipment and/or chemical supplies for diagnoses of plant diseases. Scientists may be forced to evaluate germplasm in screening programs based solely on symptoms without having the resources to ascertain the causal agents. A definitive diagnosis is mandatory when the causal agent is seedborne such as the case of bacterial leaf stripe and bacterial leaf streak diseases in sorghum. Diagnostic kits that utilize immunological procedures developed from biotechnological research such as the dot-immunobinding assay or western blots are ideal alternatives to equipping expensive laboratory facilities in developing countries. The procedure is simple, inexpensive and requires only limited equipment such as a refrigerator. Antisera of high quality and sufficient quantity to researchers in LDC's would solve problems due to poorly equipped laboratories, insufficient supplies and specialty chemicals and/or personnel with limited or no training in bacteriology. Monoclonal antisera of high quality would be available to LDC scientists upon request. Alternatively, a portion of the diagnostic procedure can be completed in our laboratories.

Covered kernel smut (*Sporisorium sorghi*) and rust (*Puccinia purpurea*) of grain sorghum occur worldwide. Prior to seed treatments, covered kernel smut was the most destructive disease of grain sorghum in the U. S. with yield losses approaching 50%. Recommended seed treatments applied prior to planting of sorghum seed has reduced the incidence of covered kernel smut to nearly zero. However, in LDCs, smut causes significant yield losses as seed treatments are too expensive and/or unavailable. In Lesotho, incidence of covered kernel smut approached 50% in several fields and lesser incidences were noted in nearly all fields examined (L. E. Claflin & M. Qhobela, *unpublished*.)There is no effective treatment for control of rust and, normally, the disease occurs most frequently after anthesis and yield losses in the U.S. are considered nominal. Rust epidemics commonly occur under cool and humid conditions. Sorghum grown under those climatic conditions will likely have significant yield losses (>50%) such as in Central America and the higher elevations in Africa.

F. moniliforme is synonymous with sorghum in that fungal cultures can be recovered from most plants, whether healthy or diseased. In cases where the such results have not been seen, problems in culture conditions (media, temperature, etc.) or identification are invariably found. We have been working with our LDC colleagues to help them realize the extent of the problem and to help them learn how to appropriately culture and identify these organisms. We also have worked with some breeding programs in the U.S. to supply appropriate strains for screening purposes to increase the efficiency of the breeding program in selecting for resistance to stalk rot.

Research Approach and Project Output

Research Methods

Fusarium spp.

The mating population to which an isolate belongs was identified through sexual crosses with standard mating type tester strains that we have developed. These strains are available on request and have been sent to researchers in Kenya, Cuba, China, Thailand, Malaysia, South Africa, Italy, Egypt, Tanzania, and numerous states in the USA. Crosses are made by spermatizing a culture of a standard tester growing on carrot agar with a conidial suspension from the field isolate. Successful crosses form perithecia that ooze ascospores 2-4 weeks after spermatization. Field isolates are assigned to a mating population on the basis of their crossing pattern with the standard tester isolates.

Vegetative compatibility was determined by pairing complementary *nit*rate nonutilizing mutants on a minimal medium with nitrate as the sole nitrogen source. When a prototrophic heterokaryon was formed, then the parents of the mutant strains were vegetatively compatible and belonged to the same vegetative compatibility group (VCG) When no prototroph was formed then the strains were vegetatively incompatible and belonged to different VCGs. *nit* mutants were selected by spontaneous resistance to 1.5% potassium chlorate, a nitrate analog. These mutants could be placed in one of three major classes - *nit1*, *nit3* and NitM - based on differential growth on media containing nitrite, hypoxanthine or ammonium as the sole nitrogen source. Pairings were usually made between *nit1* and NitM mutants since these pairings usually produced the strongest complementation reaction.

We are examining a set of approximately 100 strains from all six mating populations for isozyme variability. Fungal colonies are grown for four days on a modified Czapek's medium, flash frozen with liquid nitrogen in a protein extraction buffer, and ground to a fine powder in a prechilled mortar and pestle. Debris is pelleted by centrifugation and the supernatant divided into aliquots and stored at -80°C. Activity is maintained for at least two weeks under these conditions; samples are never refrozen once they have been thawed. Isozymes are resolved on starch gels using one of three different buffer systems. Staining protocols vary according to the isozyme being examined and the buffer that was used for the resolution. The entire time for the analysis from the start of culturing the fungus to the end of the gel staining is less than one week.

Fumonisin assays were made using established protocols based on HPLC or GC-Mass Spectrometry.

Bacterial diseases

Development of monoclonal antisera involves a hybridoma technology in which mice are injected with a purified antigen from the bacterial organism. We utilized a 3: kilodalton protein from the bacterial cell wall that wa determined by sodium dodecyl sulfate - polyacrylamide ge electrophoresis (SDS-PAGE) to be unique to *Xanthomona campestris* pv. *holcicola* (causal agent of bacterial lea streak of sorghum). Selective strains of mice (BALB/ c were immunized intraperitoneally with the protein fractior over a period of 10 weeks. The bacterial cells were growr to log phase in nutrient broth then washed in protein isolation buffer and sonicated for removal of the cell wall. The cell wall components were dialyzed in 1 M PBS overnight and then centrifuged at 15,000 x *g*. Twenty to 40μ l of total protein extract were loaded into 12.5% agarose gels and run at a constant current of 30 mA for six hours and stained overnight with Coomassie blue.

The target proteins were transferred from the acrylamide gel to a nitrocellulose membrane in an electric field at a constant current of 30 V for 16 hours at 4°C. This transfer was repeated until approximately 50 μg of protein was obtained for immunization and then injected intraperitoneally into mice. The mice were then sacrificed and the spleen removed. Spleen cells were fused with myeloma cells (cell line P3X63Ag8) to produce the hybridomas. Myelomas are essentially malignant cells that secrete antibodies and provide the immortality factor needed for continuous antibody formation. Spleen cells impart the specificity of the serum.

The dot-immunobinding assay will be used to detect the causal agents of bacterial diseases and to evaluate the efficacy of the monoclonals being developed. In brief, the procedure is as follows: Plant tissue is macerated in water for several hours and the leachate (4 μl) is applied to nitrocellulose paper. The nitrocellulose is soaked in ethyl alcohol and acetic acid (15 min.) to fix the bacteria and then rinsed in buffer (Tris-HCl). The paper is incubated overnight at 4°C in antiserum diluted 1:2000 and then rinsed several times in buffer. Following several rinses in buffer, the nitrocellulose paper is incubated in Protein A-Alkaline phosphatase for two hours. Again, the paper is rinsed several times in TBS. A substrate consisting of Fast Violet B salt and Napthol AS-M phosphate alkaline solution is added and the paper is incubated in the dark for 30 min. The nitrocellulose is rinsed with tap water. A red color on the spot where the leachate was applied indicates a positive reaction to bacteria; a negative reaction of no color indicates that the target bacteria were not present.

The DIA described above is amenable for use by scientists in LDCs as it requires minimal equipment, is rapid and easy to perform the diagnostic tests. If equipment is lacking or nonfunctional, cooperators could simply apply the leachate from diseased tissue and mail the nitrocellulose to our laboratory at Kansas State University. Research has shown that the test can be completed up to three months after the bacterial pathogens have been placed on the nitrocellulose paper. Permits for importing plant materials or cultures are not required because the process requires that the nitro-

cellulose strips be soaked in ethyl alcohol and acetic acid prior to shipment (APHIS, Personal Communication).

To determine if the bacterial stripe pathogen will overwinter within the sorghum plant, wild-type and streptomycin resistant (100 µl/ml) strains of *Pseudomonas andropogonis* will be utilized. Seventy grain sorghum accessions from the Texas A&M University (Courtesy of D. T. Rosenow, TAES, Lubbock) All Disease and Insect Nursery (ADIN) were planted at KSU's Rocky Ford farm near Manhattan, KS. Each accession was planted in 4.6 m rows with three replications. Plants were inoculated at the 12-leaf stage of growth with a Cornwall repeating syringe equipped with a 20-gauge needle. The first five plants in each row were inoculated with the wild-type strain and the last five plants with the streptomycin mutant. One month after inoculation, bacterial leaf stripe infected tissue was collected from lower, middle and upper internodes (including peduncle), leaves and seed of sorghum plants. Tissues were pulverized with a mortar and pestle. One ml of the extract was serially diluted and plated on YDCA medium. The plates were incubated at 28°C for 7-15 days. The tissues will also be examined by immunofluorescent microscopy. Plants were assayed at monthly intervals from July through May. The experiment will be repeated again for 1994-95.

Smut and Covered Kernel Smut

Sorghum accessions from the ADIN were utilized to evaluate genetic variability to rust and covered kernel smut pathogens. The 70 entries were replicated four times in a randomized complete block design at the Rocky Ford Farm near Manhattan. Seeds were planted during the first two weeks of May in rows spaced 76 cm apart and 11 cm between plants in the row. The experiment was conducted over three years (1989-1993) although not all genotypes were evaluated every year.

Inoculum consisted of *S. sorghi* infected panicles that were collected during the previous growing season and stored at -20°C. Teliospores were harvested by rubbing the infected panicles on a 60-mesh (250 µM) screen. Debris was separated from teliospores by shaking the mixture on a 200-mesh (75 µM) sieve. Teliospores were added to the sorghum seed (0.5% w/w) and planted within four hours after mixing. Natural inocula were utilized for those accessions in the rust experiment. Plants were scored for smut and rust incidence at physiological maturity.

Research Findings

Fusarium spp.

We have now formally described the F mating population of *F. moniliforme*. Female fertility is relatively low in these isolates suggesting that sexual reproduction may be relatively infrequent and that different race types could develop. Isolates from this mating population represent the majority of *F. moniliforme* isolates recovered from sorghum. We have shown that representatives of the 10 most common VCGs are not significantly different in their ability to cause lesions following toothpick inoculations. These 10 VCGs contain 75% of the F mating population isolates that we recover from sorghum in Kansas. The distribution of these VCG types in LDC settings is under investigation.

Within the six *F. moniliforme* mating populations, strains of only two, A & D, are known to make fumonisins. The D & F mating populations are responsible for most of the observed stalk rot and grain mold of sorghum; therefore, there is potential for fumonisin contamination of sorghum. The ability to produce fumonisins is a property of the mating population and is not affected by the host from which an isolate was recovered. Within the D mating population there is considerable between isolate variation in the amount of fumonisin produced with a range of 2-2000 ppm. Although the F population does not produce fumonisins at any significant level, it does produce other, as yet unidentified, mycotoxins that are at least as toxic to ducklings as are the fumonisins.

We have begun studies of the karyotype of *F. moniliforme* using CHEF gel electrophoresis. The available data suggest that all six mating populations have the same chromosome number (n = 12), and that there is relatively little karyotype variability within a mating population but that differences between mating populations appear to be substantial.

Isozymes are being tested as an alternative to crossing for the diagnosis of the mating population to which a strain belongs. At present we are testing 20 different isozymes for polymorphism both within and between mating populations. Depending on the level of variability present, isozyme analysis could provide information comparable to that provided by the current crossing protocols or to the VCG analyses.

Bacterial Diseases

A complementary DNA (cDNA) specific probe for detection of *Pseudomonas andropogonis* (causal agent of bacterial leaf stripe) continues to be sought. The vector, pBluescript, and genomic DNA from *P. andropogonis* have been isolated. Ligation of the DNA insert into the vector remains a problem. This particular research problem has now been delayed in order to complete the monoclonal antibody project for *X. c.* pv. *holcicola*.

Approximately 1200 hybridomas were screened against 30 strains of *X. c.* pv. *holcicola*, 18 other pathovars of *X. campestris* and other *Pseudomonas* spp. that incite bacterial diseases in sorghum for specificity and cross-reactivity. Six hybridoma clones were selected and the antisera tested with the DIA. Background problems developed and the cause was found to be an improper dilution with the rabbit anti-mouse serum. In addition, serious delays were encountered when subclasses of the IgG isotype developed and resulted in a

loss of specificity. Subclones of the six hybridomas were retrieved from storage in liquid nitrogen. These subclones were again tested in immunoassays to ascertain the specificity against the 32 Kd protein immunogen. Subsequently, the hybridomas were injected into mice which will result in tumerous cells and ascites fluids will be formed. One ascite secretion has been tested and the results show excellent specificity and the titer is extremely high, exceeds 10^6, whereas titers from polyclonal antisera are considered excellent at a reading of 2,160.

Smut and Covered Kernel Smut

Three ADIN entries, B35-6, SC414 and Sureño were immune in our tests to covered kernel smut. The most susceptible accessions were TX430 and BTX623 with over 50% of the plants exhibiting smutted heads (Table 1). TX2858 and 90B2662 were very susceptible to rust whereas 86EDN362, 90CW8147 and 86EDN361 were nearly immune (Table 2).

Table 1. Genetic variability of various sorghum accessions to covered kernel smut (Sporisorium sorghi)[a].

Accession	Mean[b]
TX430	56.8
BTX623	56.0
88B1016	46.0
TX2767	40.4
R9188	37.2
B8618	35.8
B1	35.6
85DG4300	35.5
QL3	35.4
MALISOR8	35.0
BTX378	34.8
BTX631	31.6
R8503	31.3
TAM428	26.9
TX2783	26.4
80C2241	24.9
BTX2755	23.8
87BH8606	23.5
TX7078	9.7
87EDN109	8.9
82BDM499	0.9
88B928	0.7
SUREÑO	0.0
SC414-14	0.0
B35-6	0.0

[a]Data collected 1989-1993.

[b]Means determined by smutted heads/total plants X 100.

Table 2. Reaction of various sorghum genotypes to rust (Puccinia purpurea) under natural conditions (1992-93).

Genotype	Mean[a]	Waller Grouping[b]								
TX2858	5.6									A
90B2662	5.4									A
X2862	4.1									B
TX7078	4.6									B
QL3	4.6									B
TX2783	4.6									B
B35-6	4.0									C
BTX2755	3.9								C	D
89BE5142	3.9								C	D
88B924	3.9								C	D
MB108B	3.6							C	D	E
BTX378	3.4							D	E	F
88B1016	3.3							E	F	C
ICSV-LM89	3.3							E	F	G
SUREÑO	3.2						E	F	G	H
90E0N328	3.1						E	F	G	H
TX2767	3.0						F	G	H	I
TX430	3.0					F	G	H	I	J
B8618	2.8					G	H	I	J	K
R8503	2.8					H	I	J	K	L
SC630-11	2.7					H	I	J	K	L
89CC132	2.7					H	I	J	K	L
90CCEDN343	2.6					I	J	K	L	M
85DG4300	2.5				J	K	L	M	N	O
91B2978	2.5				J	K	L	M	N	O
B1	2.4				K	L	M	N	O	P
R9188	2.3				L	M	N	O	P	Q
91BE7414	2.3			L	M	N	O	P	Q	R
88B943	2.2			M	N	O	P	Q	R	S
80C2241	2.2			M	N	O	P	Q	R	S
87EDN109	2.2		M	N	O	P	Q	R	S	T
91CC515	2.2		M	N	O	P	Q	R	S	T
BTX623	2.1		M	N	O	P	Q	R	S	T
87BH8606	2.1		M	N	O	P	Q	R	S	T
B2TX636	2.1		N	O	P	Q	R	S	T	U
TAM428	2.0		O	P	Q	R	S	T	U	V
BTXarG1	2.0		O	P	Q	R	S	T	U	V
88B928	2.0		P	Q	R	S	T	U	V	W
BTX635/B	1.9		P	Q	R	S	T	U	V	W
BTX631	1.9		P	Q	R	S	T	U	V	W
82BDM499	1.8			Q	R	S	T	U	V	W
R9036	1.8			Q	R	S	T	U	V	W
SC326-6	1.8				R	S	T	U	V	W
MALISOR8	1.7				S	T	U	V	W	X
89CC443	1.7				S	T	U	V	W	X
SC414-12	1.7				T	U	V	W	X	Y
SRN39	1.6					V	W	X	Y	Z
91BD1319	1.5					W	X	Y	Z	α
87EDN366	1.2						X	Y	Z	α
86EDN362	1.2							Y	Z	α
90CW8147	1.2								Z	α
86EDN361	1.1								Z	α

[a] Means based on a rating scale of: 1 = 0-2%; 2 = 3-10%; 3 = 11-25%; 4 = 26-50%; 5 = 51-75%; and 6 = >76% of the foliage exhibiting rust symptoms.

[b] Means followed by the same letter are not significantly different (P = 0.05).

Networking Activities

Workshops

Dr. Claflin attended and participated in the International Conference on Insects and Diseases of Grain Sorghum in Tibaitata, Colombia January 26 - 31, 1993. Approximately 170 scientists attended.

Dr. Leslie has been co-organizing a conference on "Biotechnology in the management of variable pathogens of sorghum and millet" that is scheduled for the Rockefeller Foundation's Bellagio conference center in November 1993.

Research Investigator Exchanges

Dr. Claflin visited the ICA (Colombia) Agricultural Research Centers in Nataima and Villavicencio in cooperation with Dr. Guillermo Munoz (INTSORMIL/MSU 111) and made plans to coordinate the International Conference on Insects and Diseases of Grain Sorghum (November 29 - December 5, 1992). Other organizing personnel included Dr. Manual Torregroza (ICA) and Mr. Fabio Polania (FENALCE).

Dr. J. R. Reddy has taken additional leave from the Plant Quarantine Unit, ICRISAT, to finalize projects on monoclonal antibodies and epidemiological research on bacterial streak disease of sorghum.

Dr. Claflin consulted with the collaborative ARC/USAID/INTSORMIL research program in Egypt from August 27–September 4, 1992.

Dr. Leslie spent 11 months (August 1992 - June 1993) on sabbatical leave in the laboratory of Dr. David D. Perkins at Stanford University.During this time Dr. Leslie was studying the underlying mechanism of the vegetative compatibility response in fungi using the model organism *Neurospora crassa* for his studies.

Dr. Leslie consulted with the collaborative ARC/USAID/INTSORMIL research program in Egypt from December 8–18, 1992.

Dr. Leslie is serving on the Ph.D. advisory committee of Mr. Anaclet Mansuetus in the Plant Pathology Department at Texas A & M University.

Germplasm and Research Information Exchange

Dr. Leslie has also been collaborating with the following scientists:

James B. Anderson, Department of Botany, University of Toronto, Mississauga, Canada.

Charles Bacon, Russell Research Center, USDA/ARS, Athens, Georgia.

Lester Burgess, Department of Agricultural Biology, University of Sydney, Sydney, Australia.

Walter A. J. de Milliano, Sandoz Seeds, Enkhuizen, The Netherlands.

Frank J. Doe, Department of Biology, University of Dallas, Irving, Texas.

Linda Kohn, Department of Botany, University of Toronto, Mississauga, Canada.

S. Muthukrishnan, Department of Biochemistry, Kansas State University, Manhattan, Kansas.

Philippe Nicot, INRA, Montfavet, France.

David D. Perkins, Department of Biological Science, Stanford University, Palo Alto, California.

Claude Seletrinnikoff, Department of Cellular and Structural Biology, University of Colorado Medical Center, Denver, Colorado.

William E. Timberlake, Myco Pharmaceuticals, Inc., Cambridge, Massachusetts.

Germplasm Conservation and Use

Dr. Leslie maintains a collection of approximately 6,000 cultures of *Fusarium* based on worldwide collections. Many of these strains have been genetically characterized, and have known mycotoxin or pathogenicity profiles. This collection complements other major collections of *Fusarium* that are maintained in Pennsylvania, Australia, Germany, and the Republic of South Africa.

Dr. Claflin maintains an extensive phytopathogenic bacterial culture collection of over 600 species that has been established in our laboratory. He has the most comprehensive collection of plant pathogenic bacteria affecting grain sorghum and pearl millet in the world.

Assistance Given

Antisera, bacterial cultures, antibiotics, and nitrocellulose paper was furnished to Mr. Ismael, ARC, Giza, Egypt.

Nitrocellulose paper and various enzymes were sent to Mr. Iven Kiriakov, Dobritch, Bulgaria.

Plant samples from the Gezira Research Station, Wad Medani, Sudan were examined for mycoplasma-like organisms at the electron microscopy section at Kansas State University.

Various bacterial cultures isolated from sorghum by scientists at Gulbarga University, Gulbarga, India were identified in the laboratory of L. E. Claflin.

Approximately 30 bacterial cultures from the collection of L. E. Claflin were furnished to the Foreign Pests and Weeds Section, USDA-ARS, Ft. Detrick Containment Department, Frederick, MD.

Assistance was provided to Dr. Elhamy El-Assiuty, ARC, Giza, Egypt in preparation of technical papers for presentation at international professional society meetings.

VCG and mating type studies were made on unusual *Fusarium* isolates from sorghum for Mr. Temam Hussein, Alemaya University, Ethiopia.

Publications and Presentations

Publications

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Presentations by John Leslie

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Zaadunie B.V. (Sandoz Seeds), Enkhuizen, The Netherlands - 2/92.

National Center for Agricultural Utilization Research, Peoria, Illinois - 3/92.

Department of Plant Pathology, Iowa State University, Ames, Iowa - 3/92.

International Chestnut Conference, Morgantown, West Virginia - 7/92.

Bay Area Yeast Club, San Francisco, California - 10/92.

Department of Plant Pathology, University of California, Davis, California - 10/92.

Department of Plant Pathology, University of California, Berkeley - 10/92.

Low Input Ecologically Defined Management Strategies for Insect Pests on Sorghum

Project MSU-105
Henry N. Pitre
Mississippi State University

Principal Investigator

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Summary

Insect pests, some common to both the United States and Honduras, were investigated to facilitate development of pest management programs. Crop mortality factors were partitioned in sorghum-corn intercropping systems in Honduras; 65% mortality was due to insects. The complex of insect pests damaging or destroying the various crop stages was identified. Pest species diversity and density levels were cataloged. Seed treatment with insecticide was required to prevent seed and seedling loss due to soil-inhabiting insects and millipedes. A lepidopterous complex, referred to as "langosta" by subsistence farmers destroys crop stands; the complex was identified to consist of three armyworm species and a grass looper. The neotropical cornstalk borer and panicle feeding insects did not appear to be major constraints to production. Biological and ecological relationships of the langosta species with non-crop and crop plants dictated the crop damaging potential and economic significance of each species. Non-crop plant "source habitats" and crop plant "sink habitats" were identified and the biotic potential of each species was determined. Parasites of armyworm species in the langosta complex were identified and their impact quantified. The international significance of a migratory pest species (fall armyworm) was elucidated in comparisons of insect biology, behavior and reaction to insecticides for insect populations from the U.S. and the Latin American Ecogeographic Zone.

Ecological approaches to insect pest management included cultural and biological control and host plant resistance. Planting strategies (seed selection and planting method) and cropping systems (e.g., cereal-legume) influenced insect pest damage. Weed control influenced the langosta species differently, thus impacting crop damage. Honduran native landrace sorghums, "maicillo criollos" with antibiosis insect resistance was identified. Insecticides were used selectively for control of insect pests on seeds, seedlings and older plants. Insect pest management was demonstrated on-farms.

Introduction

Grain sorghum is one of the world's most important food and feed crops. The value of sorghum has steadily increased in the United States, especially in the southeast over the past two decades. Insect pest management, however, remains a great concern to sorghum farmers. Annual loss estimates due to just one insect, the fall armyworm, exceeded $300 million in the U.S. in one year in the late 1970's. Yield losses

and costs of control attributed to the complex of insect pests on sorghum in the southern United States is considerable, considering that this one insect, the fall armyworm, can be responsible for this high level of expense in production of the crop. Crop and insect pest management systems must be improved to provide the sorghum farmer with a reliable scheme for management of pests with minimum use of toxic chemicals to achieve an environmentally acceptable and sustainable sorghum production system in the United States. This must be achieved in regions where insect pests on sorghum have historically been controlled with insecticides.

Honduras

MSU-105 has been involved in entomological research in Honduras throughout the INTSORMIL program. Corn and sorghum are the first and third, respectively, most important grains produced in Honduras. Ninety percent of the sorghum acreage in southern Honduras is intercropped with corn because of adverse environmental and agronomic conditions which are best characterized by erratic precipitation, high temperature, and low soil fertility. If the corn crop is lost to drought, farmers substitute sorghum for corn to feed their animals and family. Thus, sorghum is an insurance crop during dry years when the corn crop fails, which occurs in three of every five years. More than 40% of the sorghum harvested in southern Honduras is destined for human consumption.

Native landrace sorghums called "maicillo criollos" grown by subsistence farmers in fields averaging 1.5 ha in Honduras are tall (3–4 m) and sensitive to photoperiod. Because of its photoperiod sensitivity, sorghum does not differentiate and begin internode elongation until the first part of October after corn reaches maturity and is harvested. The intercropping of late maturing, photoperiod-sensitive sorghums with early-maturing corn varieties effectively utilizes the limited land available and soil moisture and nutrients.

The major insect pest constraints to sorghum and corn production in Honduras were identified during the early years of the MSU-105 project. Insect pests in the soil damage and/or destroy sorghum seed, lepidopterous pests damage or destroy seedling plants, stem and stalk borers weaken and/or kill maturing sorghum and head feeding species destroy the seed; all are important in reducing crop yields. Therefore, a range of insect pest management tactics have been evaluated to determine the effective practices that have application in developing countries in the Central American Ecogeographic Zone. Principal emphasis has been on development of non-chemical pest control practices. This is important in production areas where financial investment in crop production must be held to a minimum. These insect pest control methods have emphasized host plant resistance, and cultural and biological control tactics.

Insect pests common to the Americas, have been investigated in the United States to elucidate the biological and ecological relationships of populations and influence of these populations from specific geographical areas upon the population densities and crop damage by the pests in other geographical areas. Studies on pest biology and ecology and reactions to insecticides, as well as relationships between insects and crop and non-crop plants have contributed to the development of an ecological framework for understanding the role of insects in different sorghum production systems. MSU-105 has developed information to assist resource poor farmers in Latin America, and will facilitate further development of strategies for managing insect pests of international importance, especially those entering the continental United States.

Graduate students from Honduras have MSU-105 INTSORMIL training and all have returned to pursue entomological careers to provide sustainable agricultural practices for the region. MSU-105 has worked closely with TAM-131 and the Department of Research, Honduras Ministry of Natural Resources. This collaboration will continue.

Sudan

Collaborative INTSORMIL relationships between research entomologists in the Sudan (ARC) and MSU-105 were established in 1987 in association with the Purdue (PRF) INTSORMIL Project. The principal pest constraints to sorghum production in Sudan are shoot fly, stem/stalk borers, American bollworm, aphids and sorghum midge. The levels of damage caused by these pests vary in rain-fed areas and irrigated areas. MSU-105 collaboration to date has involved host country visits, reviews of program design and project evaluations. A graduate student from Sudan has been trained in IPM.

Present studies by in-country scientists emphasize screening of insecticides against sorghum shoot fly and stem borers. Tests to evaluate selected insecticides for efficacy against shoot fly and stem borers and implementation of insect pest control tactics into IPM programs in sorghum is needed.

Malawi

The participation in MSU-105 of a graduate student (M.S. level) from Malawi in 1991-1993 will provide an opportunity for further networking and expansion of research on insect pest constraints on sorghum in Africa. This SADC student has returned to Malawi to continue employment with the Ministry of Agriculture.

Objectives, Production and Utilization Constraints

Objectives

Study the biology and population dynamics of insect pests responsible for damage or destruction of sorghum and corn seeds seedlings and older plants.

Evaluate sorghums for resistance to specific insect pests and determine mechanisms of plant resistance.

Develop integrated insect pest management methods employing basic concepts of ecological crop management.

Constraints

Soil inhabiting insect pests damage or destroy sorghum and corn seeds thus reducing or destroying plant stands. Pest species diversity (richness) and density (evenness) were identified in selected areas in southern Honduras. Methods to assess plant damage and pest control measures were developed. Seeding rates, depth of planting, seed size and color, and insecticide use were investigated.

Defoliator lepidopterous pests were identified as the principal insect pest constraint to sorghum and corn production in Honduras. Some that occur in Central America also occur in the United States. They survive from one year to the next in both areas, or they may migrate from south to north, arriving in the United States during the crop growing season. The economic significance of migrant insect pests is influenced by time of arrival of immigrant populations, stage of crops in the affected area, fitness of the migrant insects, level of insecticide resistance, if any, in the migrant population, and other factors influencing their population dynamics. These factors have been investigated and reported in MSU-105 for fall armyworm.

Investigations of the role of each species in the langosta complex in Honduras included relationships of diversity and density, seasonal population dynamics, and behavior, biology and ecology. This information provides the base for integration of cultural, biological and chemical control tactics in the implementation of insect pest control programs.

Stalk borer and panicle feeding insect pests have been investigated to a limited extent because of their secondary importance.

Research Approach and Project Output

Soil Inhabiting Pests

Agricultural extension workers and farmers in Honduras expressed concern about soil and early-season insect pests. Since little systematically collected information was available on diversity and density of the soil inhabiting arthropod species complex damaging these crops in the area at the initiation of MSU-105, studies were conducted to obtain this information.

Wireworms, white grubs, rootworms and millipedes were among the most abundant arthropods collected. Differences in species diversity and density were observed between fields with slash and burn and slash and mulch on hillsides and fields on the plains. Wireworms, white grubs, rootworms and millipedes were the dominant pests. Increased numbers of arthropods in burned fields was related to their establishment in attractive, luxuriant regrowth vegetation. If these soil inhabiting arthropods are not controlled, replanting may be necessary at additional cost to the farmer.

Crop Stand. A good crop stand is critical for resource-poor, subsistence farmers. Subsistence farmers incur higher production expenses when additional seed is required for replanting or they may not replant due to the lack of seeds. Replanting also results in delayed maturity of the corn, which increases its vulnerability to mid-season drought and exposure to additional damage by late-season insect pests. Depth of planting of seed influences seed germination, seedling emergence, seedling vigor and subsequent plant performance. Depth of planting may be determined by seed size and type, as well as number of seed planted. These factors were examined in different cropping systems.

Ants were mainly responsible for seed destruction. Seed size and color did not influence the amount of damage to seeds and seedlings by insect pests. More seeds were destroyed or removed where seeds were planted 7.5 cm deep than at 2.5 cm. Seedling emergence was higher when seeds were planted 2.5 cm deep than at 7.5 cm. Seeds were damaged less by insects, and seedling emergence was higher where seed were planted in alternate hills than where seed were planted in the same hill planting system. Thus, information was obtained for recommending seed planting strategies to limit arthropod destruction of seeds and seedlings.

Insecticide Seed Treatment. The need for effective use of selective insecticides to protect sorghum and corn seed and seedlings from arthropod pests was determined during the early years of MSU-105. The effectiveness of chemicals in protecting seeds and seedlings was determined. Furathiocarb (Promet) provided the highest level of protection and is recommended for use; it is presently used in on-farm demonstration studies. Kerosene, applied to the seeds by some resource poor farmers, limited number of seeds removed by ants. This material is a low cost alternative for limited protection of seeds from ants.

Lepidopterous Pest Complex (The "langosta")

A lepidopterous pest complex, collectively referred to as "langosta" by subsistence farmers, was identified as a major constraint to sorghum and corn production in Honduras. Three armyworm species, *Spodoptera frugiperda* (fall armyworm), *S. latifascia*, and *Metaponpneumata rogenhoferi*, and the grass looper, *Mocis latipes* were identified as the principal insect species in the complex. The fall armyworm was the predominant species collected throughout the growing season. *S. latifascia* and *M. rogenhoferi* were present only early in the season, and *M. latipes* was present in mid-season.

The "langosta" may destroy or seriously damage the crop plants during the first and second growing seasons in Honduras and other areas in Central America. The fall army-

worm and *M. rogenhoferi* were identified as the principal pests species in this complex. Non-crop vegetation in and around the production fields serve as host plants for these insects prior to crop emergence. Removal of this vegetation influences populations of larvae and crop damage (to be discussed later).

M. rogenhoferi and *S. latifascia* were common on non-crop broadleaf, weeds and grasses in early season, attacked sorghum and corn in seedling stages, but were limited in population development on these crop host plants. This suggested that sorghum and corn may be "sink habitats" for these species; these are areas where factors are not sufficient to carry out its life functions. Whereas, the non-grass host plants in certain areas growing in suitable environmental conditions for the species to carry out its life history are "source habitats." Except for the fall armyworm, sorghum and corn were determined to serve as a sink habitat where the net lepidopterous population decreases, and survival and population increase depend on nearby non-crop source habitats. Source and sink habitats serve to complicate the ecology of the species in this complex.

Although many farmers spray insecticides to control the langosta, environmentally safe and effective control measures were investigated, including management of non-crop vegetation or source habitats and planting strategies. Monitoring source habitats and synchronizing planting dates in relation to immigration is a low cost control measure that can be employed by subsistence farmers. These tactics are within the means of resource poor farmers since they primarily involve investment of their own labor.

The diversity of the lepidopterous pest complex ensures that sustaining adequate control of the langosta depends on an array of integrated pest management practices. Because manipulation of a niche may affect one species adversely only to benefit another, as in the case with weed control which reduced the population of *M. latipes* but increased population size of the fall armyworm, knowledge of the ecology of each species is required in developing IPM programs for specific production areas.

Factors Associated With Pest Population Outbreaks. The suitability of non-crop and crop host plants for establishment of insect infestations and development of populations throughout the crop growing season has been investigated for the armyworm species in the langosta. With knowledge of the seasonal occurrence of the pests and availability of suitable non-crop host plants for the various species, insect populations can be monitored closely for pest outbreaks. Identifying "source" and "sink" habitats for the species and associated biological and ecological relationships is fundamental to the development and implementation of specific insect control tactics.

The most common weeds in sorghum production ecosystems were identified. All species in the langosta complex fed on non-crop vegetation in and around production fields. *M. rogenhoferi*, fed on *Thrianthema portulacastrum* L. (Aizoacea), *Portulaca oleracea* L. (Portulacaceae), *Cassia leiophila* Vogel (Leguminosae), *Ipomoea* sp. (Convolvulacea), *Melampodium divaricatium* (Rich. ex pers) DC (Compositae) and *Amaranthus spinosus* L. (Amaranthaceae) some of the most common broadleaf weeds in southern Honduras. *S. latifascia* fed on the above weeds as well as on other grasses like *Ixophorus unisetus* (Pres L.) Schlecht, the most common grass on the plains. *I. unisetus* was the most common weed-grass host for *S. frugiperda*. Knowledge of the preferred ovipositional and food host plants for the langosta, provides the basis for specific recommendations for management of these plants in such a way that the crops are least affected by insect pests.

The sudden appearance and disappearance of economically damaging populations of *M. rogenhoferi* and *S. latifascia* in farmers' fields in southern Honduras was investigated. No evidence was obtained to conclude that biological agents are responsible for the sudden disappearance of the two species. Rather, the crop plants serve as a sink habitat for these species. Feeding preference and feeding performance data on non-crop and crop vegetation were obtained for these two species to support this conclusion. The two armyworm species fed sorghum or corn declined in numbers as the season progressed; they have a low survival rate on these host plants.

Crop and non-crop (weed and grasses) host preferences for egg laying by the langosta species were investigated. For example, oviposition patterns by fall armyworm were elucidated using moths of different physiological ages on plants of different phenological growth stages. Information obtained is useful in establishing insect sampling procedures to determine pest infestation levels in low as well as high technology crop production systems.

Insect Migration

International Significance. Migration of the fall armyworm into the United States from southern latitudes and the possible existence of host-associated sibling species have raised some controversies over the origin of fall armyworm occurring in the United States, control success diapausing capabilities and host plant relations. To further define relationships of fall armyworm from Mississippi, Florida, Honduras, and Jamaica, biology (developmental rates), behavior (pheromone studies) and insecticide susceptibility (resistance) comparisons were conducted. These studies indicated that the fall armyworms from Honduras appeared to be more like those from the mid-south in the United States than those from Florida.

Adult insect movement and its role in population dynamics of the species is of economic importance, as well as ecological interest. Knowledge of the timing and magnitude of immigration and the relationship of local conditions to the probability of population establishment can be used to develop an "early warning system" for predicting the sever-

ity of the immigrant pest problem for a specific area in a given year. This procedure was used successfully to identify population establishment of immigrant fall armyworm populations in Mississippi.

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Insect Pest Management

Cultural Control. The MSU-105 project has emphasized the ecological approach (cultural management of insect pests) in design and conduct of investigations involving the langosta complex. Studies were conducted on hillside farms and on farms on the plains, representing the two farming systems in southern Honduras. Observations were made in pure stand sorghum, and in sorghum and corn in intercropping and mixed cropping systems. Comparisons were made between fields with burned stubble (slash and burn) from the previous crop and fields with some mulch but not burned (slash and mulch).

Planting Strategy. Cropping systems in the tropics commonly include the practice of growing together two or more crops in the same space and with some overlap of their growing period (intercropping). Crop associations may consist of cereal-cereal or cereal-legume systems. Intercropped cereals and legumes have been recognized to have yield advantages over monocultures, but weed problems exist. Studies comparing different intercropping strategies showed sorghum in fields with a natural weed infestation to have fewer fall armyworm larvae than fields without a weed infestation. Sorghum and corn planted in the same hill had lower fall armyworm infestation than sorghum planted with a corn trap crop or in pure stand. Corn (the preferred host) served to attract moths and crop interference was responsible for reduced numbers in interplantings.

Infestations of fall armyworm on sorghum and corn were similar in intercropped sorghum-corn fields with or without pigeonpea. Fields with cowpea had lower fall armyworm infestations than fields without cowpea. Corn yield was not affected by this intercropping practice, although sorghum yield was reduced. The additional legume yield from the cowpea or pigeonpea in this cropping system can be of great value in the diet of subsistence farmers.

Plant Population. Sorghum-corn intercropping systems provide greater net returns, on average, than non-intercropped sorghum or corn or some combination of the two crops. And, this planting practice could create lower yields than when the crops are planted in different systems at higher densities. MSU-105 investigated the effect of plant population on fall armyworm infestations and plant damage on sorghum. Although total numbers of fall armyworm per unit area were greater in higher plant populations, observed plant damage was lowest in the more dense plantings because the larger number of larvae was spread over an even greater number of plants.

Weed Control. The influence of weeds and grasses on insect pest populations was determined in sorghum-corn fields grown in conventional planting systems in southern Honduras. Weed control was combined with insecticide use (as required) for evaluation of the lepidopterous pest complex. Fertilizer, seed and insecticide were provided to the farmers in return for their cooperation. The close spatial and temporal relationships of these insect pests with non-crop vegetation allows for use of effective weed management practices in the management of certain species in the langosta complex.

The role of broadleaf weeds and certain grass species in the establishment and development of insect pest infestations in and around crop production fields was elucidated (reported earlier). The use of good weed control programs cannot be overemphasized in insect control recommendations to subsistence farmers growing sorghum and corn in Honduras and other countries in Central America.

Trap Crop. The effectiveness of a corn trap crop in reducing fall armyworm larval infestations on sorghum in areas where sorghum and corn are grown together in the same field (farm) was investigated in Honduras and in the United States. Infestations of fall armyworm were similar or somewhat greater on sorghum grown in small plots with and without the corn trap crop in both Honduras and the United States. The test area was too small to differentially restrict fall armyworm activity on the preferred corn plants. Corn was more heavily infested and damaged than sorghum, further suggesting the potential for use of corn as a trap crop for monitoring insect populations and its possible use as a trap crop.

Host Plant Resistance. The development and use of plants resistant to pests is essential to most integrated control approaches. This pest control tactic is an efficient and persistent method of controlling insect pests, and it is environmentally compatible. MSU-105 has emphasized host plant resistance in sorghum to the fall armyworm, identifying genotypes with various levels of resistance and mechanisms of resistance. Knowledge of the basic aspects of insect biology and behavior is critical in developing techniques for testing and evaluating resistance levels and mechanisms.

Studies in the laboratory have emphasized the development of techniques for measuring sorghum resistance to larval feeding. Meridic diets have been formulated, tested and proved to be highly successful in our fall armyworm host plant resistance evaluations. The use of meridic diets has enhanced the progress of sorghum screening for resistance to fall armyworm. The MSU-105 and TAM-131 Projects are working cooperatively with the Honduras Sorghum

Breeding Program to determine sources of resistance to fall armyworm and mechanisms of resistance to this pest.

Honduras landrace sorghums (maicillo criollos) were identified with antibiosis resistance to the fall armyworm. Insects responded to feeding on resistant plants by having low net reproductive rate and/or low intrinsic rate of natural increase of the population. Antibiosis resistance appeared to be widespread in the maicillos. The sources of resistance may be polygenic and should be stable over time. Sorghums with resistance have been crossed to achieve increased levels of resistance, but this limited effort has not been very successful. The INTSORMIL/Honduran National Sorghum Breeding Program will continue these studies.

The low cost host plant resistance insect control tactic can be used in combination with crop management (planting) strategies and limited use of chemical or biological pesticides to effectively manage infestations of the langosta species on intercropped sorghum and corn on subsistence farms.

The host plant resistance to insects research program in Georgia (MSU-105) is designed, in most part, to evaluate and develop sorghum with resistance to leaf feeding lepidopterous pests, particularly fall armyworm. Converted sorghum lines evaluated for resistance appeared to have a morphological-non-preference type expressed in the form of lack of sustained colonization by the larvae. Research completed with the new collections of sorghum (PI) from Ethiopia and Yemen represents the international scope of the plant resistance research program (MSU-105). Studies combining host plant resistant sorghum and biological control are in progress and will provide information for use in affecting effective integrated insect pest management programs in high technology, as well as low technology sorghum production systems.

Biological Control. Studies with FAW were conducted in Mississippi and Honduras to partition mortality of immatures to responsible factors, including "accidental death," predators, parasites, and entomopathogens. Survival rates of the different age classes and effects of these mortality factors on seasonal populations were elucidated. Parasitization of the fall armyworm *S. latifascia* and *M. rogenhoferi* larvae did not successfully regulate populations of these armyworms during the growing season in Honduras.

Insecticide Control. Chemical and biological insecticides were evaluated in relation to the application of effective pest management strategies. The selective use of insecticides at minimum effective rates and larval age specific mortality were investigated. Insecticide efficacy-pest mortality relationships for insects from the United States and the Latin American zones were identified. This is important because of the migratory behavior of the fall armyworm from and into different geographical regions (re: Migration section).

On-Farm Research Demonstrations. Conventional and improved crop management practices were evaluated in Honduras to determine applicability and economic feasibility for incorporation into integrated insect pest management programs in Honduras. Partial life tables were constructed for sorghum and corn for test comparisons during the very early season. Overall 65% of the total mortality of sorghum and corn plants was attributed to insects, 20% to lack of germination, 10% to abiotic factors (drought and mechanical damage), 2.5% to diseases and 2.5% to unknown causes. Total crop mortality ranged from 25% to 95% in corn and from 3% to 32% in sorghum.

Stalk Borers

The neotropical cornstalk borer was determined by farmer survey procedures and observations to be the principle insect pest in the stalks of sorghum and corn in the late whorl and reproductive stages of plant growth. Whereas burning practices appeared to be responsible, in part, for larger numbers of neotropical cornstalk borers in sorghum in fields on the hillsides, this practice of burning crop residues did not increase infestations of this pest on sorghum in fields on the plains.

Control measures recommended for neotropical cornstalk borer in some areas of Central America include crop rotation, crop residue destruction, early planting and good soil fertility. Studies indicated that in farming systems in southern Honduras, crop rotation is of little value for reducing neotropical cornstalk borer infestations.

Test revealed that the timely application of an effective insecticide may significantly reduce numbers of this pest on sorghum, reduce damage to the stalks and improve crop yield. (In the sorghum-corn intercropping system in Honduras, corn is harvested before the neotropical cornstalk borers can cause serious damage to this crop.)

Panicle Insect Pests

Surveys were conducted to identify insect pests feeding in the sorghum panicle. Observations during several years indicated that the occurrence of panicle feeders, (e.g., head bugs and head caterpillars) varied from one year to another in the same region. The collaborating Agricultural Extension personnel did not include these pests as a principle constraint, but did caution that in some years they may be responsible for some crop damage.

Networking Activities

Workshop

1993. International Consultative Workshop on Panicle Insect Pests of Sorghum and Pearl Millet. Invited speaker, Title: "Panicle Feeding Caterpillars on Sorghum in the Western Hemisphere." Niamey, Niger.

Germplasm and Research Information Exchange

Germplasm Conservation and Use

Sorghum germplasm acquisitions from Honduras, Sudan and elsewhere were received and evaluated at Tifton, Georgia for resistance to the fall armyworm.

Seed production

Sorghum seed produced in Honduras by TAM-131 in collaboration with the Honduran National Sorghum Breeding Program received and tested at Tifton, Georgia for resistance to the fall armyworm.

Impacts

Methodologies developed in the United States, reported in "Methodologies Used for Screening Resistance to Fall Armyworm in Sorghum," and published in the Proceedings of the International Workshop on Sorghum Stem Borers are techniques and procedures readily transferable and adaptable in most host plant resistance programs in developing countries. Techniques for testing and evaluating insecticide resistance (or susceptibility) in insect pests have been used successfully in similar studies in the host country. Knowledge gained from studies in the United States on sorghum planting methods and strategies, as well as, use of trap crop and insecticide methods of sorghum insect pest control have been successfully used in insect pest control on sorghum in the host country.

Assistance Given

Research dollars have been transferred to the host country to assist graduate student research in the laboratory and in the field. Equipment and research supplies have been provided to include (e.g., pick-up truck, stereoscope, refrigerator, hygrothermograph, camera with telephoto lens, tape recorder, metal cages for laboratory, screen cages for field, insect diet and rearing supplies, other laboratory, field and office supplies).

Publications and Presentations

Publications

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Role of Polyphenols in Sustainable Production and Utilization of Sorghum and Millet

Project PRF-104B and PRF-104C

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Summary

This project applies the techniques of biochemistry in an interdisciplinary manner, with LDC and other INTSORMIL collaborators, to some of the major constraints on sorghum production and utilization. It originally addressed the tannins as antinutritional factors. We developed methods, now widely used by others, for assaying and characterizing these materials. We also developed a simple method for detoxifying and improving the nutritional value of high tannin sorghum. We are elucidating the biochemical mechanisms by which tannins exert their antinutritional effects. We are also characterizing the role of tannins and related materials in resistance to birds, molds and leaf diseases.

With Drs. Ejeta and Babiker, we developed a unique and effective approach to the *Striga* problem, described in the research bulletin we published this year. We consider each stage of the *Striga* life cycle separately. We characterize the host-parasite interaction at each stage, particularly the chemical signals exchanged. For each stage we seek simple ways to detect ineffective interactions. We use these screening methods to identify crop genotypes bearing the resistance-conferring traits, and to map the traits on the sorghum genome. We plan to combine genes conferring resistance at several stages to obtain crops with durable resistance. We have fully characterized and exploited the first committed step in the *Striga* life cycle, seed germination, and its requirement for a host-derived signal. The first generation of improved *Striga*-resistant sorghums will soon be available for release in Africa.

Introduction

This project initially addressed tannins and other polyphenols which diminish the palatability and nutritional value of sorghum grain. Tannin-free sorghums are available but are more difficult to produce because of their susceptibility to grain molds and to grain-eating birds. Bird depredation, particularly by Quelea, is one of the major constraints on sorghum production in Africa. The amount of sorghum that subsistence farmers can produce is often limited by the amount of crop they can protect from birds, rather than by the amount of land available. Sending children to school diminishes their availability for scaring birds from the fields, and decreases the farmer's production. Expensive programs involving spraying avicides from aircraft have killed millions of African birds and poisoned the environment, without appreciably decreasing the damage caused by birds. Likewise, grain molds and associated weathering are severe problems in several areas of the world. Sorghums rich in tannins tend to be resistant to bird and mold damage, but are of limited value as food unless extensively processed.

As the project produced useful results and demonstrated the applicability of biochemical approaches to these problems, opportunities arose for interdisciplinary collaboration to address other production constraints (*Striga*, acid soils, leaf diseases). Observation of a unique sorghum root exudate led to inclusion of *Striga* in the constraints addressed and resulted in closer collaboration with Dr. Ejeta. *Striga* is considered to be the single greatest biological constraint on cereal production in Africa. Shifting from traditional cut and slash agriculture to modern intensified monocrop production has greatly magnified the *Striga* problem. Control methods suitable for small subsistence farmers are simply not available; they are still being advised to practice hand pulling, which only prevents seed setting but does not diminish damage to the current crop. The approach

and the screening methods we developed with Dr. Ejeta, and the germination stimulants we identified are making a major impact on *Striga* research all over the world.

Objectives, Production and Utilization Constraints

Objectives

To elucidate the biochemical basis for the antinutritional effects of sorghum tannins and associated phenols and other sorghum components including proteins.

To elucidate the biochemical basis for the resistance to predatory birds, fungal pathogens, weathering, and *Striga*, which are provided by sorghum tannins and/or other phenols and other sorghum components including proteins.

To utilize the information from the above objectives, with cultural, practical, and in-field input from LDC collaborators, to develop simple and practical approaches and/or techniques for eliminating or at least diminishing the antinutritional effects of sorghum tannins and associated phenols while maintaining or enhancing their agronomic benefits.

To develop practical and effective low-technology approaches and methods by which LDC scientists can minimize the effect of *Striga* on sorghum and millet production in Africa.

To train, establish and encourage a network of LDC collaborators in national agricultural research programs who, with help from INTSORMIL and other sources, will continue to address these problems.

Constraints

The parasitic weed *Striga*
Grain-eating birds
Grain molds
Antinutritional effects of tannins

Research Approach and Project Output

Research Approach

This is a fully integrated interdisciplinary research program coordinated closely with that of Dr. Ejeta. Our general approach is on crop improvement, but we also contribute new basic knowledge about the crop/constraints we investigate. The specific approach we often use is to collect and identify reportedly superior sources of resistance (to birds, mold, *Striga*, etc), establish in the laboratory, if possible, the biochemical mode of resistance, develop a simple method of screening for the resistant trait, screen genotypes in the laboratory for the trait, confirm their resistance in the fields of our African collaborators, and use them in breeding improved sorghums. We also rely on in vitro tissue culture to screen for resistance-conferring traits, and along with mutagenesis, to develop new genotypes with enhanced resistance. The major emphasis we place on developing pest resistant crops (rather than chemical or technological "fixes" of the pest problem) is consistent with the current thrust toward low input sustainable agriculture, and is particularly appropriate for African subsistence farmers with limited access to inputs. Other approaches we utilize in specific cases will be described below.

Project Output

Methods development. When this project was initiated in 1979, the severity of the nutritional problems caused by tannin was just being recognized. Methods for assaying and characterizing sorghum tannins and related polyphenols were relatively primitive. Therefore, much of our early work was on development of methods for tannin analysis. The result was a series of tannin/polyphenol assays either developed from scratch (Prussian blue for total phenols, protein precipitable phenols, protein binding capacity, flavan-4-ols) or improved from earlier assays (vanillin). Refining and combining these assays led to methods for further characterizing the polyphenols of sorghum: tannin specific activity, tannin degree of polymerization. These methods were used to characterize the polyphenols of a wide variety of sorghum genotypes, resulting in an improved understanding of the polyphenol traits controlled by a series of sorghum genes. With Dr. Axtell, this polyphenol characterization work has been extended to the effects of genes modified by transposable elements (candystripe mutants) and by transformation with genes from other plants. The characterization methods were applied in our laboratory to sorghum grain throughout seed development to elucidate the patterns of polyphenol synthesis and the effects of environmental stress. A method for purifying sorghum tannin was also developed and has been used by several others in the preparation of analytical standards. Methods for polyphenol analysis, purification and characterization developed by this project have been widely adopted and used by nutritionists and ecologists studying tannins in other crops and range plants. More recently we have developed a convenient laboratory bioassay for bird repellency, and several bioassays for chemical signals in the *Striga*-host association (see later).

Protein-tannin interactions. This project pioneered the investigation of the biochemical basis for the strong interaction of tannins with proteins. We developed a competitive binding assay modified from immunology, and using it demonstrated for the first time anywhere a high degree of specificity in protein-tannin interactions. We went on to show that a high proline content and a loose, floppy structure of the protein increases its affinity for tannin, that a minimum protein size is required for tannin binding, and that hydrophobic interactions play an important part in the binding. These observations provided a satisfying framework for such diverse and ancient practices as leathermaking (collagen, the principal protein in animal skin, is rich in proline and has a high affinity for tannin) and brewing (tannin used to clarify beer brings down a proline-rich sediment). We also

showed that the sugar molecules attached to certain glycoproteins can also enhance tannin binding by keeping the structure open.

Tannin binding specificity has practical significance in the use of sorghum as food or feed. We found that sorghum tannin is capable of binding more than ten times its own weight in protein, and that high tannin sorghums contain more than enough tannin to bind all the protein in the grain. But we also found that a minor protein in the sorghum endosperm is rich in proline and has such a high affinity for tannin that it partially protects the other sorghum proteins from the tannin, thus keeping more of the grain protein available for digestion and utilization. Moreover, we showed that membrane proteins in animals' digestive tracts compete with digestive enzymes for binding tannin and thereby diminish its harmful effects.

Herbivore defense against dietary tannins. With our collaborators, we discovered another mechanism which lessens the potentially severe antinutritional effects of tannins. We demonstrated that when tannins are first introduced into the diets of rats and mice, these animals show a severe response and lose weight for about 3 days, then slowly gain weight. During the period of adjustment to the dietary tannins, the parotid glands increase 3 to 5 fold in size and begin to secrete copious quantities of a peculiar type of protein. These salivary proteins secreted in response to dietary tannin contain extremely high levels of proline (over 40%) and have no sulfur amino acids, aromatic amino acids, or nutritionally essential amino acids. These unusual proteins are barely detectable in the glands of animals not consuming tannin, and their production increases over 10 fold when tannins are introduced into the diet. As expected from their high proline content, these proteins have an extremely high affinity for tannin. They are capable of strongly and selectively binding dietary tannin in the presence of a large excess of other proteins with lower affinity for tannin. It is these salivary proteins which first encounter tannin when it is consumed, and the resulting tannin-protein complex which is formed passes relatively harmlessly through the digestive tract. We later found similar tannin-binding proteins in the saliva of a wide range of herbivorous animals including such exotic species as howler monkeys and koala bears. They are not present in the saliva of carnivores. Approximately 70% of the proteins in human saliva have this proline-rich tannin-binding characteristic and appear to be present independent of diet. Others have shown that in livestock such as swine, like humans, these proteins are constitutive, rather than inducible by dietary tannin as they are in rodents. The loss of these endogenous proteins as tannin complexes in the feces accounts for much of the large increase of fecal protein induced by dietary tannin, and is not nutritionally costly because these tannin-binding salivary proteins contain very few essential amino acids.

The discovery of the role of these unique salivary proteins in defending herbivores, including humans and livestock, against dietary tannin is a major finding arising out of this research project. We demonstrated in two ways, with our collaborators, the crucial importance of this protection against dietary tannin. First, it was shown that Syrian hamsters cannot produce these salivary tannin-binding proteins in response to dietary tannins, although hamsters have the genes controlling their production and can produce them in response to other stimuli. When placed on a tannin-containing diet to which rats and mice readily adapt, hamsters fail to adapt at all. They lose weight, rather than gain, and some die in as little as three days. Second, administering low levels of propranolol, a beta-blocking drug used for human heart patients, in the diet of rats prevents them from producing the salivary tannin-binding proteins. Propranolol treated rats, like hamsters, are extremely sensitive to dietary tannin. Both these studies indicate that without the defense system of salivary tannin-binding proteins, the effects of dietary tannin would likely be much more severe, even fatal, in livestock and in humans.

Basis for antinutritional effects. The salivary tannin-binding proteins do not completely overcome the antinutritional effects of dietary tannin. With our collaborators, we have made an intensive study of the nature of the antinutritional effects and their biochemical basis. These studies involved feeding trials with chicks and rats using experimental diets containing isotope-labelled tannins and proteins, tannin-binding agents, drugs, and hydrolyzed proteins. The results show that the conventional view of tannins as primarily inhibiting digestion of dietary protein is incorrect. At least part of the antinutritional effect is on the metabolism of digested and absorbed protein and is systemic rather than being confined to the digestive tract. These effects seem to be due less to tannins than to non-tannin polyphenols exclusively associated with tannins. Low MW polyphenols from high tannin sorghum grain metabolically labelled with $^{14}CO_2$ are absorbed from the chick digestive tract, but condensed tannins are not absorbed. Thus the systemic effects of consuming high tannin sorghum cannot be due to tannin. However, the tannin fraction was far more effective as an inhibitor of rat and chick growth than are the low MW absorbable polyphenols. It seems that polyphenols as they occur naturally in the seed produce effects quite different from those caused by polyphenols purified from the grain and then added back to polyphenol-free diets.

Detoxification of high tannin sorghum. With our collaborators, we have addressed the problem of overcoming the antinutritional effects of high tannin sorghums. We showed that a traditional processing technique from East Africa, involving soaking in wood ash, germination and fermentation, completely eliminates the chick leg abnormalities caused by dietary tannin, and produces weight gains of chicks and rats equivalent to those on tannin-free sorghum. We found that it is the aqueous alkali from the wood ash which effectively detoxifies the tannin. A simple but highly effective method for using dilute aqueous alkalies, especially ammonia, to detoxify high tannin sorghum was developed in our laboratory. This process has been presented to

Protinal, the largest domestic feed company of Venezuela, for enhanced utilization of the high tannin sorghums produced there. It could be used in the development of sorghum-based foods of superior nutritional value; a modification of it is being used commercially in Burundi.

Beneficial vs harmful polyphenols. Our project research showed that the polyphenol components of sorghum responsible for the antinutritional effects in livestock diets are not the same as the components which confer resistance to birds and to grain mold. This observation opens the possibility of developing bird- and mold-resistant sorghums with good nutritional quality, something previously not thought possible.

Mold and leaf disease resistance in sorghum. We found, for example, that an assay we developed for flavan-4-ols, unusual non-tannin polyphenols unique to sorghum, gives excellent correlations with mold resistance in low tannin sorghums. Flavan-4-ols themselves do not seem to be responsible for mold resistance; we are currently pursuing the identity of the polyphenols or proteins which are responsible. Consistent with our original observation, mold resistance remains more highly correlated with seed content of flavan-4-ols than with tannins or with 3-deoxyanthocyanidin pigments. We recently found that tan sorghum plants accumulate the yellow flavone apigenin, purple plants accumulate luteolinidin and red plants accumulate apigeninidin; the latter two are 3-deoxyanthocyanidins, relatively rare in the plant kingdom but the major pigments of sorghum. As measured in mature leaves, sheath or glumes, none of these flavonoids correlate with resistance to anthracnose as evaluated in the field.

Tannin-free bird resistant sorghums. Likewise, two bird-resistant sorghums which are tannin-free and have excellent nutritional value are under intensive investigation in our laboratory. With our collaborators, we have confirmed their bird resistance in Zimbabwe and Kenya. The component responsible for bird resistance from one of these, ARK 3048, is being purified so that it can be identified and a chemical assay can be developed for it. This bird resistance factor may be of considerable importance because it seems to be specific for birds, and does not show antinutritional effects in rat diets. Moreover, it can be completely inactivated by moistening the flour, so sorghums containing this bird-resistant factor can nevertheless be used as poultry feed.

Genetic engineering. We are part of a collaborative effort with Drs. Ejeta and Bennetzen here at Purdue to develop a complete map of the sorghum genome using molecular markers. Genes controlling important traits contributing to resistance to molds, drought, birds, and *Striga* (see below) are being mapped and characterized. Our project developed several of the methods used in screening for the traits that are being mapped. Just recently Purdue University announced the first successful stable transformation of sorghum, inserting a gene for herbicide resistance stably into sorghum chromosomes. Our project's role in this collaborative effort was to provide the technology for culturing and regenerating the transformed sorghum cells (see section below on tissue culture).

Tissue culture. Our laboratory was one of the first in the world to culture sorghum *in vitro*. Tishu Cai, as part of our INTSORMIL project, has regenerated over 8000 sorghum plants from callus culture; this is more than all other laboratories in the world combined have reported in the literature. This work has generated unparalled detailed analyses of somaclonal variation rates and frequencies as a function of genotype, culture time and conditions, and explant source. Several previously unreported types of variants were observed. It was found that in *in vitro* culture, sorghum will readily lose its ability to make chlorophyll (an essential metabolite) but was never observed to lose its ability to make tannin (a nonessential metabolite, since many sorghums are tannin-free). The implications of this finding are still being explored. Ms. Cai has produced finely divided fast-growing suspension cultures of sorghum cells of six genotypes, some of which have been stable in culture for over 4 years. These culture techniques have been utilized in the sorghum transformation work mentioned above.

Striga. Our research on *Striga* has largely focussed on the chemical signals exchanged between *Striga* and its host. With our collaborators, we identified sorgoleone, a group of chemically reactive oily quinones exuded from the root hairs of sorghum, as the first natural germination stimulant identified from a *Striga* host. Sorgoleone has other activities, including herbicidal and antibiotic, and is a powerful contact allergen. In the field, *Striga* germination is not controlled by sorgoleone but by a different set of compounds exuded by host roots. These compounds are more stable and more water soluble than sorgoleone. Bupe Siame, SADC student from Zambia, identified the major *Striga* germination stimulant exuded by corn and proso millet roots as strigol. Researchers in Germany had identified the major *Striga* germination stimulants from cowpeas and sorghum as analogs of strigol. Strigol had previously been found in root exudate from cotton, which is not a host for *Striga*.

Unfortunately, strigol and its analogs are too difficult to synthesize and too unstable in soil to be applied to *Striga*-infested fields, in the absence of host crops, to induce suicidal germination and eliminate the *Striga* infestation. In an alternative approach, our major LDC collaborator Dr. A.G.T. Babiker, Sudanese weed scientist who spent 1992 supported by INTSORMIL on sabbatical leave in our laboratory, found that a mixture of two already widely used agrochemicals (TDZ, a cotton defoliant, and 2,4-D, a herbicide) is capable of stimulating *Striga* seeds to germinate. Dr. Babiker's current field tests in Sudan will determine if this suicidal germination approach to *Striga* control can be successful. Dr. Babiker had already confirmed in our laboratory that the ultimate signal for *Striga* seed germination is ethylene gas, an important plant hormone. Like the natural germination stimulants, the mixture of agrochemicals works by increasing the *Striga* seed's capacity to produce ethylene.

The most attractive and sustainable approach to *Striga* control for African subsistence farmers is the development of *Striga*-resistant crops; this is our major emphasis. On our project, *in vitro* cultures of sorghum tissue are challenged with a "toxin" produced by *Striga*, so that most sorghum cells are killed. From the survivors, new clones are established and regenerated into plants. Over 100 such sorghums have been obtained for testing for expected increased tolerance to *Striga*. The reverse approach is also being used; sorghum genotypes are being screened for possible toxicity to *Striga* cells in culture.

Sorghum SRN 39 was identified by Dr. Ejeta as having superior, widely expressed resistance to *Striga* in African fields. Dale Hess, graduate student with Dr. Ejeta and postdoc with Dr. Butler, devised a simple, rapid, nondestructive gel assay for screening individual host seedlings for production of *Striga* germination stimulant molecules such as strigol. Using the new gel assay and a more precise dilution assay, we showed that SRN 39 is resistant because its roots produce a billion-fold less *Striga* germination stimulant than do highly susceptible sorghums. Yohan Weerasuriya, Sri Lankan graduate student on the project, found that production of the germination stimulant by highly susceptible sorghums is strongly influenced by daylength. A million fold less stimulant is produced in long (16 hr photoperiod) days than in short (2 hr photoperiod) days. Dr. Ejeta showed that sorghum's capacity to synthesize the germination stimulant is controlled by a single, simply inherited gene. He crossed elite but *Striga*-susceptible sorghums with SRN 39 and other low stimulant producers and used the gel assay to identify progeny bearing the low stimulant, resistance-conferring trait. *Striga*-resistant improved sorghums developed from these crosses are likely to have a major impact on sorghum production in Africa as they are introduced in the next few years. Before the development of the gel assay, repeated attempts at breeding for *Striga* resistance had been largely unsuccessful. Preliminary screening of corn has identified two low stimulant producing (therefore likely to be resistant) genotypes, the first ever reported for corn.

We continue to pursue host-derived signals required by *Striga* further on in its life cycle. A screen we developed for the signal which causes the *Striga* seedling to form an attachment structure called a haustorium has identified a corn genotype which produces abnormally low amounts of this signal (none yet for sorghum). This is the first report of any crop genotype which produces low amounts of the haustoria-initiating signal. The resistance resulting from low production of this second signal has the advantage of helping to clean up *Striga*-infested fields. Crops with this trait produce normal levels of germination stimulant, but, for lack of the subsequent signal, the *Striga* seeds which germinate cannot attach to host roots, and simply die.

We have shown the existence of additional signals exchanged between *Striga* and its host by the effects of extracted sorghum components on *Striga* cultures and the effects of *Striga* components on sorghum cultures. We currently have evidence for both growth-promoting and differentiation signals produced by the host and required by *Striga*, and for a "toxin" produced by *Striga* which somehow controls host growth. Our overall plan, with Dr. Ejeta, is to identify host-produced signals required by *Striga*, develop screens for them, use the screens to find crop genotypes that produce abnormally low levels of the signals, and genetically combine several of these resistance-conferring traits into a single elite sorghum whose resistance to *Striga* should be much more durable than resistance based on a single trait. This approach to the control of *Striga* seems to have far more promise than others that have been used against this destructive parasite.

Networking Activities

Workshops

L.G. Butler, 2nd International Workshop on Anti-Nutritional Factors in Legume Seeds, Dec. 1-3, 1993, Wageningen, The Netherlands.

B.A. Siame, 1st Crop Science Conference for Eastern and Southern Africa, June 14-18, 1993, Kampala, Uganda.

L.G. Butler, 3rd PASCON General Workshop on Integrated Management of *Striga* for the African Farmer, Oct. 18-23, 1993, Harare, Zimbabwe.

L.G. Butler, 3rd International Workshop on Orobanche, Nov. 8-12, 1993, Royal Tropical Institute, Amsterdam.

L.G. Butler, 18th Biennial Grain Sorghum Research and Utilization Conference, March 1-2, 1993, Lubbock, TX.

T. Cai, Am. Soc. Agronomy Annual Meeting, Cincinnati, OH, Nov. 7-12, 1993.

D.A. Bell-Lelong and L.G. Butler, Symp. on Natural Phenols in Plant Resistance (Int. Soc. for Horticultural Science), Sept. 13-17, 1993, Tech. Univ. of Munich, Freezing, Germany.

Research Investigator Exchange

Dr. A. G. T. Babiker, sabbatical year.

Research Information and Material Exchange

Approximately 2000 copies of our Research Bulletin on *Striga* were distributed worldwide, mostly in workshops and meetings. Polyphenol and *Striga* germination analyses and samples of sorghum, millet, tannin, sorgoleone and other materials were provided for several of the collaborators listed and for many others not listed. Laboratory supplies were provided for Dr. A. G. Babiker, ARC, Sudan, and Dr. Dale Hess, ICRISAT Sahelian Center, Niger.

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Disease Control Strategies for Sustainable Agricultural Systems

Project TAM-124 and TAM-124B

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Summary

Diseases of sorghum continue to be major constraints to improving sorghum production in the developing world. Changes in the plant genetics affecting architecture, maturity, productivity, and other aspects tend to alter plant vulnerability to disease. Part of the responsibility of pathologists is to recognize these factors and work with other crop improvement specialists to reduce or eliminate these potential problems. The most common example is that of grain mold/head bug complex. With the introduction of earlier maturing, higher yielding hybrids there is an increase in the potential for grain mold. Tight headed cultivars with greater yield potential are more vulnerable to head bug feeding and damage. Combining early maturing tight headed traits could be disastrous in areas where these pest/pathogen combinations exist.

Most of the efforts were designed to increase the amount of collaboration among developing country scientists and with those of the U.S. Disease management requires the development of improved sorghums/millets with higher levels of disease resistance. This is best achieved with cooperation among disciplines. These projects were promoted in Brazil, Niger, Mali, Sudan, and Honduras on diseases of importance in these countries.

Major conferences on disease research were planned and carried out. There were two global conferences of diseases of sorghum and millet (India 1978 and Zimbabwe 1988), Regional Conferences on Root and Stalk Diseases (1983), and on Variable Pathogens (1993) in cooperation with the Rockefeller Foundation, Bellagio, Italy. There were several training workshops in Mexico on pathology techniques

(1981), in South Texas on integrated control of sorghum downy mildew in 1983, and periodically with breeding and quality on sorghum improvement in south Texas.

Graduate training has been a major component of the program with over 32 degrees granted during the past 15 years.

Introduction

Each country (developed or developing) has disease problems of sorghum and millet and each needs to develop approaches to reduce the damage caused by these constraints. Over the years, we identified disease problems in Brazil, Colombia, Honduras, Mali, Niger, Sudan, and Zimbabwe. Using Honduras as an example, we determined researchable priorities and addressed the diseases from the standpoint of management within the existing agroecosystem. In Honduras, downy mildew, anthracnose, and oval leaf spot were among the more significant disease problems. In Niger, long smut and head smut of sorghum and downy mildew of pearl millet have been identified as important disease constraints. In Mali, anthracnose, grain mold, long smut, and downy mildew of pearl millet are among the most important. In Sudan, most of these diseases are important; however, charcoal rot and long smut have been emphasized. In each case, we looked collaboratively at defining research approaches, which generally led to developing traditional controls such as host plant resistance with the exception of limited chemical control when seed dressings are available. Techniques for screening for disease resistance, selecting and identifying sources of resistance, and evaluation of materials in segregating generations were all employed. The philosophy has been to encourage teams of workers to collaboratively address researchable problems in areas where those problems occur.

Objectives, Production and Utilization Constraints

Objectives

Brazil

In Brazil, we worked from 1979 until 1991 on development of integrated control and management of sorghum anthracnose and sorghum downy mildew. This work was extended through a grant from the USDA for evaluation of sorghum germplasm.

Honduras

The major objectives have been to identify the most important disease constraints and design disease control strategies. Currently, we are working on evaluating the population dynamics of *Colletotrichum graminicola*, the pathogen of sorghum anthracnose, in Honduras. The Honduran National Program has a major downy mildew screening program that they provide for researchers in the area and for commercial firms. Disease evaluation and host plant resistance is a part of the National Program.

Mali

Efforts were made to develop a National sorghum and millet disease program. Progress has been made in the design of nurseries and in collaboration among workers. Currently, both the sorghum and millet pathologists are in the U.S. continuing their education and future collaboration will wait until they complete their studies.

Niger

An integrated sorghum and millet disease research program is in place. Emphasis has been on the biology and control of long smut. Initially, collaboration between workers in Sudan and Niger permitted the rapid transfer of specific technologies. Evaluation of resistance to long smut is an integral part of the Niger sorghum improvement program. Evaluation for resistance to head smut, Acremonium wilt, and anthracnose is also part of this program. Work on the control of downy mildew of pearl millet has been accelerated with the deployment of Apron® plus. Essentially, in Niger, there is a competent, dynamic sorghum/millet disease management control program in place.

Sudan

Research in Sudan began with the control of charcoal rot, resistance to long smut and related smut diseases and more recently on control of anthracnose and downy mildew of pearl millet. Host resistance work for control of charcoal rot and long smut are included as a continuing program in Sudan. Transfer of the inoculation techniques to Niger and elsewhere represents the quality and maturity of the research on sorghum pathology in Sudan. The research is interdisciplinary and collaborative.

Zimbabwe, Zambia, Malawi, Uganda, Venezuela, Argentina, Colombia, Mexico, and India

In these countries, smaller but important trials are being carried out characterizing pathogens (particularly for sorghum/millet viruses), evaluating host resistance, and growing specific nurseries, such as the All Disease and Insect Nursery, Grain Weathering Nursery, Anthracnose Resistant Converted Sorghums, etc.

Domestic

- Identify sources of resistance to disease.
- Assist in the incorporation of multiple sources of resistance to disease.
- Determine inheritance of resistance.
- Improve disease screening methods.

- Study the effects of sorghum pathogens on yield.
- Complete biology of disease where needed.
- Evaluate epidemiology of sorghum pathogens.
- Organize, maintain, and distribute the international sorghum disease and pathogen identification nurseries in collaboration with ICRISAT, and with TAM-121, TAM-122, and TAM-128.
- Maintain and strengthen the Sorghum Virus Antiserum Bank and provide antisera internationally.
- Detect, identify and catalogue sorghum viruses and strains, and *Colletotrichum graminicola* worldwide.
- Employ the new serology technique ELISA to determine virus concentration in sorghum. Virus concentration is being used as a new tool to breed for MDMV resistance in sorghum.

Research Approach and Project Output

Our approach to domestic and international work has been virtually identical. Only the locations and sometimes the diseases have been different. We begin by identifying sorghums with excellent resistance(s) to specific pathogens and assisting their incorporation into useful cultivars. Most of this work is done cooperatively with plant breeders in the Texas programs but occasionally with breeders in other states, nations (NARS), or with an International Crop Research Center, specifically ICRISAT. Much of the disease evaluation is done in large research nurseries in South Texas at all stages of introduction, conversion, or breeding generation. Since few if any cultivars are perfect and pathogens change with time and selection pressures, we periodically monitor commercial hybrids for their reaction to diseases that are economically important and/or caused by variable pathogens. This information is made available to growers in Texas and elsewhere when information is needed on disease reaction of U.S. produced hybrids. Our system of networking includes the growing of several uniform nurseries in locations where sorghum/millet diseases are important such as the International Sorghum Anthracnose Virulence Nursery (ISAVN) {This nursery is a collaborative program with ICRISAT} which is grown where anthracnose is endemic Other nurseries include a uniform nursery for head smut, sorghum downy mildew, sorghum viruses, and grain mold. Growing of these nurseries permits a quick evaluation of pathotype differences among locations and the severity of the problem. We also evaluate and distribute elite sorghums in nurseries for evaluation of the multiple resistances of the sorghum. These are international nurseries and represent a means of distributing elite germplasm from different breeding programs in INTSORMIL. The International Disease and Insect Nursery is a 30-entry test and is most widely grown. The All Disease and Insect Nursery, a 70-entry test, is also widely grown and is composed in part of unreleased experimental materials that need evaluation in many different disease environments. Both of these collections of materials are widely grown and represent one of the best means of comparing germplasm from region to region. Additionally, we have accumulated disease information on converted sorghums and with the assistance of Dr. Rosenow (TAM-122) maintain sets of anthracnose, sorghum downy mildew, and head smut resistant converted lines. These specific nurseries represent valuable sources of resistance for breeding programs as needed.

Sorghum Smuts

Long Smut

Isolation and culturing of *Tolyposporium ehrenbergii*, the causal agent of long smut, along with careful inoculation of sorghum at the boot stage resulted in excellent infection of the pathogen with sporidia. The teliospore inoculation procedure was not effective in Niger, while it worked to some extent in Sudan. Dr. El-Hilu and I do not find these differences to be alarming but recognize that in a controlled test, sporidia will cause the highest amount of infection. Issoufou Kollo noted that he must avoid plant injury in order to obtain high levels of infection. Based on inoculation during the off-season, Mr. Kollo classified MR732, MR803, MR864 and MR926 as resistant to long smut. Survival of teliospores (spore balls) was evaluated over a period of two years at three month intervals (trimesters). Desiccated spores remained viable at a higher rate over a longer period of time than those not desiccated. Very few spores survived over one year unless they were desiccated.

Head Smut

Present techniques for evaluating resistance of sorghum to infection by *Sporisorium reilianum*, the causal organism of head smut, involve trials in field nurseries using natural or artificial inoculation. These trials can be expensive in terms of time and money and are restricted to the growing season. Natural infection requires repeated trials for reliable results due to environmental effects, whereas, artificial inoculation of sporidia is labor intensive and can bypass resistance factors that provide satisfactory levels of natural resistance in the field. A technique has been developed by Dr. J. Craig (Craig and Frederiksen, 1992) to evaluate head smut resistance at the seedling stage.

Alejandro Palma, who worked with Dr. Miller, studied inheritance of nonmeristematic resistance in sorghum to head smut. His work demonstrated that some of these sources of resistance are extremely durable across pathogen races. His work supported the theory that there would be no physiological basis for differentiation. This is consistent with the R1 characterization of host resistance proposed by Craig and Frederiksen (1992). Exploitation of nonmeristematic resistance to disease will be greatly enhanced by the mapping of the sorghum genome.

Dr. Gnanambal Naidoo completed her work on the differentiation of host specialized isolates of *S. reilianum*. Texas populations of *S. reilianum*, the causal agent of head smut in maize and sorghum, exhibit two levels of host specificity. Certain isolates are restricted to the maize host, while other isolates infect sorghum predominantly. The latter type can be further divided into four races based on its reactions on a series of sorghum differentials. Head smut of both maize and sorghum is a disease of worldwide importance and is controlled by host resistance. Genetic markers associated with pathogen variability will be extremely valuable in the disease management program. An examination of morphological and physiological traits, including a previous study employing isozymes failed to provide markers to distinguish the host specialized isolates. The objective of Dr. Naidoo's study was to find unique molecular markers which would clearly differentiate between the host specialized isolates of *S. reilianum*. Polymorphisms were sought by using an arbitrary primer-PCR based assay and pulse field gel electrophoresis. Karyotype analysis of the haploid sporidia revealed a polymorphism that seems to be associated with the host specificity. The maize pathotype of *S. reilianum* possesses 15 chromosomes, while only 13/14 bands were separated from the sorghum pathotype. This difference of 750 kb in the sorghum pathotype was common in all 15 isolates examined. The additional chromosome was unique to all maize pathotypes examined.

Downy Mildew

Sorghum downy mildew (SDM) is one of those diseases that attracts attention whenever and wherever it appears. Generally, in sorghum the disease has been a minor problem since 1980, except where it has appeared or reappeared in a new region or country. Downy mildew has been found in Colombia, where most of the sorghum grown is susceptible (1990). In Egypt, it has caused significant losses in maize and has changed the cropping practices in the Delta region. It causes losses and damage in the southern African region and occasionally in South America. We began with studies on the biology of the pathogen, resulting in a monograph on the pathogen and disease. Host resistance was found and deployed, fungicide seed dressings were evaluated and introduced to growers, and aspects of the disease epidemiology and management were formulated into a program of integrated disease management for control of SDM. By the 1980's, new pathotypes of the causal organism were monitored nationally and internationally. Our program has defined numerous pathotypes from various regions of the world and identified sources of resistance to these pathotypes. Recently, host genes for resistance have been mapped and specific probes for identifying the presence of the SDM pathogen or several other downy mildew fungi have been described.

Anthracnose

This disease constitutes one of the most serious continuing problems in sorghum production worldwide. With the advent of improved varieties and hybrids with modest levels of resistance or with deployment of resistant cultivars over a long period of time, anthracnose becomes very damaging. Pastor-Corrales demonstrated the seed-borne nature of the pathogen and the effect of environment on symptom expression. K. F. Cardwell later found that isolates of the pathogen differed in regions and between wild and cultivated hosts. These observations are being examined with much larger populations today by Ms. Ute Rosewich. Carlos Casela, from Brazil where anthracnose represents the most serious disease threat to sorghum production, has defined the variability of the pathogen, proposed mechanisms of variability, as well as described both discriminatory and dilatory resistance to the disease. Phil Guthrie developed PCR/RAPD markers for *Colletotrichum graminicola*, the pathogen causing anthracnose, and he was able to demonstrate, in part, that many of the isolates possess unique genetic markers. Dr. Casela demonstrated that the fungus overseasons in sorghum in the form of resting structures known as sclerotia. RFLP markers being developed by Ms. Rosewich will be used to develop a better understanding of the pathogen population in the field and during its survival from season to season.

We developed an International Anthracnose Virulence Nursery which is used to monitor the pathogen. This nursery is now managed in cooperation with ICRISAT. Additionally, we maintain and periodically evaluate sorghum cultivars for anthracnose resistance.

Grain Mold

Grain mold is a complex disease that was defined by Loral Castor when he was a graduate student. Dr. Castor compared disease evaluations in India at ICRISAT with those in Texas and elsewhere. His work became the standard for the biology and methods of evaluation of grain mold. Following Castor, G. Forbes studied the biochemistry of resistance and indirect methods of assaying disease damage. Most recently, A. Mansuetus has defined the role of glumes in disease development and, in a joint project with SADC and Dr. John Leslie at Kansas State University, he is evaluating the population biology of isolates of *Fusarium moniliforme* present in Tanzania. His preliminary data suggest that there is a remarkable similarity between populations in the U.S. and Tanzania. Dr. J. Peter Esele attempted to define the genetics of sorghum pericarp traits with resistance to grain mold. His work demonstrated that several of the pericarp and plant pigment genes are involved in grain mold reaction. Other than the presence of the pigmented testa, a bright red seed with the intensifier gene was the most important. Mesocarp thickness was not found to be important whereas the tan plant genotype was more important than the purple. He learned that the resistance evaluations could be made as easily in Serere, Uganda as in College Station, Texas.

Sorghum Viruses

The taxonomic status of sugarcane mosaic virus (SCMV) strains reported from various parts of the world has been uncertain. Previous analysis of 17 SCMV strains with virus-specific polyclonal antibodies demonstrated that they represent four distinct potyviruses, namely johnsongrass mosaic virus (JGMV), maize dwarf mosaic virus (MDMV), sorghum mosaic virus (SrMV), and SCMV. To confirm this classification, we have now compared six strains of SCMV, three strains of JGMV, and two strains each of MDMV and SrMV using high-performance liquid chromatographic (HPLC) peptide profiling of tryptic digests as their coat proteins. The results showed that peptide profiles could be divided into four distinct groups, which are as different from each other as are peptide profiles of other distinct potyviruses. These findings confirm our previous classification of SCMV strains based on N-terminal serology.

Sorghum Yellow Banding Virus (SYBV) was observed in two nonadjacent counties and seven counties contiguous with the initial site of observation near Floresville, Texas in 1984. SYBV was identified on a sorghum x sudangrass hybrid in 1993 from Moore County, Texas in the Northern Panhandle. This is over 400 miles from where it was first observed. SYBV occurred naturally only on sorghum x sudangrass hybrids except for one occurrence on grain sorghum tillers. No SYBV was observed on primary growth and initial or highest incidence was generally observed at field perimeters on basal rather than stem tillers. Aphids did not transmit the virus and vectors are yet unknown, but results indicate a soilborne mechanism for SYBV. Mechanically-inoculated sudangrass and sorghum x sudangrass hybrids differed in resistance to the virus. Sorghum x sudangrass hybrid tissue of SYBV infected plants, analyzed serologically for the presence of SYBV, demonstrated that the virus was present in roots, leaves, culms, pedicels, stem exterior, and flowers. SYBV showed an apparent increase in incidence after ratooning, but the increase occurred only in new tillers of plants already infected. A definite synergistic effect between SYBV and MDMV-A on the grain sorghum host exist. The multiple infected plants were more severely diseased than those with either virus alone. All plants doubly infected died after 17 days.

MDMV-B infected plants with necrotic reactions were reduced in height, panicle height, and stem diameter by 40%, 40%, and 25%, respectively. Yield was reduced an average of 70% in plants with necrosis. In 1990, one hundred fifty commercial grain sorghum hybrids were evaluated for their reactions to MDMV-A under field conditions. Disease pressure was very high with about 99% of the plants infected.

Biotechnology

Progress has been made in defining the location of several genes conditioning resistance to head smut, sorghum downy mildew, acremonium wilt, and anthracnose by Drs. B. Gowda and B.J. Oh. *Shs*, a gene designated for sorghum head smut is located in linkage group A, 8.8 cM between RFLP marker txs560 and 6.0 cM from RAPD marker opg5-2 (Fig. 1). This smut resistance gene was obtained from SC325C which has been resistant to all isolates of the sorghum head smut pathogen in Texas. Resistance to sorghum downy mildew (*Sdm*) is located in linkage group F, 6.6 cM from RFLP marker txs361 and 6.1 cM from RFLP marker txs552 (Fig. 2). This *Sdm* gene is also derived from SC325C and conditions resistance to pathotypes 1 and 3 of *Peronosclerospora sorghi*. Other genes for SDM resistance from sorghum cultivars QL3(Ind) and BTx623 have also been linked with RFLP or RAPD markers but not placed within linkage groups. A gene for resistance to acremonium wilt was found on the tip of linkage group J (Fig. 3). A gene conditioning resistance to anthracnose has been located on linkage group G, 23.8 cM from RFLP marker txs309 and 20.2 cM from RFLP marker txs 1090. This gene derived from SC326-6 was located by Dr. Abdou Tenkauano while working in Dr. Hart's sorghum RFLP laboratory.

Networking Activities

Workshops

The following are major conferences in which the PI Chaired or Co-Chaired.

Global Conference on Sorghum and Millet Diseases, 1978, Hyderabad, India and 1988, Harare, Zimbabwe. At these conferences, workers from all sorghum growing regions of the world participated. The proceedings resulted in major publications that are standard references on the status of sorghum/millet disease and disease research. Limited plans are being made for the next Global Conference to be held in the Americas in 1998.

International Conferences on Downy Mildew (1989), Stalk and Root Rots (1984), and Variable Pathogens of Sorghum and Millet (1993). These meetings were all held at the Rockefeller Foundation Center at Bellagio, Italy.

Co-organized and assisted in sponsoring with ICRISAT a Central American Workshop on sorghum disease management at CIMMYT in 1981.

Assisted or co-organized the South Texas sorghum field days, more or less on an annual basis since 1967. These programs have focused, in part, on disease management or integrated crop production systems. Recent South Texas Nursery field days have included many of the INTSORMIL PI's and workers from the sorghum seed industry.

A vast number of LDC sorghum workers have visited the program. These have included visitors from Asia (China, India, and Malaysia), South and Central America (Mexico, El Salvador, Honduras, Colombia, Venezuela, Brazil, Uruguay, and Argentina), Africa (South Africa, Zimbabwe, Zambia, Uganda, Kenya, Mali, Niger, and Egypt), Europe

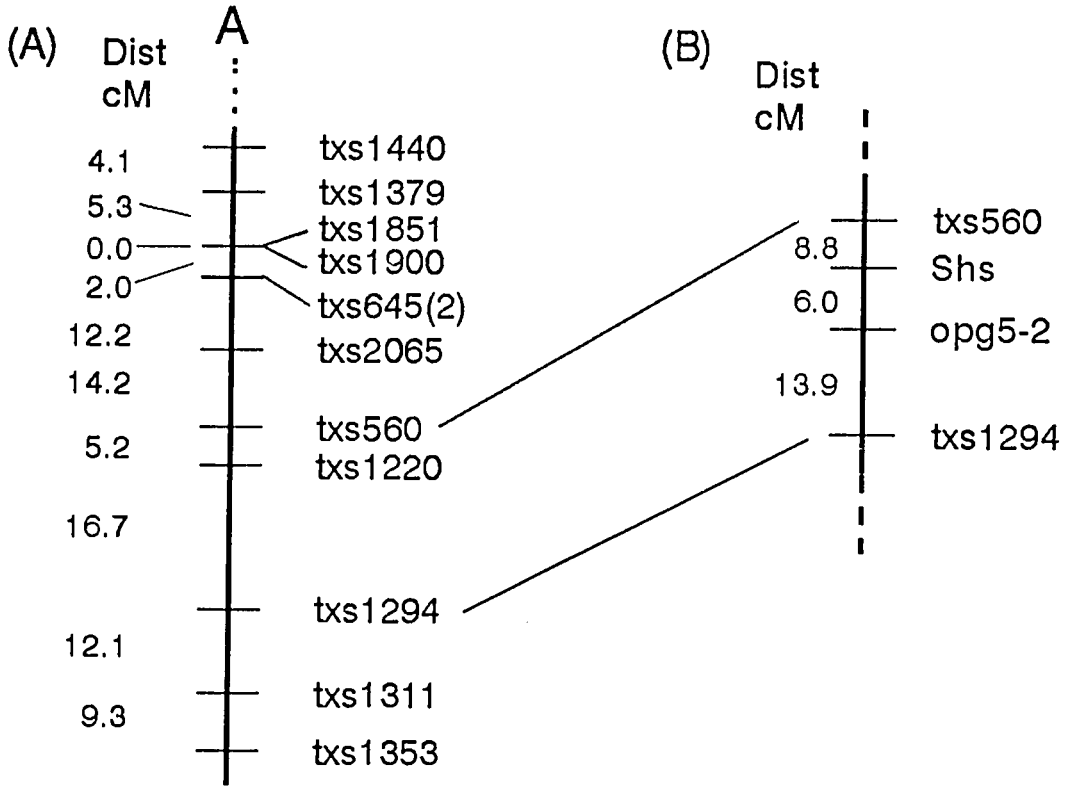

Figure 1. Position of the *Shs* locus on the RFLP linkage map of sorghum. (A) Linkage group A as derived from a segregating population (IS3620C x BTx623) used for the sorghum RFLP map (Xu et al. 1993). (B) a part of sorghum linkage group showing the linkage maps around the *Shs* locus as derived from SC325 (resistant) and RTx7078 (susceptible).

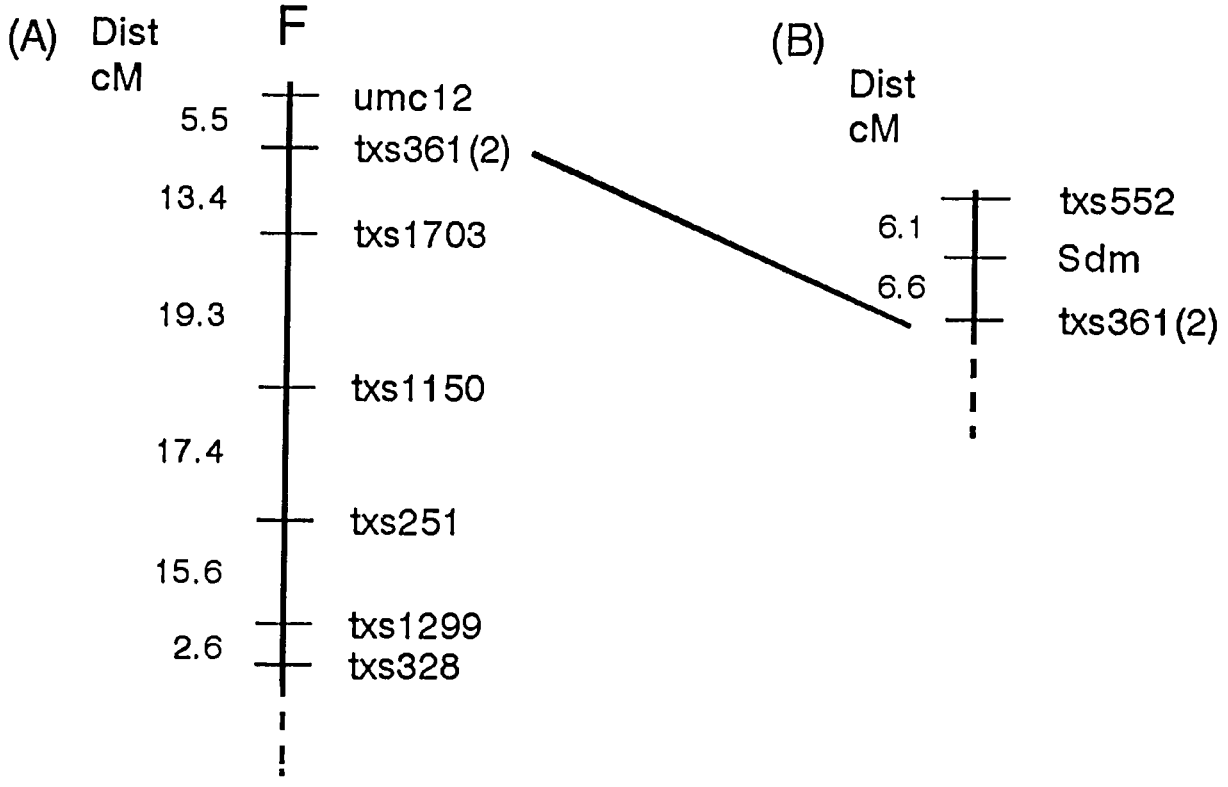

Figure 2. Position of the *Sdm* locus on the RFLP linkage map of sorghum. (A) Linkage group F as derived from a segregating population (IS3620C x BTx623) used for the sorghum RFLP map (Xu et al. 1993). (B) A part of sorghum linkage group showing the linkage maps around the *Sdm* locus as derived from SC325 (resistant) and RTx7078 (susceptible).

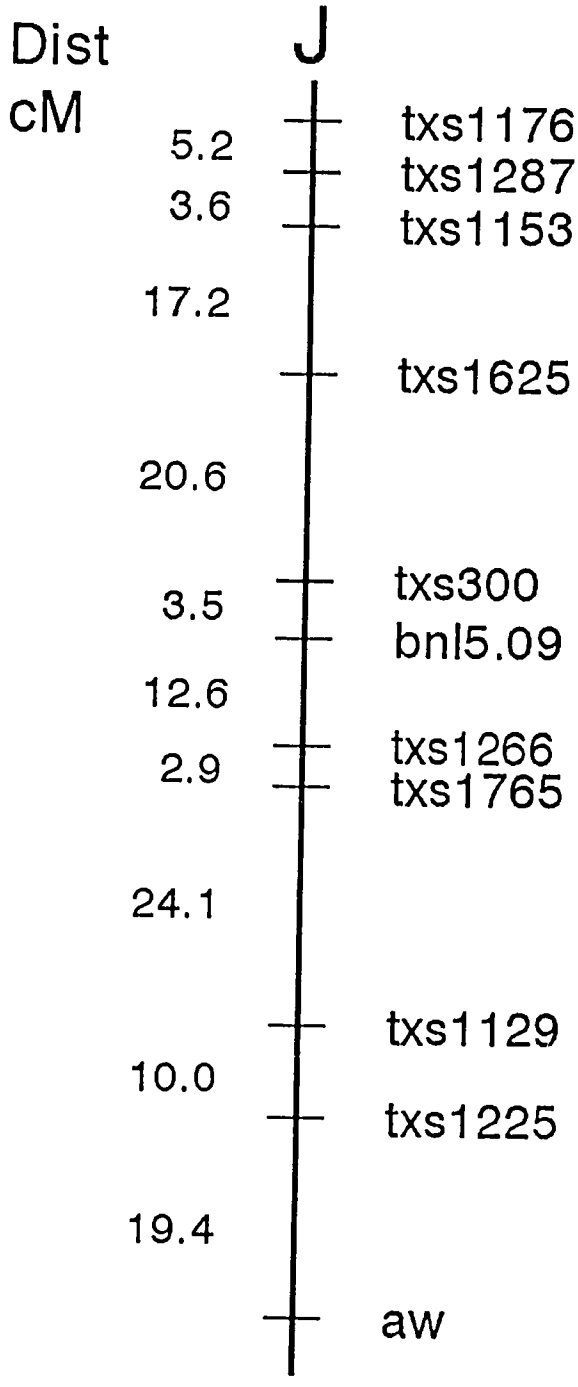

Figure 3. Position of the *aw* locus on the RFLP linkage map of sorghum. Linkage group J as derived from a segregating population (IS3620C x BTx623) used for the RFLP map (Xu et al. 1993) showing the linkage maps around the *aw* locus as derived from SC325 (resistant) and RTx7078 (susceptible).

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Integrated Insect Pest Management Strategies for Sustainable Agricultural Systems

Project TAM-125
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Summary

The objective of this project for the 15-year period has been to develop sustainable, integrated pest management (IPM) strategies for insect pests that are constraints to sorghum production in West and Southern Africa, Central America, and the United States. Insect pests reduce yields and the sustainability of grain yields, and increase production costs. The research emphasized plant resistance to insects and identified non-chemical, ecologically compatible, insect pest suppression, and IPM tactics. This project is a companion to a biological control of insect pests project.

On-site collaborative research activities have been concentrated in West Africa, especially Niger and Mali, on African sorghum head bugs. Research in Southern Africa has been to identify sorghums resistant to sugarcane aphid, and to incorporate aphid resistance into locally adapted sorghum cultivars. Insect pests of sorghum in Texas include sorghum midge, greenbug, and yellow sugarcane aphid. Research has been conducted to develop technology applicable to all areas of the world where these insects occur and to educate foreign and U.S. graduate students in sorghum entomology and IPM.

During this project, sound international collaborative research programs with NARS and ICRISAT scientists have resulted in the development of sustainable insect management strategies and identification of sorghums resistant to sorghum midge, greenbug (biotypes C, E, and I), African sorghum head bugs, sugarcane aphid, and yellow sugarcane aphid. Mechanisms and inheritance of resistance have been determined, and genes conferring resistance have been introgressed into elite parental lines that have been evaluated alone and in hybrid combination. Levels of resistance have been quantified, and economic injury levels established for most of them. The role that insect resistant sorghums play in an integrated pest management system has been assessed, and the compatibility of plant resistance and other IPM tactics has been elucidated, along with approaches to improve the effectiveness of resistance. Ancillary research on insect pest biologies and population dynamics has been conducted to support the deployment of IPM technology.

The collaborative research on African sorghum head bugs in West Africa, especially Niger and Mali has quantified damage (yield and quality loss); identified resistant genotypes, including practical methodology to screen for resistance; and described bug species composition, biology, and population dynamics. Research in Mali confirmed the resistance of MaliSor84-7 to head bugs. Research on the sugarcane aphid was conducted in Botswana and Zimbabwe, sorghums resistant to this insect were identified, and the mechanisms and inheritance of resistance assessed. Sorghum midge-resistant sorghums have been evaluated in Honduras. Research in Texas has employed a holistic ap-

proach to identify, evaluate, and deploy sorghum midge, greenbug, and yellow sugarcane aphid-resistant sorghums as a component of IPM, and develop and validate sorghum plant and sorghum midge dynamics computer models. Significant advances were made in developing the technology to allow farmers to manage these sorghum insect pests. The research has resulted in 129 published articles, 115 invited or submitted paper presentations, and 21 graduate degrees.

Introduction

Insect pests in developing countries reduce sorghum grain yields and are a deterrent to sustainable sorghum production. In the United States, insect pests reduce yields, and insecticide use adds to production costs and decreases profit. Insect pests that ravage sorghum must be dealt with in a biologically/ecologically sound manner. The negative impact of sorghum midge, African sorghum head bugs, aphids, and panicle-infesting caterpillars in traditional farming systems in developing countries is dramatically increased when improvements in agricultural production are attempted through breeding and changed cultural practices. The public mandate in the United States for safe food, clean water, and natural resource conservation requires insect pest control strategies that are less dependent on insecticides. The species of insect pests that infest sorghum vary geographically, and in intensity and persistence. In different production areas, at least one key insect pest species, and several occasional insect pests attack sorghum. Reducing the amount of loss caused by these insects requires an integrated approach using several management tactics. This project has focused on developing insect pest management technologies applicable to sustainable agriculture systems in developing and developed countries. The tactics developed and evaluated include plant resistance to insects and manipulation of cultural practices that reduce insect pest severity. Each tactic is supported with ancillary research on insect pest biology, ecology, and population dynamics to ensure their proper use and impact of the tactics in insect pest management. The project's approach involves on-site collaborative research, complementary United States technology development activities, and graduate student education.

Improvements in sorghum production in developing countries is usually through changes in agronomic practices and the use of genetically improved sorghum cultivars. Inevitably these changes disrupt existing ecosystem stability, cause insect pests to be more severe, and create problems with new insect pest species. Such is the case with the African sorghum head bug in West Africa, and the sorghum midge in most sorghum-producing areas.

At project initiation, insecticide use to control sorghum insect pests in the United States was at an all-time high. Approximately 60% of the sorghum acreage in Texas was treated with insecticides between 1965 and 1978.

Objectives, Production and Utilization Constraints

Project Objectives

Emphasize genetic plant resistance and develop integrated pest management strategies for insect pests of sorghum including sorghum midge, aphids, and panicle-infesting caterpillars and true bugs.

Determine the biology, systematics, behavior, and seasonal abundance of sorghum insect pests and associated predators and parasites as support tactics in IPM schemes.

Educate foreign and United States graduate students in sorghum entomology, and develop appropriate institutional and organizational linkages to promote collaborative research, technology development, and technology exchange in a manner that is mutually beneficial to agriculture in the United States and developing countries.

Initially there was a biological control objective for this project, with Dr. F. Gilstrap as co-investigator, but that research was separated from this project and is reported separately.

Specific Research Objectives

Determine species composition, biology, and population dynamics of sorghum panicle-feeding bugs, especially the African sorghum head bug; develop practical techniques for screening sorghums for resistance to head bugs; identify resistant genotypes; relate resistance to glume, kernel, and grain-texture characteristics; and relate head bug abundance and kernel damage to pathogen infection, grain deterioration and food quality.

Identify and evaluate sorghums resistant to sorghum midge, greenbug, yellow sugarcane aphid, sugarcane aphid, and panicle-feeding caterpillars and bugs; determine resistance mechanisms; investigate plant-to-insect and insect-to-plant responses; and determine economic injury levels.

Assess the biology, habits, seasonal abundance, and damage of sorghum midge, greenbug, yellow sugarcane aphid, and panicle-feeding caterpillars and bugs to support nonchemical management tactics in an IPM strategy.

Constraints

Insect pests limiting production and sustainability of agricultural systems must be dealt with in a biologically/ecologically sound manner. The negative impact of aphids, panicle-feeding bugs, sorghum midge, and panicle-infesting caterpillars in traditional farming systems is dramatically increased when improvements in agricultural production are attempted through breeding and changes in cultural practices. Also, a public sensitive to environmental and human health issues requires insect management strategies less dependent on insecticides.

The constraints addressed by this project are those caused by major insect pests of sorghum in selected developing countries and the United States. Sorghum head bugs in West Africa are a created problem resulting from attempts to change from local, adapted, photosensitive sorghum to improved, non-photosensitive cultivars with compact panicles. These bugs lay eggs in and suck juices from developing kernels causing yield loss and grain deterioration, especially in conjunction with infection by pathogens that ruin food quality of grain. Sorghum midge, the most cosmopolitan insect pest of sorghum, causes severe damage when flowering is slightly delayed in the United States or occurs at an inappropriate time in developing countries. Sugarcane aphid is an insect pest of sorghum in many areas of the world, but is especially troublesome in Southern Africa. The aphid is most severe during dry periods, and naturally occurring beneficial insects alone do not reduce aphid abundance enough to protect sorghum from damage. Greenbug and yellow sugarcane aphids are primarily American insect pests, although greenbug is cosmopolitan in distribution. These aphids suck juices from sorghum leaves and stems and inject a toxin as they feed that reduces the ability of the plant to produce maximum yields. Sorghum panicle-feeding caterpillars are occasional insect pests in almost all sorghum growing areas.

Research Approach and Project Output

Research Approach

The project's approach involves on-site collaborative research in developing countries, complementary technology development activities and technology exchange, and graduate education programs. Collaborative research in West Africa focuses on damage assessment and plant resistance to the African sorghum head bug complex. Collaborative research in Southern Africa focuses on plant resistance to the sugarcane aphid. Research in Texas supports foreign and domestic graduate student education and utilizes a holistic approach to identifying, evaluating, and deploying sorghum midge-resistant sorghums as a component of integrated pest management, and developing and validating sorghum plant and sorghum midge dynamics computer models. Also, greenbug- and yellow sugarcane aphid-resistant sorghums are developed and evaluated in Texas, and resistance mechanisms and inheritance determined.

Research Output

African sorghum head bug, Eurystylus sp. research in West Africa: The collaborative research program on African sorghum head bugs began in earnest in West Africa in 1985 with the placement of Dr. Gary Steck, Texas A&M University Research Associate, at the Tara Experiment Station at Maradi, Niger. He conducted research there for two years with INRAN entomologist, Dr. Seyni Maiga. That research identified *Eurystylus marginatus* Odhiambo as the most important and abundant head bug species of sorghum. Steck's research was first to assess damage and elucidate the seasonal dynamics of the bug. Bugs reduced grain weight per panicle by 19-62%, and kernel vitrosity by 20%. Bug infestation significantly reduced grain quality and germination as a result of oviposition and feeding in kernels. Glume characteristics, percentage of grain surface covered by glumes, and time from anthesis to opening of the glumes were significantly correlated with reduced head bug numbers.

After two years of head bug research in Niger, the research project was moved to Mali, where a collaborative relationship was established with Dr. Y. O. Doumbia, IER entomologist. That project continues. The objectives of the collaborative research identified through annual work plans were to develop practical techniques for screening sorghums for resistance to head bugs; screen sorghums for resistance; relate resistance to glume, kernel, and grain texture characteristics; relate head bug abundance and kernel damage to pathogen infection, yield loss, grain deterioration, and food grain quality; and determine bug biology and population dynamics. This collaborative project has been very productive.

Resistance Screening and Methodology: Several hundred sorghum genotypes have been screened for resistance to African sorghum head bugs. It was from this research that the resistance of MaliSor84-7 was found and confirmed. Sorghum breeders have used MaliSor84-7 to produce progenies with more favorable plant characteristics and with some resistance to the head bugs. Equally important is the screening methodology developed. A procedure was designed and tested whereby bug-damaged and undamaged panicles of test genotypes could be compared. This method allows plant breeders to accurately determine with little effort during selection of large numbers of entries, relative damage by bugs. Three methods were used to protect sorghum panicles from bugs: constructed cages, plastic pollinating bags, and insecticide. The plastic pollinating bags were the simplest way to protect panicles from bugs. Breeders can use these bags to cover sorghum panicles, later remove the bags, and compare protected panicles with panicles that were exposed to natural bug infestation to determine the relative amount of damage to that genotype. Dr. Doumbia, Mr. Conare, and I presented a paper on this research at the panicle insect workshop in Niger.

Biology and Population Dynamics: Important aspects of the biology of African sorghum head bugs are yet unknown. For example, it is not known how the head bugs pass the off-season. However, much has been learned. Adult bugs infest and lay eggs within the endosperm of kernels soon after sorghum panicles complete flowering. These eggs hatch into nymphs, and both adults and nymphs suck juices from the developing kernels. Only one generation is produced on a panicle, but there are two major peaks in abundance when later developing panicles are available. Usually one peak is in September and one is in early October. Other

aspects of the biology and population dynamics are too detailed to present in this report.

Relationship of Head Bugs and Pathogens: Research conducted through this program has determined the relationship of head bugs and pathogens. Experiments were conducted on sorghum that was untreated, treated only with an insecticide, treated only with a fungicide, and treated with both an insecticide and a fungicide. The results of these experiments provided a means of assessing the bug/pathogen relationship. To summarize, bugs cause more damage than pathogens, but pathogens are more severe as bug abundance and damage increases. Pathogens can occur without bugs, but are significantly more serious when bugs are present. The severity of pathogen infection is much increased when rains continue late into the season, that is, when sorghum matures during wet conditions. Results of these experiments were presented in a joint paper by Dr. Doumbia and Dr. Ratnadass at the panicle insect workshop in Niger.

Sugarcane aphid research in Southern Africa: This research project was conducted in Botswana and Zimbabwe in collaboration with Dr. Chris Manthe, Department of Agriculture entomologist in Botswana, and Dr. Klaus Leuschner, SADC/ICRISAT Southern Africa Regional Sorghum/Millet Research Program entomologist in Bulawayo, Zimbabwe. Four hundred and sixty-four sorghum lines were screened for resistance to sugarcane aphid. Forty-one lines had low plant damage and aphid abundance ratings. In Botswana, TAM428 and IS12661C were determined highly resistant, and IS12609C, IS12610C, and IS12664C were moderately resistant. In Zimbabwe, TAM428, IS12661C, IS12609C, and IS12664C were highly resistant and IS12610C was moderately resistant. Some differential host plant reactions were noted between aphids from Botswana and Zimbabwe. Among the resistant sorghums, high levels of antixenosis were found, usually in seedling and mature plants. Aphid mortality was high and fecundity low on most resistant sorghums. The resistance appeared to be inherited as a single, dominant gene.

Technology Development and Student Education Research

The following is a summarization of technology development that supports international research collaboration, and the results of graduate student research projects associated with INTSORMIL since 1980.

Technology Development

Integrated pest management strategy for sustainable sorghum production in developing and developed countries begins with the identification and/or development of applicable management tactics. Research on biology, habits, and ecology of pest insects provides the knowledge required to take advantage of cultural manipulations that work against the insect pest and in favor of the producer. Development of insect pest-resistant sorghum cultivars begins with an effort to identify sources of resistance and should end with release of a resistant cultivar for farmer use. Knowledge of the insect pest density to plant damage relationship is required to determine resistance level and to establish economic injury levels. Mechanisms of resistance and the inheritance of resistance need to be understood for breeding purposes and to assess stability of the resistance.

Thousands of sorghums have been screened in Texas for resistance to sorghum midge, greenbug (different biotypes), and yellow sugarcane aphid. An important source of material to screen, especially for sorghum midge resistance, is the Sorghum Conversion Program. Other sources are from existing breeding programs, the world sorghum collection, and those collected around the world. Screening of sorghums for resistance to some insect pests is under field conditions with natural infestations, while screening for other pests is done in a greenhouse using cultured insects, especially aphids.

Beginning with the identification and confirmation of the resistance of the converted sorghum line IS12666C (SC0175-9) (released as TAM2566 germplasm) to sorghum midge, this line and others from the conversion program and other programs such as AF28 (released as ISR1 and Tx2782) have been used to develop agronomically acceptable, sorghum midge-resistant parental lines and hybrids. During this project, cooperation between sorghum breeding and sorghum entomology projects has resulted in the registration and release of 65 sorghum midge-resistant A- and R-lines (Tx2754-Tx2781, Tx2801-Tx2815, Tx2869-Tx2890).

The development of greenbug resistant sorghum hybrids has been a successful product of this project but has been confounded by the development of greenbug biotypes. Sources of greenbug biotype C resistance was discovered in sorghum lines such as IS809, SA7536-1, PI264453, and KS30, but this resistance became ineffective in 1980 with the occurrence of biotype E. Resistance to biotype E greenbug was discovered in sources such as PI264453, Capbam, and others. This resistance is still effective, but a new biotype, biotype I was identified in 1990. Resistance to biotype I was found in sources such as PI550610 and PI550607, and these are being introgressed in elite parental lines. During this project, 33 sorghum lines resistant to biotype C (Tx2567 & Tx2568, Tx2734-Tx2752, TAM Bk41-44), and 11 lines resistant to biotype E (Tx2783, Tx2859-Tx2868) were registered and released. Of these releases, ATx2752 and RTx2737 were extensively used in commercial sorghum hybrids for resistance to biotype C, and RTx2783 and its derivatives were extensively used for commercial hybrids resistant to biotype E.

Resistance to yellow sugarcane aphid was confirmed in the Ethiopian sorghum lines PI457709 and PI45391. Genes from these photosensitive sorghums have been crossed into elite sorghum parental lines which were evaluated.

The impact of the insect-resistant sorghums described briefly above has been dramatic. As earlier stated, insecticide use on sorghum in Texas was at an all-time high at the initiation of this project. In 1978, ~60% of the sorghum acreage in Texas was treated with insecticide, while in 1990 only ~24% of the acreage was treated. The savings gained from not using insecticide were $6,000,000 per year, and this does not consider the ecological or environmental benefits, or benefits from the reduction in insect pest resurgence or secondary pest outbreaks. During this project, the economic benefit to Texas farmers has been at least $90,000,000.

R. M. Anderson, Research Associate with this sorghum entomology project has conducted on-going experiments to determine insecticide efficacy and optimal frequency, interval, and times of day for insecticide applications for remedial integrated pest management of sorghum midge. These experiments complement other efforts on non-chemical management tactics. Insecticides have the significant advantage of being curative while non-chemical tactics are preventive. Research on sampling procedures and economic threshold levels is designed to ensure that insecticide use is economically justified. The environmental consequences of insecticide use are an important consideration in these experiments. For example, insecticide applications begun during the mid (50%) to later (75%) stages of panicle anthesis resulted in less damage, higher grain yields and the need for fewer applications than when applications were made prior to these anthesis stages. Optimal sorghum midge control was achieved when hourly insecticide treatments were applied during the early to mid-morning hours (0600-1000). Other experiments were conducted to evaluate the effectiveness of various "oil-only" treatments for control of sorghum midge. Grain yields and kernel damage data indicated that treatments of cottonseed, corn, soybean, peanut, and canola oils resulted in significant increases in yield and reductions in damage when compared to untreated sorghum, and some were as effective as some insecticides.

Student Education Research

D. G. Hall, U.S., Ph.D. student: This research involving panicle-infesting bugs in Texas was a companion project to the African sorghum head bug research conducted in West Africa. Six species of bugs: *Oebalus pugnax* (F.), *Nezara viridula* (L.), *Leptoglossus phyllopus* (L.), *Thyanta accerra* (McAtee), *Euschistus servus* (Say), and *Chlorochroa ligata* (Say), infested sorghum. Alternate hosts from which these bugs moved into sorghum included johnsongrass, dallisgrass, oats, Texas thistle, and silverleaf nightshade. Bugs fed on stems, rachis branches, and glumes, but were primarily kernel-feeders. Damaged kernels were smaller and lighter in weight than undamaged kernels and were often shriveled and discolored. Kernel damage was positively related to bug abundance. Bug feeding reduced grain weight and germination. From bug density/kernel damage relationships, economic injury levels were established.

R. W. Fisher, U.S. M.S. student: This research provided valuable information on time of sorghum midge emergence and oviposition and environmental factors that affect them. This information has been important to sorghum midge management. Males emerged shortly after daybreak, 1-2 hours before females emerged. Most females laid eggs on flowering sorghum between 1000 and 1200 hours. Few sorghum midges were present at night. Time of emergence and oviposition were affected by relative humidity and temperature, and rain delayed these activities. Sorghum midges began to emerge from infested spikelets 10-13 days after infestation, and peak emergence was 19-22 days after infestation.

C. L. Lippincott, U.S., M.S. student: This research identified the hymenopterous parasitoids of the sorghum midge and parasitoid biology. Four species parasitized sorghum midge and were mostly ectoparasitic. Development time from egg to adult corresponded to that of sorghum midge. Parasitism did not adequately suppress sorghum midge abundance.

K. D. Melton, U.S., M.S. student: This research was the first to examine in resistant sorghum hybrids, mechanisms of resistance to sorghum midge. It showed that there was some nonpreference resistance, but the major effect was production of 40-60% fewer offspring by sorghum midges infesting resistant sorghums than those infesting susceptible hybrids.

G. J. Hallman, U.S., Ph.D. student: This research was the first to assess the relationship of sorghum midge adult abundance to resulting damage to resistant and susceptible sorghums and provided the data on which current economic injury levels are based. From 36-51 kernels per sorghum midge adult were destroyed on susceptible sorghums but only 9-13 on resistant sorghums. Also, no compensation for damaged spikelets by undamaged spikelets occurred. Resistance primarily resulted from reduced oviposition.

F. P. Baxendale, U.S., Ph.D. student: This research was first to develop bio-physical mathematical computer models to simulate sorghum midge development. Two temperature-dependent models were formulated which described spring emergence from overwintering and development of nondiapausing generations of the sorghum midge.

J. M. Waquil, Brazil, Ph.D. student: This research confirmed the effect of resistant sorghums on reduced oviposition by sorghum midge, and the presence of adult visitation nonpreference. It characterized the "confused" actions of females on resistant sorghums.

M. I. Becerra, Colombia, M.S. student: This research confirmed the economic advantage of sorghum midge-resistant sorghum hybrids over that of susceptible hybrids. It compared yields when the two types of hybrids were insecticide treated under different application schedules and not treated. Net returns from the resistant hybrid when insecti-

cides were used and not used, were 58.7 and 101.8% higher, respectively, than that from the susceptible hybrid. When sorghum midges were very abundant, net returns from the resistant compared to the susceptible hybrid were 79.3 and 505.4% higher when insecticide was used and not used, respectively.

J. P. Breen, U.S., M.S. student: This research assessed the damage by yellow sugarcane aphid to sorghum. Aphid densities of 2 to 8 per plant reduced yields from 0 to 35%. Aphid damage increased the time to 50% flower by 2 to 12 days. Yield reduction per aphid was 2.5%. Dynamic economic injury levels were calculated.

A. E. Ali, Sudan, M.S. student: This research screened newly available converted exotic sorghums for resistance to sorghum midge. Based on damage ratings and yield loss assessments, the following new sources of resistance to sorghum midge were identified: IS8232C, IS8112C, IS7193C, IS8237C, IS6946C, IS7132C, IS8087C, IS6984C, and IS3390C. Also, the resistance was determined to be dominant for some, incompletely dominant for others, and recessive for others.

M. E. Merchant, U.S., Ph.D. student: This research was the basis for improved sampling procedures for sorghum insect pests based on within-field spatial patterns, and assessed farmers and pest management advisors' attitudes and practices regarding sorghum pest management and field scouting. A "beat bucket" method was found suitable for field scouting. From 30-39% of farmers and 56-72% of pest management advisors did not follow state Extension Service guidelines for economic thresholds of sorghum midge, corn earworm, and rice stink bug.

M. J. Scully, U.S., M.S. student: Population dynamics of corn earworm were determined. Life tables were constructed for corn earworms infesting compact and loose panicle sorghums. Egg and larval mortality were similar for the insect on either panicle type, and mortality exceeded 98%. More larvae in compact than loose panicles were a function of more eggs laid.

H. P. Thindwa, Malawi, Ph.D. student: This research assessed the resistance mechanisms of sorghum resistant to biotype C and E greenbugs and determined the effect of temperature on the expression of resistance. Tolerance was the major resistance mechanism and was more pronounced at 30 than at 21 or 26° C. Antixenosis and antibiosis were evident, but at low levels, and were affected by temperature.

C. S. Manthe (see research output section).

N. C. Jimenez, Colombia, M.S. student: Improvements in the level of resistance to sorghum midge were evident when resistant were mixed with susceptible sorghums to increase the effectiveness of nonpreference resistance. This research was first to show that the spikelet flowering of resistant sorghum did not coincide with the presence of ovipositing female sorghum midges.

B. B. Pendleton, U.S., Ph.D. student: Data on the population dynamics of the sorghum midge in relation to anthesis of sorghum were used to refine and validate a model to simulate sorghum midge incidence and abundance. Ability to predict sorghum midge occurrence in relation to sorghum flowering would improve sorghum midge management capabilities. Sorghum hybrid and length of panicle accounted for 47.8% of the variability in the number of spikelets per panicle. Most spikelets in a field were in anthesis on days seven and eight, and most spikelets on a panicle were susceptible to sorghum midge oviposition on days 3-4 of anthesis. The model was formulated by combining a temperature-dependent poikilotherm development model, a temperature-independent distribution of sorghum midge development times, a distribution of abundance of sorghum spikelets in anthesis in a field, and assessments of daily abundance of ovipositing sorghum midges. The model accurately predicted sorghum midge emergence and occurrence of generations. Sorghum midge generation time ranged from 15.8-21.0 d. Abundance increased from no, or few, ovipositing sorghum midges in May to a maximum in mid-July. The static economic threshold density of one ovipositing sorghum midge per panicle in anthesis was estimated to be exceeded on 27 June, during the last days of the season's third generation of sorghum midges. Wind was the primary determinant of the direction and probably distance of dispersal of sorghum midges. Most sorghum midges trapped during late-July and August dispersed toward the northwest, but a few dispersed against the prevailing wind direction and toward nearby sorghum. Sorghum midges were trapped >400 m from where they had emerged.

D. J. Jost, U.S., M.S. student: In cooperation with Temple TAES scientists, research was conducted to validate the sorghum midge component of the sorghum crop growth model, SORKAM. Incorporation of the sorghum midge component into SORKAM would allow prediction of the initial emergence of sorghum midges, abundance increases, and sorghum yield loss. Sorghum midge abundance in 1991 was considerably higher than in the previous year and yields were higher because of more annual rainfall. Field parameters required to run SORKAM were incorporated into the model. Observed data were compared to SORKAM'S predictions. Initial comparisons indicated that further modifications to the model were needed. Data from nine of 36 fields were used to refine the model. Modifications to the model included adjusting initial johnsongrass densities. The model was then re-evaluated and further modifications of SORKAM were made. Although the model still requires refinement, close approximation between observed and predicted values are being recorded. Statistical analysis remains to be conducted.

R. Magallanes, Mexico, Ph.D. student: Differential feeding behavior and survivorship of sorghum midge infesting resistant and susceptible sorghum were evaluated. Two

sorghum midge-susceptible (RTx430 and RTx7000) and three resistant sorghum lines (RTx2782, RTx2767 and RTx2890) were used for comparison. At anthesis, floret samples were collected every other day until physiological kernel maturity. Florets chosen were dissected to record number and location of immature stages of sorghum midges. Sample size was increased to help reduce data variability and effort was made to account for differences in plant development. Data collected included life cycle length, egg location and rate, larval feeding site in the floret, and rate of sorghum midge survivalship. Also recorded was rate of female sorghum midge floret visitation, and subsequent grain yield. Seasonal behavior patterns were also investigated and will be related to sorghum midge feeding behavior.

A. Paliani, Malawi, M.S. student: Greenhouse screening trials confirmed that PI457709 and PI453951 are moderately resistant to yellow sugarcane aphid when compared to a susceptible standard check, Tx430. These sorghum lines were more resistant to yellow sugarcane aphid in the very early seedling stage (4-10 cm) than at later seedling stage (18-35 cm) when plants were infested with 5 or 10 aphids per plant. When early-stage seedlings were infested with 20 aphids per plant, all plants of the resistant lines were killed within two weeks. Nonpreference was not a major resistance mechanism of the resistant lines. Based on plant growth, the two resistant lines showed greater tolerance to yellow sugarcane infestation than did susceptible sorghum and uninfested plants. Antibiosis was shown to exist and is a resistance that component affects survival and progeny production.

Networking Activities

Workshops

Major international sorghum entomology workshops organized are as follows:

International Sorghum Entomology Workshop. 15-20 July 1984, College Station, Texas. Sponsored by INTSORMIL, ICRISAT, and Texas A&M University.

International Consultative Workshop on Panicle Insect Pests of Sorghum and Pearl Millet. 4-7 October 1993, Niamey, Niger. Sponsored by ICRISAT.

International workshops participated in are as follows:

INRAN/INTSORMIL/NCRP Sorghum/Millet Workshop. 13-17 October 1985, Niamey, Niger. Sponsored by INRAN and INTSORMIL.

International Workshop on Plant Resistance to Insects. Biennially each February since the start of the project.

Research Investigator Exchanges

An average of 10 international scientists visited the sorghum entomology program at Texas A&M University each year of the project. Short-term training programs were directed for Mrs. Niamoye Diarisso Yaro from Mali, and Mr. Abdul Jalil from Bangladesh.

Germplasm, Equipment and Supplies, and Information Exchange

Seed requests were received from an average of 10 international scientists each year for the life of the project, and these were forwarded to Dr. Gary C. Peterson. Publication reprints or copies related to sorghum entomology were sent to 119 international scientists. Research supplies and equipment were sent to Mali, Niger, Botswana, and Zimbabwe to support on-site research activities. Material for cages, bags to cover panicles, insect-collecting supplies, insect-preservation supplies, computer software, and other research-related supplies were provided.

Important collaborative linkages were maintained with Dr. K. F. Nwanze, Principal Cereals Entomologist ICRISAT, Patancheru P.O., Andhra Pradesh 502 324, and Dr. Klaus Leuschner, Entomologist, SADC/ICRISAT Southern Africa Sorghum/Millet Improvement Program, P.O. 776, Bulawayo, Zimbabwe.

The development and distribution of the *Sorghum Insect Identification Handbook* has been a valuable tool in technology exchange.

Publications and Presentations

Publications

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Presentations

Teetes, G. L. 1992. Sorghum midge up-date. Texas Plant Protection Conference, College Station, TX.

Jost, D. J. & G. L. Teetes. 1992. Refinement and validation of the sorghum midge component of the grain sorghum crop model - SORKAM. Texas Plant Protection Conference, College Station, TX.

Anderson, R. M. & G. L. Teetes. 1992. Sources of biotype I greenbug resistance in sorghums. Texas Plant Protection Conference, College Station, TX.

Magallanes-Cedeno, R. & G. L. Teetes. 1992. Sorghum midge infestation pattern of resistant and susceptible sorghum. Texas Plant Protection Conference, College Station, TX.

Pendleton, B. B. & G. L. Teetes. 1992. Predicting sorghum midge population dynamics. Texas Plant Protection Conference, College Station, TX.

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Jost, D. J. & G. L. Teetes. 1993. Refinement and validation of the sorghum midge (Diptera: Cecidomyiidae) component of the grain sorghum crop growth model - SORKAM. 18th Biennial Grain Sorghum Research and Utilization Conference, Lubbock, TX.

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Biological Control Tactics for Sustainable Production of Sorghum and Millet

Project TAM-125B
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Summary

For 15 years, the objective for this project has been to contribute knowledge needed for implementing sustainable integrated pest management (IPM) strategies to deal with insect constraints to sorghum and millet production. The focus of this research has been in Honduras, Niger and the United States. This research has emphasized the biology and ecology of pest insects and their natural enemies, assessment of key natural enemies and development of conceptual models for using biological control in annual crops. This project is a companion to an INTSORMIL project on plant resistance and IPM.

On-site collaborative research has been conducted on natural enemies of stem borers and whorlworm on sorghum in Honduras, and on natural enemies of stem borers and millet head miner on millet in Niger. Research in Honduras examined biology and ecology of whorlworm and stem borer natural enemies, especially how to manipulate these enemies to improve biological control of whorlworm. Three students conducted research in Honduras during this program, and two of these students have returned to an LDC to begin their professional careers. In Niger, the initial focus was on stem borers attacking millet; more recently the focus is on millet head miner. In both cases, the research was conducted by student trainees. One of these students is now employed by ICRISAT at the Sahelian Center. This research continues, and is now focused on the millet head miner. In the United States, the research has focused on insect pests that are analogous to those in Honduras and Niger, including stem borers, midges, aphids and spider mites.

During the course of this project, strong cooperative ties have been established with collaborators in Honduras and Niger. These collaborations have resulted in development of sustainable biological control strategies for stem borers, and information on pest and natural enemy biologies has contributed to improved approaches to IPM. For whorlworms in Honduras, techniques were developed to manipulate key natural enemies; for stem borers in Honduras, an efficient natural enemy was imported, released in Honduras and established; for stem borers in Niger, natural enemies were demonstrated to occur in greater densities in natural vegetation than in millet, a suggestion that the substantial changes to cultivated millet is interfering with biological controls; and for millet head miner in Niger, the biology and impact of head miner natural enemies must be assessed before progress can be made for biological control of the head miner. For spider mites in the United States, phytoseiid predators have been demonstrated as an effective alternative to pesticidal control; for stem borers in the U.S., parasites were shown to be effective on the American sugarcane borer attacking sorghum; for midges in the U.S., parasites of midges were demonstrated to be present in most johnsongrass (alternate host) stands in Texas, and may be useful as commercial controls if a numerical relationship is promoted in johnsongrass; and for aphids attacking sor-

ghum in the U.S., predators were demonstrated as key natural enemies for effective biological control of the aphids, other aphid species were demonstrated as important nonpests that support the needed natural enemy complex on aphids, and predators were shown to be important to the overall IPM strategy on sorghum crop protection.

During the course of this project, significant advances have been made in biological control and these advances contribute to improved IPM of sorghum and millet, and to improved concepts for using biological control in annual crops. Moreover, in 15 years this project has conducted research that resulted in 84 published articles, 45 invited or submitted paper presentations and 21 graduate degrees either conferred or in progress.

Introduction

Arthropod pests are among many external stresses that reduce or prevent stable yields of sorghum and millet in developed and developing countries. Among the most important of these arthropods are aphids, panicle feeding caterpillars, stem borers, armyworms and midges. Where possible, these pests are often controlled by chemical pesticides which are generally expensive and ecologically disruptive. In recent years, the public is demanding safe food, an unpolluted environment and conservation of wildlife and other natural resources. These demands are generally incompatible with chemical pesticides, and thus require alternative control strategies that are sustainable and minimize dependance on insecticides. Biological control is a sustainable alternative, and is typically very effective when integrated with other sustainable practices.

Sustainable pest management strategies generally require more detailed understanding of pests' ecology and their natural enemies. Biological control in perennial crop ecosystems places a premium on natural enemies that work best with habitat stability, whereas biological control in annual crop ecosystems places a premium on natural enemies that are adaptable for survival on varying host plants and on varying species of hosts-prey. Thus, to be sustainable, biological control often requires detailed information about the pest, relatives of the pest, and the natural enemies of these phytophagous arthropods. This information is especially important for times of year when the pests inhabit non-crop portions of the agroecosystem.

Biological control of arthropods is a tactic that has a long history of success. However, most of this history is in developed countries and with exotic natural enemies imported to control exotic pests on perennial crops. This history provides almost no insight on how to use indigenous natural enemies to control indigenous pests on annual crops. Also, this history fails to illustrate the special importance of assessing natural enemies before advocating their use for biological control. Preliminary assessment of natural enemies is especially important for a pest management strategy that uses biological control by augmenting or conserving natural enemies. Biological control implemented without proper enemy assessment results in needless failure. This is especially important in the low input and fragile farming systems typical of developing countries. In these systems, omitting or improperly assessing enemies not only misses an opportunity for reliable and inexpensive pest control, but also increases prospects for significant crop losses.

This project seeks to develop scientists from national agricultural research systems (NARS) in developing countries. These scientists are trained to be specialists in biological control, and to develop biological control technologies and concepts that can be useful to subsistence and high-input crop production systems. The project uses on-site collaborative research, development of new technology, evolution of vital biological control theory, and a strong focus on graduate student training. Student training is particularly important for this CRSP because ultimately scientists trained in this program are the key to sustainable NARS resources who will develop future pest control strategies. Research in the United States provides a platform for training, evolving theory, conceptualizing and defining functional ecosystems of pests, developing methodologies for measuring actual and potential impacts of natural enemies, and validating results of biological control after implementation.

Objectives, Production and Utilization Constraints

Objectives

Central America

Assess the efficacy of natural enemies that may be useful for biological control of stem borers, fall armyworm and other pests of sorghum; optimize the implementation of effective enemies for producing local sorghum crops.

West Africa

Assess the potential of biological control agents attacking millet head miner (MHM) and millet stem borers, and in field trials to assess agent value for biological control; conduct field studies for implementing conservational and augmentational biological controls in integrated crop protection strategies.

United States

Provide graduate level training programs and develop strategies for implementing biological controls in sorghum and millet; develop examples of concepts and tactics for implementing biological control in annual crop ecosystems; investigate plant-pest ecology and identify potential biological control agents for use against sorghum and millet pests; and develop understanding needed to integrate effective biological controls with host plant resistance and other local production practices.

Constraints

Insect pests of sorghum and millet addressed by this project are key pests and primary constraints to efficient crop production in Niger, Honduras, and the United States. Sorghum and millet sustain losses and control costs from infestations of key insect pests, and these losses and costs are variables that can be minimized with improved management practices. Ideally, management practices for these pests are compatible with other agronomic needs, and are ecologically sound. Detailed ecological understanding of target pests and their natural enemies is key to a sustainable pest management strategy.

Research Approach and Project Output

Research Approach

TAM-125B uses on-site collaborative research in developing countries as complements to research in the United States. The primary research focus is to develop understanding for using biological control as part of improved integrated pest management strategies. The collaborative research in West Africa consists of biological and ecological experiments to better understand millet head miner and millet stem borers and their respective natural enemies. The research in Honduras consists of biological and ecological experiments to better understand fall army worm (i.e., whorlworm) and stem borers and their respective natural enemies. In the United States, research consists of biological and ecological experiments on spider mites, aphids and sorghum midge and their respective natural enemies. In all research, the program is developing ideas and approaches needed in biological control to effectively use natural enemies in a sustainable process that is compatible with integrated pest management.

Project Output

Central America

Experiments were conducted on fall armyworms and stem borers in Honduras during 1982 through 1988. This research collaborated with Drs. Keith Andrews, Jeff Bentley and Dan Meckenstock to identify the most important enemies of FAW. Fall armyworm (FAW) (i.e., whorlworm), *Spodoptera frugiperda*, has many natural enemies in Honduras. Results revealed that three of these enemies can be particularly useful and may be manageable. These enemies are an earwig (*Doru taeniatum*), the tropical fire ant (*Solenopsis geminata*), and a species complex of paper wasps (*Polybia* spp.). Research to date has determined the biology and seasonal phenology of the earwig, the impact of fire ants, and tactics for manipulating fire ants and *D. taeniatum*. This work also showed that FAW and other pests are more abundant on maize than sorghum, and that the abundance of FAW and other pests is greater in mixed maize and than in sorghum monocultures. Research has progressed sufficiently to begin investigations on manipulating the enemies of these pests. Discussions in 1990-92 with faculty at the Pan American School of Agriculture sought to identify a student from Central America for Ph.D. graduate training. When identified, this student will consolidate research results of the prior three M.S. programs on biological control. Research on stem borers in the Honduras maize/sorghum ecosystem released and recovered an exotic parasite, *Cotesia flavipes*. Further surveys are needed to confirm this parasite as permanently established.

West Africa

Research on millet was initiated in Niger in the Spring of 1986 and focused on the millet stalk borer (MSB), *Haimbachia ignefusalis* (Lepidoptera: Pyralidae), and the millet head miner (MHM), *Heliocheilus albipunctella* de Joannis (Lepidoptera: Noctuidae). In the summer of 1993, additional work was initiated on *H. albipunctella*. Research conducted on these pests included identification of non-crop host plants, natural enemies, oviposition behavior, affects on crop loss, survival in excised millet stalks, and population dynamics. The MSB was collected in Niger from 14 plant species and seven gramineous and non-gramineous families, with *Andropogon gayanus* being the most commonly infested non-crop plant. MSB apparently uses these non-crop plants as a diapause refuge. Our research indicates that MSB causes serious damage to both early and late planted millet, though greater numbers of MSB occur in early millet. Results of work on MSB ovipositional sites indicated that green millet stalks with intact leaf sheaths were preferred over flat green or dry leaves. This behavior complicates insecticide strategies for controlling MSB because the larvae bore into the stalks immediately after hatching and thus are not exposed to the toxicants if applied. Research on MSB damage showed a negative correlation between grain weight and numbers of exit holes in mature plants, that diapausing MSB larvae occurred in all stalk internodes but were most numerous in internodes distal to the plant base, and that damage was greatest when MSB occurred on internodes distal to the plant base. Though several parasite species attack MSB in millet, densities of MSB are not suppressed by these parasites. This result supports importing additional parasites from other parts of the world into Niger. Research on MHM is currently examining the impact of specific natural enemies. This research is a precedent to developing tactics for manipulating extant MHM natural enemies, either in a conservation or an augmentation approach to implement biological control.

United States

TAM-125B, Biological Control Tactics for Sustainable Production of Sorghum and Millet, has worked with populations of arthropod pests and their natural enemies in the U.S. in sorghum and Nigerien millet. These two crops are typical of annual crops that often are perceived as isolated and discontinuous life systems. This perception promotes viewing these crops as temporary or ephemeral arthropod refugia. Actually they are parts of larger ecosystems com-

prised of not only crop refugia, but also of enduring noncrop refugia such as noncrop weedy host plants, streams, hedge rows, turn rows, fence rows, ditches, roadsides, and pastures. These enduring habitats occur near annual crops, and harbor relatively undisturbed vegetation and populations of arthropods. Noncrop habitats are well recognized as sources of arthropods that damage crops, but usually are not managed to take advantage of their value as refugia for natural enemies of these pests. Since 1979, TAM-125B INTSORMIL research in the United States has developed and examined several models for using natural enemies from noncrop refugia to control pests in sorghum and millet. In Model I, a nonpest invades the crop early and "holds" significant numbers of immigrating natural enemies in the crop until the "real" pest arrives. An example is coccinellids that immigrate from nearby crop and noncrop refugia to occupy grain sorghum. Here they prey on corn leaf aphids (*Rhopalosiphum maidis* (Fitch)) (i.e., nonpest) until greenbugs (*Schizaphis graminum* (Rondani)) arrive; as the key pest greenbugs are available, the coccinellids become principal natural enemies for biological control of this pest (Kring and Gilstrap 1986). Model II features early movements of natural enemies into a crop from noncrop refugia, and these enemies then show a within-crop numerical response to changing pest densities in the crop. An example is movement of natural enemies of spider mites moving from weedy refugia (i.e., johnsongrass) into grain sorghum where they respond numerically to Banks grass mite (*Oligonychus pratensis*) and two-spotted spider mite (*Tetranychus urticae*.) In Model III, a natural enemy numerical response occurs in a noncrop refuge and these enemies suppress the pest before it moves from the refuge to grain sorghum. Examples of this model are (1) sorghum midge on johnsongrass (i.e., noncrop) and grain sorghum, and (2) the stem borers on *Andropogon* and millet.

Technology Development and Student Education Research

Technology Development

The research approach of TAM-125B consists of on-site collaborative research, complimentary research in the United States to develop supporting theory, and graduate student training. Collaborative research in Niger and Honduras is focused mostly on implementing biological control of the millet head miner and fall armyworm, respectively. In the United States, the goal is to implement biological control of spider mites, aphids and sorghum midge. Research in the United States provides the platform for understanding and validating results of biological controls when implemented. Specific project activities include: (1) use literature to determine the known diversity, geographic distribution, and host plant affinities of natural enemies of sorghum pests in selected sorghum producing regions of the world; (2) collect, culture and evaluate natural enemies that attack sorghum and millet pests to develop their biology, behavior and seasonal abundance profiles; (3) initiate working relationships and informational exchanges with investigators in sorghum and millet producing regions of the world; (4) use classical techniques for studying the biology of sorghum and millet pests and their associated natural enemies are used and include laboratory, greenhouse and/or field studies; (5) determine the effects of various environmental factors on natality and mortality of arthropods associated with sorghum and millet; and (6) determine the temporal and spatial distributions of sorghum and millet insects and their associated natural enemies.

Student Education Research

Imad Bayoun, Lebanon, Ph.D. student: This research is assessing the merits of three approaches for measuring the impact of aphid enemies in Texas Panhandle. The research seeks to develop improved methodologies and expand theory for evaluating parasites of aphids. Specific objectives are to (1) select insecticides and application rates to selectively remove natural enemies from plots and estimate the impact of natural enemies, (2) determine the value and role of chemical versus caged exclusions from measuring the impact of natural enemies, and (3) determine how host exposures can be useful for estimating the impact of natural enemies in habitats that are dynamic within permanent agroecosystems.

Robert Behle, U.S., Ph.D. student: Changes in the nonstructural carbohydrate (NSC) levels in grain sorghum, *Sorghum bicolor* (L.) Moench, due to greenbug, *Schizaphis graminum* (Rondani) feeding were examined. Concentrations of fructose, glucose, sucrose, fructan, and starch in greenbug-infested and uninfested sorghum plant samples were determined using high performance liquid chromatography. Objectives of this research were to observe the effects of greenbug feeding on the nonstructural carbohydrate concentrations (NSC) of sorghum plants at three plant growth stages and determine if greenbugs create a nutrient sink at the feeding site, which competes with the normal plant nutrient sinks. For seedling sorghum plants grown in the laboratory, greenbug feeding infested plants had greater glucose and starch concentrations in the shoots compared with uninfested plants. Also, greenbug infestations reduced shoot length, shoot fresh weight, shoot dry weight, root fresh weight, and root dry weight ($df=3$, $P \leq 0.05$). Greenbug-infested vegetative sorghum had a greater total concentrations of NSC in roots compared with uninfested plants. Increasing greenbug densities caused deficiencies in the shoots before depleting NSCs from the roots. For reproductive plants when greenbugs were confined to the third leaf below the head, greenbug-infested plants had greater concentrations of total NSCs in the infested leaf while uninfested leaves above and below the infested leaf, peduncle and root samples had reduced concentrations of NSCs compared with uninfested plants. Results suggested that greenbugs feeding initially triggers a plant response that increases the concentration of NSCs, then creates a nutrient sink near the feeding site that draws NSCs from roots of seedling plants and other leaves of reproductive plants. For all three growth stages, greenbug feeding depleted NSCs from the infested plants

and may explain why greenbug damaged plants exhibit delayed recovery after the aphids are removed.

Gary Brooks, U.S., M.S. student: This research examined the parasitism of sorghum midge, *Contarinia sorghicola* (Coquillett), on a ubiquitous host plant, johnsongrass (*Sorghum halepense*). These studies revealed that a) the soft dough stage is the best stage of development for optimal midge and midge parasite emergence, b) the tertiary branchlet is the least variable sample unit for monitoring midge and midge parasite population dynamics on johnsongrass, c) adults of the midge parasite, *Tetrastichus blastophagi*, emerge from midge hosts significantly earlier than do other midge parasites and thus should not be included in estimates of percent parasitism when samples are collected as in our studies, d) *T. blastophagi* emerged only from pedicellate spikelets, and e) in addition to *T. blastophagi*, other species of parasites attacking midge on johnsongrass are *Eupelmus popa* (60% of the total for the 3), *T. nr. venustus* (36%), and *Aprostocetus diplosidis* (4%). These results facilitate efforts to collect additional species of midge parasites on gramineous hosts in other parts of the world for use in biological control of sorghum midge.

Matthew Ciomperlik, U.S., Ph.D. student: This research is seeking to develop a capability for separating populations of *Diaeretiella* sp nr *rapae*, important for biological control of aphids. The work was conducted subsequent to importation biological control project that imported eleven strains of *D. rapae* for biological control of aphids on grain sorghum. Standard horizontal starch gel electrophoresis techniques were used to survey seven geographic strains of *Diaeretiella rapae* for isozyme polymorphisms. The separations are necessary as an antecedent to field research that will determine the respective impact of these new natural enemies versus those already present on aphids in the sorghum-wheat ecosystem. The electrophoresis work used twenty-three enzyme strains and five buffering systems. Each enzyme stain was tested with each of the five buffering systems for all of the parasites strains. Twenty eight isozyme loci were identified for the *D. rapae* strains, 6 were polymorphic and twenty-two were monomorphic for all strains. None of the identified loci revealed fixed genetic differences between the *D. rapae* strains. Average heterozygosities (i.e., H_{exp}) for the seven strains ranged from 0.065±0.031 to 0.02±50.018. H_{exp} values were low, but were of the same magnitude reported for other haplodiploid parasitic Hymenoptera. Nei's unbiased genetic distance and identity coefficients indicated that the seven strains are genetically similar. The F_1 hybrid progeny from reciprocal crosses of the strains were electrophoresed to determine the inheritance of the isozyme banding patterns. Two allelic forms of aldolase were inherited as co-dominants in the F_1 progeny, where segregation was determined in the haploid males as well as in the diploid females. Additional work on courtship and pre-zygotic isolating mechanisms are in progress as additional tools to separate these populations.

Jeffrey Edwards, U.S., M.S. student: These studies investigated the competition between two coccinellid predator species (*Coccinella septempunctata* L. [C7] and *Hippodamia convergens* Guerin-Menville [HC]), and the effects of this competition on the suppression of greenbugs. Competition between two predator species and their ability to suppress aphid populations were investigated. These experiments showed that competition among individuals of mixed species is about the same as it is among individuals of one species when one species is caged alone. These studies also found no conclusive evidence that C7 interferes with HC population increase or HC predation. In fact, the presence of C7 apparently complimented predation of HC.

Daniel Flores, U.S., Ph.D. student: This research is developing biological controls for spider mites, and seeks to understand the links between "banding" with Comite® and impact of naturally occurring predators, and ecology of phytoseiids. Specific objectives are to (1) document the timing, rates and impact of Comite® and other key acaricides on naturally occurring predators, (2) document the role of natural enemies in making plant banding with Comite® work, and (3) develop the biology of key naturally occurring enemies of spider mites, especially using alternate food sources.

Daniel Friese, U.S., M.S. student: This research examined the survival and efficiency of three species of spider mite predators at low levels of prey availability. These established a relationship between the prey killing powers and developmental times for each predaceous phytoseiid when feeding on two species of spider mites which occur on sorghum and other crops. Predatory stages of *Phytoseiulus persimilis* killed about 30% more spider mites/instar hour than respective stages of either *Amblyseius californicus* or *Metaseiulus occidentalis*. Reproductive females of *P. persimilis* killed more than 3 times the number of prey eggs killed by *A. californicus* and more than 5 times the number killed by *M. occidentalis*. *Phytoseiulus persimilis* in the presence of excess prey has the shortest developmental time for active stages (69.3 hour), the greatest reproductive longevity (482.4 hour), kills the most prey as an immature (13.4 eggs) and as a reproductive adult (503.1 eggs), and consistently kills the greatest number of prey/h as post-larval instars or as reproductive females. An index of predator capability estimates that protonymphal *P. persimilis* can function at 1 tetranychid egg/74.3 cm^2 versus 85.6 cm^2 and 66.8 cm^2 for *A. californicus* and *M. occidentalis*, respectively. The index estimates that adult *P. persimilis* can find 1 spider mite per 47.1 cm^2; whereas *A. californicus* must encounter adult prey at 1/35.7 cm^2 and *M. occidentalis* at 1/24.5 cm^2.

Robert Jones, U.S., M.S. student: This research consisted of experiments on *Doru taeniatum*, an earwig predator of fall armyworm (= whorlworm) in Honduras. Experiments revealed that a) this predator is closely associated with the fall armyworm in temporal and locational distribution, b) is predaceous on larval stages of fall army-

worm, and c) has a behavioral preference for occupying the plant whorl, the same habitat as damaging instars of fall armyworm. These experiments provided key information for later experiments that sought to manipulate *D. taeniatum* and the tropical fire ant for biological control of fall armyworm on sorghum in Honduras (see Lastres, M.S.).

Timothy Kring, U.S., M.S. student: This research assessed the population dynamics and within field distribution of greenbug, *Schizaphis graminum* (Rondani), and its parasitoids in central Texas. Samples showed that greenbug was the most abundant aphid species present, followed by the bird-cherry oat aphid, *Rhopalosiphum padi* (L.). The primary parasites reared from greenbug in order of abundance, were *Lysiphlebus testaceipes* (Cresson), *Diaeretiella rapae* (M'Intosh), and *Aphelinus nigritus* (Howard). The hyperparasites in order of abundance were *Alloxysta* sp. (*megourae* complex), *Asaphes lucens* (Provancher), and *Pachyneuron siphonophorae* (Ashmead) (see Kring, Ph.D).

Timothy Kring, U.S., Ph.D. student: This research evaluated all the biotic mortality factors affecting the population dynamics of greenbug, *Schizaphis graminum*, on Texas sorghum. The efficacy of greenbug natural enemies was measured in grain sorghum using mechanical exclusion techniques and paired comparisons. Environmental parameters were not significantly different between cages where natural enemies were excluded and those where natural enemies had complete access. Greenbug densities on caged plants excluding natural enemies rapidly exceeded established economic thresholds and killed the plants. Greenbug densities on caged plants that allowed access to natural enemies remained well below threshold levels. Predators were the only natural enemies present during most of the studies, and in the absence of greenbugs increased to high densities by feeding on corn leaf aphids, *Rhopalosiphum maidis* (Fitch). Parasite activity was not significant until mid- to late-season.

Lorena Lastres, Honduras, M.S. student: This research examined the pest/beneficial role of the fire-ant, *Solenopsis geminata*, in a maize-sorghum intercrop system in Honduras, and demonstrated the role of *Solenopsis geminata* and *Doru taeniatum* to control the whorlworm (WW), *Spodoptera frugiperda*. Naturally occurring earwig densities are not great enough in the field to reduce WW or aphid infestations. Thus, research to improve biological control manipulated *D. taeniatum* by using whorl-like structures to increase *D. taeniatum* field densities. These structures served as artificial refuges for *D. taeniatum*. Field work showed that population densities of *D. taeniatum* can be doubled by attaching the artificial structures to plants. In field cage studies, *D. taeniatum* at densities of about one earwig per plant provided useful levels of predation on second instar WW at two weeks after plant emergence. Predation of second instar WW by *D. taeniatum* was more influenced by plant size than by prey density. Field studies on *S. geminata* indicated that predation by *S. geminata* is an important source of mortality to WW larvae when fire ants densities exceeded 10/m^2. *Solenopsis geminata* also reduced *Listronotus* sp. infestations and cutworm damage to seedling corn plants. In laboratory studies, short day photoperiod (11L:13D) stimulated diapause in *D. taeniatum*. Photoperiod, relative humidity and diet were important in regulating the development of *D. taeniatum*. *Doru* developed the fastest on corn pollen, and the slowest on pelletized dog food. The fire ant did not adversely affect crop yield or parasite abundance, but did reduce FAW densities in both maize and sorghum during the early whorl stage.

Leslie McKinnon, U.S., M.S. student: This research characterized the mummified remains of greenbugs and determined the causes and frequency of parasite pre-emergent mortality. A key was developed which helps identify the hyperparasite species and trophic level (secondary, tertiary, etc.) by examining empty aphid mummies; a second key allows identifying types of predators that kill a developing parasite. Preference experiments were conducted with three predator types (*Hippodamia convergens* adults and larvae, and *Chrysoperla rufilabris* larvae), and these indicated that all three will feed on mummified aphids when unparasitized aphids are present. Only *C. rufilabris* larvae showed a preference for unparasitized aphids over *Lysiphlebus* mummies.

Charles Pickett, U.S., Ph.D. student: This research evaluated all indigenous and two exotic phytoseiids predators for biological control of Banks grass mite. Predators of spider mites were sampled and monitored in commercial fields and adjacent vegetation in Texas during 1981-83. Several species of predaceous arthropods were found associated with spider mite infestations. *Orius insidiosus* and *Feltiella macgregori* were the most abundant predaceous insects collected. The most common naturally occurring phytoseiid was *Neoseiulus setulus* (Fox). Several naturally occurring predators responded numerically to increases in spider mite densities, but usually well after spider mites reached damaging levels. *Phytoseiulus persimilis* and *Amblyseius californicus* were augmentatively released into commercial fields in the Texas High Plains in 1982 and 1983. Both predators significantly reduced spider mite infestations and maintained these infestations below economically damaging levels. Timing of releases was critical to the efficacy of the phytoseiids. Plots with *P. persimilis* generally had lower spider mite densities than plots treated with *A. californicus*, though statistical differences were detected in only one season.

Asha Rao, India, M.S. student: Researching use of insecticide check method to evaluate natural enemies of aphids on wheat and sorghum. Experiments are in progress to develop specific methodology for using the insecticidal check method to assess the efficacy of natural enemies of aphids. Specific objectives are to determine the efficiency of removing aphid parasites by three insecticides applied at the (1) same dosage but at different frequencies, (2) different methods of application, one for removal of enemies, and the other for trapping the enemies, and (3) determine the mecha-

nism for preventing natural enemy activity, mortality or avoidance.

Edgar Rojas, Costa Rica, M.S. student: Research sorted out the biology and control of mites infesting and contaminating fungus cultures in mycology laboratories. These studies measured the effects of four temperatures, five fungal diets, eleven toxicants, and a predaceous mite on the development, reproduction and survival of *Caloglyphus* new sp., *Tarsonemus* new sp. and *Tyrophagus putrescentiae* (Schrank). Each pest mite is a serious problem in laboratories that work with stored products, especially those that deal with fungal pathogens of plants.

Edgar Rojas, Costa Rica, Ph.D. student: Researching interaction between biological control and host plant resistance. Specific objectives are to (1) determine the within generation impact of parasitism on the pest insect, (2) determine the effects of parasitism on between generations of the pest, (3) determine the impact of selected insecticides on the pest and its 4 parasites.

Javier Roque, Mexico, Ph.D. student: Researching segregation of exotic and native races of *Aphelinus sp. nr. varipes*, natural enemies of aphids that attack grain sorghum and other small grains. This research seeks to separate six races of *Aphelinus varipes* (Föerster), a group of parasites that are key natural enemies of aphids in wheat-sorghum in Texas. Specific objectives are (1) assess the host aphid acceptability and suitability of each parasite race, (2) compare the mating behavior of respective races, (3) use starch gel electrophoresis to describe the isozymic patterns of the six strains, and (4) examine the reproductive isolation of each strain by using reciprocal crosses among respective races.

Ronaldo Sequeira, Honduras, M.S. student: This research examined biological control agents attacking stem borers and crop losses due to stem borers at several locations; quantified the effects of four different sorghum cropping systems on the population dynamics of several pests of sorghum and maize; and released several species of exotic stem borer parasites in Honduras. More than 140,000 parasites were sent to Honduras, consisting mostly of *Cotesia (= Apanteles) flavipes*, a proven natural enemy of stemborers in Texas and Caribbean countries where it is already established. As a result of Sequeira's research in Honduras, a very intensive program on biological control of stemborers is now making progress in Honduras and El Salvador. Recent reports verify that *Cotesia* is definitely established in Honduras, and is already widely distributed outside areas where it was initially colonized. Regarding the effects of four different cropping systems on pests and their enemies on maize and sorghum, data showed the following general trends: 1) pests were more abundant in maize than in sorghum, 2) pest abundance was usually greater in mixed systems than in sorghum monoculture, 3) pest incidence in the mixed systems was usually not significantly different from pest incidence in maize monoculture. Mixed crops did not result in important decreases in population levels of whorlworm, neotropical corn borer, or *Geraeus* as compared to maize monocultures. Corn leaf aphid was an exception, being 1) more abundant in sorghum than in maize, 2) more abundant in the monoculture sorghum than the rest of the cropping systems considered as homogenous entities, 3) less attracted to sorghum when present in a system with maize, and 4) abundance was not affected in maize by the addition of sorghum in a same hill or alternate hill system. Predators and parasites in all the cropping systems were more abundant in maize than in sorghum.

Kenneth Summy, U.S.A., M.S. student: This research surveyed greenbug parasites in West Texas, and was completed in 1981. Results showed that only three primary parasites attack greenbugs in this part of Texas, and that parasites alone are not effective natural enemies. This work was the beginning phase of research on natural enemies of aphids on sorghum, and initiated the concept that early season predation by coccinellids is far more important than previously thought for biological control of greenbugs.

Ousmane Youm, Senegal, M.S. student: This research evaluated indigenous and exotic parasites attacking stemborers on sorghum in the Texas Rio Grande Valley. These studies developed understanding and methodology needed to conduct similar studies in Niger (see Youm, Ph.D.). Results showed that a) three species of stem borers commonly attack Texas sorghum, b) stem borers are not abundant on sorghum or corn until late summer or early fall, c) the stem borers in Texas are each attacked by one or more parasites, and d) parasites attacking stem borers in south Texas sorghum include parasites established to attack these same species of stem borers in sugar cane.

Ousmane Youm, Senegal, Ph.D. student: This research evaluated natural enemies associated with stemborers and the millet head miner, *Heliocheilus* (=*Raghuva*) *albipunctella*, attacking millet in Niger. Earlier work on stemborers in Texas was an important precedent to this work (see Youm, M.S.). The results on population dynamics of the stem borers *Haimbachia ignefusalis*, *Sesamia calamistis* and *Raghuva albipunctella* in millet monoculture showed that mean numbers of eggs and larvae of *H. ignefusalis* and *S. calamistis* were greatest in the first planting and mean numbers of pupae were generally low. Populations of *H. ignefusalis* were consistently greater than those of *S. calamistis*, indicating that *H. ignefusalis* is probably the most serious pest of the two borers. Many of the same species of parasites associated with *Haimbachia ignefusalis* on millet also attack this borer on wild, non-crop hosts. This information is needed for developing crop refuse management strategies that will minimize diapausing stem borers, and to maximize the effects of parasites on stem borer populations. Experiments on post-harvest holding of millet stalks showed that stacking infested millet stalks in or around villages increases prospects for stem borer survival between growing seasons. Millet stalk borers were collected from 14 species of plants belonging to seven families of noncrop host

plants, and *Andropogon gayanus* was the most commonly infested host plant over several locations. This suggests that the millet stalk borer uses alternate host plants primarily as a refuge for diapause. The larval parasite *Euvipio* sp. was reared from the millet stalk borer on more hosts than any other parasite. Studies on MSB damage versus millet grain production showed a negative correlation between grain weight and numbers of exit holes in mature plants, and damage was greatest when borers occurred on internodes distal to the plant base. MSB on the fourteen alternate host plants were parasitized by a complex of parasite species that occurred both on millet and seven of the alternate host plants. Results showed that natural enemies do not control MSB on millet. Many diapausing MSB larvae died during the dry season; however, a substantial number survived due to the stacking of millet stalks. MSB population densities were not reduced by adjusting millet planting dates, but were affected by millet growth stage. Life table studies of the millet head miner were inconclusive, but provided methodology used in experiments in 1993.

Networking Activities

Workshops

Sorghum in the Eighties Symposium. 2-7 November 1981, Patancheru, India. Sponsored by INTSORMIL, ICAR and ICRISAT.

International Sorghum Entomology Workshop. 15-20 July 1984, College Station, Texas. Sponsored by INTSORMIL, ICRISAT, and Texas A&M University.

WCAMRN-ROCAFREMI Workshop for the Central Africa Millet Research Network. 20 March - 3 April, 1992. Sponsored by SAFGRAD, ICRISAT and NARS of West Africa.

International Consultative Workshop on Panicle Insect Pests of Sorghum and Pearl Millet. 4-7 October 1993, Niamey Niger. Sponsored by ICRISAT.

Research Investigator Exchanges

Mr. Henry Fuentes, Ministry of Natural Resources, Honduras; Ing. Rafael Reyes and Ing. Leopoldo Serrano: October 1985, Ronaldo Sequeira, two Salvadoran scientists, and a Honduran scientist prepared a joint work plan for 1986-87 stem borer biological control research in El Salvador and Honduras, and in November 1985 Sequeira trained a Nicaraguan scientist (affiliated with INRA-Nicaragua) on the same topic for work in Central America. Mr. Sequeira gave reports of his research findings at an October 1985 meeting in Guatemala (of Central American Sorghum Research Group), and at a second meeting in December 1985 El Salvador (Second Basic Grains Seminar in San Salvador), and at a third meeting in El Salvador in March 1986 (Central American Food Crops Research Group). In April 1986, two Salvadoran scientists visited the Gilstrap laboratory in order to obtain specialized training in biological control procedures for stemborers attacking sorghum.

Juan Marenco, Honduras, special training, March-May 1988: Mr. Marenco worked in the Gilstrap's INTSORMIL laboratory, learning to rear and identify parasites of stemborers that attack sorghum in the Texas Rio Grande Valley. He also worked with Ronaldo Sequeira reexamining data on stem borers from Honduras.

Myo Chit, Burma, special training, August 1986-May 1988: Working on the biology of an exotic parasite of the sugarcane mealybug. Mr. Chit was supported by USAID grant funds from Burma. Mr. Chit also worked with the INTSORMIL research program, developing and maintaining cultures of aphids and aphid parasites. Learned culture techniques for each aphid and parasite, and the protocol for working with natural enemies in an importation program.

Jose Monroy, Honduras, special training, February-May 1992: Research determined the host range of an aphid parasite, and worked with laboratory program to maintain cultures of five species of aphids and 17 species of parasites. Learned culture techniques for each aphid and parasite, and the protocol for working with natural enemies in an importation program.

Jorge Leyva, Mexico, special training, August 1985-August 1990: Research dealt with the biology, distribution and impact of parasites attacking the Mexican fruit fly, and this was supported in part by funds from a Mexican governmental grant to educate Mexican students. Also worked with laboratory program to maintain cultures of five species of aphids and 17 species of parasites. Learned culture techniques for each aphid and parasite, and the protocol for working with natural enemies in an importation program.

Bentara Dayawathie, Sri Lanka, special training, January 1979-December 1983: Research dealt with the biology, distribution and impact of parasites attacking the yellow rice stem borer, and this was supported in part by funds from a USAID grant to the University of Peradenyia (Sri Lanka) to improve the institutional capability of the university. Ms. Dayawathie also worked with the INTSORMIL research program, developing and maintaining cultures of aphids and aphid parasites. Learned culture techniques for each aphid and parasite, and the protocol for working with natural enemies in an importation program.

Evasio Kapeya, Malawi, special training, June-December 1988: Worked on biology and colonization of two dipterous predators from Botswana which feed on aphids attacking sorghum. Mr. Kapeya was supported by a grant from USAID/SADC.

Mr. Nouhou Kondo, INRAN, Niamey Niger. Mr. Kondo was trained as a collaborating scientist during the research of Ousmane Youm in 1985-86. Mr. Kondo was trained to take field samples, identify adult and immature stages of

millet stem borers and millet head miner, conduct laboratory insect rearing, and make insect diet.

Assistance Given

Each year during 1979-1993, 7-10 international scientists visited the sorghum entomology and biological control programs at Texas A&M University. Short term training was provided scientists listed above for Research Investigator Exchanges. Additionally, research supplies were sent to Honduras, El Salvador and Niger to support on-site research programs. Computers, computer programs, insect diet, diet blenders, cages, netting for cages, books, insect-preservation supplies, etc., were sent to collaborators in support of collaborative programs. Important linkages were maintained with Dr. Ousmane Youm, Principal Scientist, ICRISAT-SC, Sadore Niger; and with Francisco Gomez, SRN, Honduras.

Publications and Presentations

Publications

Jones, R. W., F. E. Gilstrap, and K. Andrews. 1993. Dinàmica Poblacional de la Tijereta *Doru taeniatum* (Dohrn) (Dermaptera: Forficulidae) en Malz y Sorgo en Honduras. Ceiba 30: 67-80.

Youm, O. and F. E. Gilstrap. 1993. Life-fertility tables of *Bracon hebetor* Say (Hymenoptera: Braconidae) reared on *Heliocheilus albipunctella* de Joannis (Lepidoptera: Noctuidae). Insect Sci. Applic. 14. In Press.

Gilstrap, F. E. 1993. The six-spotted thrips: a gift from nature that provides control. Proc. 1993 Internat. Conf. on Thysanoptera. Sep 28-30, 1993. Burlington VT. In Press.

Gilstrap, F. E. and I. Bayoun. 1993. Biological control of the millet head miner: Needs, tactics and prospects. Proc. Workshop on Millet Panicle Pests. Niamey, Niger. Oct 4-9, 1993. In Press.

Presentations

December 1992. Gilstrap presented ESA Symposium titled, "Biological Control in Ephemeral Habitats," and presented paper entitled "Importation biological control: Conflict between theory and practice."

Development of Plant Disease Protection Systems for Millet and Sorghum in Semiarid Southern Africa

Project TAM-128
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Summary

Strategic regional nursery sites were identified in collaboration with national programs and SADC/ICRISAT for leaf blight (Henderson Station, Zimbabwe), and anthracnose (Primary-Mansa, Zambia, Secondary-Golden Valley, Zambia). TAM-128 assisted SADC/ICRISAT in development of regional disease nurseries through introduction and evaluation of TAES and other cultivars which represented a significant number of entries having both excellent disease resistance and wide adaptation. Several cultivars with SC326-6 in their genetic background demonstrated good general adaptation to the SADC region and possessed excellent disease resistance needed in some areas of the region (leaf blight and anthracnose). Genetic relatedness between 119 isolates of *C. graminicola* from around the world including the SADC region was more correlated with geographical origin than with susceptibility or resistance of the sorghum host source when their DNA was compared using RAPD markers. No pathotype specific RAPD banding pattern was found. In U.S. studies on corn, sorghum, and cotton, predominant Fusaria were *Fusarium solani* and *F. equiseti* below ground, and *Fusarium* spp. section Liseola above ground. Corn and sorghum tissues contained large numbers of *Fusarium* spp. section Liseola including *F. moniliforme* mating population A (pink in culture) that predominated on corn, and mating populations A and F (yellow in culture) that predominated on sorghum. Cotton did not contain large numbers of any *Fusarium spp.* Eleven different species of *Fusarium* were identified from 71 representative isolates obtained from sorghum and pearl millet grain samples collected in Zambia, Zimbabwe, and Botswana. Predominant species, in order of frequency, were *F. equiseti*, *F. semitectum*, *F. chlamydosporum*, and *F. moniliforme*. *Fusarium equiseti* occurred on 90% of samples from both hosts and *F. semitectum* on 60 and 75% of the millet and sorghum hosts, respectively. All mating populations A,B,C,D,E, and F of *Fusarium* section Liseola were recovered on sorghum grain collected in Tanzania with F occurring at the highest frequency. A cultural method was developed to produce large volumes of conidia of *Ramulispora sorghi* (causal agent of sooty stripe) which could be

used as inoculum in field and greenhouse screening. Isolates of *Macrophomina phaseolina* (causal agent of charcoal rot) from diverse hosts in Botswana could generally be distinguished in culture as being from a gramineous and non-gramineous host. A *Gaertneriomyces spp.* parasitic to soilborne oospores of *Peronosclerospora sorghi* (causal agent of sorghum downy mildew [SAM]) was identified as *Gaertneriomyces semiglobiferum*. In field studies it reduced both soilborne inoculum of *P. sorghi* and subsequent SAM in corn and sorghum planted in that soil.

Introduction

Throughout Southern Africa there are divergent environments which favor one or more diseases of sorghum and millet in a variable manner by location and by year. The occurrence of many diseases was recognized in many regions of SADC but their relative importance was often not known. Through collaboration with national and SADC/ICRISAT scientists, a concerted effort was made to accomplish three goals simultaneously. They were to: 1. Identify and characterize major pathogens across the SADC region 2. Identify stable, adapted sources of resistance for those pathogens or develop alternative controls and 3. Develop and utilize standardized nurseries to evaluate general and specific resistance to diseases and to assess the relative importance of various diseases. Identification of major diseases also includes the determination of their impact, and the characterization of genetically-variable pathogens across locations. This information will assist breeders in the identification and incorporation of the most appropriate resistance into improved cultivars and better ensure their longevity in production. Where applicable, alternative disease control systems were sought to augment and conserve host plant resistance or function in lieu of host plant resistance. The effort included pearl millet but predominantly involved sorghum. Some of the major diseases evaluated were charcoal stalk rot, smuts, several foliar diseases, grain mold, and sorghum downy mildew. The project was initiated using standardized nurseries primarily from the U.S. that were evaluated across multiple locations in the SADC region over several years. Coincidently, selections from these nurseries, and from national, SADC, and other sources were used to develop standardized nurseries for the SADC region with cultivars more specifically adapted to the region and targeted more to the disease and pest problems of Southern Africa.

The use of multilocational nurseries, at least some of which are standardized and planted at several of the same locations over several years, will maximize both breeding and disease control efforts because cultivars are evaluated under diverse environments. These nurseries can be structured to help determine major diseases for each location but a few strategic locations should be chosen where one to a few major diseases can be evaluated without interference from other diseases or other problems. Multiple pest and disease resistance is extremely valuable but locations with pressure from multiple diseases can interfere and prevent identification of valuable sources of specific disease resistance. Some cultivars are not agronomically suitable for production in many areas where they are being evaluated but their response under higher disease pressure at that location better determines their relative levels of resistance than evaluation in their primary production area. The multilocational approach also helps to identify those cultivars with the greatest adaptation across geographical areas, environments, and knowledge of their pest resistance strengths and weaknesses better determines where they might be successfully grown.

Objectives, Production and Utilization Constraints

Broad Pathology Objectives

Identify major disease constraints of millet and sorghum in Southern Africa with emphasis on Botswana, Zambia, and Zimbabwe.

Develop integrated disease control systems including cultural and biological controls to complement host plant resistance.

Field Nursery Objectives

Deploy TAES nurseries and other sorghum to SADC/ICRISAT for use at several SADC locations to evaluate resistance to specific pathogens and to characterize pathogen populations. Develop and deploy standard and disease specific germplasm nurseries throughout the SADC region to monitor variability and impact of major sorghum pathogens and to identify the best adapted sources of disease resistance. Diseases for specific evaluation include charcoal rot, sorghum downy mildew, unknown viruses, leaf blight, sooty stripe, and anthracnose.

Assist in development of improved natural and inoculation screening techniques to assess pathogen resistance in sorghum and millet in the SADC region.

Determine stability and sources of resistance to major foliar pathogens through field screening nurseries at strategic locations. (leaf blight, sooty stripe, anthracnose)

Specific Disease Objectives

Determine effect of seed treatments on stand establishment (Botswana, Zimbabwe) and on incidence of sorghum downy mildew (Zimbabwe).

Evaluate cross pathogenicity and virulence of *Macrophomina phaseolina* collected from diverse hosts in Botswana including sorghum and millet. Determine if these isolates can be differentiated by analysis of cultural characteristics.

Table 1. TAES sorghum nurseries grown one or more years in the SADC region for disease evaluation and adaptation.

Location	Acronym	Location: Primary disease evaluated*
All Disease & Insect Nursery	ADIN	Zimbabwe: LB, SDM Zambia: LB, SS, AN, Viruses
International Sorghum Anthracnose Virulence Nursery	ISAVN	Zimbabwe: LB, AN Zambia: AN, SS
International Sorghum Virus Nursery	ISVN	Zimbabwe:Virus Zambia:Virus
Anthracnose Resistant Germplasm Nursery**	ARGN	Zimbabwe:LB Zambia:AN
Extended Anthracnose Virulence Nursery	EAVN	Zimbabwe:LB, AN Zambia:AN
Leaf Blight and Sooty Stripe Nursery**	N/A	Zimbabwe:LB, SS Zambia:LB, SS
Sorghum Downy Mildew Virulence Nursery	SDMVN	Zimbabwe:SDM Zambia:SDM

*LB=leaf blight, AN=anthracnose, SDM=sorghum downy mildew, SS=sooty stripe

**Nurseries developed by TAM-128 for use in the SADC region.

Table 2. Strategic sorghum nursery sites used for most disease evaluations involving TAM-128.

Location	Diseases evaluated*
Mansa, Zambia	AN (P)
Golden Valley, Zambia	AN, SS (P), LB, SDM
Henderson Station, Zimbabwe	LB (P), SS, AN
Panmure Station, Zimbabwe	LS (P), SDM, LB, SS
Mt. Makulu Station, Zambia	MDMV-A (P), AN
Lusitu, Zambia	CR, SS
Sebele, Botswana	CR
Pandamatenga, Botswana	LB, SS, SDM
Matopos, Zimbabwe	SDM (P-Inoculated)

* LB=leaf blight, AN=anthracnose, SDM=sorghum downy mildew, SS=sooty stripe, LS=ladder spot, CR=Charcoal rot, MDMV-A=Maize Dwarf Mosaic Virus-Strain A. (P)=Primary site for a specific disease evaluation

Develop sporulation techniques for *Ramulispora sorghi* and evaluate their use in greenhouse and field inoculations to enhance natural disease screening techniques.

Identify and characterize the *Fusarium* species occurring on pearl millet and sorghum in the SADC region and assess the potential for their involvement in mycotoxin contamination of seed used for human consumption.

Identify pathotypes and compare relatedness of *Colletotrichum graminicola* from Southern Africa and other geographic areas using differential cultivars and biotechnology.

Evaluate naturally occurring and introduced biological control techniques for sorghum downy mildew of sorghum.

Research Approach and Project Output

Nurseries

TAES sorghum nurseries (Table 1) and other selected cultivars were grown at one or more strategic sites (Table 2) in one or more years from 1986-1993. In addition to disease response, most cultivars were evaluated for other factors including adaptation and potential use in the SADC region. Early and mid-season evaluations for disease and other pest and agronomic factors in these nurseries were conducted by national scientists and the former SADC/ICRISAT plant pathologist (W. deMilliano). Final disease, agronomic, and other evaluations were most often conducted jointly with the TAM-128 principal investigator through on-site visits in these countries. TAM-128 also assisted in disease evaluations of several other disease or agronomic nurseries at several locations. These joint evaluations maximized the training value of the disease identification and evaluation process that was of mutual value to all participating scientists. It also allowed efficient communication between scientists about those cultivar traits of greatest interest to the national scientists for use in their countries and those of greatest potential use throughout the SADC region. Sorghums from many of these TAES and other nurseries were selected because of good adaptation, general or specific disease resistance, and other pest or agronomic factors and incorporated into regional SADC/ICRISAT and national nurseries. Promising, improved cultivars were continuously incorporated into these nurseries as they were identified. Others were removed depending upon their consistency of performance and other factors as they were evaluated at the strategic disease nursery sites and other national sites where regional SADC/ICRISAT nurseries were grown. Examples of these SADC/ICRISAT nurseries are the Regional Anthracnose Resistance Screening Nursery (RARSN), Regional Advanced Disease Resistance Screening Nursery (RADRSN), and the Regional Preliminary Disease Resistance Screening Nursery (RPDRSN).

The cultivars SC326-6, SC414-12E, BTX378 (Redlan), SC748-5, SC120, TAM428, RTX434, BTX631, BTX638, RTX636, RTX436 and others derived from crosses with some of them had good adaptation to many SADC regions. Several cultivars with SC326-6 in the genetic background (including 86EON361, 86EON362, selections from them, and 86EON374) were among those with the best overall foliar disease resistance and best general adaptation to the SADC region. However, 86EON361 was intermediate in susceptibility to aathracnose. TAM428, selected from SC110, was fairly well adapted to Botswana and had resistance to the sugarcane aphid but was vulnerable to anthracnose. BTX631, RTX636 (SC120 in background), and BTX638 had good anthracnose resistance in Zambia (Mansa) but had medium to high susceptibility to leaf blight in Zimbabwe (Henderson). RTX436 (SC120 in background) had good leaf blight resistance but was intermediate

in susceptibility to anthracnose. SC414-12E had good overall leaf disease resistance but, as a line, it occasionally had incidence of ergot dramatically higher than proximal cultivars at the same stage of maturity.

Foliar Diseases

Leaf blight and sooty stripe

Foliar diseases of sorghum are generally not a problem in Botswana so it was surprising that two of the popular land race varieties from Botswana had good general resistance to foliar diseases when evaluated in Zimbabwe. Segaolane demonstrated good resistance to sooty stripe and leaf blight during a late season epiphytotic at Kadoma station, Zimbabwe in 1985 and Segaolane and Town consistently showed good resistance to leaf blight at the Henderson station in Zimbabwe in 1986 and subsequent years. Nurseries for leaf blight and sooty stripe evaluation were developed using the best sources of resistance to each disease and evaluated at Henderson station and Golden Valley, Zambia. These nurseries had some cultivars in common because of their known resistance to both pathogens. At the Golden Valley location G. Kaula enhanced natural infection of sooty stripe by seeding between the rows with sooty stripe infested debris. The natural development of sooty stripe was enhanced using this technique and good sources of resistance to sooty stripe were confirmed but it was apparent that this resistance was not valuable unless coupled with resistance to leaf blight. Some cultivars with good sooty stripe resistance at Golden Valley had all or most leaves killed by leaf blight at both Golden Valley and Henderson. Some microclimate effects were observed at Golden Valley that might lead to erroneous evaluation of sooty stripe response; a few shorter cultivars had a greater apparent susceptibility to sooty stripe than some taller cultivars because sooty stripe destroyed most leaves on the shorter plants but killed only the lower to mid-leaves on the taller plants.

TAM-128 developed a method by which large volumes of conidia of *R. sorghi* could be produced in laboratory culture for use as inoculum in field and greenhouse screening. Conidia of *R. sorghi* produced in this manner maintained viability at 6-10C for long periods of time if maintained in their original gelatinous matrix but rapidly senesced when dispersed in free water.

Anthracnose

The importance of anthracnose was dramatically noted in 1988 in Zambia although it previously was observed destroying very susceptible cultivars at some Zambia and Zimbabwe locations. Beginning in 1989, the Mansa, Zambia location became a primary site for anthracnose evaluation for the SADC region because the disease occurred there at consistently high severities with minimal interference from other foliar pathogens.

A Regional Anthracnose Resistance Screening Nursery (RARSN) was grown for several years at several SADC locations where anthracnose screening information was desired. This nursery contained a large number of entries from anthracnose and other nurseries of TAES.

Using RAPD markers, P. Guthrie compared the DNA of 119 isolates of *C. graminicola* from around the world including several sorghum isolates from the SADC region, especially Zambia and Zimbabwe. He determined that genetic relatedness between isolates was more correlated with geographical origin than with susceptibility or resistance of the sorghum host source. No pathotype specific RAPD banding pattern was found.

Charcoal rot

At Sebele, Botswana, the greatest charcoal stalk rot on sorghum and millet occurred when stress occurred primarily after anthesis rather than occurring before or throughout the season. Some high yielding millets introduced by the SADC/ICRISAT program developed high levels of charcoal rot at Sebele in 1986 and 1987 and some died prematurely as early as the initiation of grain fill. Other more adapted millet cultivars had less severe or no visible incidence of charcoal rot. Tissue samples of *M. phaseolina* were collected from several diverse hosts in Botswana and from a few in Zambia over a period of several years. Isolates of *M. phaseolina* were obtained from these samples and a large number were evaluated in culture for differences that might indicate host preference mechanisms similar to those determined in the U.S. for isolates from corn and soybeans. Sensitivity to potassium chlorate in cultural media helped differentiate the predominant isolates from these two hosts and we determined generally similar responses with isolates from Africa but the results were somewhat variable. In general, we could distinguish isolates from gramineous and nongramineous hosts. This may have some relevance in the intercropping environment where an increase of sclerotial inoculum from a gramineous host does not increase the risk of charcoal rot in the nongramineous host (or vice versa) but this assumption remains to be proven or disproven.

Sorghum Downy Mildew

Later dates of planting had increased amounts of sorghum downy mildew in tests conducted at Panmure station, Zimbabwe. Cultivar reaction of the SDMVN(Sorghum Downy Mildew Virulence Nursery) at several SADC sites indicated the possible existence of more than one pathotype of *Peronosclerospora sorghi* in the SADC region although most initial reactions resembled pathotype 2 responses. Later reactions at Golden Valley indicated an entirely new pathotype of *P. sorghi* which attacked the previously immune cultivar QL3 (India).

The Ph.D. work of S. Kunene characterized the hyperparasitism of a chytrid fungus on oospores of *P. sorghi* and assessed its potential as a biocontrol agent for control of this

disease. She demonstrated that the chytrid, a *Gaertneriomyces* spp., parasitized soilborne oospores which reduced both soilborne inoculum and subsequent SDM in corn and sorghum planted into that soil. She also utilized various other research techniques to identify the previously unclassified chytrid as *Gaertneriomyces semiglobiferum*.

Viruses

At Mt Makulu, ZSV-1 and some entries of the International Sorghum Virus Nursery (ISVN) had a high incidence of an unknown virus in 1986 and 1987. Samples collected by the PI and later evaluated by TAM-124 (R.W. Toler) by ELISA tests indicated that the virus was MDMV-A. The same virus was identified from samples collected at Nhlangano, Swaziland in 1987. The high, uniform incidence of virus at Mt Mukulu, Zambia in 1988 allowed excellent screening of germplasm including the ISVN that had entries QL3 and QL11 free of virus and TX 3048, TX7000, and New Mexico 31 with the most severe virally indiced leaf necrosis. A high incidence of virus and red (or tan) leaf necrosis in some cultivars at Pandamatenga, Botswana in 1993 indicated that viruses could be economically important on some cultivars in some years if they were highly susceptible.

Seed Treatment/Stand Establishment

Variable stands in seedling establishment tests in Botswana and Zimbabwe indicate no apparent activity of *Pythium* and generally no benefit of seed treatment over the control or captan. Metalaxyl protected sorghum against systemic infection by *P. sorghi* in Zimbabwe. All seed produced by the Botswana Seed Multiplication Unit is treated with captan before distribution to growers. Captan seed treatment controls covered kernel smut which is an endemic problem for farmers who save their own seed and do not apply a seed treatment before planting.

Head Smut

In 1988, G. Kaula modified the PI's technique for isolation of soilborne oospores to isolate and quantitate the much smaller soilborne teliospores (14mu) of *Sporisorium reilianum* (head smut) . He used the technique on a variety of soil samples taken from various sorghum nursery sites in South Texas; the technique's ability to distinguish teliospores from other spores was evident in the number of teliospores (2/g) isolated from a pasture site adjacent to a sorghum head smut nursery (116-172/g).

Grain Mold and *Fusarium* Studies

Grain from sorghum and millet was collected by the P.I. from various sites in Zambia, Zimbabwe, and Botswana in 1989 and the species of Fusarium occurring on that grain was identified by Paul Nelson of Penn State. Eleven species of *Fusarium* were identified from the 71 total isolates selected for identification and the predominant species, in order of frequency, were *F. equiseti*, *F. semitectum*, *F. chlamydosporum*, and *F. moniliforme*. *Fusarium equiseti* occurred on 90% of samples from both hosts and *F. semitectum* on 60 and 75% of the millet and sorghum hosts, respectively.

In *Fusarium* studies in South Texas, A.S. Ring determined that mating population A (*F. moniliforme*, pink in culture) predominated on corn, and mating populations A and F (*F. moniliforme*, yellow in culture) predominated on sorghum. All *Fusarium* species were low on cotton. Initial characterization to mating population and type (+ or -) were conducted with standards provided by KS-108 which facilitated intercrossing of local isolates and further established the ability of the local population to sexually recombine.

In October 1993, A. Mansuetus completed his Ph.D. research on characterization of isolates of *Fusarium* section Liseola obtained from sorghum grain samples he collected in Tanzania in 1991. In *Fusarium* section Liseola, sexual stages are useful in the identification of mating populations that represent different biological species in the absence of distinct morphological characters. Mating populations were identified on sorghum grain from Tanzania by using standard mating type testers. All mating populations A, B, C, D, E, and F were recovered on sorghum from Tanzania. Mating population F occurred in higher frequencies than mating populations A-E. Vegetative compatibility studies across the three locations in Tanzania (Ifakara, Ilonga, and Kachiri) demonstrated eleven vegetative compatibility groups (VCGs) within mating population A and five VCGs within mating population F. Strains from each location appeared to be more genetically similar to each other than to strains from other locations. The variability of mating populations within *Fusarium* section Liseola on sorghum in Tanzania appears to be similar to that on sorghum in the United States but variability of VCGs is less similar. The predominance of mating population F on sorghum in Tanzania may indicate a lower potential for the occurrence of the mycotoxin, fumonisin, because isolates in the F group produce little or no fumonisin unlike isolates from mating population A (KSU-108).

Networking Activities

Principal Investigators Conference: TAM-128 P.I. served on the conference planning committee, poster committee, and organized nursery field tours for the International Sorghum Millet CRSP Conference held July 8-12, 1991 in Corpus Christi, TX.

Germplasm exchange: Over the nine years of interaction with SADC countries, TAM-128 through TAM-121, TAM-122, TAM-123, TAM-124 and some other INTSORMIL and non-INTSORMIL breeders has introduced over 300 lines and cultivars for evaluation in the SADC region and approximately 30 lines were acquired from the SADC region for evaluation in the U.S.

TAM-128 participated in the Second World Review of Sorghum and Millet Diseases March 7-11, 1988 in Harare, Zimbabwe by making two presentations and contributing to two others.

Mr. Godwin Kaula of Zambia participated in a one year short term training program at Texas A&M under the supervision of TAM-128 and TAM-124 (R.W. Toler). He completed his program in September 1988 with submission of a research report entitled, "Development and Use of Techniques to Quantitatively Isolate Teliospores of *Sporisorium reilianum* from Soil".

A 50-slide set of sorghum and millet diseases was developed in 1986 and more than forty sets were distributed to key personnel in Southern Africa and to many SADC and other LDC students.

Requested equipment and supplies were provided to B. Matilo in 1986 to enhance her abilities to conduct plant pathology research in Sebele, Botswana.

Funds have been provided in 1993-94 to E. Mtisi in Zimbabwe to support collaborative research nurseries investigating leaf blight resistance at the Henderson and Panmure stations.

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Sustainable Production Systems

Modelling Millet and Sorghum Establishment and Growth and Sustainable Crop Production

Project KSU-106
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Summary

Pearl millet seed either screened for larger size or produced by partial removal of the head resulted in better establishment and in many cases improved yields. The exception was under extremely severe stress conditions in Botswana. Germination responses of both pearl millet and grain sorghum to temperature and soil moisture have been quantified. Interactive effects between seed quality and environmental conditions were variable. A field germination and establishment model should be developed from these results to allow simulation of field establishment under a wide range of environmental conditions. The grain sorghum growth model SORKAM was validated, improved and utilized to develop a replant decision to allow for U. S. conditions.

Introduction

Poor stands are constraints to production in semiarid areas where sorghum and millet (Peacock, 1982) are grown. Both sorghum and millet in the semiarid tropics, where they are grown as food crops, and sorghum in the U.S., where it is grown as a feed crop, generally are grown where climatic conditions are characterized by moisture limitations, extreme variability in amounts and patterns of rainfall, frequently high temperature stress at various stages of crop development, and thus the expectation of extremely variable yields and frequent occurrences of low yields or complete yield failures. This means that, in general, the amount of input available and/or utilized on these crops frequently is low as the risk of failure or no economic return is high. The approach to addressing the establishment problem in this project has been two-fold. First, to try to determine the seed characteristics that might improve establishment capability and relate these to environmental conditions, both during seed production and during establishment. Secondly, because of the extreme variability in climates, a crop growth modelling approach has been utilized to try to capture the information obtained and apply it to relatively long term climatic data bases.

Objectives, Production and Utilization Constraints

Objectives

Determine seed characteristics important in stand establishment and assess or develop methods of improving these characteristics.

Quantify the effects of environmental conditions, particularly temperature and moisture, on stand establishment and determine the extent of interaction with seed characteristics.

Determine the relationships, if any, between stand establishment and subsequent crop yields.

Develop or refine crop growth models to provide specific management options for producers.

Constraints

Constraints to productivity include climatic, edaphic and biological factors. The climate of sorghum and millet producing regions has low and erratic rainfall, with high within - and between - year variability. Solar radiation is high due to frequent cloudless conditions and humidity is low, resulting in high potential evapotranspiration (PET) rates. For example, in Botswana, PET exceeds precipitation in every month. Soils are often of low fertility and are prone to crusting, rapid drying and high soil temperatures which reduce crop establishment. Sorghum and millet are small seeded crops requiring shallow planting. Low yields are the norm in these regions and crop failure is common. Farmers may be unable to produce subsistence grain or even seed for the following season. Low yields are a function of the harsh environment, which often does not enable an adequate stand to establish. Because of the probability of crop failure, traditional subsistence farmers have developed means of minimizing risk. For example, Botswana farmers will plant following each "planting rain" and will expend little additional effort on each planting in order to make as many plantings as possible. If stand establishment could be improved perhaps fewer plantings could be made and additional management, for example weed control, would be possible on relatively fewer plantings and result in more stable production. Even under the relatively more favorable conditions in temperate regions, stand establishment frequently is a problem and replant decisions are common.

Research Approach and Project Output

- Objective 1. Determine the seed characteristics important in stand establishment and assess or develop methods of improving these characteristics.

Research Methods

Laboratory vigor tests which have been used on grain sorghum were tested with pearl millet to see if field establishment could be adequately predicted. These included standard germination, ammonium chloride treatment, sodium hydroxide treatment, accelerated aging, and use of a vigor analyzer, which measured leachate from the seeds. Pearl millet seed was separated into seed size and seed density categories, and evaluated for germination and emergence. Seed crop management treatments including tiller removal, spikelet removal, additional nitrogen application, hill planting, and head selection were utilized to attempt to influence seed characteristics. Genetic differences in seed size and mesocotyl length were investigated to determine their importance in stand establishment.

Research Findings

Results with the seed vigor measurements generally showed significant correlation with field establishment, however, none of the vigor tests consistently accounted for more than 50% of the variation in field establishment and thus would be of limited value (Mwageni and Vanderlip, 1986). Increases in either seed size or seed density generally resulted in improved stand establishment (Lawan, et al., 1985, Okonkwo and Vanderlip, 1985, Gardner and Vanderlip, 1989). Manipulation of the seed crop, particularly removal of a portion of the spikelets from the head resulted in significant increases in seed size and, in most cases, increased field establishment (Okonkwo and Vanderlip, 1985). Dr. Tareke Berhe, INTSORMIL Agronomist at the WSARP location in Sudan also found that increased seed size resulted in increased stand establishment of millet under the very severe conditions at El Obeid.

- Objective 2. Quantify the effects of environmental conditions, particularly temperature and moisture on stand establishment and determine the extent of interaction with seed characteristics.

Research Methods

Pearl millet and/or sorghum seed were tested under a range of temperature and moisture conditions imposed by a temperature gradient table, growth chamber, greenhouse, and field experiments both in the U. S., Botswana, and the Sudan.

Research Findings

As would be expected, temperature and moisture both have tremendous effects on stand establishment (Mortlock and Vanderlip, 1987; Mortlock and Vanderlip, 1989; Gono, 1993). Interactive effects between environmental conditions and seed quality were variable (Mortlock and Vanderlip, 1989; Gono, 1993).

- Objective 3. Determine the relationships, if any, between stand establishment and subsequent crop yields.

Research Methods

Pearl millet seed differing in seed size and density obtained either through screening and flotation, or through crop management was planted at a number of locations to evaluate not only stand establishment, but subsequent yields. Relative effects of plant population on sorghum and pearl millet were determined under a range of environmental conditions, using planting dates, plant populations, and different genotypes to assess the expected variability.

Research Findings

Early results under Kansas conditions (Okonkwo and Vanderlip, 1985; Gardner and Vanderlip, 1989) and the work by Berhe in the Sudan showed increased grain yields of pearl millet with increased stand establishment. Later work in Kansas (Freyenberger, 1986) and work in Botswana (Mortlock and Vanderlip, 1987) showed no increase in yields with increased establishment. M'Khaitir and Vander-

lip, (1992) showed that plant population, and therefore establishment was much more critical with sorghum than pearl millet. Pearl millet was able to tiller and compensate over a very wide range of plant populations.

- Objective 4. Develop or refine crop growth models to provide specific management options for producers.

Research Methods

Existing crop growth models were evaluated for strength and weaknesses and where weaknesses were found, experiments were designed to address those specific aspects of the crop growth models.

Research Findings

An outline for a pearl millet growth model was developed (Huda et al., 1984) however, because of shifts in emphasis and reduced funding, this was not continued. The grain sorghum growth model SORKAM, (Rosenthal et al., 1989) was used to evaluate management practices in Botswana (Thompson, 1988). Subsequent evaluation of the model indicated that the tillering and grain-fill portions of the model either lack sensitivity to environmental conditions, or resulted in unrealistic results. The tillering response was evaluated by Coulibaly (1992), however, the range of tillering responses obtained under controlled conditions were not adequate to predict field response. The grain filling problem was addressed by Heiniger et al., (1993a, 1993b), and subsequent validation indicated that the grain filling portion of the model is now very responsive to environmental conditions and produces realistic results under a wide range of combinations of environmental conditions, plant populations, and planting dates. The problems with tillering appear to be related to temperature responses and this is presently being addressed by another student (not funded by INTSORMIL). Validations, sensitivity analysis, improvement of the model, and use of the model to develop replant guidelines is nearly complete, (Heiniger, 1994, partially funded by INTSORMIL). Results from this modeling effort have been used to develop a computerized decision aid package (Vanderlip, et al., 1993) for transfer of the information to U.S. producers (not funded by INTSORMIL).

Networking Activities

Although not funded by INTSORMIL, INTSORMIL made arrangements for Mr. Lemma Zewdie to spend six weeks with me in a short-term growth modeling experience so that he could evaluate the use of the sorghum and corn models in Ethiopia.

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Sustainable Production of Sorghum and Pearl Millet in Fragile, Tropical Acid Soils

Project MSU-111

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Summary

The main constraint to Colombian sorghum production is the high production costs. The national average yield is 2.6 t/ha. Because most sorghum is grown on high value lands, production costs can be reduced by incorporating marginal lands. But production constraints on these low-cost lands are numerous, demanding the development of adapted varieties or hybrids.

Acid soil, well-watered savannas account for more than 10% (76 million hectares) of land in Latin America and the Caribbean. They constitute a potential region for sorghum production and are, therefore, a logical focus for the project's work. Other regions of interest are the forest margins, where grain mold diseases are the main constraint, and the semiarid zones, where drought is prevalent.

Wherever farmers grow sorghum in Latin America they need low-input technology and invest considerable effort in preventing resource degradation. Research on sustainable agricultural systems is therefore mandatory.

Before INTSORMIL began it's project, sorghum could not be grown on soils with levels of Al saturation higher than 60%. Since 1982, five cultivars, the result of collaboration between ICA, commercial companies, and INTSORMIL, have been released. These cultivars produce profitably in soils with as high as 60% Al saturation, opening up more than 200,000 ha of marginal land in Colombia alone.

INTSORMIL strengthened ICA's Acid Soils Research Program through training and funds. It also helped establish nurseries to select germplasm adapted to the acid soils of the Llanos Orientales in Colombia (Colombian Eastern Plains), to improve agronomic characteristics, and tolerance to panicle diseases.

Introduction

The project, initiated in 1981, has changed its research focus three times: *first*, the project identified suitable sources of sorghum germplasm with potential for commercial grain production. Evaluation methodology and scale, based on field soil aluminum saturation level, were also developed. *Second*, germplasm selected from the world collection was evaluated. Agronomic data were also collected for the official release of four varieties adapted to different tropical ecosystems with acid soils. The varieties, Sorghica Real 60, Sorghica Real 40, Icaraván 1, and Icaraván 2 were released by Latin American national agricultural research programs (NARS). *Third* (and current), the

project actively exchanges germplasm and information with entities from both private and public sectors to encourage research efforts and accelerate the delivery of new cultivars to farmers. Varieties and hybrids, agronomically superior to those originally released and tolerant to head fungal diseases, are undergoing preliminary evaluation.

At first, institutional relationships were limited to informal relationships among individual sorghum breeders focusing on acid soils. Relationships became more complex as more scientists and institutions, such as the National Federation of Cereal Growers (FENALCE), became involved.

Objectives, Production, and Utilization Constraints

Objectives

To establish a Latin American network for the evaluation and exchange of sorghum germplasm.

To establish a regional program to develop sorghum and pearl millet germplasm that is adapted to tropical environments and tolerant of low pH and Al toxicity in tropical soils.

To develop minimum-input technology strategies for evaluating Al-tolerant lines grown in tropical savanna soils.

To screen and evaluate Al-tolerant sorghum hybrids according to Al-saturation levels.

To screen and evaluate part of the world's sorghum and pearl millet collections for tolerance to Al and manganese (Mn) toxicities, and low phosphorus (P).

To incorporate sources of tolerance to Al and Mn toxicities, and low P into elite U.S. and tropical sorghum genotypes.

To distribute sorghum and pearl millet germplasm developed by INTSORMIL and ICRISAT to national programs of Latin America and Africa.

To train and assist Latin American and African scientists in the use of effective breeding and screening methods for adapting sorghum and pearl millet to acid soils.

To assist other INTSORMIL PIs in conducting research in Colombia.

Constraints

Most Latin American countries are opening up their markets by freeing imports. International prices will lower domestic prices of some products, especially grains. Production costs must therefore be competitive. Most Latin American sorghum is grown on high value lands, making production unprofitable. One way of reducing production costs is to incorporate acid soil affected marginal lands into the production system.

South America has the world's largest acid-soil areas. They contain levels of Al and, sometimes, Mn that are toxic enough to inhibit the growth of major cereal crops. Soil acidity is therefore the most important constraint to increased sorghum and pearl millet production. It can be overcome by using tolerant germplasm.

A second constraint is the inadequate management of these highly fragile soils. Indeed, the ecosystem as a whole can be easily destroyed. Maintaining and, if possible, improving soil structure and nutrient balance are essential. If the savannas can be cultivated under a sustainable agricultural system, the pressure for land would lessen. Agriculture in the savannas can be more easily mechanized and harvested products would be closer to population centers than from the Amazon region. Crop rotation, improved fertilization and soil preparation practices, and integrated pest and disease management must become part of the research tool kit for the future.

The third most important constraint to sorghum and pearl millet production in Latin America is drought, caused by variable rainfall patterns.

A fourth constraint to sorghum production is panicle diseases, which thrive in humid areas, where most sorghum is grown. Under high relative humidity, grain molds increase and the grain loses quality.

Research on acid-soil constraints would benefit both developing countries and the U.S.: first, in both regions, sorghum production on acid soils would increase while inputs decrease. Second, the U.S. would probably benefit most through commercial seed companies. By using proven Al-tolerant germplasm for hybrids in overseas operations, multinational seed companies would encourage spinoff improvement in U.S. hybrids, especially if a large enough demand develops — which may occur in Latin America and Central Africa, both of which lack grains for food and feed.

Research Approach and Project Output

Research Methods

Adaptation of Genotypes to the Environment

The INTSORMIL Colombian Program has developed and distributed sorghum germplasm which is adapted to the many different ecosystems in Latin America where sorghum is grown (Table 1). Because sorghum in Latin America is generally planted as a second crop, it must be evaluated and selected for hardiness as the characteristic which makes it more attractive than other crops. But, if it is to compete in international markets, production costs must be reduced. Sorghum's international prices are usually low, especially in countries, such as Argentina, where production costs are

Table 1. Germplasm provided by INTSORMIL for Latin American research.

Country	Institution	Germplasm	Characteristic
Panama	IDIAP	A and B-Lines	Al tolerant
		Segregating populations	
Colombia	ICA	A and B-Lines	Al tolerant
			Drought tolerant
		Segregating populations	Al tolerant
			Drought tolerant
			Midge tolerant
	FEDEARROZ	A and B-Lines	Al tolerant
			Drought tolerant
		Segregating populations	Al tolerant
			Drought tolerant
			Midge tolerant
	El Alcaraván	A and B-Lines	Al tolerant
			Drought tolerant
		Segregating populations	Al tolerant
			Drought tolerant
			Midge tolerant
Venezuela	FONAIAP	A and B-Lines	Al tolerant
		Segregating populations	
	PROSEGRA	A and B-Lines	Al tolerant
		Segregating populations	
Argentina	ICI	A and B-Lines	Al tolerant
		Segregating populations	
	CIBA-Geigy	A and B-Lines	Al tolerant
			Midge tolerant
		Segregating populations	

low and productivity high, or in countries with subsidized prices.

For the Colombian Eastern Plains, the Project has developed genotypes that tolerate as much as 60% Al saturation. The new genotypes must be highly tolerant to panicle diseases, adapted to soils with low fertility, and resistant to bird damage. They also need to be resistant to flooding and drought.

Characterization and Determination of Ecological Areas for Sorghum Production in Latin America

To develop adapted germplasm, an international program must define the areas and objectives with which it works. The CLAIS meeting at Villavicencio, Colombia in 1993, approved those ecological areas of sorghum production that were defined by the INTSORMIL MSU-111 Project, headquartered at CIAT.

INTSORMIL's role must complement that played by private research. Essentially, the greatest effort should be directed toward the development of germplasm for the humid tropics, where most of the continent's sorghum is produced. A definition of the different ecological areas where sorghum is cultivated in Latin America, follows:

Mechanized agriculture

Ecosystem 1. Soils with no salinity or Al saturation. More than 600 mm of rain, high relative humidity (Colombian North Coast, Montería).

Ecosystem 2. Soils with salinity or Al saturation. More than 600 mm of rain, high relative humidity (Colombian Eastern Plains, Arauca).

Ecosystem 3. Soils with salinity or Al saturation. Less than 600 mm of rain, relative humidity may be high or low (Brazilian Cerrados).

Ecosystem 4. Soils with pH limitations, but no Al toxicity. Less than 1,000 mm of rain, relative humidity may be high or low (El Tigre, Venezuela).

Ecosystem 5. Soils with normal pH, neither Al toxicity nor salinity is a production constraint. Drought is the main constraint. Less than 600 mm of rain, relative humidity may be high or low (Colombian North Coast, Codazzi).

Ecosystem 6. Soils with normal pH, neither Al toxicity nor salinity is a production constraint. Drought is not important. Less than 1,500 mm of rain, humidity may be high or low. An excellent ecosystem for sorghum production. High technology and good infrastructure are available (Cauca Valley, Colombia).

Nonmechanized agriculture

Ecosystem 1. Soils with normal pH, neither Al toxicity nor salinity is a production constraint. Most cropping systems are on hillsides. Drought is an additional constraint. Less than 600 mm of rain, relative humidity may be high or low (San Pedro, Honduras).

Ecosystem 2. Soils with normal pH, neither Al toxicity nor salinity is a production constraint. Most cropping systems are on hillsides. Drought is not a constraint. More than 600 mm of rain, relative humidity may be high or low (Santander del Norte, Colombia).

Research Progress

Breeding and Germplasm Improvement

The private sector is more interested in the production of hybrids than of varieties. Because conquering acid soils would be easier with several research programs involved, the INTSORMIL MSU-111 Project developed and evaluated A and B-lines, which were then made available to the private sector.

The F1 hybrid progenies from INTSORMIL progenitor lines are highly adapted to tropical conditions. The selection program includes evaluation under low-input technology, with no fungicides or insecticides, thus guaranteeing maxi-

mum protection of the environment. Another important characteristic is the development and evaluation of genotypes that are stable under humid tropical conditions.

Standard research methods are used for all breeding-related activities in Colombia. Early generation (F2) breeding material is received each year from Project MSU-104 and is evaluated at each level of Al saturation and screened at several sites by all participating institutions. Over the years, several sets of germplasm were sent to ICA and the El Alcaraván Foundation for screening in both acid and non-acid soils. TAM-128 breeding lines and hybrids for drought tolerance have been increased at CIAT. Low-input technology was used at all sites (using 60-60-60 N-P-K fertilization).

Because the world collection's first-generation lines are very tall, selection has focused on reducing height, while maintaining high yields and tolerance to panicle diseases. The selection process is designed to include different levels of Al saturation, and expected yields are based on the degree of Al toxicity. These levels have been established as follows:

Level 1	0%-35%	Class 1	0%-20% Al
		Class 2	21%-35% Al
Level 2	36%-60%	Class 1	36%-45% Al
		Class 2	46%-60% Al
Level 3	> 60%	Class 1	61%-75% Al
		Class 2	> 75% Al

For example, a grain yield of 2.5 t/ha will be satisfactory for level 3, whereas at least 3.5 t/ha is expected for level 1.

Since 1982, the sorghum breeding program has had a series of research successes toward developing sustainable production systems for Latin America's acid soils. The first accomplishment was finding germplasm adapted to acid soils and with acceptable agronomic characteristics. These lines were evaluated at several sites and chosen from mass selections carried out by scientists at ICA and INTSORMIL. They were released as varieties Sorghica Real 40 (156-P5-Serere 1) and Sorghica Real 60 (MN-4508), and are tolerant to soils with 40% and 60% Al saturation, respectively.

Through collaborative agreements between MSU, INTSORMIL, El Alcaraván, and CIAT, genotypes IS-3071 and IS-8577 were released from the world collection. Sorghica Real 40 and Sorghica Real 60 were used as checks.

IS-3071 is exceptionally hardy and characterized by a production of more than 3 t/ha when aluminum and fertilization levels are low. It also tolerates partial flooding after flowering—an essential characteristic in poorly drained savannas. This variety was selected for multiplication by the El Alcaraván Foundation and was released as Icaraván 1. IS-8577, released as Icaraván 2, is very Al tolerant and has good agronomic characteristics.

The INTSORMIL MSU-111 Project followed a policy of cooperation and pooling of common efforts with the private sector. Germplasm was given to stimulate seed production and technology transfer. As a result of this cooperation, FEDEARROZ will release a hybrid for the dry Caribbean region of Colombia, which will use an A-line from the INTSORMIL MSU-104 Project and an R-line from Texas A&M University. Most South American seed companies with breeding programs use INTSORMIL's germplasm which should benefit Latin American farmers.

Concurrently, Al-saturation levels have been defined enabling breeding objectives to be established according to physiological performance, adaptation, and production within each level of Al saturation for given ecological zones. Breeding has been carried out with low-input technology and in a framework of sustainable production systems.

Evaluation in the field

Not all lines or hybrids have been found to perform equally well at different levels of Al saturation. Some genotypes are excellent for vega soils (low levels of Al saturation), but do not perform well at high levels of Al, even if one parent is tolerant. Lines and hybrids are therefore screened at the three levels of Al saturation in separate nurseries. Some of these genotypes will be tested next year in yield trials.

Sets of selected lines are sent to ICA-La Libertad from the El Alcaraván project each year and from CIAT's headquarters to both locations.

For levels above 60% Al saturation, hybrids may provide an alternative for increased grain yield. A full set of hybrids is being tested in Arauca and ICA-La Libertad at the three levels of Al saturation. Two growing seasons per year have been used for evaluating Al-tolerant material. Some genotypes performed better in the first season and the height of all lines and hybrids is reduced in the second season. Also, compared with commercial hybrids, this breeding material shows less incidence of panicle diseases.

Breeding and Institutional Building in Colombia

During eight years of research in Colombia, considerable effort has gone into evaluating acid-soil tolerant lines from the world collection. ICA and the El Alcaraván Foundation, with INTSORMIL's support, recently released two lines adapted to Arauca (Colombian Eastern Plains): IS-3071 (Icaraván 1) and IS-8577 (Icaraván 2).

Originally, 30 lines of the world collection were evaluated in the remote region of Arauca where supplies are hard to get. This is the most important reason for selecting low-input technology for both production and evaluation. INTSORMIL defines low-input technology in Latin America as requiring fertilization levels lower than 30 kg/ha of N, P, and K, with no fungicides or insecticides.

In Latin America, rice, soybeans, or cotton are rotated with sorghum as a second crop. Rice is planted in the rainy season and sorghum in the dry season when lack of water could be a problem. As a result, INTSORMIL has developed technology that can use residual fertilization from the main crop, and thus efficiently exploit the soil inputs.

Significant advances have been made in ICA's breeding program through collaboration with INTSORMIL and the El Alcaraván Foundation. Research conducted by INTSORMIL in collaboration with ICA and other organizations in Colombia has attracted private-sector funds, furthering long-term research goals. The El Alcaraván Foundation has provided substantial operational and training funds for research conducted in Arauca. This research is oriented toward plant breeding for both acid and non-acid soils, agronomy, phytopathology, and sorghum utilization.

New Germplasm

Advanced lines

Advanced breeding material has been evaluated with the objective of decreasing plant height, retaining resistance to panicle diseases, and having yield potential above three tons of grain per hectare, while using low-input technology at levels 1 and 2 of Al saturation. These lines have been distributed from the Arauca Project through ICA-La Libertad. Their levels of acid-soil tolerance are the same as those of the first-generation lines from the world collection, but their architecture is more acceptable to farmers.

Hybrids

National and multinational seed companies in Latin America have a special role in the development and research of the sorghum crop. Both research and extension activities are employed, with emphasis on the production and commercialization of hybrids. Considering that today's agricultural frontiers are the savannas of Latin America with high Al-saturation levels, germplasm must be developed for those specific conditions, increasing the total production area while preserving the natural resource base.

INTSORMIL developed basic germplasm which allowed the seed industry to be involved in the development of new hybrids for this ecosystem. INTSORMIL is providing Al-tolerant A and B-line pairs which commercial companies can use as seed parents with their own R-lines as pollinators, thus allowing each company to retain exclusivity for its final product. Such methodology will have a multiplier effect, because each company will evaluate the basic germplasm according to specific genetic combinations and to the specific markets they target.

In summary, INTSORMIL will distribute the basic germplasm and the commercial seed companies will develop and commercialize the final product. At the same time, INTSORMIL aims to decrease the original large number of A and B-lines by evaluating the general and specific combining abilities of the original 125 A and B-line pairs, using IA 28, ICA Nataima, and TX 430 as pollinators.

Every year, ICA, INTSORMIL, FENALCE, and El Alcaraván develop detailed work plans which become a formal part of INTSORMIL's collaborative effort. An operating budget is then developed to support the research formalized in the work plans.

In close cooperation with MSU-104, the main breeding and evaluation research was conducted in Colombia at CIAT-Palmira, ICA-La Libertad, and Arauca, and in the U.S. at Mississippi State University. ICA carried out breeding at Nataima and La Libertad, and evaluations at La Libertad and other acid-soil sites in the region. INTSORMIL conducted collaborative breeding and screening activities at MSU-104 winter nursery research sites in Colombia and also at other sites in Africa.

Most of this year's research was directed toward support of ICA in developing the agronomic packages for the release of future varieties and hybrids. Emphasis was to develop minimum-input technologies for the evaluation and production of Al-tolerant cultivars grown in tropical savanna soils. Uniform regional yield trials were conducted at sites determined by national programs in Colombia (La Libertad and Arauca), Venezuela, Peru, and Brazil.

Because of quarantine problems with Texan germplasm, the seed of genotypes sent by Dr. Darrell Rosenow in 1991 are being increased at CIAT. In cooperation with other INTSORMIL projects, drought tolerant sorghum germplasm (TAM-122) was evaluated in Motilonia (in collaboration with FENALCE) on the Colombian North Coast, and at Nataima. Pearl millet germplasm (UNL-118 and KSU-101) was evaluated at ICA-La Libertad. Future phosphorus-efficiency research will be conducted with UNL-114.

Breeding material has been generated from crosses among Al-tolerant sources, agronomically elite lines, and new sources of tolerance. Different sets of segregating material were sent from MSU-104 to be screened in Colombia. Insect resistant lines from TAM-125 have been increased at CIAT and tested under different levels of Al saturation with good results. They were further screened for plant height and tolerance to panicle diseases. Because the first-generation acid-soil tolerant lines from the world collection are tall and late maturing, directed selection was to reduce plant height and maturity while keeping tolerance to panicle diseases. Yield trials of the agronomically best performing and Al-tolerant hybrids were conducted by ICA at three different levels of Al saturation (Tables 2, 3 and 4).

All research conducted by INTSORMIL MSU-111 follows the low-input technology approach. Dolomitic limestone (300 kg/ha) is used more as a source of calcium and

Table 2. Ten best hybrids from each of three sets of Al-tolerant experimental steriles using ICA Nataima and IA28 as pollinators and Al-tolerant pollinators of TX623 or TX635 steriles evaluated at La Libertad, Colombia, 1992 B, level 1 Al saturation.

Pedigree	Yield (kg/ha)
MS (AT1)-27-2-1-1-1-1 x ICA-Nataima	6407
MS (AT2)-4-3-1-2-1-1 x ICA-Nataima	6273
MS (AT1)-24-6-1-1-1-2 x ICA-Nataima	5305
MS (AT2)-25-1-2-2-1-5 x ICA-Nataima	5102
MS (AT1)-24-6-1-1-1-3 x ICA-Nataima	5064
MS (AT2)-29-2-1-1-1-1 x ICA-Nataima	4938
MS (AT2)-14-1-1-1-1-2 x ICA-Nataima	4779
MS (AT2)-25-1-2-1-1-2 x ICA-Nataima	4740
MS (AT2)-25-2-1-1-2-1 x ICA-Nataima	4611
MS (AT2)-14-2-1-1-1-3 x ICA-Nataima	4603
MS (AT1)-26-2-1-2-1 x IA-28	6434
MS (AT1)-55-2-1-1-2 x IA-28	5389
MS (AT1)-20-2-1-1-1 x IA-28	5064
MS (AT1)-45-3-1-1-1 x IA-28	4956
MS (AT1)-22-2-1-1-1 x IA-28	4955
MS (AT1)-30-3-2-1-2 x IA-28	4464
MS (AT1)-30-3-2-1-1 x IA-28	4422
MS (AT1)-26-1-1-2-1 x IA-28	4091
MS (AT1)- 7-3-1-2-1 x IA-28	4069
MS (AT1)-13-1-1-1-1 x IA-28	4065
MS TX623 x (TX430 x IS9084)-27-2-2-1	4114
MS TX623 x (NB9040 x IS8577)-26-2-2-1	3797
MS TX635 x (NB9040 x IS8577)-26-2-2-1	3463
MS TX623 x (TX430 x IS8577)-26-1-2-1	2975
MS TX623 x (TX430 x IS8577)-8-1-2-1	2796
MS TX635 x (NB9040 x IS9084)-10-1-1-1	2685
MS TX635 x (NB9040 x IS9084)-8-1-2-1	2563
MS TX623 x (TX430 x IS6944)-8-1-1-1	2559
MS TX623 x (TX430 x IS6944)-18-1-2-1	2390
MS TX635 x (TX430 x MN4508)-14-1-1-1	2380

Table 3. Ten best hybrids from each of three sets of Al-tolerant experimental steriles using ICA Nataima and IA 28 as pollinators and Al-tolerant pollinators on TX623 or TX635 steriles evaluated at La Libertad, Colombia, 1992 B, level 2 Al saturation.

Pedigree	Yield (kg/ha)
MS (AT2)-25-1-2-2-2-1 x ICA-Nataima	2225
MS (AT2)-7-2-1-1-1-1 x ICA-Nataima	2308
MS (AT1)-3-3-1-2-2-1 x ICA-Nataima	2071
MS (AT2)-4-3-1-2-1-1 x ICA-Nataima	1900
MS (AT2)-25-1-2-2-1-4 x ICA-Nataima	1891
MS (AT2)-7-2-1-1-2-1 x ICA-Nataima	1884
MS (AT2)-25-1-2-2-2-2 x ICA-Nataima	1851
MS (AT1)-45-1-2-1-1-1 x ICA-Nataima	1841
MS (AT1)-28-1-1-2-2-1 x ICA-Nataima	1834
MS (AT2)-25-1-2-2-1-5 x ICA-Nataima	1833
MS (AT1)-10-4-1-1-1 x IA-28	2294
MS (AT2)-24-3-1-1-1 x IA-28	2015
MS (AT1)-36-5-2-2-1 x IA-28	1811
MS (AT1)-24-5-1-1-2 x IA-28	1511
MS (AT1)-5-1-1-2-2 x IA-28	1501
MS (AT1)-26-1-2-1-1 x IA-28	1476
MS (AT1)-24-2-1-1-1 x IA-28	1366
MS (AT1)-24-2-1-1-2 x IA-28	1352
MS (AT1)-17-4-2-2-1 x IA-28	1130
MS (AT1)-5-6-1-2-1 x IA-28	1066
MS TX635 x (TX430 x IS9084)-60-3-2-1	3462
MS TX635 x (NB9040 x IS8577)-9-2-1-1	2538
MS TX635 x (TX430 x IS6944)-12-2-1-1	2391
MS TX635 x (TX430 x FGUNK)-1-2-1-1	1890
MS TX635 x (TX430 x MN4508)-14-1-1-1	1855
MS TX635 x (NB9040 x IS9084)-10-1-1-1	1786
MS TX635 x (NB9040 x IS8577)-21-1-2-1	1755
MS TX635 x (TX430 x IS8577)-1-2-2-1	1718
MS TX623 x (NB9040 x IS8577)-31-1-1-1	1559
MS TX623 x (TX430 x IS8577)-1-1-2-1	1484

magnesium than for correcting the acidity of the soil. Fertilizer with 30 kg/ha each of N, P, and K is used.

Networking Activities

Introduction

In general terms, Latin American countries lack sources of germplasm. They also lack stable networks which would allow access to elite materials available from germplasm banks in developed countries or from INTSORMIL and ICRISAT.

Although INTSORMIL has successfully established scientific contacts with cooperating countries, some national Latin American programs need a more mature system. Some countries, such as Panama, need permanent contact or continuous exchange of information with international scientists and research programs. Other countries, such as Brazil, need new sources of germplasm and innovative research methodologies that allow highly qualified personnel to establish research projects.

What all countries lack are networks for exchanging germplasm and holding international scientific meetings that would update knowledge and exchange ideas among scientists. Networking activities must form a major objective of any international project.

Colombia is the only Latin American country where universities, the private sector (El Alcaraván), national research institutions (FENALCE and ICA), and an international center (CIAT) collaborate with INTSORMIL to accomplish research and training goals. In contrast, net-

Table 4. Ten best hybrids from each of three sets of Al-tolerant experimental steriles using ICA Nataima and IA28 as pollinators and Al-tolerant pollinators on TX623 or TX635 steriles evaluated at La Libertad, Colombia, 1992 B, level 3 Al saturation.

Pedigree	Yield (kg/ha)
MS (AT2)-7-2-1-1-2-1 x ICA-Nataima	1509
MS (AT1)-3-3-1-2-2-1 x ICA-Nataima	1118
MS (AT2)-25-1-2-2-2-1 x ICA-Nataima	1036
MS (AT2)-25-1-2-2-1-4 x ICA Nataima	1019
MS (AT1)-3-3-1-3-1-2 x ICA-Nataima	1007
MS (AT1)-36-4-2-2-1-1 x ICA-Nataima	978
MS (AT2)-4-3-1-2-1-1 x ICA-Nataima	948
MS (AT1)-3-3-1-2-1-1 x ICA-Nataima	889
MS (AT1)-24-5-2-1-1-5 x ICA-Nataima	873
MS (AT2)-25-1-2-2-2-2 x ICA-Nataima	790
MS (AT1)-35-3-1-2-2 x IA-28	2255
MS (AT1)-7-2-1-1-1 x IA-28	1278
MS (AT1)-6-1-1-2-1 x IA-28	1010
MS (AT1)-7-2-1-2-2 x IA-28	948
MS (AT1)-5-5-1-1-2 x IA-28	765
MS (AT1)-2-2-1-2-1 x IA-28	744
MS (AT1)-24-2-1-1-1 x IA-28	595
MS (AT1) 7-4-1-2-1 x IA-28	524
MS (AT1)-5-5-1-1-1 x IA-28	470
MS (AT1)-5-6-1-2-2 x IA-28	441
MS TX635 x (TX430 x MN4508)-73-1-1-1	1222
MS TX635 x (NB9040 x IS9084)-8-1-1-1	1192
MS TX635 x (TX430 x IS8577)-8-1-2-1	1118
MS TX623 x (TX430 x IS8577)-1-2-2-1	1083
MS TX635 x (NB9040 x IS8577)-29-1-1-1	1067
MS TX635 x (TX430 x FGUNK)-6-2-2-1	951
MS TX635 x (NB9040 x IS8577)-26-2-1-1	932
MS TX635 x (TX430 x IS6944)-46-1-1-1	907
MS TX635 x (NB9040 x IS8577)-9-2-1-1	892
MS TX623 x (NB9040 x IS8577)-9-2-1-1	873

working activities in other Latin American countries are very weak.

Workshops

An annual workshop is organized by ICA, the El Alcaraván Foundation, FENALCE, and the universities to share all research results of experiments conducted in Colombia. The El Alcaraván supports the annual publication of the proceedings. The workshop is significant, being the only opportunity where a full updating is carried out and a work plan implemented with the participation of all institutions involved in Colombian sorghum research. Since 1990, the private sector has become involved and future results are expected to be better.

International meetings, emphasizing topics of interest to Latin American scientists, have been held once or twice a year in Colombia, with the participation of all Latin American countries and INTSORMIL. INTSORMIL has been one of the major organizers of these meetings.

In January, 1991, the first international sorghum meeting for Latin America, organized by ICA, El Alcaraván, FENALCE, and INTSORMIL, sought to strengthen the relationships and exchange of germplasm among Latin American countries.

Comite Interinstitucional del Sorgo (CIS) (ICA, El Alcaraván, FENALCE, and INTSORMIL) organized the second international sorghum meeting for Latin America in July 1992. The main themes were crop protection and further strengthening of relationships, especially with the private sector, for joint research.

CIS and CLAIS organized the third international sorghum meeting for Latin America in August 1993. The main topics were sustainable agriculture for acid soils, the establishment of a Latin American sorghum network, and the future of ICRISAT and INTSORMIL in Latin America. The consensus was to continue supporting INTSORMIL's work in Latin America, using CIAT as headquarters.

Collaboration with ICA and the El Alcaraván Foundation

Regional Trials

For the last three years, regional trials formed the MSU-111 project's main approach to acid soils in Colombia. Because ICA also has a scientist assigned to Arauca (Sr. Walter Rendón), all research conducted at El Alcaraván is replicated in full with ICA-Arauca. The El Alcaraván provides support for the evaluation of new segregating materials and hybrids. Joint evaluation of these new lines will strengthen cooperation and result in better defined goals and objectives among El Alcaraván, ICA, and INTSORMIL.

Two new sets of Al-tolerant lines, developed by INTSORMIL, were tested in regional trials located at ICA-La Libertad, which lies in well-drained savannas, and at Arauca, which is in poorly drained savannas. The savannas were also classified according to the levels of Al saturation in their soils.

La Libertad is the main site for evaluating and selecting materials adapted to acid-soil conditions in well-drained savannas. Arauca is a new research area for INTSORMIL, beginning in 1988, with the collaboration of the El Alcaraván Foundation, which provided the funds for the experiments.

Both normal and acid-soil sites were used to evaluate and test selected advanced materials of sorghum and pearl millet. Regional trials have been conducted with first-generation lines, and resulting progeny was tested in semi-commercial fields. In Arauca, research was conducted at three sites with high levels of Al saturation and at five

sites with non-acid soils, according to the classification of Al-saturation levels.

Formation of a Network for the Introduction, Exchange, Storage, Increase, and Distribution of Germplasm

The INTSORMIL Colombian Program, headquartered at CIAT, has promoted and established a Latin American network. Involving both public and private sectors at national and international levels, the network emphasizes the introduction, exchange, storage, increase, and distribution of germplasm. The network will maintain samples of the most advanced sources of genetic resistance and variability available in advanced research institutions around the world for those Latin American research institutions which work on sorghum and pearl millet.

The companies which will benefit most are the small national companies. They will be able to use these germplasm sources for developing the new lines available in the main research centers but which, for several reasons, are not available to the small Latin American research institutions. Even with few resources, this network can have great impact in Latin America.

Germplasm and Research Information Exchange

Uniform regional yield trials were conducted at Quilichao, La Libertad, and Arauca (all in Colombia), and at sites determined by national programs in Venezuela, Peru, and Brazil.

Because two varieties were released in 1993, considerable effort was directed toward semi-commercial fields, consistent with the specific levels of Al saturation for which each variety was released. FENALCE, ICA, CRECED, and the El Alcaraván Foundation were, and will continue to be, in charge of these semi-commercial fields.

In cooperation with other INTSORMIL projects, drought-tolerant sorghum germplasm from TAM-122 was evaluated at Codazzi in collaboration with FEDEARROZ, and in regional tests in the Colombian North Coast and Nataima. Phosphorus efficiency research will be conducted in cooperation with UNL-114. Studies of sorghum as a raw material for food products will involve direct consultation between ICA and INTSORMIL's food quality projects.

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Economic and Sustainability Evaluation of New Technologies in Sorghum and Millet Production in INTSORMIL Priority Countries

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Summary

The economic impacts of Hageen Dura 1 in the Sudan and of Sureño on the hillsides of southern Honduras show substantial returns to agricultural research and extension. The Hageen Dura experience indicates the importance of the expansion of a private seed industry and a fertilizer distribution system to support the rapidly increasing demand for both inputs once a new hybrid is introduced. In Honduras the investment in the soil conservation technology made possible the introduction of an intensive technology system (yield increasing) including fertilization, better agronomic practices, and a new cultivar.

In Burkina Faso and Niger fallow rotation used to be the principal method for restoring soil fertility. High population densities and communal land holding systems have been eliminating the fallow systems so this extensive system is now resulting in falling yields and soil degradation. We have studied the economic factors influencing the shift from extensive, low input systems, where the principal innovation is animal traction, to intensive systems with purchased input use and improved cultivars. To increase yields profitably it is generally necessary to respond to both the water availability and the soil fertility constraints. The types of technologies required vary with soil types and economic environments. On the crusting, clay soils the water retention is critical to increase the returns and reduce the risks of fertilization. On the sandy dune soils fertilization increases both soil nutrient levels and water use efficiency. On both types of soils decreasing land availability and increased profitability of agriculture both accelerate the introduction of intensive technologies. Intensive technologies not only increase yields but are more sustainable systems than the extensive systems presently practiced. Many of these intensive systems are highly profitable and their water-retention features result in little increase in riskiness of the combined systems.

We have identified a series of technology and economic policy recommendations to accelerate technology diffusion. The potential farmer demand for medium and longer season cultivars and the importance of reducing the cereal price collapse in good rainfall years both became obvious in country studies in Niger and Burkina. In Sudan Hageen Dura diffusion was related to the functioning of the input markets, extension contacts, and farmers' taste preferences. The traditional farm and farmer characteristics most commonly identified in diffusion studies were shown to be related to the rationing associated with input supply constraints rather than with differences in the demand for the new technology.

Finally, the impact of agricultural and household technologies on the welfare of women has been analyzed. With most types of household decision making both types of

technologies have substantial positive impacts on female (and household) incomes. Since household heads receive less benefits than the women but generally make the decisions about household investments, they need to be made aware of the economic value of household technologies in releasing the time of women for directly productive activities especially when new agricultural technologies are increasing the demand for the time of women.

Introduction

During the last eight years of the existence of the present economics program we have evaluated various aspects of the impacts of new technologies in Burkina Faso, Niger, Honduras, and Sudan. New involvement in 1993/94 is taking place with field research in Mali and Senegal. Technologies are identified by other INTSORMIL staff or management. Some of our analysis pursues other issues relevant to development such as our recent concern with sustainability issues and the effects of various types of technologies on the welfare of women.

At the beginning of this project there were few economists working in the NARS and few ideas about how to integrate economists into NARS or even INTSORMIL activities. Hence, in the early years of this project we needed to establish our own credibility within INTSORMIL and in the NARS. We concentrated on producing research and training economists to work in multi-disciplinary projects. Ph.D. students (principally Africans) in the Economics Program of INTSORMIL do fieldwork in our priority countries in collaboration with NARS economists. The evidence of our impact is reflected in our publications and in the economists trained in this program now working in the IARCs and NARS.

Within the NARS there is now a growing recognition of the need to document the effects of new technology in order to generate more national support for research investment. This is presently a rapidly expanding area of demand for the services of economists in the NARS. The Farming Systems movement in the '80s also created a demand for economists to participate in multi-disciplinary teams to undertake on-farm testing and evaluation of new technologies. There are presently more and better trained economists in the NARS. Moreover, economists are increasingly recognized in the NARS for their potential contributions to on-farm technology analysis. In this new environment with more trained economists and some appreciation of their roles in the NARS, it is now easier to design more collaborative activities with them.

Objectives, Production and Utilization Constraints

Objectives

Estimate the potential impact and sustainability of new technologies in various priority regions for INTSORMIL.

Evaluate the farm-level impact of various agricultural and economic policies in facilitating technology introduction.

Undertake farm-level surveys in priority regions for new technology introduction to estimate diffusion and to construct more realistic farm-level models.

Identify farm-level constraints to new technology introduction, including those from technical, policy, and farmers' objectives.

Evaluate the impact of the performance of input and product markets in affecting technology introduction and recommend policies to improve this performance.

Constraints

In previous reports we have documented various constraints to technology diffusion and potential introduction in various countries. The most important constraint that we study in the INTSORMIL program is the information constraint: How are the new technologies associated with the collaborating NARS and with INTSORMIL performing on farmers' fields? What are the technical and economic constraints to their more rapid diffusion? What economic factors influence the technology requirements and the speed of adoption?

Several specific constraints identified in our work over the past eight years are:

Deteriorating soil fertility resulting from extensive production practices as the land supply becomes too limited to continue fallowing (Burkina, Niger, Sudan).

The water availability constraint making it too risky to resolve the soil fertility constraint unless both constraints are resolved simultaneously. This problem is most serious in the heavier clay soils with crusting problems (Burkina).

The foreign exchange constraint pushing national governments to avoid chemical input purchases. Some areas such as the sandy dune soils of the Sahelo-Sudanian zone can resolve both water availability and soil fertility problems with fertilization and higher densities. However, they have to import the chemical fertilizer (Niger, Sudan, Burkina).

On the hillsides soil conservation and soil fertility problems need to be simultaneously resolved. The farm has to be prevented from washing down into the valley before more intensive techniques become appropriate (Honduras).

The cereal price collapse associated with good rainfall years (Niger, Honduras).

The slow evolution of the necessary input markets for rapid technological change especially the private seed in-

dustry and an adequate fertilizer-distribution system (Sudan).

Research Approach and Project Output

Research Methods

We evaluate technology performance with field interviewing and statistical analysis. For example, in the Gezira study of the introduction of Hageen Dura the farm and regional level factors associated with adoption were analyzed econometrically. This type of analysis can give insight on how to accelerate the diffusion process and help identify other constraints as an input into future research priorities.

For new technologies that have been tested only on the experiment station or in trials on farmers' fields, we estimate the expected consequences of their introduction. We identify technical and policy related constraints with mathematical programming and with simulation models. The objectives are the same as above to anticipate the consequences and the constraints to new technology introduction and to accelerate this introduction with policy support.

Finally, there is an emphasis not only on describing and anticipating the effects of technologies but also on analyzing the role of agricultural and economic policies in influencing technology adoption. Moreover, we are presently becoming more involved in evaluating the functioning of the input markets.

Research Findings

Sudan

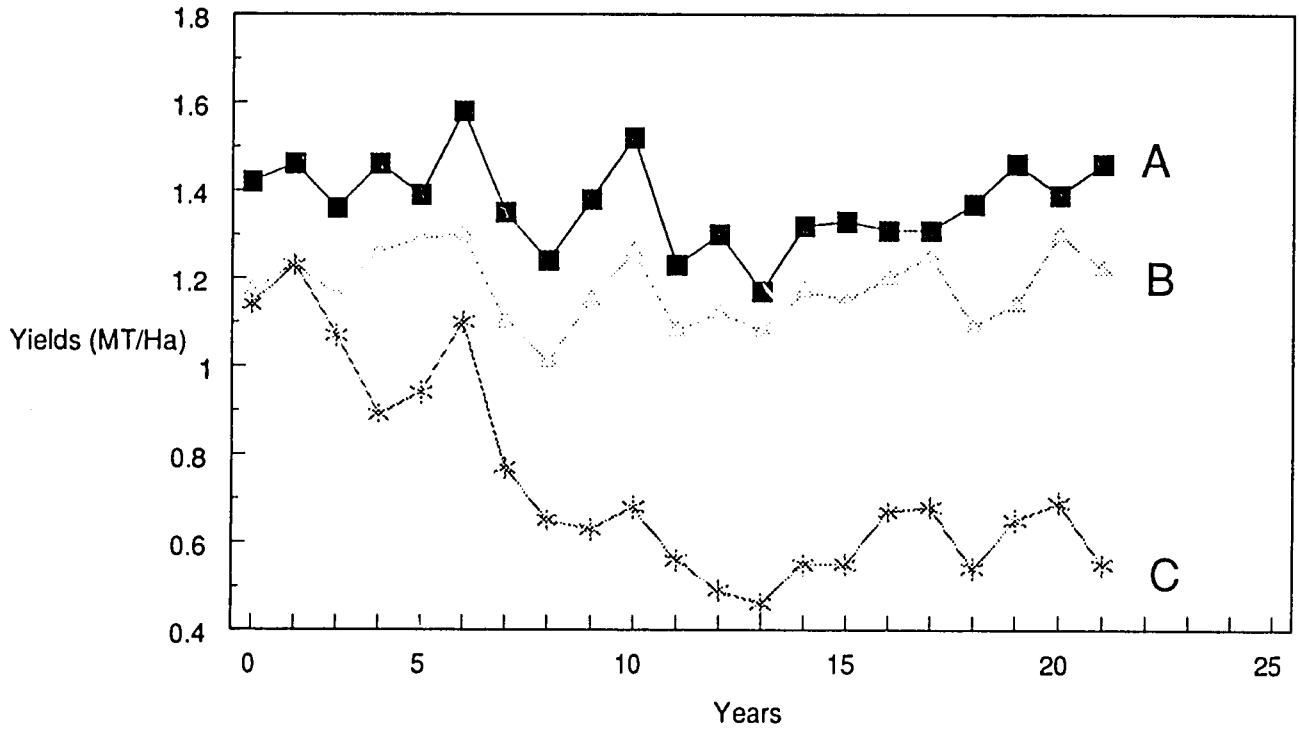
In the Sudan, we have been principally concerned with analyzing the diffusion process of the new hybrid, Hageen Dura-I. Previous diffusion studies have emphasized farm or farmer characteristics, such as farm size and education. Most studies have assumed that there are no supply constraints for obtaining the required inputs for the new technologies. In this case, these inputs include the hybrid seed and higher levels of chemical fertilizer. In the Sudan the public seed production agencies have had problems in recent years in responding to a rapidly increasing demand for this hybrid in the Gezira irrigated zone. Moreover, farmers complained of the difficulty of obtaining as much fertilizer as they wanted to buy.

When an adjustment is made for these supply restrictions, the traditional variables explaining diffusion are no longer significant. The farmer variables, such as farm size and education, apparently explain the differential ability of farmers to obtain these rationed inputs rather than variations in the demand for the new technology. When all farmers who wanted to buy the rationed inputs were assumed to be able to get them, then extension contacts and farmers' taste preferences about this new sorghum were the decisive variables determining diffusion. Extension contacts clearly represent more knowledge or information about the new cultivar.

Tastes were observed to change over time (see the INTSORMIL annual report for 1992). This was also an important result because many diffusion studies have emphasized the importance of tastes, especially farmer complaints at the initiation of the introduction process. The two diffusion studies in the Gezira region noted that over time farmers changed their preferences with regard to the "kisra" quality of the high-yielding Hageen Dura-I. This should not be a very surprising result since food habits have been observed to change in many regions with variations in the availability and the prices of different foods. There often are resistances to these changes but there are apparently dynamic aspects to food consumption and some of these were captured in this statistical analysis. Within some range of food quality, consumers (farmers) were apparently willing to change their initial resistances to a new sorghum taste if the price (or in this case yield) advantage were sufficient. This dynamic nature of tastes is important for other diffusion studies and for research priorities of food scientists and breeders.

Also in the Sudan we are evaluating the long-run sustainability effects of present and potential technologies on the vertisols. An extensive agriculture of mechanization on large farms has been encouraged by governmental policies subsidizing land, machinery and interest costs for approximately 30 years. During the '80s, sixty-four percent of Sudan's sorghum came from this rainfed, mechanized region. Sorghum is the principal food staple of the Sudan occupying 55% of food crop area (Salih, 1993, p.1). Since there is so much weather variation and some farmers practice fallowing, there is a debate on whether sorghum yields have been declining in this zone. The crop/water/soil model (Erosion Productivity Impact Calculator-EPIC) enables us to look at changes in crop yields and soil characteristics over time. Extensive sorghum production has led to an approximate 50% decline in yields after about eight years according to model results. In the extensive, low input system presently practiced sorghum yields have fallen to around 0.6 mt/ha.

With moderate fertilization and an improved cultivar sorghum yields can be doubled from these low yields with soil depletion. Moreover, the model results indicate that yields can be maintained at this level. The extensive, low-input agriculture is not sustainable but leads to soil degradation and declining yields. The use of moderate levels of chemical fertilizer, an improved cultivar, and improved agronomic practices can raise yields and maintain them at 1.2 to 1.4 mt/ha. These are not outstanding sorghum yields internationally but they are a substantial improvement over present yields (Figure 1). These improved technologies were also highly profitable.



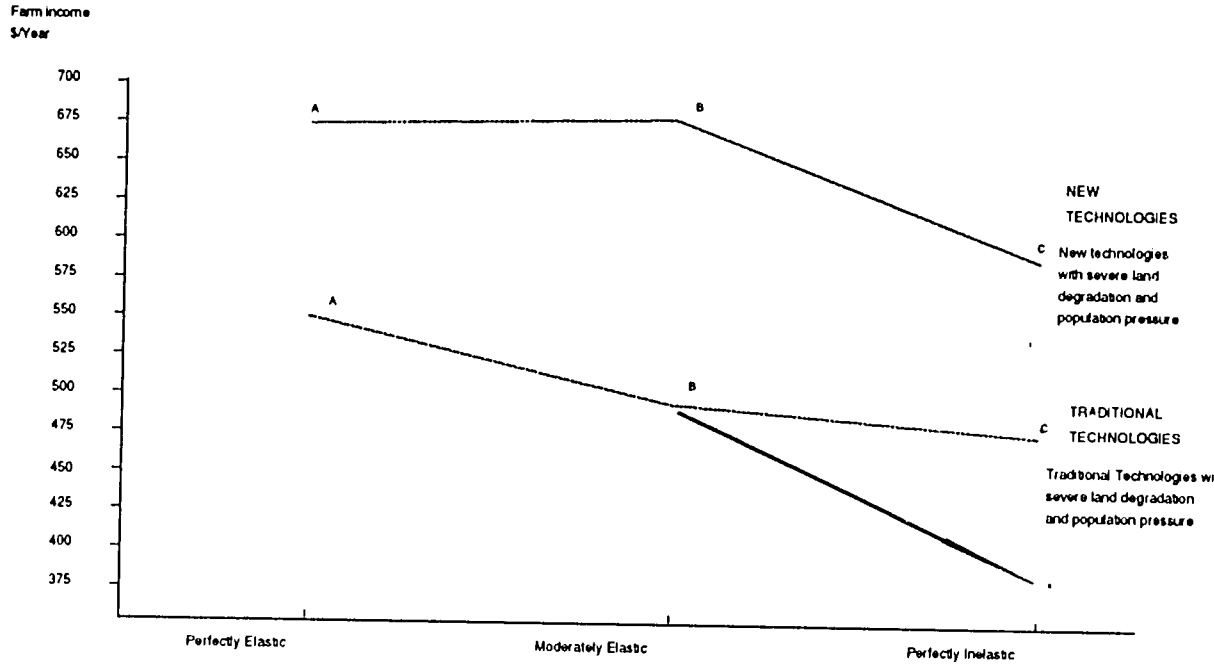
A:Improved sorghum cultivar, moderate nitrogen, and improved agronomy under historic rainfall.
B:Improved sorghum cultivar, moderate nitrogen, and farmers' agronomy under historic rainfall.
C:Traditional extensive sorghum production, continuous sorghum, traditional cultivar, and farmers' agronomy under historic rainfall.

Figure 1. Estimated sorghum yields over time of present extensive sorghum production and two improved technologies in the mechanized rainfed vertisols of the Sudan (EPIC model).

Burkina Faso

In the heavier clay soils, the soil crusting over time often makes the water retention a critical investment. For the crusting soils of the Central Plateau of Burkina (Sudanian zone), yields are falling and farmers are extending cultivation into more marginal agricultural regions. In these conditions, higher input use to increase land productivity is critical. Higher chemical input use also increases risks. But the combination of water-retention techniques and chemical fertilizer reduces risks, makes agriculture more profitable, and makes this a more sustainable system. A simpler and less effective technology of contour dikes, constructed outside the crop season and combined with organic fertilizer, is already being rapidly introduced. In the Sudanian zone in Burkina Faso, the introduction of the contour dikes has been very successful with an estimated 60,000 hectares in these dikes in the late '80s.

A tied ridges-fertilization technology overcomes the same constraints but these inputs are more expensive and must be undertaken during the crop season. Since many farmers will encounter seasonal labor constraints, the technology combination will require animal traction and an animal traction ridger. However, the combined effects of this more complicated technology combination on yields and profits are also substantially increased according to model results (Ramaswamy and Sanders, 1992). The combined introduction of tied ridges, fertilization, and a new animal traction implement has the economic potential to not only substantially increase sorghum yields but this higher input system is more sustainable than the deteriorating low input system generally practiced now. Figure 2 indicates the economic effects of introducing these new technologies at different levels of land availability and degradation with the vertical shift upward being the income increase from technology adoption.



Notes: Farm income includes the value of home consumption. The moderately inelastic land supply was modeled by introducing a time cost of travel. The perfectly inelastic land supply was modeled by fixing the supply of bush-fallow land at 3.5 ha/farm. The exchange rate in 1990 was 273 FCFA/US$ (IMF, 1990).

Source: Ramaswamy and Sanders, 1992, p. 368

Figure 2. Farm incomes with traditional and new technologies as the supply of bush-fallow land becomes more inelastic

Table 1. Female worker's annual income after the introduction of new technologies and incorporating the different household-behavior theories (US$).

Household* decision-making	Traditional agriculture	Introduction of new agricultural technology	Introduction of new household technology and new agricultural technology
Competitive	100	160	187
Exploitive	100	100	117
Bargaining	100	131	154

*Includes only households dependent upon human power. Households with animal- traction were not included.

Also in Burkina, we have looked at the effects on women of new technology introduction. In agricultural systems with rapid technological change, women are made better off with the new technology introduction even if its use is concentrated among the men for most types of family decision-making. There is substantial empirical evidence from other studies that most family decision-making is done in a bargaining framework. With this bargaining, female incomes are increased 31% with agricultural technologies (Table 1). If decision-making is made in a bargaining framework, then specific policy measures to aim the technology at the women generally are not as efficient in raising female incomes as accelerating the introduction of the new technology. If family decision-making is made in an exploitative manner, then women are not made better off with new agricultural technologies. We also explored the effects of new household technologies in raising female incomes. Household technologies, such as the wood-burning stoves, are presently treated as a durable consumer good with environmental, health, and financial consequences for the family and the economy. These financial consequences are in terms of money saved in fuelwood purchases by the urban households. The productive potential of household technologies is ignored since the opportunity cost of women's time is assumed to be negligible. This study estimates the economic impact of household technologies by putting a value on the time saved in performing household chores that could be used in generating income. The introduction of wood stoves and steel-tipped pestles raises the total farm income from $1,111 to $1,177, a 6% increase, while it raises the income of women under bargaining from $131 to $154, an 18% increase. In fact, household technologies raised the income

of women irrespective of decision-making. Even in the more extreme case of exploitation, women were made better off with the introduction of household technologies (Table 1); they experienced a 17% gain in income.

An important aspect of our recent research was to examine the investment determinants for these household technologies. We looked at why investment in these technologies was low and what types of policy measures could increase household investment in these technologies. So long as the investment decision is dominated by the male household head, adoption of household technologies will be limited. The benefits that the household head receives from these investments are much smaller than those received by the women. Hence, he prefers to purchase a motor scooter or radio rather than a wood stove or improved food-processing equipment. This consumption pattern was also observed in developed countries where investment in household technologies lagged behind other major consumption expenditures, such as radios, televisions, and cars, until the opportunity cost and labor-force participation of the women were clearly higher. From a policy perspective, this research suggests that raising the opportunity cost of women through the introduction of agricultural technologies and more off-farm opportunities, if combined with increasing awareness of the household head and government officials of the opportunity costs of women and the productive potential of household technologies, will raise the rate of diffusion of these technologies.

Marketing the different household technologies directly to women via female extension agents may reduce the marketing costs and increase the diffusion rate since women with higher opportunity costs may invest in these technologies themselves. Public intervention to promote the diffusion of household technologies, particularly the wood stoves, is also recommended since the social costs of nonadoption are high in terms of deforestation and continuing soil degradation.

Niger

In Niger on the sandy dune soils, crusting is usually a less serious problem but the water rapidly infiltrates deeply into the soil so that the plant roots are not able to tap it. Moderate fertilization and higher plant densities have been shown to simultaneously increase soil fertility and water-use efficiency. This makes technology introduction on these sandy dune soils much less complicated than on the clay, crusting soils as in Burkina, where the simultaneous introduction of at least two and often three new inputs was required. Here on these soils chemical fertilizer and higher densities alone resolved the two critical constraints of water availability and soil fertility. In the region early cultivars of millet and cowpeas are being introduced but no fertilizer.

Since fertilizer is the critical input to make this a sustainable agricultural system, we then analyzed in detail various policy changes and technology modifications that would result in the introduction of chemical fertilizer on the farms. In the higher rainfall Libore region the analysis indicated the importance of not overinvesting in early cultivars and in first introducing phosphorus alone (Table 2). Both of these technology modifications and an input subsidy result in fertilizer utilization according to the model results. In contrast in the lower rainfall, Kouka region no feasible changes in technologies or in economic conditions would result in farmer adoption. For some regions improved crop technology may not be appropriate. Rather it will probably be necessary to encourage out-migration of farmers and to put these crop areas into more extensive uses such as agro-forestry or grazing. Technological change is not a panacea for all regions and for all low income farmers.

Honduras

In Honduras, we studied the economic impacts of combined technologies for the hillsides of southern Honduras. Table 3 indicates that the soil conservation technique by itself increased farm incomes by 36 to 42%. Adding in the

Table 2. Effects of various policy instruments on adoption of fertilizer in Libore and Kouka, Niamey region, Niger.

	Fertilizer use (ha)	
Policy or program	Libore	Kouka
Current practices - improved cultivars	0	0
Price support (50 FCFA)	-	0
Input subsidy (10%)	1.2	-
Input subsidy (50%)	-	0
Credit program (10,000 FCFA at 0% interest)	0	0
Phosphorus only	2.1	0
Long-cycle millet variety	1.5	0
Adaptive livestock choices	-	0

- Indicates that this technology or policy choice was not evaluated.

Exchange Rate: 298 FCFA/US$.
Source: Shapiro, 1990; Shapiro et al., 1992.

Table 3. Potential income* effects of soil conservation techniques(sct) and a new sorghum cultivar and related technologies for hillside farmers in southern Honduras at two levels of risk aversion.

Description	Traditional farm with: No new technologies	SCTs only	SCTs and new sorghums
No Risk Aversion			
Income level ($)	276	374	415
% Change from base case		36	50
Area under new sorghums (% of total crop area)	—	—	81
Total grain production (kg)	2,590	2,735	4,439
% Change	—	6	71
Extreme Risk Aversion			
Income level ($)	262	371	401
% Change	—	42	53
Area under new sorghums (% of total crop area)	—	—	73
Total grain production (kg)	2,168	2,735	4,290
% Change		26	98

*A price floor was included in these calculations of income. The lowest values in the distribution of maize and sorghum prices in the model were increased from $.04 and $.02/kg to $.10 and $.07/kg, respectively. So everywhere there was a lower value in the price distributions, they were replaced with these minimums. These were the prevailing minimum prices offered by the official marketing agency in 1990.

Source: Lopez-Pereira, Miguel, John H. Sanders, Timothy G. Baker, and Paul V. Preckel, 1993. "Farm-Level Economic Effects of Erosion-Control and Seed-Fertilizer Technologies for Hillside Farming in Honduras." West Lafayette, IN: Purdue University, Dept. of Agricultural Economics, mimeo, p. 30.

new sorghum technologies further increases farm incomes by another 11 to 14% (Table 3). The soil conservation devices (SCTs) reduce runoff and hold more water on the hillside thereby reducing the risk from fertilization. Hence, even extremely risk adverse farmers are willing to make these investments according to the model. Once these water retention investments are made, then the more intensive cropping system with the new cultivar and fertilization becomes profitable.

The principal constraint on these farms is the very large labor requirements to construct the terraces. Since the terraces can be built outside the crop season, investment in this technology depends upon farmers' opportunity costs outside agriculture. Farmers on the southern hillsides of Honduras have been investing in these combined technologies but their labor time on the SCTs has been subsidized by various food for work aid programs. An impact analysis was also undertaken of the SCTs alone and of the combined technologies with the new sorghum cultivar (see the Project Highlights to this report).

Mali

In Mali, we are now looking at the same water retention/soil-fertility improving technologies that we considered in Burkina Faso. The agro-ecological and economic conditions are very similar so this will be an important case study to see how we can extrapolate results between regions and what regional modifications need to be made when we are evaluating these combined technologies.

Networking Activities

Workshops

Presented a paper summarizing INTSORMIL research to three groups: USAID/AFRICA and related professionals, June 1993; development economists at the premeetings of the American Agricultural Economists Association, July 1993; and agricultural professionals in the World Bank, Oct. 1993.

Impacts from the above workshops are greater recognition of INTSORMIL's contribution to economic analysis of new technologies and policy recommendations. This enters the policy dialog influencing research-resource allocation and agricultural-development policies for developing countries.

Research Information Exchange

Did an impact evaluation of four commodity programs of SAFGRAD, the regional agricultural research network. The commodities included sorghum and millet. Spent a month in Burkina Faso in collaboration with Dr.Taye Bezunch, research director of SAFGRAD, doing this report.

These results were presented in a seminar to 22 Directors General of NARS. The report showed the high returns to agricultural research. This is important to generate greater national support for these research systems.

Research Investigator Exchanges

In the Sudanese fieldwork, Tennassie Nichola worked closely with Abdelmoneim Taha of the ARC. They collaborated on the fieldwork and Tennassie provided Taha with the software for analyzing Tobit and Probit models and showed him how to use it.

Publications and Presentations

Publications

Shapiro, B.I., J.H. Sanders, K.C. Reddy, and T.G. Baker, 1993. "Evaluating and Adapting New Technologies in a High-Risk Agricultural System – Niger," *Agricultural Systems* 42(1-2):153-171.

Ramaswamy, S., and J.H. Sanders, 1992. "Population Pressure, Land Degradation, and Sustainable Agricultural Technologies in the Sahel," *Agricultural Systems* 40(4):361-378.

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Sanders, John H., and Sunder Ramaswamy, 1993. "Impacts of New Technologies in Burkina Faso and the Sudan: Implications for Future Technology Design," in *Proceedings of the Workshop on Social Science Research and the CRSPs*, June 9-11, University of Kentucky, Lexington. Lincoln, NE: INTSORMIL Publication 93-3.

Salih, Ali, 1993. "Sustainability and Profitability of Intensive Cropping Technologies on the Dryland Vertisols of Sudan: A Simulation Approach With EPIC," unpublished Ph.D. dissertation. West Lafayette, IN: Purdue University, Dept. of Agricultural Economics.

Presentations

Sanders, John H., 1993. "Economic Impact of the Commodity Research Networks of SAFGRAD," paper presented in Ouagadougou, Burkina Faso, to the directors of 22 national agricultural research institutions of West and Central Africa, Mar. 22.

Sanders, John H., 1993. "Technology Development for Semi-Arid Sub-Saharan Africa: Theory, Performance and Constraints," paper presented at an USAID/Africa Bureau Collaboration Workshop on Technology Development and Transfer, Washington, DC, June 29.

Sanders, John H., and João Carlos Garcia, 1993. "The Economics of Stress and Technology Development in the Sahel and 'Cerrados' of Brazil," paper presented at an INTSORMIL-sponsored Workshop on Adaptation of Plants to Soil Stress, Lincoln, NE, Aug. 2.

Ahmed, Mohamed M., William A. Masters, and John H. Sanders, 1993. "Returns From Research in Distorted Economies: Hybrid Sorghum in Sudan," paper presented at American Agricultural Economics Association conference, Orlando, FL, Aug., and to be published as an abstract.

Lawrence, Pareena G., and John H. Sanders, 1993. "Household Decision-Making and the Evaluation of New Agricultural and Household Technologies in Sub-Saharan Africa," paper presented at the Sixth International Forum of the Association for Women in Development, Washington, DC, Oct. 23.

Resource Efficient Crop Production Systems

Project UNL-113

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Summary

Cropping system research has been conducted in INTSORMIL UNL-113 to address water and nutrient constraints in grain sorghum and pearl millet production. Efforts address factors that improve the production environment to allow improved cultivars to express their higher grain yield potential. Project UNL-113 research results have demonstrated 18 to 203% yield enhancement of pearl millet and grain sorghum yields by use of crop rotation with legumes, and a sizeable nitrogen equivalent contribution to cereals following legumes. The rotation effect is complex, as is obvious from results showing rotational effects on root distribution, soil water extraction, microbial biomass, mycorrhizal infection and grain quality. Although the basis of the rotation effect are unclear, producers worldwide can take advantage of the benefits by use of crop rotations. Intercropping has shown land use efficiency increases over sole crops, and also to enhance yields of succeeding crops. Obviously legume production, no matter the system, is important to producing optimal yield when nitrogen fertilizer is limiting and improved cultivars are available.

Introduction

Water and nutrients, especially nitrogen, are the major natural resources limiting grain sorghum and pearl millet production worldwide. During the past 10 years, INTSORMIL Project UNL-113 has focused on development and extension of cropping systems that are water use efficient to improve the growing environment through the use of nitrogen fixation by legumes so that improved varieties and hybrids can express their higher grain yield potential. Research efforts in Nebraska and several African sites have studied intercropping and crop rotational systems. This effort has been slowed by the limited availability of trained production agronomists in Africa and the long-term nature of cropping systems studies. Efforts to improve the human resource base has been made by providing graduate training for 26 students from Bhutan, Botswana, Egypt, Honduras, Malawi, Mali, Niger, Nigeria, the Philippines, Senegal, Sudan, Tanzania, and Zambia.

Although not the major focus of this project, several research studies have been conducted to address other related production issues that influence expression of yield potential by improved varieties and hybrids. These studies included stand establishment problems, genotype x environment interaction, crop residue management and weed/water use.

Objectives, Production and Utilization Constraints

Objectives

Study the "rotational effect" in sorghum-soybean and millet-soybean rotations by evaluating:

Nitrogen and phosphate contribution of legumes and soil water relationships

Long-term studies to determine sorghum/peanut and millet/cowpea cropping systems (monoculture, rotation, intercropping) by nitrogen fertilizer rate interaction effects will be continued in Mali.

Long-term studies to determine the influence of crop residue removal, incorporation and leaving on the surface will be continued in Mali.

Long-term studies to develop improved green manure and fallow systems will be initiated in Mali.

Evaluate the nitrogen by water interaction on grain and stover yield of sorghum hybrids and local cultivars.

Constraints

We have primarily focused on crop productions systems which increases the probability of obtaining higher yield. This involves systems which increases nutrient and water availability, better stands, and basic physiological process so available resources can be used efficiently by crop plants. Cropping systems research requires special considerations. First, they are long-term investments. For instance, once a rotation or intercropping system is started it cannot be stopped and restarted easily. Second, a host scientist must be genuinely interested in these long-term projects, and they require stable funding over time. Third, training of scientists in crop production and continued support of their work after return to home countries is needed to improve presently used cropping systems.

Research Approach and Project Output

Sorghum and millet are usually grown in stressful environments with high temperatures and lack of a predictable and adequate water supply. Generally, lack of water is considered the most influential environmental factor controlling plant growth and yield in these environments. The second most influential environmental factor affecting plant growth and yield is often adequate nitrogen and/or phosphorus. The importance of these elements is becoming even greater with more intensive cropping practices used when availability of new land is limited. Legumes become a viable alternative for improving soil fertility (especially nitrogen status) as availability and monetary constraints for purchasing fertilizer occurs. Improved fertility also improves water use efficiency of grain crops, indicating that major gains in sorghum and millet yields requires improved genetics combined with production practices to provide adequate water and fertility.

- International

West Africa

In West Africa there exists a need to increase yield and yield stability of pearl millet and grain sorghum. At present yields are low, and fertilizer inputs are either unavailable or too expensive for small farmers. Priorities have been established in both Mali and Niger to develop cropping systems that increase yields, improve yield stability, and minimize the use of fertilizer nitrogen through crop rotational or intercropping systems.

Mali

Cropping Systems on Sorghum and Millet
Grain and Stover Yield (1990 - Present)

On-going long-term cropping system studies were initiated in 1990 at Samanko (Sorghum/Peanut), and Cinzana and Koporo (Millet/Cowpea). Sorghum-peanut intercropping increased the land use efficiency ratio (LER) by 4, 13 and 41% over sole crops at zero, 40 and 90 kg ha^{-1} N, while millet-cowpea intercrop increased the LER by 29-33% at all N levels. Sorghum grain and stover yield was increased by 40 kg ha^{-1} N application in all three years, and by 80 kg ha^{-1} two out of three years. Millet grain and stover yield showed little response to more than 20 kg ha^{-1} N fertilizer application. These responses to N fertilizer indicate that the present production systems N needs of grain sorghum and pearl millet could be met by crop rotation, but if yield potential were increased dramatically, commercial fertilizer would also be required.

Research in Mali has shown clear yield advantage to rotation of sorghum following peanut and millet following cowpea, and a smaller yield advantage following intercropping (Table 1). This yield increase is impressive considering that all peanut/cowpea grain and residue were removed from the field. Although adoption of rotational cropping systems requires a "big change in present farmer mind set", it appears to be the only viable alternative to supply needed N for grain yield if commercial fertilizers are unavailable or are too expensive. Research has been initiated to evaluate several potential green manure crops and improved fallows to further capitalize on this benefit.

Long-term studies in Mali have been initiated to study the effects of residue removal, incorporation or leaving residues on the soil surface on sorghum and millet yield, and maintenance of the soil natural resource. After three years no differences in grain or stover yield have been found either in sorghum or millet areas, which contrasts with other research in Niger. Crop residue management in sustainable crop production deserves much greater attention in the future.

With IER restructuring, Project UNL-113 has become associated with the pearl millet agronomy team. Planning efforts in 1993 will result in increased research efforts on nutrient cycling, intercropping systems with alternative crops, weed management, green manure crops, and improved fallow systems. Collaborators are actively pursing increased collaboration with other disciplines, and on-farm trials with the extension service.

Table 1. Cropping system effect on grain sorghum and pearl millet yield.

Location	Years	Crop: Previous	Crop: Present	Yield (Mg ha^{-1})	Percent yield increase
Nebraska	1978-92	Sorghum	Sorghum	3.72	- -
		Soybean	Sorghum	6.10	63.7
Nebraska	1981-92	Sorghum	Sorghum	5.45	- -
		Soybean	Sorghum	6.51	19.4
Nebraska	1986-87	Millet	Millet	4.95	- -
		Soybean	Millet	6.12	23.6
Niger	1988-90	Millet	Millet	0.49	- -
		Traditional Millet/Cowpea	Millet	0.64	29.6
		Improved Millet/Cowpea	Millet	0.77	56.1
		Cowpea	Millet	0.84	71.4
Mali	1991-92	Sorghum	Sorghum	1.42	- -
		Sorghum/Peanut	Sorghum	1.74	22.5
		Peanut	Sorghum	2.22	56.3
Mali	1991-92	Millet	Millet	1.57	- -
		Millet/Cowpea	Millet	1.66	5.7
		Cowpea	Millet	1.85	17.8
Sudan†	1989	Sorghum	Sorghum	1.71	- -
		Phillipesara	Sorghum	2.04	19.3
		Clitoria	Sorghum	2.40	40.4
Botswana					
Good Hope	1983	Sorghum	Sorghum	0.98	- -
		Peanut	Sorghum	2.68	173.5
Sebele I	1983	Sorghum	Sorghum	0.65	- -
		Cowpea	Sorghum	0.91	40.0
Sebele II	1983	Sorghum	Sorghum	0.30	- -
		Cowpea	Sorghum	0.86	186.7
		Peanut	Sorghum	0.91	203.3

†forage legumes

Niger

Cowpea Cropping Systems Influence on Pearl Millet Yield (1987-90)

Millet grain yields increased with N fertilizer application, but the optimal rate varied across years. The optimal N rate was 25 kg ha^{-1} in 1990, 50 kg ha^{-1} in 1988 and 1989, and 75 kg ha^{-1} in 1987. Intensive intercropping with cowpea increased the land use efficiency by 35% at 46 kg ha^{-1} N and by 61% without N fertilizer application. Pearl millet yields increased greatly following a cowpea intercrop or sole crop cowpea (Table 1). These results demonstrate the importance of a cowpea legume crop and N fertilizer in improving millet yields under the stressful Nigerien conditions.

Botswana

Yield Stability of Grain Sorghum in Low Rainfall Environments (1984-86)

Identification of characteristics associated with yield stability aids in varietal development for marginal environments. The objectives of this study were to determine characteristics associated with yield and yield stability of grain sorghum in low rainfall environments of southeastern Botswana. Eight grain sorghum varieties with differing yield and stability potentials were identified from national variety trials conducted between 1969 and 1979. Rainfall during this period was greater than 400 mm year^{-1}. The eight varieties were grown in 24 environments created by factoring two fertility levels with two planting dates at three locations over two years. Rainfall during these two years was below 350 mm year^{-1}. Varietal grain yields averaged

across the 24 environments ranged from 0.56 Mg ha^{-1} for 8D to 0.93 Mg ha^{-1} for Segaolane. Mean stover yields ranged from 1.28 Mg ha^{-1} for sorghum variety 65D to 2.47 Mg ha^{-1} for Town. Grain yield was positively correlated with the percentage of plants reaching anthesis, duration of the flowering period, plant height, head number, kernel weight, kernels per head, stover yield, and harvest index. High stover yield was associated with taller plants, greater leaf number, and more tillers. Grain yield stability was primarily due to maintenance of head number and kernels per head in poorer environments. Regression coefficients of grain sorghum yields on mean environment yields calculated from these 24 low rainfall environments were compared to coefficients obtained from the variety tests in years of normal rainfall. This was to determine if relative stability among the eight genotypes was maintained. Varieties that had been identified as stable in environments where rainfall was above 400 mm year^{-1} were not stable in low rainfall environments. The results suggest that specific varieties can be developed that have stability for high- or low-yielding environments.

Yield and Quality of Stover in Low Rainfall Environments (1984-1986)

The potential for using sorghum and millet crop residues as fodder was studied in southeastern Botswana. This region is characterized by low, unevenly distributed rainfall and shallow sandy soils. There were significant differences among cultivars for grain and stover yield, digestibility, crude protein, and mineral content, but no differences between sorghum and millet were observed. Stover from all entries was adequate for cattle maintenance in *in vitro* dry matter digestibility (IVDMD) (57.0-63.6%) and most of the minerals tested, but crude protein (6.6 - 8.1%) and phosphorus (0.10 - 0.15%) levels did not always meet the minimum requirement. The deficient phosphorus levels were compounded by high calcium (0.41 - 0.51%) levels. This mineral imbalance could lead to bone abnormalities and reduced fertility in livestock.

Sudan

Grain Sorghum as Affected by Crop Rotation and/or Applied N (1989-90)

The experiment was conducted at Gezira research station, located in Sudan Gezira (14 - 15 °N, 33 - 34 °E), on irrigated Suleimi soil series (fine, montmorillonitic, isohyper thermic entic Chromsterts) during the 1988 through 1990 cropping seasons. The first season was considered as a baseline for the cropping system.

The main crop in the experiment was sorghum (S) "cv. SRN-39" which was rotated with forage legumes of clitoria (C) *Clitoria ternata L.* and phillipesara (P) *Phasulus trilobus Ait.* in a two-course rotational system. The experiment was planted on July 7, 1989 and on July 18, 1990. Urea (0, 43, and 86 kg N ha^{-1}) was applied to plots at planting. Plant samples were taken according to sorghum growth stage. Grain and forage yield, yield components, nitrogen content and other agronomic characteristics were collected.

Both legume previous crops greatly increased sorghum yield over that of continuous sorghum. However, clitoria performed better than phillipesara as a previous crop. In both leaf and stalk, N uptake was greater following the legumes (Clitoria > phillipesara > sorghum), and applied N. In all treatments N effect was higher when applied to continuous sorghum or as a first dose in a rotated sorghum. The maximum cumulative daily N uptake (CNU) occurred at GS_6 and GS_7 in both years. The N uptake during reproductive period (NUR) was 12 and 17 kg N ha^{-1} higher for rotated sorghum than continuous sorghum for 1989 and 1990. The average effect of clitoria and phillipesara exceeded the yield from continuous sorghum by 19% and 40% (Table 1). The response of kernel m^{-2} per N level was 30% for the first level and was reduced to 12% when the second level was applied.

Honduras

Grain Yield and Photosynthesi of Landrace Sorghum (1993)

Landrace populations are resilient primitive cultivars characterized by low but stable grain yields. In Central America, subsistence farmers use a group of photoperiodic landraces called maicillos criollos intercropped with maize to reduce drought risk. Twelve sorghum cultivars (3 maicillos, 3 temperate varieties, and 6 enhanced maicillo cultivars or DMV), were evaluated in 1992 at Mead, NE and El Zamorano, Honduras in collaboration with Dr. Dan Meckenstock (TAM-131) for intercropping and shade tolerance. Comparisons were made of pure stand (monoculture), *casado* or a mixed intercrop (sorghum and maize planted in the same row), and *aporque* or row intercrop (sorghum planted between maize rows at cultivation). Maize, Maicito (Zamorano) and JX3 (Mead) was used to provide natural canopy shade. Photosynthesis was measured in full sunlight and shade.

Sorghum grain yield was lower as the competition level of the component crops increased. Temperate varieties were affected most, reducing average grain yield from 2.0 Mg ha^{-1} in pure stand to 0.85 Mg ha^{-1} in *aporque* (-57%), whereas the DMV's were the least affected reducing their average grain yield from 3.68 Mg ha^{-1} in pure stand to 2.72 Mg ha^{-1} in *aporque* (-26%). DMV's planted in *casado* (low competition level) had higher average grain yield, 4.41 Mg ha^{-1}, than any other cropping system-sorghum type combination.

Maximum photosynthetic rates of the temperate variety TAM428 decreased from 40.35 µol CO2 m^{-2} s^{-1} in pure stand to 25.75 µol CO2 m^{-2} s^{-1} in *casado* (-36%) and 18.84 µol CO2 m^{-2} s^{-1} in *aporque* (-53%). San Bernardo III, a maicillo criollo, maintained photosynthetic rates across

cropping systems. Maximum values were 38.37 µol CO2 m^{-2} s^{-1} in pure stand, 38.96 µol CO2 m^{-2} s^{-1} in *casado*, and 37.42 µol CO2 m^{-2} s^{-1} in *aporque*.

These results indicate the adaptation of maicillo to reduced irradiance during vegetative growth. This trait may have some usefulness in maintaining photosynthesis and productivity when reduced light occurs (cloudy day, early morning, late evening) as well as in intercropping systems with tall species such as maize and pearl millet.

Tanzania

Cropping Pattern Interactions of Tropical Sorghum, Maize, and Cowpea (1982)

Small farmers in East Africa grow their cereals in association with other crops. If a genotype by cropping pattern interaction exists, then, breeding programs should consider the importance of developing cultivars that will perform well in the mix systems.

The objective of the study was to determine if a genotype by cropping pattern interaction existed. Eight varieties each of sorghum, maize and cowpeas of contrasting yield and growth habits were used. Cropping patterns consisted of monoculture (cowpea, sorghum, maize) and intercropped (cowpea-sorghum, cowpea-maize, sorghum-maize). The Ifakara Station (rainfed) and Ilonga station (irrigated) were used as locations.

Results indicated that there were differences among genotypes and among cropping systems indicating genotypes could be developed for complex systems. Cereal/cowpea systems provided a fairly constant protein value which is an important consideration. The monetary advantages of intercropping show the monoculture return of sorghum and cowpea was 30% of gross return of the crops grown in association. For maize, the mean return from sole crop maize and sorghum was 40% of the gross return of those intercropped.

- Domestic

Crop Rotation - Grain Sorghum or Pearl Millet and Soybean (1979 - present)

Research Procedures

Two sorghum soybean rotation studies have been in progress for over 15 years. These rotations have focused on determining the "rotational effect". One rotation experiment includes nitrogen rates to allow study of grain yield and quality, and nitrogen dynamics. The other rotation experiment includes nitrogen and manure treatments, and has been used to study grain yield, soil water extraction, root distribution, microbial biomass and mycorrhizal infection.

Research Results

Yield Enhancement - Efforts to determine the magnitude of yield response to rotating grain sorghum and pearl millet with soybeans has been a major focus. Long-term studies have shown yield increases of 19 to 64% following soybeans (Table 1). Yield increases were very consistent across years. Rotation with soybean has shown important yield increases for the second sorghum crop following soybean, but by the third year no economical yield response was present. Stover yields responses have been similar to those for grain (Table 2).

Grain and Stover Quality - Cereal rotations with legume crops also improve the quality of the grain and stover. Grain protein was improved from 6.5% to 7.9% when sorghum was grown after soybean which combined with yield enhancement, almost doubled protein yield (from 234 to 454 kg ha^{-1}). Nitrogen fertilizer also increased protein yield, with the highest yield being when both rotation and N fertilizer were used. Stover protein improvement provides better quality feed for animals or aiding in recycling of nutrients contained in the stover.

Crop Growth and Maturity - Sorghum and millet crops growing under stress conditions such as inadequate N have delayed flowering date and physiological maturity, thus increasing the probability of frost damage before maturity. Our research has documented rotation effects on crop root distribution following a continuum of continuous grain sorghum < grain sorghum following soybeans < soybean following grain sorghum < continuous soybean (Table 2)

Soil Nitrogen - Sustainable, economical crop production systems often involve crop rotation to enhance grain yield and quality, and reduce the need for commercial N fertilizer. Research results show that at least 50 kg ha^{-1} N equivalent is contributed by soybean to the next cereal crop. Our studies show that soybeans also contribute 20 kg ha^{-1} N equivalent to the second year sorghum crop. Soybean residues decompose rapidly during the growing season, thus releasing N as the succeeding crop needs N for plant growth. However, even at the highest N rates, rotated sorghum and millet often outyield continuous crops, suggesting that other factors than N are involved in the yield enhancement.

Other Soil Properties - Our research has documented that the amount of microbial biomass present for nutrient recycling and season soil water extraction of the crop are closely related to the root distribution differences caused by crop and cropping season (Table 2), but the cause and effect relationship is not clear. Our research has shown that sorghum has more vesicular-arbuscular mycorrhizal fungi colonization than soybean, and that both crops had greater colonization when sorghum was the previous crop. Although difficult to quantify, visual observations indicate that sorghum or millet following soybean emerge more rapidly and uniformly, and seedling growth is enhanced. Soybean

Table 2. Sorghum cropping system influence on yield and root distribution, soil water content, microbial biomass and vesicular-arbuscular mycorrhizal fungi infection.

	Yield		August				
Sorghum cropping system	Grain (Mg ha^{-1})	Stover (Mg ha^{-1})	Root length (km m^{-2})	Root mass (g m^{-2})	Soil water content (mm)	Microbial biomass (Mg ha^{-1})	Mycorrhizal arbuscules (%)
Rotated	5.1	5.5	26.6	152	332	2.9	20
Continuous	4.4	4.6	33.3	198	345	3.2	32

previous crop also facilitates use of no-till systems due to less residue and producing a mellow soil.

Economic Analysis - Profitability and financial risk characteristics determine the success of a cropping system. Analyses were performed to determine the effect of nitrogen (0, 56, 112 and 168 kg ha^{-1}) fertilization and crop rotation of sorghum and soybean in a long term experiment. Systems compared were continuous grain sorghum (CGS), continuous soybean (CSB), grain sorghum-soybean rotation (GS/SB), and continuous sorghum and soybeans each on 50% of a unit area (CGS/CSB). Nitrogen treatments were only used on grain sorghum plots. Yields, historic commodity prices, and production costs for the period from 1979-1990 were used in the analysis. The two highest N levels in the CGS system resulted in the highest net returns and lowest financial risk. Comparison of the CGS/CSB and GS/SB systems showed the rotations produced higher net returns and lower risks at comparable N levels, but these rotational benefits were due to the instability in the CSB system yields. The sorghum component of the CGS/CSB system at 112 and 168 kg ha^{-1} produced a higher return with lower risk than the rotational counterpart.

Crop rotation research in this project has generated basic knowledge about the rotation effect, and provided results for use in extension education programs. The long-term studies have served as a "laboratory" for training of 15 graduate students from developing countries.

Stand Establishment - Emergence Potential in Crusted Soils (1991 - present)

Stand establishment of sorghum is a major factor as many environments where sorghum is grown have soils that crust. This research was conducted to develop a technique for estimating emergence potential of genotypes in crusted soils, determining morphological traits associated with emergence potential, and estimating the heritability of this trait.

Studies were conducted using grain sorghum kernels of 8 genotypes produced during the 1988, 1989 and 1991 growing seasons. Emergence potential was estimated using an *in vitro* screening technique by measuring the distance between the growth tube cap and the tip of the protruding piston shaft immediately after transfer to growth tubes and 120 hours later. Coleoptile diameters were determined in growth tubes with piston assemblies, and in germination paper. Coleoptile diameters were measured 1 cm from the top and bottom of coleoptiles, and in the middle using a micrometer. Coleoptile length and curling, kernel weights and percent potential germination at 32 and 128 hours were also determined.

Piston displacement in the *in vitro* screening technique was affected only by the genotype, while year of seed production and year X genotype interaction effects were not significant. There were large differences in piston displacement among the 8 grain sorghum genotypes studies indicating that considerable variability in emergence potential through crusted soils exists in grain sorghum germplasm. Piston displacement by genotypes in this *in vitro* screening technique was relatively stable across years and apparently was not greatly influenced by the seed production environment.

Coleoptile diameters were greater in piston containing growth tubes than in germination paper. Large differences in coleoptile diameter were found among genotypes. Year of seed production X genotype interactions were present for all methods used. However, in all three years and for both methods of measurement, the genotype IA9 had the greatest coleoptile diameter, while KS33 had the smallest. These results suggested that genetic differences among genotypes for coleoptile diameter exist, and that these differences are magnified when growth is physically impeded.

Piston displacement by grain sorghum genotypes in the *in vitro* screening technique was positively correlated with coleoptile diameter and kernel weight, and negatively correlated with percent potential germination at 32 hours and the degree of coleoptile curling. The magnitude of correlation coefficients between piston displacement and coleoptile diameter (0.84 to 0.87) indicated that coleoptile diameter is a key morphological characteristic associated with emergence potential through a crusted soil and may serve as an useful screening technique for this trait.

Studies found that narrow-sense heritabilities for piston displacement (0.7) and coleoptile diameter (0.5 to 0.7) were high, and that large additive effects were present. Breeding programs selecting and crossing superior males and females for these traits could improve the emergence potential of grain sorghum genotypes in crusted soils. Hybrid performance indicated that the genotype IA9 is a valuable male germplasm source to increase coleoptile diameter and emergence potential in crusted soils.

Weed Control - Effect on Sorghum grain production (1990 - 91).

Resources (water, nutrients, and light radiation) determine the amount of biomass that can be grown in a field. For sorghum fields, this biomass can be partitioned into crop (grain and stover) and weeds. Control of weeds is very important since they directly compete with crops for available resources.

An experiment was established in 1990-91 to determine the effect of weeds on sorghum grain yield and precipitation use efficiency. Three genotypes were planted with three weed treatments: no weed control, one cultivation 2 weeks after planting, and complete weed control. Three levels of nitrogen were also included. Grain yield and other agronomic data were taken.

On an average, grain yield was increased from 1.3 mg ha^{-1} to 3.6 mg ha^{-1} with one cultivation and to 5.0 mg ha^{-1} with complete weed control (Table 3). Grain yield was related to the precipitation use efficiency (PUE). On an average, PUE was 15.6 kg ha^{-1} mm^{-1} for sorghum with complete weed control as compared to 11.2 kg ha^{-1} mm^{-1} for sorghum with one cultivation and 4.0 kg ha^{-1} mm^{-1} for no weed control. Weed control strategies merit more attention in sorghum production research.

Table 3. Grain yield for field grown sorghum as affected by weed management (Mead, NE, 1990).

Weed management	DK 48[1]	DK39Y	Segaolane	Mean
	- - - - - - - - Mg ha^{-1} - - - - - - - -			
No weed control	1.4	1.1	1.5	1.3
One cultivation	4.1	3.4	3.4	3.6
Complete weed control	5.4	5.6	4.1	5.0
Mean	3.6	3.4	3.0	

[1]DK = DeKalb Plant Genetics hybrids.

Networking Activities

Workshops

American Society of Agronomy Meetings, November 1-6, 1992. Minneapolis, MN.

EEP Review, March 5-12, 1993. Botswana and Zimbabwe.

Plant Adaptation to Soil Stress. Aug. 1-4, 1993. University of Nebraska, Lincoln, NE.

EEP Review, September 13-14, 1993, University of Nebraska, Lincoln, NE.

Latin America Workshop on Sustainable Production Systems for Acid Soils. Aug. 30-Sept. 1, 1993. Villavicencio, Colombia.

Latin America Sorghum Research Scientist Workshop. Sept. 2-4, 1993. Villavicencio, Colombia.

Research Investigator Exchanges

Visited collaborators and other IER scientists in Bamako, Mali, May 10-18, 1993.

Visited Sorghum Research Program, Estacion Experimental de Aula Dei, Zaragoza, Spain, May 19-22, 1993.

Visited collaborators in Botswana, March 5-12, 1993.

Research Information Exchange

Equipment purchased for Malian collaborators/IER included:

Computer Printer

Digital Soil Thermometer

Roller Belt Assembly for Leaf Area Meter

2 Soil pH Meters

Membership for collaborators in the American Society of Agronomy.

Publications and Presentations

Publications

Kasalu, H., S.C. Mason, and Gebisa Ejeta. 1993. Temperature on germination and seedling emergence of grain sorghum genotypes. Trop. Agric. (Trinidad) 70: (In Press).

Mason, S. C., J. Lasschuit, and J. M. Lasa. 1993. Interrelationship of sorghum coleoptile morphology with emergence potential in crusted soils. Eur.J. Agron. 2: (In Press).

Mohamed, M.S., and M.D. Clegg. 1993. Pearl millet-soybean rotation and nitrogen fertilizer effects on millet productivity. Agron. J. 85:1009-1019.

Youngquist, J.B., D.C. Carter, W.C. Youngquist, and M.D. Clegg. 1993. Phenotypic and agronomic characteristics associated with yield and yield stability of grain sorghum in low rainfall environments. Trends in Agricultural Sciences (in press).

Clegg, M.D. and C.A. Francis. 1993. Crop Management, Chapter 5. *In* J. L. Hatfield and D.L. Karlem (ed) Sustainable Agriculture Systems. Lewis Publishers, Boca Raton, Florida.

Presentations

Mason, S. C. 1993. Crop rotation - A viable option for acid soils in the tropics. Latin America Workshop on Sustainable Production Systems for Acid Soils. Aug 30-Sept. 1, 1993. Villavicencio, Colombia.

Mason, S. C. 1993. Emergence potential of grain sorghum genotype in crusted soils. Seminar to IER Scientists, Bamako, Mali. May 14, 1993.

Nutrient Use Efficiency in Sorghum and Pearl Millet

Project UNL-114
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Summary

Project UNL-114 has been involved in INTSORMIL since the inception of this CRSP in 1979. During the period of 1981-1986, one of the principal investigators conducted collaborative research in the Philippines to establish sorghum as a potential crop for rice based systems. This work showed that use of early maturing sorghums planted 5 to 10 days after rice harvest worked best in bunded rice paddies. Some tillage enhanced seedling emergence and favored higher yields. Sorghum planted in the southern Philippines as a sole crop was possible when using selected genotypes such as VG146 which yielded as much as 4 Mg ha^{-1}. Even though available markets were scarce for the crop, use of some fertilizer N was economically feasible. High local production tended to force prices downward with no or little government stabilization of prices which often proved to be a disincentive for production.

Another co-principal investigator worked extensively with Brazil and Colombia in acid soil research. These investigations showed that all mineral elements were affected by acid soil stresses, but that silicon and calcium in plant tissue were most closely related to acid soil tolerance. These may have reduced the effects of toxic aluminum. An effective laboratory screening technique was devised to screen sorghum seedlings for acid soil tolerance.

Studies on mycorrhizal (VAM) colonizations on sorghum showed that VAM associations on roots can assist in the extraction of phosphorus (P) from low P soils. However, the higher the inherent soil P level, the lower the VAM association which occurred. VAM colonization was also greatly retarded by high aluminum and low pH.

Project UNL-114 has been conducting collaborative research with scientists in both Mali and Niger, West Africa since 1988 with sorghum and pearl millet. The research in Niger showed that these crops can gain benefits from added N in either a wet or a dry year. If a legume/cereal rotation is used to obtain "fixed N", then some addition of P is needed to maximize yields. Another advantage to having adequate N in the system is that it allows varieties to express their full drought resistance characteristics. Coping with one stress is easier than coping with two.

Research in Mali has shown that grain yields do not always increase with applied N when conditions are extremely dry such as at the Bema location. However, in the higher rainfall regimes, yield increases are obtained with N application and the local varieties such as Tiemarifing have consistently higher N use efficiency than the improved types such as Malisor 84-7. Very often, the inherent superior

qualities of the improved types is masked by their susceptibility to pathogens or insect pests, and often by poor seed quality which results in poor stands. Nitrogen management packages have been developed for sorghum as a result of UNL-114 collaboration which are now being disseminated to local farmers.

Introduction

Sorghums and millets are generally grown in areas where stresses of various types persist. The most common stress which constrains grain and forage production is water because it is so obvious in its devastating effects to crops. However, a stress of major importance and often overlooked is nutrient stress. Where crops are grown continually without the benefit of fertilizer or other nutrient replenishing systems, soils are depleted of important minerals, and yields are constrained even when moisture is adequate.

Nutrient stresses can be largely relieved by two major methods i.e. better management including fertilizer additions if possible, and improving genotypes for nutrient use efficiency. Project UNL-114 has concentrated research efforts in both of these areas during the past 12-13 years. Additionally, some 24 students have completed advanced degrees in the project and returned to their home countries to conduct their own research programs and often assume roles of major leadership responsibility. UNL-114 project P.I.s have spent considerable time mentoring these former students and collaborating with them in their research programs. In this manner, UNL-114 has contributed directly to an LDC's capacity to resolve problems in one of their major targeted areas of constraint i.e. nutrient stress. As a result, several countries collaborating with INTSORMIL have made positive advances in the judicious use of fertilizers (particularly nitrogen) in cropping systems which enhance resistance to water stress and sustain production at higher levels. A part of this advance also lies in the fact that the project assisted in identifying methods for plant breeders to use in improving both sorghum and pearl millet genotypes for nutrient use efficiency and can now better cope with nutrient deficient soils. These same improved types also respond better to good management, especially when moisture is favorable.

Objectives, Production and Utilization Constraints

Objectives

Identify sorghum and pearl millet genotypes which are superior in nutrient use efficiency (primarily nitrogen).

Determine the physiological and morphological mechanisms which allow genotypes to be nutrient use efficient.

Quantify the effects of environment on genetic response at different soil fertilities (primarily nitrogen).

Determine optimum nitrogen and phosphorus management practices for arid and semi-arid environments.

Provide long and short term training experiences for students and scientists of collaborating institutions, as well as certain technical expertise for collaborative efforts related to overall INTSORMIL objectives.

Constraints

Soil nutrient deficiency stresses.

Lack of adequate nutrient use efficiency in current sorghum and pearl millet cultivars.

Inadequate knowledge of proper management practices to help cope with nutrient stresses.

Lack of technically trained personnel who can devise and carry out sound research programs.

Research Approach and Project Output

International

Philippines 1981 - 1986

The objective of this research was to develop sorghum as an alternative to corn as a feed and potential food for the Philippines. The work was concentrated on finding sorghum genotypes suitable for both paddy and nonpaddy rice cropping systems. Within the paddy systems, a lot of effort was made to find proper management procedures so stands could be established and the crop could grow in the heavily puddled soil structure remaining after the rice crop was removed. In the upland areas, complete production packages were devised and included varieties, pest control procedures and fertilizers. On-farm trials were initiated to demonstrate the feasibility of producing sorghum in the dry season as a corn alternative. Considerable effort was spent on evaluating economic production costs and marketing potential including various uses of the grain for both animal and human consumption.

The most important output from the INTSORMIL funded research was identification of variety VG 146 which showed promise as a potential yield improving type for either feed or food use. Trials in 1985 showed the variety outproduced the local type by as much as 43%, reaching 4 mg ha^{-1} which made it economically better than corn even though the sorghum market price was lower. Variety VG 146 is the same variety as Sureño, a dual purpose grain/forage cultivar released in Honduras and recommended for 10-20% of the country's total acreage. In addition, VG 146 gained in popularity as a specialty crop because it could be "popped" and consumed as food, a practice not common for sorghum in the Philippines. Since this is a variety rather than a hybrid, seed production would be relatively simple and the cost minimal and affordable by most farmers in the region.

The "on-farm" demonstration/research trials showed that during the January-April cycle, three fertilizer levels were economically feasible. However, there was a strong interaction between fertilizer level and growing cycle as the March-June cycle did not require fertilizer levels similar to those of the early cycle. This was thought to be due to the dry condition of the soil during the latter cycle.

Experiments on sorghum production following lowland rice showed that 5 to 10 days after rice harvest was the best time to plant sorghum. Tillage of the bunded paddy enhanced emergence and resultant yield. Germination was highest if seeds were planted 3 to 5 cm deep. It was also shown that early maturing sorghums are best fitted to the post-rice condition. Under the best conditions, sorghum yields were as high as 2.9 Mg/ha^{-1}.

Economics of producing the crop were favorable, but market price dependent. As a rule, corn imports from the U.S. or other sources greatly influenced a millers decision to buy locally produced grains. High local production tended to force prices downward with no or little government stabilization of price which often proved to be a disincentive for sorghum production.

Brazil and Colombia 1981-1988

Research by Dr. R. B. Clark in these countries centered primarily on developing laboratory and field methods of screening for mineral element tolerances, primarily aluminum relating to acid soils and low phosphorus conditions.

A laboratory procedure was developed and published to screen sorghum in nutrient solution for high aluminum tolerance at the seedling stage. The procedure was significantly correlated to sorghum response in the field under acid soil conditions. About 10,000 sample analyses were made annually at Nebraska relative to mineral tolerances and efficiencies with about half of these coming from Brazil and Colombia. These results were used to help define the mechanisms of tolerance.

The research showed that all mineral elements were affected by acid soil stresses, but that silicon and calcium in plant tissue were most closely related to acid soil tolerance. Silicon nutrition could alleviate some symptoms of aluminum and manganese toxicity. High silicon concentrations had no visual toxicity symptoms or caused any dry matter yield reductions in sorghum.

Sorghums screened by a newly developed screening test in the laboratory were identified as tolerant or susceptible to acid soils and grown on an acid soil at Quilichao, Colombia, South America at 40% and 60% aluminum saturation to evaluate growth traits. Sorghum genotypes identified as being tolerant showed favorable growth and yield traits when grown under relatively severe acid conditions i.e. 60% Al-Sat and pH 4.1. High concentrations of leaf calcium and silicon may have reduced the effects of toxic aluminum.

Studies were conducted on the effects of mycorrhizal (VAM) colonizations on growth and phosphorus nutrition in sorghum. It was shown that VAM infected plants produced 14 times as much shoot and 13 times as much root dry matter as uninfected plants. Higher concentrations of phosphorus and some other elements also occurred. The higher P uptake of the VAM plants was attributed to a larger surface absorption area because of root proliferation as well as to VAM hyphae external to the root. These results indicated that a strong VAM association in sorghum production can assist the extraction of P from low P soils and partially alleviate deficiencies in the plant tissue. However, VAM colonization was greatly retarded in high aluminum and low pH soils. Mycorrhizal associations did not affect genotype tolerance to aluminum.

Niger 1988 - present

Project UNL-114 research has been concentrated on pearl millet exclusively in this country. The work was conducted at Maradi research station by Mr. Cherif Oumarou and Mr. Seyni Sirifi in the initiation stages. Mr. Sirifi later came to Nebraska for M.S. studies and graduated in August, 1993. The Maradi trials were set up to determine the response of millet varieties to N rate under these relatively dry conditions and sandy soils. Three varieties were used being hill planted and grown at four N rates including 0 kg/ha as control. Seasonal precipitation was a little more than 500 mm per season.

The results showed that all varieties responded to N application even though rainfall was rather low. For the varieties tested, 45 kg/ha appeared to be at or near the optimum rate for a one Mg grain yield per hectare using urea. It appeared evident that some inputs of nitrogen will be needed to boost yields in either wet or moderately dry years. If a legume/pearl millet rotation is used to obtain "fixed" N from the atmosphere, then some phosphorus fertilizer will be needed to insure adequate legume growth and yield. Cereals can also take advantage of any residual P in the rotation since that element does not leach or volatilize. Another advantage to having adequate N in the system is that it allows varieties to express their full genetic drought resistant characteristics. Coping with one stress i.e. drought, is easier than coping with a combination of two, i.e., drought plus N (or phosphorus).

Since Mr. Sirifi's return, plans are underway to switch to research on either pearl millet or sorghum and the place of these crops in vegetable or horticultural cropping systems. Research objectives and approaches are being formulated in Niger to initiate this program under the guidance of Mr. Sirifi and in collaboration with INTSORMIL PI's.

Mali 1988 - present

Research in Mali has been concentrated on sorghum and proper N management for this crop in the higher rainfall areas where fertilizer responses can consistently be ex-

pected. Another phase of the collaboration has focused on developing methodology to measure N use efficiency for varietal improvement as well as to make better judgements on management options.

Research 1988-1991 (Abdoulaye Traore). A series of experiments were conducted using local and improved sorghums to test yield response to rate and time of N application. The experiments were conducted at either two or three locations ranging in precipitation from very low to average. The results have generally shown that the improved types respond more favorably to N application than the local providing that good stands are established and pests can be effectively controlled. The local sorghum produced greater amounts of forage (stem material) in comparison to its grain production which is a valuable resource in this region. It was evident from the research that a good N management program will require splitting the N application into two growth periods. The first is generally to apply 1/4 to 1/2 of the intended rate at planting and the remainder at either tillering or preboot.

Overall N use efficiency was slightly better for the improved types than the local at higher rates of applied N. However, the local had higher N use efficiency at zero or very low N rates.

When sorghums were compared for N response in a very dry location (350 - 400 mm), it was found that grain yields did not increase with applied N. There was some evidence that stover production was higher with some N fertilizer in improved types, but not conclusive.

1992 Research (Abdoul Toure). Four genotypes (CSM-388, Tiemarifing, S-34, and Malisor 84-7) were compared at five nitrogen levels (0, 40, 80, 120 and 160 kg/ha) at Sotuba and N'Tarla. CSM-388 and Tiemarifing were used as local types and S-34 and Malisor 84-7 as improved types. The Sotuba location is characterized by a loamy sand soil type with an average annual precipitation of 975 mm over 42 years and N'Tarla by a sandy loam soil with an average annual precipitation of 875 mm over 42 years. At Sotuba, the plot received 50 kg/ha N in 1991 and 100 kg/ha of major nutrient in 1992. At the N'Tarla location in 1993, the plot received 300 kg of tri-calcic phosphate (natural phosphate of Tilemsi) and 5000 kg/ha of manure.

Parameters of interest were grain and stover yields, NE1 as the ratio of plant total biomass to plant total N and NE2 as the ratio of plant total grain weight to plant total N (Maranville, 1980). However, because of financial problems related to the cost of plant analysis, N use efficiency was finally calculated as the difference between treatment grain yield and the check grain yield divided by the fertilizer N applied on the treatment assuming that the soil N content in the experimental plots was at the same level.

The differences for both stover and grain produced were significantly different among genotypes and N rates at the N'Tarla location. There was no genotype x fertility rate interaction. The variety Tiemarifing was the highest yielding genotype and Malisor 84-7 the lowest. The low yield of Malisor 84-7 may be explained by its poor seed quality which affected the plant population. An estimated yield from a regression analysis of grain and stover yield and plant population may give a better yield potential of Malisor 84-7. Nitrogen efficiency calculated as a factor of yield increase per N applied resulted in the variety Tiemarifing having the highest overall N use efficiency followed by S-34. Variety CSM-388 had the lowest. Each variety reacted differently to increased N levels, but generally decreased as N was increased up to 120 kg ha^{-1}.

Yields from the Sotuba location were statistically different among genotypes, but only for grain when increased N was applied. Similar to the N'Tarla location, Tiemarifing yielded the most and Malisor 84-7 the least over all N levels. Nitrogen use efficiency was much lower, and at times, even negative at the Sotuba location indicating that some N rates resulted in yield reductions. Overall, Tiemarifing was the highest and Malisor 84-7 the lowest, and N use efficiency decreased up to the 120 kg ha^{-1} level similar to the N'Tarla results. The negative values observed were due mainly to lack of a good stand more than the inherent value of the variety.

With the return of Mr. Abdoul Toure to Mali (M.S. Nebraska, 1992), a new research direction is being proposed for UNL-114 collaboration. The following area of research was devised for implementation.

Research Area: Sorghum Responses to N fertilizer in Relation to the Previous Crop

Objectives

Assess the influence of various legumes or cereals as a previous crop to sorghum production.

Evaluate proper N fertilizer needs to maximize yields of sorghum in relation to legume or cereal previous crop.

Define physiological parameters associated with increased yields under proper N and crop rotation management schemes.

Evaluate several sorghum genotypes for production potential in crop rotation schemes.

Make economic analyses to maximize yields at efficient monetary inputs.

The experiments are planned for six years and include three legumes on two cereals in rotation. Fertilizer inputs include manure alternating with variable rates of N (0 kg ha^{-1} to 80 kg ha^{-1}) every other year. The proposed scheme is as follows:

Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
cowpea (C)	sorghum	C	S	C	S
peanut (P)	sorghum	P	S	P	S
dolicos (D)	sorghum	D	S	D	S
sorghum (S)	sorghum	S	S	F_1	F_2
millet (M)	sorghum	M	S	F_1	F_2
millet (M)	sorghum	M	S	St_1	St_2
millet (M)	sorghum	C	S	St_1	St_2
millet (M)	sorghum	P	S	C	S

Manure will be applied years one and three (0 kg ha^{-1} vs 1000 kg ha^{-1}) and N fertilizer will be applied to sorghum only in years two and four. At least two locations will be used (Sotuba and Cinzana) having different total rainfall. Residues will be utilized in part for animal feed and in part for mulch. General agronomic and physiological data will be collected each year, and economic assessments made during the third year and thereafter.

The experiment is designed to bring several research disciplines together, and eventually lead to on farm demonstrations of certain rotational systems which may include some fertilizer inputs.

Domestic

Pearl Millet

Studies on this crop were conducted by one student from Mali and one from Niger in pursuit of an M.S. degree. The studies were similar in that pearl millet genotypes were tested from their response to N fertility in soils having relatively high residual N or N release properties. One of the studies also incorporated three soil moisture regimes. The genotypes chosen were either African or Indian local landraces or improved types generally of shorter stature.

Results of the first thesis (Abdoul Toure) showed that the pearl millet crop did not respond very well to N application from 28 to 112 kg ha^{-1} rates. This was not surprising since other researchers have shown the same thing when the crop is grown on soils to which it is not normally adapted. There was a tendency for the improved millet to increase in grain yield with increased N but not stover. The landrace millet had a maximum production at the lowest N rate applied.

If N application was split at the higher rates (applied at planting and preboot), there was a tendency for grain and stover yields to increase slightly. Nitrogen use efficiency (dry matter produced per unit N uptake) was decreased with increasing N rate, but was not affected by splitting the application. Generally, pearl millet response to N rate, N application timing (early vs. late) and splitting of the rate was genotype dependent.

Results of the second thesis (Seyni Sirifi) which incorporated a broader range of genotypes and soil moisture conditions than the first experiment, showed that improved genotypes took advantage of good management better than the unimproved i.e. landrace types. There was often a genotype by N rate interaction in the high moisture situation indicating that soil moisture influenced genotypes differently in their response to N. Only slight increases occurred in grain yield with increased N rates at low or moderate soil moisture conditions in these high N release soils.

Nitrogen use efficiency (biomass produced per unit N uptake) differed among genotypes, showed the normal decline with increased N application, and was not greatly influenced by soil moisture status. The highest N use efficiencies were found in the landrace types and the lowest in the improved types. Water use efficiency did not vary among genotypes significantly although there was a tendency for those with greater grain or total biomass production to have greater water use efficiencies. Genotypes with the greatest leaf area index were the best grain producers.

Sorghum

Study 1 (Cassim Masi)

Field and greenhouse experiments were conducted in year 14 to investigate the role of sorghum roots in the uptake of N under varied soil and climatic environments. Ten genotypes of diverse origin were chosen for the study based on recommendations from David Andrews (Project UNL-115). Genotypes were grown in the field under low N conditions for total N uptake, biomass and grain production, and N use efficiency for grain or biomass. The test site had been previously depleted of N by growing continuous sorghum without fertility for the previous two years.

Table 1 shows the grain, biomass, total N and N use efficiency values of the 10 selected genotypes on a per plant basis. Genotypes CE151 produced the greatest amount of both total biomass and grain. Even though TX631B produced a lot of total biomass, its grain yield was relatively low. The genotype WSV387 had good grain yield in relation to its total biomass production. Generally, total N per plant was a function of the total biomass produced as indicated by genotypes CE151, TX631B and WSV387 having high total N values.

Nitrogen use efficiency for biomass production (NE1) was highest for TX631B followed closely by PI8358 and M90378R. The best genotypes relative to N use efficiency for grain (NE2) were M90378R, CE151 and WSV387 which was obviously related to their ability to yield substantial grain under depleted soil N. The lowest in NE2 was TX631B.

Root morphology was determined in greenhouse experiments using a procedure developed at Nebraska to describe branching through fractal dimensions. Plants are grown in

Table 1. Average grain yields, biomass, N uptake, NE1 and NE2 of field grown sorghum genotypes at the physiolo cal maturity, Mead, 1992.

Genotype	Grain wt. g plant^{-1}	Biomass wt. g plant^{-1}	Plant N* g plant^{-1}	NE1	NE2
				- - - g DM/g N - - -	
TX631B	49.78	198.16	1.44	137.42	34.52
KS57	57.18	120.13	1.16	103.20	49.12
PI8358	44.66	133.62	1.06	125.48	41.94
TX631A x WSV387	50.16	142.19	1.30	109.10	38.48
TX631A x M90378R	53.23	107.57	1.15	93.78	46.41
Naga White	55.54	134.62	1.16	115.67	47.73
M90378R	60.12	134.43	1.06	126.71	56.67
CE151	125.90	246.96	2.29	107.77	54.94
IR[illegible] 5	51.90	94.54	1.10	85.85	47.13
WSV387	74.92	136.41	1.47	92.94	51.04

Means calculated on the basis of three replications and three plants.

*Plant N is total N concentration from grain, stem and leaves.

Biomass wt. does not include root dry matter.

peg boxes (120 cm x 120 cm x 5 cm) in 4:1 sand/soil mixtures. At the 12-leaf growth stage, the soil mix is washed from the roots which stay in place by being suspended on the closely spaced pegs. Photographs are taken of 9 equal segments of the root system (each segment is 1025 cm^2 of the rooting surface area), and the fractal dimension determined by the published procedure (see Eghball, B., J.R. Settimi, J.W. Maranville and A.M. Parkhurst 1993). Fractal analysis for morphological description of corn roots under nitrogen stress. Agron. J. 85:287-289). The procedure estimates the amount of root branching as well as root abundance.

Table 2 shows that the greatest branching occurred with WSV 387 closed followed by its hybrid TX631A x WSV 387. The least amount of branching was found in KS57B.

The genotype with the greatest abundance of roots in the profile was IR 204 followed by Naga White. The genotype with the least abundance was the one with the greatest branching (per unit rooting surface) or WSV 387.

Table 2. Means of values for fractal dimension (branching) and root abundance of ten sorghum genotypes grown in peg boxes in greenhouse experiments.

Genotype	Fractal dimension (Branching)	Slope (Abundance)
WSV 387	1.93	1.01
TX 631A x WSV 387	1.88	1.10
M 90378 R	1.84	1.07
Naga White	1.84	1.13
CE 151-262	1.82	1.08
TX 631A x M 90378 R	1.76	1.06
PI 8358	1.71	1.11
IR 204	1.71	1.18
TX 631 B	1.69	1.06
KS 57 B	1.62	1.07

The genotypes with the greatest abundance of roots di not coincide with those producing the greatest amount c biomass (Table 1) in these separate experiments. Genotype WSV387 and M90378R which had relatively high grai yields also produced highly branched rooting pattern: There appeared to be little relation between N use efficiene traits and root branching or abundance. Further studies wit roots extracted from field grain plants are being conducte

Study 2 (Abdoulaye Traore)

Studies were conducted with sorghum to understan better the uptake and metabolism of nitrate and its influenc on N use efficiency. Field and greenhouse experiments wer used to study 15 sorghum genotypes from the programs o Professor David Andrews (UNL-115) regarding how nitrat is related to growth and N use efficiency. The field experi ments were grown near Mead, NE at a site previousl depleted of N. Two levels of N were used (0 kg ha^{-1} and 10 kg ha^{-1}), and water stress was not a factor.

Results of the field study (Table 3) showed that VG14 accumulated the highest reduced N content followed b S34. These are both tall types which produced a lot of tota biomass. These two genotypes also appeared to retain th highest quantity of NO_3- in the tissue. However, the tota NO_3- appeared to be more a function of biomass accumula tion than NO_3- concentration since the concentrations wer relatively low. Hoegemeyer hybrid H640 had high reduced N levels but was among those low in total NO_3- and NO_3 concentration. Low NO_3- content or concentration in tissue indicates efficiency in reducing that ion to a useable form. The less NO_3- and reduced N retained in the tissue, the greater the efficiency of N utilization.

Figure 1 shows that NO_3- concentration is higher in stem tissue than leaves, is higher in fertilized than unfertilized plots, and decreases with age.

Nitrogen use efficiency for biomass production is calculated as total above ground dry matter per unit reduced N

Table 3. Means of total N plant^{-1}, NO_3^- plant^{-1} and NO_3^- concentration at physiological maturity in 15 sorghum genotypes grown in the field at two soil N levels.

	Total N		Total NO_3^-		NO_3^-conc.	
Genotype	0 kg	100 kg	0 kg	100 kg	0 kg	100 kg
	g plant^{-1}		mg plant^{-1}		%	
M-35-1	58.3	74.3	8.5	12.6	.032	.046
P720	73.1	72.2	10.3	12.5	.043	.046
VG146	119.9	133.1	17.8	18.3	.022	.025
TX7078	67.3	65.8	7.0	14.4	.023	.038
873151	82.0	89.8	8.9	14.0	.024	.036
87034	59.0	68.6	10.9	8.0	.021	.033
SC56	64.1	74.5	9.8	9.8	.029	.028
Martin B	85.7	95.5	8.0	16.8	.020	.051
CK60	77.1	89.7	13.0	13.7	.035	.032
Malisor 84-7	88.4	93.0	16.5	22.2	.031	.041
S34	110.2	131.0	18.0	35.1	.025	.046
P8855	75.5	78.6	9.7	16.6	.040	.067
HH640	106.1	107.2	8.1	12.7	.020	.037
G1422	68.7	59.6	7.6	7.7	.031	.028
NK5356R	79.3	105.0	8.5	17.4	.027	.050

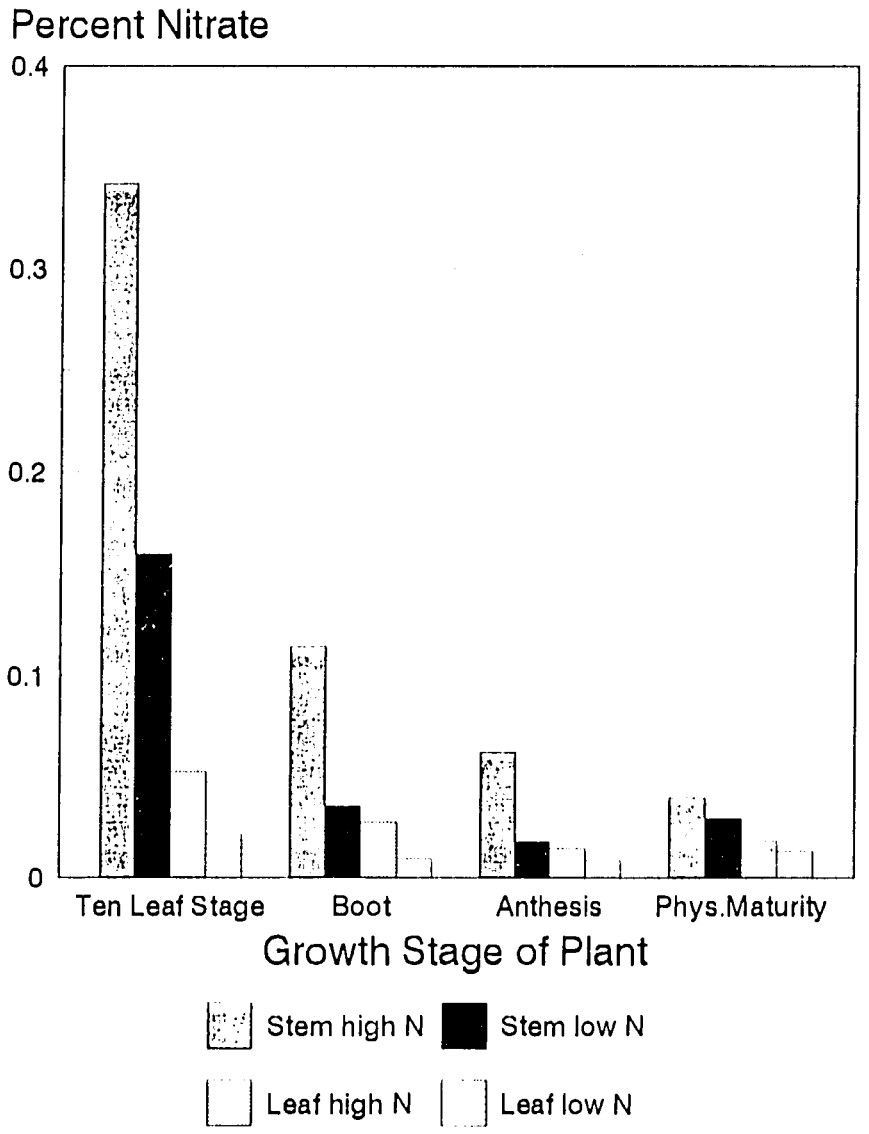

Figure 1. Means of nitrate concentration in 15 grain sorghums grown at low and high soil N levels.

Table 4. Nitrogen use efficiency (NE1) values for 15 sorghum genotypes grown at two soil N levels calculated wi and without the tissue nitrate N content.

Genotype	Low fertility		High fertility	
	without NO_3 N	with NO_3 N	without NO_3 N	with NO_3 N
	g g^{-1}			
VG146	145.1	144.4	84.7	83.9
Malisor 84-7	123.1	122.5	68.7	68.4
873151	107.1	106.9	63.8	63.7
S34	107.1	106.9	75.1	74.8
NK535GR	107.0	106.7	71.2	71.0
HH640	100.7	100.5	66.6	66.5
CK60	97.1	96.7	69.9	69.7
G1422	95.8	95.6	73.4	73.3
P8855	92.4	92.1	66.5	66.3
Martin B	89.5	89.4	60.4	60.3
TX7078	86.7	86.5	50.5	50.4
SC56	82.7	81.8	58.8	58.7
87034	80.1	79.9	62.7	62.6
M35-1	75.6	75.5	57.3	57.2
P720	74.0	73.8	62.8	62.6

Table 5. Nitrate reductase activity in 15 sorghum genotypes as a mean of two greenhouse experiments replicat four times each.

Genotype	Activity	Genotype	Activity	Genotype	Activity
	µmole g^{-1} h^{-1}		µmole g^{-1} h^{-1}		µmole g^{-1} h^{-1}
TX7078	2.82	S34	2.43	CK60	2.00
M35-1	2.69	SC56	2.41	VG146	2.00
873151	2.54	P8555	2.02	NK535GR	1.84
Martin B	2.53	G1422	2.01	87034	1.71
P720	2.52	HH640	2.01	Malisor 84-7	1.65

according to the definition of Maranville, Clark and Ross (J. Plant Nut. 2:577-589, 1980). This has been designated as NE1. Table 4 shows NE1 values for 15 sorghum genotypes calculated with only reduced N remaining in tissue or with nitrate N added. These results indicate that very little change in the NE1 value occurs with the inclusion of nitrate N, and genotype rank does not change any. Therefore, calculating NE1 in the traditional manner is sufficient and saves the expense of having to do nitrate analysis.

The capacity to reduce nitrate to a useable form is mediated to a certain extent by nitrate reductase activity. Anything which reduces the activity of this enzyme, such as water stress results in accumulation of nitrate which affects growth potential. Genotypes which do not accumulate nitrate in tissues are presumed to be more N use efficient as shown in Table 4. Genotypes varied in the nitrate reductase potential (Table 5) indicating a metabolic difference in at least one component of N use efficiency. In a greenhouse experiment, the highest nitrate reductase activity was found in TX7078 followed by M35-1. NE1 did not relate well to nitrate reductase activity (r = .041), and shows that N use efficiency is very complex with many factors involved, and which needs much further study.

Networking Activities

Chaired a committee which planned and carried out workshop at the University of Nebraska entitled: "Adapt tion of Plants to Soil Stresses".

UNL-114 supplied $9000 to Mali for collaborative r search in nitrogen agronomy and physiology.

Traveled to Mali exclusively on UNL-114 funds to pla new phases of collaborating in both agronomy and physio ogy.

Publications andPresentations

Publications

Youngquist, J.B., P. Bramel-Cox and J.W. Maranville. 1992. Evaluation alternative screening criteria for selecting nitrogen use efficient gen types in sorghum. Crop Sci. 32:1310-1313.

Sinfi, S. 1993. Nitrogen uptake and utilization by pearl millet grown different soil moisture and nitrogen regimes. M.S. Thesis. Universit of Nebraska. 93 pp.

Presentations

Made presentation to the External Evaluation Panel of INTSORMIL rela tive to Nebraska projects dealing with UNL-114.

Physiologically Derived Cultural and Genetic Enhancements of Water and Temperature Stress Induced Limitations

Project UNL-116

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Ermson Nyakatawa, Zimbabwe
Rachel N. Msikita, Zambia
Timothy Schilling, SPARC Project, Bamako, Mali

Summary

A workable preanthesis stress screening program based on yield component analyses to help identify the time of stress damages was developed. Knowing the times of damage are required (1) in order to fine tune the application of stress and (2) to permit sensible stress mechanism research. Growth related responses determining seed number and seed size are more sensitive to stresses than is photosynthesis (PS) or stomatal activity. Testing the screening methodology involved a population type approach because stress resistance is complex - it involves either complex processes or a large number of simple processes interacting simultaneously to produce complex consequences. In either event high numbers of recombinations, which can be achieved cheaply through genetic sterility (and other ways as well if resources are available) are required. One stress resistant population which is primarily good quality light colored seed from tan plants is being released. The population is currently being used in six countries and will soon be available to private breeders.

Current stress research is centered on preanthesis stress mechanisms (metabolic efficiency, heat shock protein development, etc.) and post anthesis stress research as it relates to improving seed size. Improving seed size capacity is probably a valuable preanthesis stress compensating factor. Modest seed size capacity also holds sorghum yield potential low compared to maize under good conditions.

Legume stress screening methodology is being developed to improve N fixation in sorghum and millet based cropping systems.

Introduction

Water and temperature stresses are the two foremost abiotic stresses limiting sorghum and millet production. Water stress is almost always limiting in both the SAT and the US Great Plains. Furthermore, water stress is almost always accompanied by high temperature stress. Minimizing the damages caused by these stresses can be accomplished by (1) screening for stress resistances to improve genotypes and (2) developing cultural practices which minimize the stresses.

Recognition of these realities by the INTSORMIL program development group assembled by USAID at the University of Missouri in 1978 led to the following Missouri program objectives (direct quotes) to be addressed at the University of Nebraska within grant financial constraints.

Selecting for Drought Resistance in GS - Nebraska: Objectives: 1) define physiological characteristics most affected by drought stress, 2) identify tolerance and avoidance mechanisms, 3) develop and apply practical techniques for screening and selecting in U.S. and LDC's.

Temperature Stress in GS/PM - Nebraska: Objectives: 1) determine yield response to temperatures at critical development stages, 2) determine range in different genotype responses, 3) determine mechanisms responsible for favorable responses, 4) develop breeder screening techniques.

GS Grain Fill Period - Nebraska: Objectives: 1) determine variability in length of grain fill, 2) develop new lines with extended grain fill period, 3) test new hybrids with this characteristic.

Adaptation and Yield Stability - Nebraska: Objectives: 1) study adaptation and yield stability under wide range of conditions of lines and hybrids, 2) determine trait association with stability and adaptability, 3) develop populations for genetic source pool with these characteristics.

Research addressing these issues is necessarily both (1) basic in nature to expose and evaluate stress resistance mechanisms and (2) applied in nature to achieve the development of stress screening techniques and practical application of them. The latter objective has required the integration of physiology and breeding research, particularly in the development of practical field stress screening techniques and extended grain fill period research. This part of the research was a pointed effort, as specified in the Missouri USAID contract objective above, to apply physiological research to the development of practical field screening techniques. An effective preanthesis field stress screening technique has, in fact, been devised and a stress resistant tan plant population for midseason preanthesis stress has been developed using this field screening technique. This population has been or is being used in Niger, Senegal, Sudan, Egypt, Mexico and the US by public breeders and will be released soon to commercial companies. Also AN96 and RN91 have been released. The female parent A96 is being used commercially by at least one company in Mexico. Also its hybrids have performed well in Senegal and are being evaluated in Egypt. Derivatives of A96 x U.S. grain B lines are often found at the top of stress tests in the U.S. RN91 is not being used commercially in the U.S. to our knowledge since the hybrids tend to be about six inches too tall. RN91 is being used in commercial breeding programs because of its stress resistance and relatively high yield.

An improved millet/cowpea intercropping system in Niger demonstrated 20 to 60% higher cowpea yields and 20 to 40% higher millet total dry matter yield (see next section). The level of utilization is unknown.

The greatest contribution from this project has been students trained and either returned home or will soon. They include students from Nigeria (1), India (3), Sudan (1), Zambia (1), Zimbabwe (2), Botswana (1), Egypt (2), Mexico (4) and the U.S. (4), plus serving on committees and helping with the research of many others. Sorghum developmental descriptions and associated growth stage terminology have been used in the training of most students who passed through ICRISAT over the last 15 years. Research knowledge gained has been used heavily the last 5 years as a cooperating scientist over the past 5 years in the India/USDA OICD research program utilizing PL480 funds. Two substantial programs on improving genotypes to supersede M35-1 are involved where our stress screening appears very useful. There are also two cultural practices intercropping/relay cropping projects and one very basic legume improvement program at the biochemical level.

Objectives, Production and Utilization Constraints

The importance of drought, temperature and general adaptation constraints are outlined in the "Introduction" in terms of how they relate stress screening and stress mechanism research to genetic improvement. Over half of the effort in this project has been directed to stress screening and mechanism research. The remainder has been directed to cultural improvement of production under the same water and temperature constraints. Three areas emphasized are improving pearl millet/cowpea intercropping systems, developing legume stress resistance screening methodology and developing seedling emergence screening methods. Emphasis on enhancing legume production in sorghum based cropping systems is critical because improving sorghum or pearl millet yields depends on improving legume production where N fertilizer is too expensive for farmers to buy.

Objectives

1. Develop preanthesis stress screening methodology

2. Conduct limited stress mechanism research in conjunction with stress screening.

3. Improve pearl millet/cowpea intercropping in Niger

4. Legume stress screening

5. Expand grain fill duration and grain metabolism research to increase seed size because (a) in LDC's there is a consumer large seed preference for human consumption and U.S. feeders have a large seed preference to decrease feed preparation costs and increase starch availability which are utilization constraints, (b) there are seed size implications as a post anthesis stress resistance mechanism to compensate for preanthesis seed number stress losses and, (c) large seed size capacity could be a mechanism to increase yields in favorable conditions more in line with maize yield potentials.

6. Develop seedling emergence screening methodology.

Research Approach and Project Output

Objectives 1 and 2

- Develop preanthesis stress screening and evaluate stress mechanisms

Stress screening is only marginally successful more often than not because (1) people generally do not acknowledge the complexity of the problem and end up viewing it too narrowly and (2) even with a perfect approach it is difficult because water stress magnifies field soil variability problems making CV's high. However, some simple but very basic assumptions which underlie our approach help make stress screening and stress mechanism research more under-

standable and useful. First grain production (work) is a function of metabolic productivity (how effectively the plant is working) and how long it works (effective rate x time). Metabolic considerations dictating effective metabolic productivity are photosynthetic assimilate supply, how tightly respiratory energy expenditure is coupled to essential synthetic activities (starch, protein, etc. syntheses) and the rate of metabolism. The time factor within the "effective rate x time" concept is simply how long the plant is working during different developmental stages.

An analysis of effective production rate x time is of limited value unless it is tied meaningfully to economic product - grain in this case. That is accomplished by analyzing yield in terms of yield components - that is its seed number (seed m^{-2}) and seed size (g 100^{-1}) components. A yield component analyses tells one when the yield limiting period(s) was and narrows the period(s) over which stress mechanism research should be conducted. Simple but functional growth stage terminology was developed by Eastin and Sullivan for this purpose. The vegetative stage prior to inflorescence initiation is GS_1 when stand establishment is determined, inflorescence initiation to anthesis is GS_2 when seed number potential is set; anthesis to black layer (physiological maturity) is GS_3 when seed size is set (within genetic limits). Obviously yield reductions caused by loss of seed number need to be evaluated primarily in terms of GS_2 events while seed size yield reductions will relate more to GS_3 events. GS_1 event limitations relate mostly to adequate germination, seedling emergence and seedling vigor to insure stands sufficient for favorable GS_2 and GS_3 performances.

Lee et al. (U.S.) and Dhopte (India) did a detailed time analysis of floret development over the entire GS_2 period of about 30 days. Microsporogenesis, megasporogenesis and fertilization events were emphasized. Eastin determined that GS_2 is a developmental stage where sorghum is very sensitive to temperatures less than 5 C either side of optimum. Ogunlela (Nigeria) regulated night canopy temperature in the field at 5 C above ambient and noted a 28% grain yield reduction at 15 to 21 days after panicle initiation which is during microsporogenesis and early megasporogenesis. Ambient plus 5 C from 7 to 14 days and 22 to 29 days caused yield reductions of about 20%. Dhopte used growth chamber and temperature controlled greenhouses to determine anatomically the nature of floret damage responsible for seed number reductions. Stress induced microsporogenesis damage centered in the tapetum which nurtures developing microspores. Stress induced damage disrupted nutrient absorption by the megaspore also. The ovule became nonviable concomitant with or by virtue of degeneration of the nucellus.

Tapetal damage is associated with excess callose production. Callose synthetase is considered to be a heat shock protein. Therefore, research on production of heat shock proteins (HSP), as a potential stress resistance mechanism, has been initiated in cooperation with Dr. James Partridge. Dr. P. Verma (India) found that a stress resistant hybrid produced a variety of HSP's in the panicle at 35 C. A normal hybrid produced fewer HSP's and generally only after the temperature reached 40 C, by which time stress damage had already occurred (1992 INTSORMIL Annual Report). HSP 70, one of the proteins produced in this case, is felt to have a stress protective function which fits generally with field observations of the normal and stress tolerant hybrids. The protective function theoretically relates to maintenance of proper protein folding but the functions of HSP's are not well understood. Nonetheless, it still may be possible to use HSP formation as a stress screening tool in the near future. This stress resistance mechanism research is continuing through 1994.

A second stress resistance mechanism effort relates to analyses of production (metabolic) efficiency differences between stress resistant and stress susceptible genotypes. One study showed that a stress resistant hybrid consumed only half the O_2 required to produce a gram of root dry matter as did a stress susceptible hybrid making the stress resistant hybrid twice as efficient in utilization of respiratory energy. Since root growth is very rapid during microsporogenesis and megasporogenesis, there appears to be a floral development (seed number)/vegetative expansion competition for available photoassimilates when seed number potential (and yield potential) is being set. The main difference, in fact, between the stress resistant and stress susceptible hybrids is that the latter has a more stable seeds m^{-2} under stress than the stress susceptible hybrid. No differences in photosynthetic capacities between the two hybrids have been noted in the field.

A third stress resistance mechanism study has dealt with measuring differences between canopy and air temperatures (DT). A negative DT indicates the canopy is cooler than the air by virtue of transpirational cooling. Roots are obviously exploring the soil to extract water, stomata are relative open and the plant is photosynthesizing. Stress resistance in genotypes of this type usually is due primarily to stress avoidance mechanisms (root exploration, etc.). Since sorghum generally is more of a stress avoider rather than tolerator, there usually is a negative correlation between canopy DT and yield which can be useful in stress screening. In addition, DT helps separate drought avoiding vs drought tolerating sorghums. If stomates close or roots fail to extract soil water to the point where canopy temperature exceeds air temperature appreciably, the plant will rely more on stress tolerating mechanisms to produce or survive. Identifying genotypes with tolerating versus avoiding mechanisms should be useful to plant breeders when targeting moderate stress environments versus severe stress environments. Contrasting genotypes will also be useful in stress mechanism studies.

Table 1. Grain and total dry weights (kg ha^{-1}) of millet in response to different amounts of crop residue left on th surface as a mulch (Quallam, Niger, 1988).

Residue applied t ha^{-1}	Grain weight	% increase in grain wt. over 0 t ha^{-1}	Total dry wt.	% increase in total dry wt. over 0 t ha^{-1}
0	191		743	
1	775	306	2621	253
2	1065	458	3321	347
3	1231	545	3581	382
$LSD_{.05}$	239		632	

Objective 3

- Improve pearl millet/cowpea intercropping in Niger

Major problems in Niger are drought, low fertility and stand establishment. A residue management experiment (Verma, Eastin) demonstrated the utility of residues. Table 1 shows respective increases in total dry matter yields for 1 and 2 tons of millet stover of 253 and 347% with respective grain yield increases of 306 and 458%. This highlights the importance of residues in controlling wind erosion to permit good stand establishment and subsequent nutrient release. Assuming the critical value of residues, parallel experiments were run to optimize soil nutrient status in millet/cowpea intercropping systems. The emphasis was on improving cowpea growth (to enhance N fixation) without decreasing or even increasing millet yields. Several treatments compared to the traditional intercropping system proved superior. The traditional system consisted of planting millet first and cowpeas about 2-3 weeks later which were quickly shaded by the millet. The most interesting, most practical and most appealing deviation from the traditional to farmers was to plant millet and cowpea simultaneously in equidistant rows (two millet to one cowpea row). The higher light level for cowpea increased total cowpea dry matter 53% and gave a 42% higher millet yield of 2514 kg/ha (the increase was 741 kg/ha - 742 kg was required for statistical significance). Water use efficiency was higher in the new system compared to the traditional system. The system was being tried in on-farm tests and appeared popular with farmers but program changes in Niger have not permitted us to see any recent results.

It is obvious in many developing countries that nutrient deficiencies are almost as limiting as water deficiencies. In developing countries where fertilizer costs are prohibitive, it is clear that if you want to increase the yields of millet or sorghum, the best way to do it is by increasing the yields of the intercropping or rotation cropping legumes in the system. This is the reason Mr. G. I. Gandoul is being trained for stress screening legume crops. It is also clear that greater use of legumes as fertilizer N substitutes is a more environmentally friendly practice in the U.S.

Objective 4

- Legume stress screening

Given the importance of legumes in sorghum/mille based cropping systems, as noted in the previous paragraph Mr. G. I. Gandoul has been trained for the benefit of Sudan and Eastern Africa in stress screening for legumes first in relation to N fixation as measured indirectly by growth and second in relation to monitoring physiological processes critical to N fixation, growth and efficient water use. Initial studies were with normal and dense pubescence soybean isolines since pubescence reportedly moderates leaf temperature and transpiration. Therefore, photosynthesis, transpiration and respiration were monitored under favorable and stress conditions and reported in the INTSORMIL 1989 Annual Report (p. 74). Results of pod formation are typical. The two isolines showed significant differences for four attributes. The dense pubescent isoline (CD) exhibited greater photosynthetic rates and IWUE while maintaining lower leaf temperatures and transpiration rates under stress. Averaged over water levels the CD isoline fixed significantly more CO_2 and used water more efficiently than the normal pubescent (CN) isoline under water limiting conditions, however, there were no significant differences under wetter conditions. Comparison between isolines at different moisture levels over 24 hour periods showed significant differences between isolines at each water level. The trend is always for higher PS and R rates under the higher water level. Under the lower moisture, CD exceeded CN for PS and R. Since N fixation is a high energy requiring process, monitoring PS is a reasonable way to determine likely energy availability for N fixation.

Since photosynthetic/transpiration equipment is not always available in developing countries, other means of testing for legume differences under limited water are needed. While photosynthesis is a classical measurement to make a much simpler and even more sensitive measurement in cell growth which can be reasonably estimated through the expansion of a leaf or extension of a stem for stress screening purposes. An experiment was conducted where CN and CD isolines were all placed in a 100 l container so roots intermingled to assure an identical water supply. Two water levels were used - fully irrigated and no water to

Table 2. Mean leaf extension rate (LER mm day^{-1}) and total leaf water potential (MPa) of dense (CD) normal (CN) pubescence Clark, and dense (HD) and normal (HN) pubescence Horosoy soybean isolines measured at three different days under wet and dry conditions.

	WET					
	Day 2		Day 3		Day 4	
Isoline	LER	MPa	LER	MPa	LER	MPa
CD	9.00a*	-0.58a	9.00a	-0.59a	3.75a	-1.13a
CN	5.25b	-0.66a	5.00b	-0.64a	2.50b	-1.31b
HD	10.25a	-0.56a	4.00c	-0.53a	4.75c	-1.07c
HN	6.25b	-0.64a	3.50c	-0.63a	6.00d	-1.23d
LSD (0.05)	2.79	-0.21	1.78	-0.17	1.27	-0.21
	DRY					
CD	8.25a	-1.16a	5.55a	-1.89a	5.25a	-1.81a
CN	4.25b	-1.17a	4.75b	-1.92a	6.00b	-1.87a
HD	9.75a	-1.00a	6.75a	-1.57a	5.00a	-1.68a
HN	6.50b	-1.16b	6.75a	-1.62a	5.00a	-1.73a
LSD (0.05)	3.76	-0.14	0.73	-0.39	0.78	-0.21

*Means within a column with same letter are not significantly different.

measure the comparative water potentials and leaf expansion extension (Table 2). The wet treatment serves as a standard and demonstrates that LER of the normal pubescent (CN - HN) lines are slower than the dense pubescent (CD and HD) isolines on day 2. After an additional day of drying the differences narrows but the CD LER is still faster than the CN. There is no difference between the HD and HN. A reversal occurs by day 3 because the CD leaves are fully expanded. Overall leaf extension trends between normal and dense pubescent isolines are the same as PS, R and transpiration trends. Observing comparative growth trends amongst various genotypes within a species or amongst species likely will give a useful indication of comparative stress resistances. Comparisons amongst species will be more difficult but still may be useful if developmental stage differences are taken into account. Even when equipment for PS, R, etc. is available, growth analyses done first will help narrow the numbers of genotypes on which to make detailed physiological (mechanistic) measurements. Mr. Gandoul's complete report will be filed in 1995.

Objective 5

- Expand grain fill duration and grain metabolism research to increase seed size and yield

Yield in cereal grains is a function of seed number and seed size. The seed size component of yield generally has a statistically significant positive correlation with grain yield. Past stress selection for a relatively high and stable seeds m^{-2} has allowed the development of a stress resistant sorghum population from which both stress resistant and high yield potential hybrids have been developed. The relatively high seed number in the hybrids has resulted in small seed size (2.3 to 2.5 g/100) as a rule. Housewives in DC's generally prefer medium to large seed. Also livestock feeders object to small seeds because they fracture less readily in roller mills, consequently may yield less readily available starch and require more energy to roll compared to corn. Therefore, increasing seed size is of interest from an economic point of view. Large seed size capacity is also of interest as a potential post anthesis stress resistance mechanism.

Two seed size problems bear attention. First, seed size often does not correlate positively with grain yield as does seed number. Second, seed number and seed size are negatively correlated. When seed size is moved up seed number generally decreases as does yield. These generalities have discouraged people from working as extensively on increasing seed size as on seed number. However discouraging this may be, as pointed out above there are housewife preferences and other economic processing reasons to increase seed size plus potential stress resistance reasons for large seed size capacity since seed size is the only yield compensation avenue available to a crop if preanthesis stress has reduced seed number. Can seed size be increased without suffering yield losses in general? A brief consideration of how developmental paces and times influence the seed number and seed size components of yield is in order. Observations from controlled environment studies follow.

Seeds m^{-2} is generally increased (exceptions exist) as length of GS_2 (inflorescence initiation to anthesis) is increased. Length of GS_2 is controlled mostly by temperature in temperate zone sorghums while both temperature and photoperiod responses are factors in many tropically adapted sorghums. Temperature controls metabolic pace which relates to developmental pace. Fast developmental pace reduces GS_2 length, reduces seed number and grain

yield. Slower developmental paces lengthen GS_2 and generally increase seed numbers and grain yields. Floral development is more adversely affected by a fast developmental pace than is simultaneous vegetative development. For example, 5 C above, a near optimal night temperature for several sorghums caused a 10-15% GS_2 reduction and resulted in seed number and yield reductions on the order of 25% with only a modest effect on vegetative production.

A similar higher temperature - rapid developmental pace response holds during GS_3 grain fill. A 5 C above near optimal night temperature reduces grain fill length 20% and more. The yield reduction picture is less consistent but is substantial. Clearly, developmental pace and metabolic pace are key factors in determining adaptation to a range of environments and the fitness of adaptation to any particular environment. This being the case, attention needs to be directed toward developing a quick means of classifying germplasm in terms of metabolic pace as it relates primarily to developmental pace and also production efficiency. Production efficiency (partly metabolic efficiency) will not be discussed generally here but needs to be recognized as a yield bearing factor along with developmental pace and developmental period length effects on grain yield and its seed number and seed size components.

Respiration seems to be the best general indicator of metabolic pace in a plant or plant part. This appears to be logical since respiration is coupled to and drives most essential plant synthetic activities except photosynthesis. Respiration is the means through which energy is transferred to drive essential syntheses. Therefore, variation in the pace of respiration should reflect variation in general metabolic pace except under more extreme environmental conditions where uncoupling between respiration and various essential syntheses occurs.

Most of our current effort relates to the influence of grain fill length and metabolic pace on seed size and yield. While most of our selections for midseason stress resistance have high seed numbers and small seeds, a few notable medium seed size selections were found (17473 and N91.) Yield test data of 17473 and N91 hybrids from two different females (Wheatland and TX 3042) caused us to begin evaluating the relationship between length of grain fill, seed size and grain yield. The Wheatland hybrids bloomed 5.3 days later and yielded 14% more than the Tx 3042 hybrids even though they had a 19% lower seeds m^{-2}. The yield compensation for a lower seed number came from a 26% higher seed weight in the Wheatland hybrids which was accounted for by a 10 day (33%) longer GS_3. These data suggest a more thorough evaluation of the influence of grain fill length (metabolic and developmental pace) on seed size and grain yield is in order. Taking grain fill lengths is a tedious, time consuming process. By contrast metabolic pace (and perhaps developmental pace or grain fill length) estimates can be made fairly rapidly through respiration rate measurements on developing panicles. Results from one 1993 population sampling are given in Figure 1. Respiration measurements are on plants which bloomed within 3 day of each other. The metabolic pace range in the stress toleran population (Fig. 1) at 26 C is about 22 to 62 μmol CO_2 k dry weight s^{-1} or a 3 fold response range. These measure ments illustrate that at any given bloom date within a popu lation there is considerable metabolic pace variability durin grain fill. In other words, GS_2 and GS_3 metabolic paces ar somewhat independent. Therefore, we should be able t select earlier bloom date plants with the hope of extendin grain fill length. We are now evaluating to see whether o not the variability in metabolic pace during grain fill can b used to select for longer grain fill length and larger seed siz (greater sink capacity) in grain sorghum. Judging fro comparative sorghum/corn yield testing, this may be a critical point to be addressed. Our results show that while cor and sorghum require similar season lengths, corn yield is about 30% more than sorghum and fills grain about 35% longer. Research on relating length of grain fill to seed size and yield is being continued by Ms. Rachel Ngulube Msiska from Zambia. It is a complex problem which will require considerable time to address.

Objective 6

- Developing seedling emergence screening methodology

Mr. Ermson Nyakatawa completed his M.S. thesis (1993) titled "Effect of Temperature and Soil Moisture Stress on Seedling Emergence Force of Selected Grain Sorghum (*Sorghum bicolor* (L.) Moench) Genotypes Under Simulated Soil Crust Strengths". Co-advisors were Jerry Eastin and Timothy Schilling. The emergence force of seedlings was measured by placing different weights on a piston which was moved vertically by developing seedlings. Maximum seedling force was generated at a 37/28 C day/night temperature combination. Soil moisture stress was inversely related to emergence force developed by seedlings which decreased linearly from 0 to -0.30 MPa. Genotypic spread was greatest in the soil water potential range of 0 to -2.0 MPa. Selected African sorghums adapted to soil crusting problem area generated more emergence force than TX 430 and PTX 3197. The technique holds promise of being a good laboratory screening tool and merits trial by plant breeders. A detailed report will be given in the INTSORMIL 1994 report.

Networking Activities

Research Investigator Exchanges

Hosted 10 short term Egyptian scientists, one three-month trainee, one two-year trainee. Visited Egypt twice on cooperative projects. Hosted a number of scientists from other countries also.

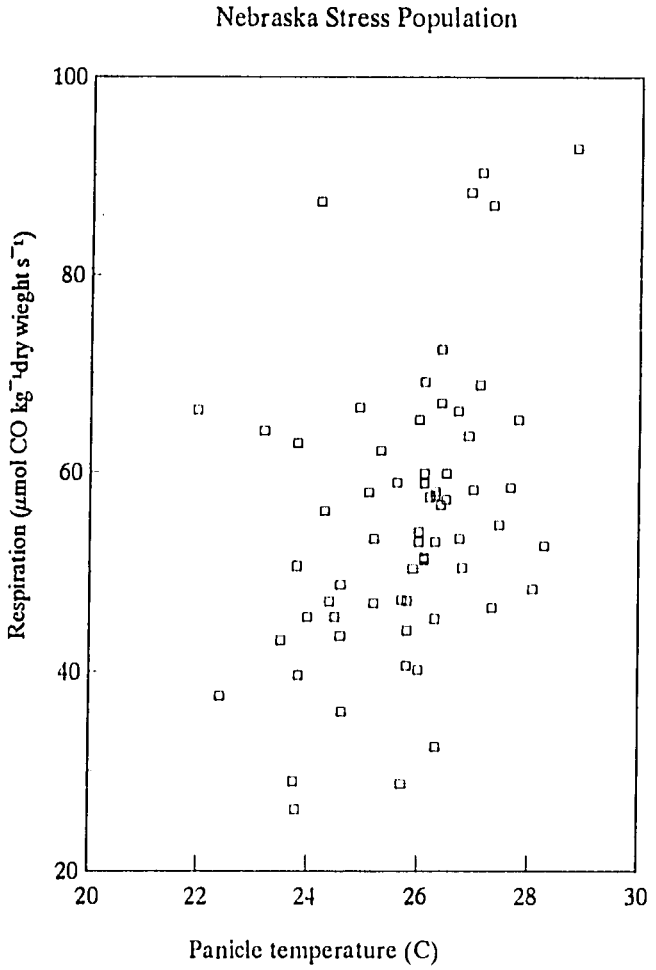

Figure 1. Respiration rates from panicles (18 days after anthesis) which bloomed within a two to three day period in a Nebraska stress population.

Germplasm and Research Information Exchange

Sent over 1000 lines to Egypt. Collected 180 seed size lines from the GA germplasm bank.

No new line releases.

Cultural practice research impact in Niger unknown due to political changes.

Publications and Presentations

Nyakatawa, Emmson Zuva. 1993. Effect of temperature and soil moisture stress on seedling emergence force of selected grain sorghum (*Sorghum bicolor* (L.) Moench) genotypes under simulated soil crust strengths. M.S. Dissertation, University of Nebraska, Lincoln, NE. pp. 1-72.

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Kubik, K.K, J.D. Eastin, and M.D. Clegg. 1993. Supersweet (Shrunken-2) sweet corn: strategies for improved stand establishment. Agronomy Abst. ASA-CSSA-SSSA Annual Meetings, November 7-12, Cincinnati, OH.

Mechanisms of Environmental Stress Resistance in Sorghum and Pearl Millet Relative to Sustainable Production Systems

Project UNL-123
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Summary

This project has been active since the inception of INTSORMIL. It has been primarily concerned with the physiology of drought and high temperature stress which constitutes a threat to crop production in most of the INTSORMIL collaborative countries and in many areas of the United States. A collaborative project was initiated with the Institute of Rural Economy (IER), Mali in 1981 and continued until the retirement of the P.I. in 1993.

The following were some of the highlights that occurred during this project:

It was shown that genotypes could be selected for tolerance of the photosynthetic mechanisms to stress. In this regard, heat tolerance of pearl millet was found to be higher than that of the sorghums. Plants evaluated in the field, greenhouses, and growth chambers, gave similar results. The line-source irrigation system was first used on this project to select for drought resistance in sorghums. Field and hydroponic studies of root systems revealed significant differences among genotypes for root weight, depth of growth, and water use efficiency. A method was developed to select for deep rooting sorghums. The involvement of abscisic acid (ABA) in stress resistance was studied. Foliar spraying of sorghums with ABA increased yields of some genotypes under drought stress, mainly due to increased seed numbers, while decreasing or having no effect on the yield of well watered plants. Seeds treated with ABA had increased germination, longer root growth, and better seedling tolerance to drought stress. The ABA treatment was more effective on stress susceptible genotypes. The accumulation of solutes, primarily sugars, in sorghum cells, or osmotic adjustment, during drought stress was found to contribute significantly to drought resistance, but differed among genotypes. Proline accumulation during stress was also shown to contribute to stress resistance, again with differences in response among genotypes. Those sorghums accumulating high amounts of proline had significantly greater heat and desiccation tolerance than those that accumulated less proline. Plants grown from seed produced in a stressful area in Mali had more seedling drought resistance than plants grown from seed of the same genotypes produced in a less stressful area. Those with greater stress resistance had higher concentrations of conjugated-ABA in germinating seed. Local Malian sorghums acclimated to environmental stress to a greater degree than introduced genotypes. The evaluation of adaptation to stress in Mali showed that the local Malian sorghums were superior in a combination of several physiological characteristics that were identified as contributing to drought and high temperature resistance, and that these characteristics can be selected in a breeding program. Sorghum pollen germinated in closed vials without added media, and viability was maintained for several hours when it was kept at high relative humidity and not allowed to desiccate. Progress was also made in the germination of pollen in liquid media, and often occurred within a few seconds.

Introduction

Environmental stress is a continued threat to crop production in many countries of the world as well as parts of the United States. Localized droughts and high temperature extremes may be devastating to crop production unless irrigation water is applied, and that is often not possible.

Sorghum and millet are recognized as crops that produce well under conditions of stress, although it is also recognized that improvements in their performance is possible through selection, breeding, and management. This project has been aimed at understanding the basic physiology and biochemistry of sorghum and millet stress resistance, and eventually incorporating the identified stress resistance factors into more stable, resistant genotypes in cooperation with the plant breeders, geneticists, pathologists, entomologists, and agronomists. A better understanding of the responses to stress is also helpful in making management and production decisions that improve the performance of these crops.

Objectives, Production and Utilization Constraints

Objectives

Define plant physiological and biochemical mechanisms involved in drought and high temperature stress resistance and identify those which may be selected or managed for improved resistance.

Develop and implement practical selection techniques for genotypes with desirable physiological responses, and identify cultural methods which will improve yield or yield stability in stressful situations.

Constraints

Environmental stress is a primary constraint, particularly drought and high temperatures. Germination, seedling emergence, stand establishment and drought, often accompanied by high temperatures, are major problems in Mali. This project is aimed at investigating some of the physiological mechanisms associated with performance under stressful conditions.

Research Approach and Project Output

Research Methods

Proline Accumulation and Stress Tolerance

Proline accumulates in plant tissues when they are exposed to drought and temperature stresses. These studies were a continuation of previous research. Plants were grown in growth chambers, greenhouse, and field and sampled at the desired stage of growth.

Heat and desiccation tolerance tests were performed on leaf disks by the conductivity method as previously described.

Pollen Viability and Germination.

Pollen was collected from plants when near 50% bloom early in the morning when the ambient relative humidity (RH) was 80-85%. For desiccation studies, pollen was exposed to an ambient RH of 50-55% and sampled periodically, then tested for viability. Viability was determined by the tetrazolium chloride test, by ability to germinate, or seed-set on male sterile plants. Pollen was rehydrated after desiccation by placing it in an atmosphere of 97% RH for 24 hours.

Abscisic Acid

Abscisic acid (ABA) was prepared in dilute aqueous solutions as previously described.

Field Research in Mali

Field research continued in Mali on responses of sorghum and millet to different drought and high temperature stress levels developed by plantings at different dates and locations in Cinzana, Bema and Sotuba. Plantings were made on different dates and comparisons in response made at different stress levels, taking into account the flowering date at a given time and level of stress. A bird-net system was constructed at Cinzana to protect plants in the off-season when the bird problem is at a maximum. Stress screening in the seedling stage also continued at Cinzana by use of the charcoal pits where high temperature and drought stress were induced at this stage of growth. The response of sorghums to fertilizer levels relative to water use and yield was studied at Bema.

Research Findings

Proline Accumulation and Stress Tolerance

Proline accumulation in sorghum leaves was previously shown to differ significantly among genotypes when they were drought stressed under field conditions. In further research in which root media water potentials were controlled by polyethylene glycol-8000, it was found that there were significant differences between genotypes in quantities of proline accumulating in roots, stems and leaves. It was further demonstrated that those sorghums accumulating high amounts of proline had significantly greater heat and desiccation tolerance than those that accumulated less proline. However, when plants were grown in high temperatures, the proline levels decreased, while cellular membrane stability to high temperatures increased. Landraces obtained from Mali had high heat and desiccation tolerance, and when water stress was relieved, they resumed growth more rapidly than U.S. sorghums, indicating less metabolic injury occurred during the stress.

In pollen, proline concentrations were found to increase when plants were exposed to low temperatures (20/10°C, day/night) and increased dramatically when plants were drought stressed. Seed-set positively correlated with pollen proline concentrations, suggesting that proline contributed to maintenance of pollen viability.

It was concluded that the accumulation of the amino acid proline when plants are exposed to stress is a protective mechanism, since membrane stability and pollen viability were improved in genotypes that accumulated the greatest quantities of proline. Screening for plants that accumulate more proline when stressed, at the same leaf water potential, would be desirable.

Pollen Viability and Germination

Considerable progress was made in defining the conditions needed for the germination of sorghum pollen. Pollen collected in an atmosphere of high RH usually germinated within 5 to 10 minutes without added media when kept in a closed vial at high relative humidity (RH 85%). In order to remain viable, the pollen could not be allowed to desiccate appreciably. It was found that sorghum pollen viability was completely lost in about 15 minutes exposure to a desiccating atmosphere. Pollen even in the sorghum head lost its viability before being shed later in the morning when the ambient humidity decreased and temperatures increased. It was questioned whether desiccated pollen would regain viability if rehydrated. Using plant growth chambers it was confirmed that pollen lost all viability in 15 to 30 minutes of exposure to a RH of 50 to 55%. Rehydration of the pollen at 95 to 97% RH did not restore its ability to germinate. By keeping the pollen hydrated, it was possible to quickly transfer it to a germination media and microscopically observe the germination process, which occurred in less than one minute and often within a few seconds. Pollen that germinated in liquid media always gave a positive reaction in the tetrazolium tests.

Prior to this study it was difficult to consistently germinate sorghum pollen *in vitro*, and this is necessary when studying maintenance of pollen viability. Numerous media were prepared containing different additives in an effort to accomplish consistent sorghum pollen germination. A basic media containing high molecular weight polyethylene glycol (PEG) was found to be the most successful (see publication, Lansac, et al.).

These results will be very useful in developing conditions for storage of sorghum pollen. Sorghum pollen has not been successfully stored for long periods of time, but it would be useful in crossing sorghums with different bloom dates.

Abscisic Acid

In previous research it was found that seed pretreated with dilute ABA solutions had increased drought resistance. To further investigate sorghum responses to ABA, some experiments were conducted in cooperation with a senior visiting scientist, in the UNL Agronomy Department, Dr. Abraham Blum, Ministry of Agriculture, Israel. Sorghum genotypes were grown hydroponically, with ABA added to the nutrient solution for uptake by the roots. Plants were drought stressed with PEG-8000. The stress alone reduced the relative growth rate (RGR) by 27% to 58%, with or without ABA, except in one genotype, SC326-6, when ABA was added the RGR was not reduced by stress, as compared to the controls.

The results continue to indicate that ABA has a major role in regulating stress resistance of some sorghums, since its accumulation may contribute to increased desiccation tolerance, seed germination, root growth, and even grain yields (due to increased seed numbers). Screening for plants with higher levels of endogenous ABA before stress occurs may be a method of selecting for potential drought resistance.

Research Results in Mali

The results of the Mali Agrophysiology Research have been reported in the proceedings of the Comite Du Programme Cultures Cerealieres Et Legumineuses, Bamako, 1993.

Networking Activities

Research Investigator Exchanges

After retirement of the P.I. of this project from the University of Nebraska, an invitation was extended by the Director General of IER, Mali, to participate in the celebration of the 10 year anniversary of the Cinzana Research Station in Mali in September, 1993. The invitation was accepted. At Cinzana the P.I. was presented a gold lapel pin by the Ministry of Rural Development in recognition of contributions to the development of the Cinzana Station. This presentation was very much appreciated. During that visit there was opportunity for discussions and exchange of ideas with many Malian officials, collaborators, Ciba-Geigy and USAID representatives, and other participants. Field plots and demonstrations, laboratories, and facilities were toured, including the new plant physiology laboratory. Private discussions were held with scientists concerning project activities and future plans.

Dr. Jerry Maranville, who is well acquainted with this project and who has an active project with Mali, has agreed to continue working with the personnel associated with this project.

Dr. Aboubacar Toure, Mali Host Country Coordinator, visited the University of Nebraska in February, 1993. Discussions were held on ideas for collaborative research, training, equipment needs, and future research.

Germplasm and Research Information Exchange

Discussions were held with the collaborators on project research, results, and activities, and assistance given in the purchase of several major pieces of research equipment and supplies.

Assistance Given

Several pieces of equipment and supplies were purchased for the physiology/agronomy project in Mali. Assistance was also given in the operation, repair, maintenance and recalibration of the equipment.

Publications and Presentations

Publications

Barker, D. J., C. Y. Sullivan, and L. E. Moser. 1993. Water deficit effects on osmotic potential, cell wall elasticity, and proline in five forage grasses. Agron. J. 85:270-275.

Lansac, A. R., C. Y. Sullivan, K. W. Lee, and B. E. Johnson. 1994. Viability and germination of the pollen of sorghum [Sorghum bicolor (L.) Moench]. Annals of Botany (accepted and in press).

Zaifnejad, Mojtaba. 1993. Growth relations of water deficit and aluminum toxicity in sorghum. Ph.D. Thesis, Agronomy Department, University of Nebraska, Lincoln.

Germplasm Enhancement and Conservation

Pearl Millet Germplasm Enhancement for Semiarid Regions

Project KSU-101

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Summary

The primary objective of this project is to develop pearl millet materials possessing agronomic, yield, and quality characteristics that address production constraints common to both LDC' and the U.S. Central Great Plains.

A total of 48 Malian millet cultivars and synthetics have been imported since 1991 and crosses to elite KSU-101 breeding materials have produced 279 hybrids. Efforts to transfer KSU germplasm as F_4 and F_5 inbred lines failed in 1991 because of severe damage by downy mildew disease, but when transferred in crosses to Malian cultivars as F_1 hybrids and F_2 families survival and plant development was good. Differences in drought stress tolerance among S_1 selections of our Malian cultivars could not be determined in 1992 because of above normal rainfall, whereas good differentials were obtained in 1991 with season long drought stress. Very low recovery rates of phenotypically desirable long-headed segregates are obtained from crosses of KSU and Malian cultivars. The Malian cultivar, GR-P1, has produced a large number of long-headed segregates and with genetic manipulation, it is expected to contribute to improved recovery of long-headed progenies from crosses involving other Malian cultivars.

Nearly all accessions entering the program are routinely screened to determine levels of tolerance to the phytotoxins produced by the greenbug aphid, an insect that severely damages susceptible sorghum. Over a 12-year period approximately 75 percent of the accessions had moderate to high levels of resistance. Preliminary inheritance data indicates resistance is conditioned by a single dominant gene.

Inbred line development continued with selection within 3500 F_3 to advanced generation materials. Improved stand establishment has been obtained by selecting rapidly emerging seedlings from planting depths of 100 mm in the greenhouse and 75 to 80 mm depths in the field. Selections surviving this type of screening emerge 0.5 to 2 days earlier than unselected lines when planted at normal depths and produce larger plants at 10 days after emergence.

Several superior seed parents have been obtained from the male-sterilization backcross program whose F_1 hybrids appear to have similar grain yield potentials when compared to sorghum hybrids of similar maturity. Excessive plant height and susceptibility to lodging are problems that must be corrected to gain acceptance in mechanized farming regions. Although few B-lines selected from crosses involving landrace cultivars survive screening for adaptation and productivity they are valuable as sources of genetic diversity in crosses to elite KSU lines.

Good rates of progress have been made reducing lodging caused by poor root/soil attachment, nodal abscission layers, and charcoal stalk-rot. Progress is being made but at a slower rate in reducing lodging caused by parenchyma shrinkage and detachment from the rind of the culm.

Population improvement using mass-selection and S_1 progeny performance recurrent selection methods have been used on seven to nine populations each year. These selection programs have resulted in improvements in tolerance to drought and low soil fertility, increased stand establishment capability, and excellent bird resistance in bristled populations.

Collaborative research with Dr. Glenn Burton has provided evidence that yield potential of a dwarf, low-yield landrace-type population can be improved using recurrent restricted phenotypic selection. This method of population improvement should be applicable to adapted landrace cultivars in LDC's and could provide one cycle of improvement per year.

Introduction

The landrace varieties of pearl millet that were developed by farmers throughout the dry tropics typically are narrowly adapted to their region of origin. They have been selected for low input, subsistence farming on soils low in fertility and, while consistent in their ability to produce at least a small crop under adverse conditions, they usually have low harvest indices (HI). Frequently these varieties have reduced levels of tolerance or resistance to one or more of several serious insect and disease pests, and to *Striga* parasitism. Grain yields are often reduced by production hazards such as poor stand establishment, drought stress, lodging, and bird depredation. Several of these factors are constraints encountered in the development of pearl millet as a mechanized grain crop for the U.S. Great Plains area. Characters incorporated into KSU-101 millets that result in improved ranges of adaptability, HI, stand establishment, drought stress tolerance, and lodging resistance have been successfully exploited in India through collaboration with ICRISAT personnel but have been difficult to place into African millets. Downy mildew (DM) disease susceptibility of KSU-101 materials has been the main obstacle in the transfer of U.S. germplasm to Africa. Whereas KSU-101 materials possessed sufficient residual DM resistance to allow reselection for increased resistance under Indian disease conditions, these levels of resistance are insufficient under the virulent DM pressure in West Africa. Attempts to transfer these characters as advanced inbred lines have failed but it now appears that crossing Mali varieties to KSU-101 breeding lines and returning the F_1 and F_2 progenies to Mali followed by selection for the desired traits should be successful.

Objectives, Production and Utilization Constraints

Objectives

To develop widely adapted, early-maturing pearl millet populations, lines, germplasms, and hybrids with: a) improved drought tolerance, seed size and density, seedling stand establishment characteristics, lodging resistance, and grain yields; b) insect, disease, bird, and *Striga* resistance and c) acceptable food quality characteristics.

To select and evaluate materials developed in this program under a wide range of environments in developing countries.

Constraints

Numerous constraints to successful pearl millet production exist throughout the dry tropics. Each constraint varies in importance and/or severity in the different ecogeographic zones addressed by INTSORMIL and in the ease and degree of success by which plant breeding efforts influence it. Drought and heat stress are the primary constraints in much of the dry tropics since millet is grown in areas receiving limited amounts and erratic patterns of precipitation. Drought and heat stress are involved with poor seedling establishment when associated with factors such as reduced speed and vigor of germination and seedling elongation, shallow planting depths, elevated soil temperatures, and rapid surface soil drying that interrupts germination. Seed and seedling characteristics are also involved in the capability of a seedling to penetrate and emerge through crusted soils. The need for adequate levels of resistance or tolerance to several insects and diseases such as downy mildew, smut, and rust, and diseases affecting stalk and grain quality is a continuing constraint, as many of these organisms readily mutate to forms that overcome plant resistance. Bird depredation is a common occurrence and the incidence of *Striga* is becoming more severe as fields remain in cultivation for longer periods of time between periods of fallow. Several constraints and problems are associated with the use of the crop, ranging from stalk characteristics needed for construction and forage to the apparent food quality of the grain in regard to nutritional value, ease of processing, and consumer acceptability.

Research Approach and Project Output

Research Methods

Standard breeding procedures for open-pollinated crops are used. The pedigree breeding method is used for early development of nearly all materials entering the program, the advancement of elite lines, and lines extracted from populations undergoing recurrent selection. Mass selection, gridded mass selection, S_1 progeny performance testing, and recurrent restricted phenotypic selection (RRPS) methods are used in population improvement. Screening and evaluation is conducted at several U.S. and LDC locations.

New sources of breeding materials and materials for collaborative work are obtained each year as landraces, improved cultivars, F_1 hybrids, inbred lines, and germplasm sources of desired genetic traits. As these materials pass through the quarantine greenhouse, seed is obtained from random-mated plants (within the line), self-pollinated plants of each line, and from crosses involving elite Kansas

materials as seed parents. All new accessions are routinely exposed to the greenbug aphid, *Schizaphis graminum* (Rondani), in seedling screening trials to determine resistance/susceptibility reactions to damage caused by the aphid.

As part of the collaborative work with Malian millet breeders, a study will determine if it is feasible to select within groups of S_1 lines of Malian introductions for root systems capable of penetrating the B horizon of the silty clay loam soils found in western Kansas. These soils are characterized by a firm, hard, silty clay B horizon that contains an average clay content of 45 to 52% in the B_2t horizon. Many of the accessions entering the program appear to have varying degrees of reduced drought tolerance when planted on these soils, apparently because of difficulty establishing root systems that will penetrate the B horizon, explore the soil profile, and extract stored soil moisture deep in the profile. Selection for improved plant:soil relationships or the ability to penetrate these subsoils is possible within many of the accessions when planted on these soils. This relationship, as a form of drought tolerance, appears to be effective on several other soil types. Differences between lines appear as variations in total biomass production and date of onset of leaf rolling under stress conditions. A primary concern regarding selection for drought tolerance in the absence of downy mildew disease pressure is that reduced levels of resistance to downy mildew occur if selection extends beyond the S_1 or F_2 generations. Selection for this type of drought tolerance will be limited to testing S_1 lines in Kansas and returning remnant seeds of superior S_1 lines to Mali for evaluation and recombination under Malian growing conditions. Superior S_1 lines are backcrossed to the best hybrids and progenies obtained from crosses made during the quarantine growout and are crossed to additional breeding lines to generate segregating materials for selection in Mali.

Seed and seedling characteristics affecting stand establishment are studied and evaluated under laboratory, greenhouse, and field conditions. Materials selected for long mesocotyl and seedling lengths are planted 100 mm deep in greenhouse soil beds to obtain initial germination and emergence indices, seedling vigor scores, and plant weights. Field tests are conducted on raised beds to minimize damping-off disease problems associated with water-logged soils and standing rain water. Seeds of materials placed in field screening tests are planted at depths of 75 or 100 mm to identify lines possessing superior emergence characteristics.

Research Results

Emphasis is being placed on developing a population of breeding materials, elite inbred lines, and genetically broad based populations useful to collaborators in LDC's and in U.S. agriculture. This is a continuing activity with imported accessions entering the program each year to increase the genetic diversity within the program. Progress, as measured by increases in yield potential, agronomic fitness, and adaptability to a wider range of environments, is enhanced with new accessions that have received breeding inputs in the cooperating program.

Accessions

A total of 48 Malian millet cultivars and synthetics have been imported since 1991 and crosses to elite KSU-101 breeding materials have produced 279 hybrids. Photoperiod sensitivity is common in the Malian materials and only a few lines such as the Souna/Sanio and Souna/Togo materials flower sufficiently early to allow crossing under field conditions in Kansas. The early maturity of the Kansas parental materials is dominant in about 80 percent of the hybrids and segregation for a wide range of maturities occurs in the F_2 generation. Photoperiod sensitive hybrids are grown in the greenhouse to produce F_2 seeds, however, recovery of early maturing segregates within these materials requires the growing of large F_2 families. Drought stress evaluations of S_1 selections from four Malian cultivars could not be determined this year. Above normal rainfall throughout the growing season provided good growing conditions. Differences in biomass production were evident and superior S_1 lines will be used in future crossing efforts.

The characteristic long-headed phenotype of West African pearl millets appears to be regulated by several recessive genes. Maximum expression of this phenotype occurs in medium- and late-maturity genetic backgrounds. With the exception of one cross all hybridization efforts between short-headed (Togo-type) and long-headed millets result in short-headed hybrids and very low recovery rates of long-headed progenies in segregating generations. It is usually more expedient to backcross superior segregates to the long-headed parental line to obtain phenotypically desirable long-headed progenies.

The cross Serere $3Ad_2$ (78-7088) X GR-P1 produced a tall, long-headed (60-80 cm) F_1 hybrid with head characteristics similar to those of GR-P1. The GR-P1 head is 60 to 75 cm long with a base diameter of 45 to 55 mm and tapered to a tip 25 mm wide. Heads of 78-7088 are also tapered and 22 to 28 cm in length. This cross has produced several desirable F_2 and F_3 segregates producing three to five synchronously flowering tillers per plant, head lengths of 34 to 75 cm, and ranging in height from dwarf to tall. Crosses to a variety of materials are being made to determine if the GR-P1 head length characteristics can be utilized to improve recovery rates of long-headed segregates from crosses involving other Malian cultivars.

Greenbug Aphid

Although the greenbug aphid has been found on sorghum in Africa, it never became a problem as in the United States. Susceptibility of pearl millet to the phytotoxins produced by the aphid has been demonstrated in greenhouse seedling screening trials but it has never been observed under field

conditions. Plantings of greenbug susceptible and tolerant millets within fields of heavily infested sorghum remain nearly free of aphids with counts of none to three aphids per millet plant. Adjacent sorghum plants often had colonies of several hundred aphids per plant. However, when millets are exposed to the greenbug in the greenhouse both resistant and susceptible materials are readily colonized and susceptible millets are killed as rapidly as susceptible sorghums. Millet lines resistant to the aphid appear to have tolerance levels higher than those of greenbug resistant sorghums.

Nearly all new accessions of millet entering the program are routinely screened for seedling tolerance to the aphid. Over a 12 year period about 70 percent of the accessions were tested to the E-biotype and the remainder to the I-biotype. A comparison of a uniform set of 50 millets exposed to the E and I biotypes indicated no apparent differences existed in the reactions of these lines to the two biotypes. Preliminary inheritance data from crosses of resistant and susceptible millets indicate resistance is conditioned by a single dominant gene.

Approximately 75% of the accessions tested have moderate to high levels of resistance to the greenbug, with most of the injured lines producing sufficient numbers of tolerant plants for effective selection. Table 1 summarizes the responses of the latest groups of accessions received to damage caused by the greenbug.

Pedigree Breeding

Inbred line development continued with selection within 3500 F_3, S_2, and advanced generation lines derived from both the pedigree breeding and population improvement programs. Rainfall throughout the growing season was above normal following a three to four year period of moderate drought conditions. Several genetic height modifiers influence the expression of plant height within the range of plant heights considered to be controlled by the d_2 height gene. In dry years plant heights of these materials range from 70 to 120 cm and in years of average or above normal rainfall, particularly if conditions are optimal when culms are elongating, the d_2 height range extends from 90 to 175 cm. Selection for improved grain yield potential in droughty environments results in retaining an increased proportion of segregates from the upper end of the d_2 height range. The longer internodes of these plants increase the distance between leaves which apparently improves light interception and photosynthetic activity of the plant canopy. Whereas plant heights of 90 to 150 cm are desired fo mechanized agriculture, the taller plant heights would b acceptable for Malian intercropping situations. For this pur pose, several elite, tall (150-175 cm) d_2 dwarfs are crosse to accessions from Mali to generate segregating material for selection in Mali.

Improved stand establishment characteristics have bee obtained by selecting for increased mesocotyl length b planting to depths of 100 mm in the greenhouse and 75-8 mm depths in the field and identifying early emergin seedlings with rapid rates of mesocotyl elongation. Whe placed at normal planting depths seedlings of lines havin long and rapidly elongating mesocotyls emerge 0.5 to 2 day faster than unselected lines. Limited data indicates lines wit improved emergence capability produce larger plants wit increased dry matter contents at 10 days after emergence. Several superior lines have been selected that emerge from 75 to 80 mm planting depths to final stands that equal thei stands attained when planted 35 mm deep although emergence from the deeper planting depths requires an additional one to two day period of time.

Male sterilization by backcrossing in the A_1 and A_4 systems was continued within 260 A/B pairs. Another group of 137 A-lines, including several A_4 lines, were tested in hybrid combinations with two tester R-lines. The maintainers of A_1 lines with good combining ability in hybrid combinations are being backcrossed into the A_4 male sterility system along with several superior R_1 lines. At this time, with only limited testing, we have not identified any restorer lines for the A_4 system within this program but more than 200 lines have been crossed to A_4 lines for evaluation. Several ICRISAT and UNL-118 R_4 lines have been obtained and are being crossed to elite R_1 lines. Nearly all of the lines presently in the sterilization program are derived from crosses involving advanced KSU and ICRISAT materials that have received previous breeding attention. Few B-lines selected from initial crosses involving landrace and village varietal materials are sufficiently adaptive and productive to survive screening but their value as sources of diversity increases following additional crossing and backcrossing to elite KSU lines.

The data presented in Table 2 are indicative of the progress made and problems that exist in developing pearl millet as a grain crop for the central Great Plains. The development of millet hybrids with maturity characteristics that approximate maturities of adapted sorghum hybrids has

Table 1. Plant resistance/susceptibility reactions to the I-biotype greenbug of pearl millet accessions received from Mali and ICRISAT Center, Patancheru, India, 1992.

Source	Total accessions	Accession reaction		
		Resistant	Intermediate	Susceptible
	N	N	N	N
Mali	23	5	13	5
ICRISAT	145	40	43	62

Table 2. Agronomic and yield responses of advanced A_1 lines in hybrid combinations compared to a sorghum hybrid, averages of seven tests, Kansas and Nebraska,[1] 1992.

Hybrid[2]	Grain yield (kg ha^{-1})	Days to 50% bloom	Plant height cm	Lodged culms %
90-0240A/89-0083	5530	67	167	41
90-0328A/89-0083	4610	63	148	46
81-1163A/89-0083	4240	58	135	42
Sorghum	5010	67	122	14

[1] Locations: Mead, NE; Garden City, St. John, and Hays (4 tests), KS.
[2] Pedigree: 89-0083: T239D$_2$B$_2$ / 3*Serere 3A (81-2019) / 2 / B282/ ¾ Ex Bornu (481-R80)
90-0240B: T23D$_2$B$_1$ / 2 * PI185642(79-2068B) / 2 /81B
90-0328B: T23D$_2$B$_1$ / 2 * PI185642(79-2068B) / 2 /J1623 / ¾ Ex Bornu
81-1163B: T23D$_2$B$_1$ / 2 * PI185642
Sorghum hybrids: Funk 550 or DeKalb DK39Y

resulted in similar grain yield potentials. However, breeding and selection is needed to reduce plant heights of these hybrids to 150 cm or less and to improve resistance to lodging before pearl millet hybrids can be considered as adapted to mechanized farming conditions.

Inbred lines BKM 81-1163 and BKM 79-2068 were receiving their fourth backcross into the A_1 cytoplasmic-genic male-sterility system at the time the KSU-101 project was started. Exchanges of improved germplasm materials with ICRISAT have been continuous since 1979. Crosses made in 1982 and 1985 resulted in the development of R-line 89-0083 and A-lines 90-0240 and 90-0328. Inbred lines derived from crosses involving 1985 to 1988 introductions are presently producing experimental hybrids with improved plant and agronomic characteristics and with yield potentials equal to yields reported in Table 2.

Lodging

Lodging of culms and plants of millet is a production problem occurring in both LDC and mechanized farming systems. Harvest of the crop in the dry tropics is often performed when the grain is physiologically mature but prior to the drying of foliage and stalks, whereas with mechanized harvest, the crop must remain standing in the field until the entire field is ripe and the grain has dried sufficiently to thresh and separate cleanly from plant debris. Lodging of millet can be caused or influenced by several factors: diseases and insects, root lodging in clay or hardpan soils, reduced secondary and brace root development, nodal abscission layers, and shriveling and disintegration of parenchyma tissues in the stalk peduncle and internodes when the plant is drought stressed as it approaches physiological maturity.

Root lodging is observed only in tall landrace accessions whose root systems spread horizontally and penetrate poorly into hardpan and the B horizon of the soil. These plants are easily uprooted in severe wind storms. Breakage at a node of the culm appears to be inherited as a simple recessive and can be eliminated by selection in early segregating generations. Crown lodging associated with stalk diseases such as charcoal rot occurs frequently in this environment. The post-flowering drought stress necessary for charcoal rot development is present in varying degrees in nearly all growing seasons. This provides an opportunity to select for reduced incidence and severity of charcoal rot and improved lodging resistance in nearly every generation in the development of lines and populations.

Lodging resulting from parenchyma tissue shrinkage and detachment from the culm rind when millet is stressed during the late seed fill period continues to be a severe problem. Apparently, this type of lodging does not occur in the dry tropics, however, it occurs in culms of every tropical accession that flowers sufficiently early to produce mature seed at this latitude. It is closely associated with improved seed set and grain yield indicating the presence of a source-sink relationship. Materials with seed sets of 10 to 30 percent seldom lodge but lodging percentages rapidly increase as seed set levels of 80 to 100 percent are obtained and as grain yield levels increase.

Crosses involving IP2789, an early-maturing, club-headed line from Mauritania (via the ICRISAT germplasm repository) have produced early-maturing progenies in which parenchyma tissues remain intact and attached to the rind of the culm. Superior progenies have been crossed and backcrossed to elite maintainer and fertility restorer lines. Lodging resistance in F_2 and F_3 progenies appears to be controlled by a recessive factor but good data sets have not been obtained. Some of the hybrid combinations of susceptible X resistant lines have intermediate levels of lodging indicating the factor conditioning lodging resistance may act as a partial dominant in some genetic backgrounds.

Population Improvement

Recurrent selection using mass-selection has been used on six to eight populations each year and the S_1 progeny performance methods is used to advance one or two populations each year. Three normal height populations are advanced using mass-selection. Two of these populations, HMP559 and HMPWCC, are based on different germplasm sources and are being improved for drought tolerance and yielding ability under low soil fertility conditions. HMPBR, a bristled, bird-resistant population, has a normal height

phenotype but also possesses d_1 and d_2 dwarfing genes. PI185642 is a medium-tall, early-maturing, large-seeded, Togo-type landrace from Ghana that has been mass-selected for increased seed size and lodging resistance.

Dwarf (d_2) subpopulations have been extracted from both HMPBR and PI185642 using glyphosate (Roundup) applied with a wick applicator to destroy normal height plants prior to anthesis. Phenotypically the dwarf subpopulations with plant heights of 0.9 to 1.2 m appear to be nearly identical to the original populations (plant heights of 2.0 to 3.1 m) except for the differences in height. Severe bird depredation on non-bristled isolated populations and crossing blocks caused seed losses of 40 to 90 percent in both 1991 and 1992. Birds were occasionally seen in the bristled HMPBR isolations but no apparent damage was seen.

The development of dwarf population LMSE for improved characteristics affecting stand establishment continues to show promise. Four cycles of selection pressure using 75 to 85 mm planting depths has significantly reduced the incidence of short mesocotyl genotypes and long mesocotyl seedlings unable to emerge through the soil overburden. Selective thinning of the stand following emergence has been effective in increasing the proportion of vigorous seedlings showing rapid plant development and leaf expansion. Selective thinning has also reduced the frequency and/or sighting of seedlings in which mesocotyl and coleoptile elongation ceases before the tip of the coleoptile emerges from the soil forcing the first leaf to emerge through the upper 3 to 10 mm of soil cover. This type of seedling could result if, a) maximum elongation of mesocotyl and coleoptile structures had occurred resulting in a short seedling or, b) premature elongation and expansion of the first leaf occurs rupturing the side of the coleoptile before emergence and releasing the first leaf through the side of the coleoptile instead of the tip. The improved stand establishment capability of LMSE was noted in 1992. Comparative data were not obtained in 1993 because of heavy rains during the period of emergence and the presence of dampening off diseases. This method of mass selection is now being applied to populations HMPBR d_2 and PI185642 d_2 by planting alternating four row blocks within their isolations at 75 to 85 mm. Seeding rates were increased 10-20 percent in the deep planted blocks and resulting stands were comparable to stands of normal-depth planted blocks.

Collaborative work was started with Dr. Glenn Burton Tifton, Georgia to determine if the RRPS procedure could be adapted to improve grain yield potential of a narrow genetic-based millet population with a low to moderate grain yield potential. Dr. Burton's use of RRPS to increase forage yields of Pensacola bahiagrass resulted in the same rate of progress being obtained with both narrow and wide genetically based populations and the gain per cycle was four times more efficient than standard mass-selection. The largest seeds (seeds held on a 3.2 mm round hole screen) of PI185642 d_2 were used as a base population to establish the initial polycross of 208 plants in the Tifton winter greenhouse. Restricted half-sib progenies were generated by pollinating each plant with bulked pollen collected from all flowering plants in the population. The 80 progenies with the highest per plant grain yields and the base population were planted in a 9 X 9 lattice progeny performance test at FHES. Phenotypic variability for grain yield (59 to 132 percent of the test mean) was greater than expected considering the narrow base of the population. A 20 percent selection factor (Table 3) gave a 14.87 percent selection differential for the 16 entries selected for the cycle 2 polycross. The KTPC study is similar to the NTPC study of UNL-118 as both populations have narrow genetic bases but differ in grain yield potentials. If the RRPS method can effectively increase grain yield potentials of these populations it could be an appropriate method to improve well adapted LDC landrace cultivars.

Networking

Research Investigator Exchanges

Sept. 24-25, 1992. Traveled to Lincoln and Mead, Nebraska to view UNL-118 program and evaluate KSU-101 materials.

Sept. 28-29, 1992. Prof. D. J. Andrews and Dr. J. Rajewsky, Millet Breeders, University of Nebraska.

Sept. 28-Oct. 1, 1992. Dr. K. N. Rai, Senior Scientist, ICRISAT Center, Patancheru, India.

May 24-25, 1993. Travel to Manhattan to meet with Dr. B. Gebrekidan and INTSORMIL scientists to discuss elements of the INTSORMIL 10-year strategic plan.

Table 3. Selection differentials for grain yield and lodging of progenies selected for recombination from the first cycle of progeny performance testing within the Kansas Tifton Polycross Composite (KTPC).[1]

KTPC	Plot yield		Lodged culms	
	kg	SD%	Score[2]	SD%
Mean of 16 selected progenies	2.488	14.87	2.86	-5.61
Test mean, 80 progenies	2.166	- -	3.03	- -

[1] Experimental design: 9X9 lattice, 5 replications
[2] Lodging score: 0-9, 1 = 10%; 9 = 90-100% lodged

Germplasm Exchange

Accessions acquired

Nineteen inbred A, B, and R lines and a B-composite were received from ICRISAT Center, Patancheru, India and grown in quarantine. A second group of 145 items was received from ICRISAT too late for quarantine growout in 1993 but will be processed in the 1993-94 greenhouse. Six A-B pairs, 14 inbred restorer lines, and 29 S_1 selections from NCD2 (Nigerian Composite Dwarf Population) were received from UNL-118. Fifteen germplasm accessions and 15 F_1 hybrids involving Kansas lines and introduced accessions were provided to a commercial seed company.

Fifty-two F_1 hybrids and 48 F_2 families derived from crosses of elite Kansas lines and Mali accessions were sent to Mali IER collaborators. A group of 200 of the elite R-lines, A-B pairs, and early generation materials selected by Dr. K. N. Rai during his visit were sent to ICRISAT Center, India with the remaining materials to be sent at a later date. Twelve F_1 and F_2 families were sent to INRAN/Niger and six items were sent to the Egyptian National Research Center. Domestically, 96 items were provided to UNL-118, 16 to UNL-116, and numerous seed requests and grain samples were provided to public and private workers for agronomic studies, instructional uses, and food studies in quantities ranging from a few seeds to lots of several hundred kg.

Dr. S.C. Gupta, Principal Millet Breeder, SADCC/ICRISAT Southern Africa Regional Sorghum/Millet Research Program, P.O. 776 Bulawayo, Zimbabwe.

Dr. J.D. Axtell, Sorghum Geneticist, Department of Agronomy, Purdue University, West Lafayette, IN 47907.

Dr. W.L. Rooney, Cereal Chemist, Department of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843.

Mr. Shankar Podduturi, Pearl Millet Breeder, Pioneer Hi-Bred International, Inc. Box 1506, Plainview, TX.

Dr. J. Maranville, Sorghum/Millet Physiologist, Department of Agronomy, University of Nebraska, Lincoln, NE.

Dr. P. Bramel-Cox, Sorghum Breeder, Kansas State University, Manhattan, KS 66506.

Dr. L. Claflin, Plant Pathologist, Department of Plant Pathology, Kansas State University, Manhattan, KS 66506.

Dr. D. Seifers, Plant Pathologist, Fort Hays Experiment Station, Kansas State University, Hays, KS 67601.

Dr. C. Klopfenstein, Cereal Chemist, Department of Grain Science and Industry, Kansas State University, Kansas State University, Manhattan, KS 66506.

Dr. J. D. Eastin, Sorghum/Millet Physiologist, Department of Agronomy, University of Nebraska, Lincoln, NE.

Impacts

Three KSU-101 cytoplasmic-genic male-sterile inbred lines and their maintainer lines have been used extensively for several years in the ICRISAT breeding program in India and have been released to public and private breeding programs in India for utilization in the production of hybrids. The Chaudary Charan Singh Haryana Agricultural University (HAU) at Hisar recently announced the release of hybrid, HHB68, using AKM 79-2221 (842A) as the female parent. This hybrid has the same pollinator parent, H77/833-2, as hybrid HHB67, released in 1992, in which the female parent is AKM 79-2068 (843A). Although AKM 2221 has been widely used for hybrid seed production by private seed companies in India, HHB68 is the first publicly-bred hybrid to be released using this female line. Hybrids of AKM 2221 mature two to six days later than hybrids of AKM 2068 (60 to 65 days). When compared to the 74 to 80 day maturity requirements of older hybrids HHB50 and HHB60 the reduced growth duration of HHB67 and HHB68 permits a wider range of planting dates giving increased flexibility for use in sequential multiple cropping systems and acts as a drought escape mechanism in years when the monsoon withdraws early. The high per day productivity potential of HHB67 and HHB68 produces grain yields that average within 95 to 99 percent of yields produced by HHB50 and HHB60. The HAU has also released an improved male-sterile line and its maintainer derived from a cross involving BKM 2068 for hybrid seed production in the state of Haryana.

Hybrids using AKM 2068 as the female parent are widely grown throughout the low rainfall areas of Northwest India. Although the downy mildew resistance of AKM 2068 has broken down, its hybrids can be grown because disease pressure is reduced in these drier areas. AKM 2068 hybrids are popular because of their early maturity, large seed size, lodging resistance, and drought tolerance. Following the recent testing in the All India Coordinated Millet Improvement Program trials of two hybrids submitted by ICRISAT having AKM 1163 as the female parent it's possible the area in India planted to hybrids with KSU-101 female parentage may increase in higher rainfall areas. Both AKM 1163 and AKM 2221 have acceptable levels of downy mildew resistance and good combining ability in hybrid combinations.

Breeding Sorghum for Tolerance to Infertile Acid Soils

Project MSU-104

Lynn M. Gourley
Mississippi State University

Principal Investigators

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Collaborating Scientists

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Mr. Luis de Angulo, Vice President Community Affairs, Arauca Project, Occidental de Colombia, Inc., Apartado Aereo 092171, Bogota, Colombia
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Mr. C. Mburu, Sorghum Breeder, and Mr. C.O.A. Oduori, Millet Breeder, Kakamega Regional Research Center, P.O. Box 169, Kakamega, Kenya
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Dr. John Axtell, Sorghum Breeder, PRF-103 PI; and Dr. Gebisa Ejeta, Sorghum Breeder, PRF-107 PI, Department of Agronomy, Purdue University, West Lafayette, IN
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Summary

Much progress has been made in the nearly 15 years of conducting acid soil research in Colombia, but many aspects of plant-soil interactions remain unclear. It is now known that genetic variability for tolerance to the tropical acid soil complex exists in the genus *Sorghum*. Tolerant varieties have been released and are producing economic grain yields for resource-poor farmers in marginal production areas using low-input technology. Information has been obtained concerning gene action and inheritance of tolerance to Al, Mn, and acid soils in general. The primary root will penetrate deep into acid soils where adventitious roots will not grow, killing the susceptible sorghum genotype. Genetic variability has been found for differential mineral uptake which suggests the possibility of different tolerance mechanisms and plant utilization efficiencies.

Acid soil tolerant sorghum varieties and hybrids developed in this project are being evaluated on acid soils or other low-input environments in Colombia, Brazil, other Latin American countries, Kenya, Niger, Zambia, and other African countries. Much of this germplasm will also tolerate low fertility levels in neutral pH or slightly acid tropical soils. Stress screening for tropical acid soil tolerance appears to impart tolerance and stability to sorghum growing in low-input environments. In subsistence agriculture, stable performance under low-input production practices is more important than high yields.

Inbred lines which produce high yielding hybrids, tolerant to the Al-toxic, infertile soils of the tropics, will be the next generation of releases from the collaborative research of this INTSORMIL Project and national sorghum breeding programs. Since tolerance to the acid soil complex appears to be dominant in sorghum, either tolerant pollinator or seed parent lines can be used to produce commercial cytoplasmic-genic hybrids in tropic or temperate zones.

Introduction

This project was one of the original INTSORMIL projects and has continued to conduct research concerned with breeding stress tolerant sorghum varieties and hybrids to overcome the constraints of the acid soil complex. In the 1970's, reports started appearing in the literature about the vast areas of infertile soils of the tropics, usually those which were very acid and contained levels of aluminum and manganese too high for crop production using available cultivars. A real fear of the world's population increasing faster than food production stimulated funding for research into uses of the under-utilized agricultural lands of the tropics.

Sorghum, like many cereal crops, is not recognized as being a species tolerant to low-pH soils. However, most breeding programs have been conducted in neutral or calcareous soils. Plant breeders have recently recognized that different genes are needed for achieving maximum yield in low-input environments than those for high-input conditions. Two factors have been primarily responsible for redirecting some breeding efforts, especially in the acid soil regions of the humid tropics. They are the economics of modern high-input agriculture as they apply to resource-poor farmers, and the requirement to bring more agricultural land into production.

In 1982, the MSU-104 PI was assigned for a two-year period to the International Center for Tropical Agriculture (CIAT), Cali, Colombia, to initiate a program for breeding and screening sorghum germplasm for tolerance to the acid soil complex of the humid tropics (Project MSU-111). This ongoing project was an attempt to provide the INTSORMIL Colombia Prime Site with sorghum germplasm which would produce a reasonable grain yield on soils of pH 4.5 or below, with an Al-saturation level of 60% or more, and significantly reduce the large capital outlay for lime and fertilizer required with the current cereal production technology. This low-input research was conducted in collaboration with the National Program of Colombia, ICA, and other National Programs in Latin America. In 1990, the MSU-104 PI was assigned to Kenya through an INTSORMIL buy-in to transfer this new technology to the resource-poor farmers in acid soil areas of Africa.

Objectives, Production and Utilization Constraints

Objectives

The objectives of this project were originally interdisciplinary in nature because the project included staff from the departments of Agronomy, Plant Pathology and Entomology. In 1982, it was reorganized into discipline projects. Entomology objectives will be cover under MSU-105 of this report. The Plant Pathology project, MSU-106, was discontinued in 1985 and its' grain mold and weathering objectives were incorporated into other projects. The objectives of MSU-104 were and continue to be as follows:

Screen and evaluate sorghum and pearl millet, in the laboratory and field, for sources of tolerance to infertile soils, low soil phosphorus (P) content and availability, and aluminum (Al) and manganese (Mn) toxicities.

Enhancement of elite U.S. and LDC sorghum germplasm with sources of tolerance to infertile soils, and Al and Mn toxicities.

Train selected U.S. and LDC personnel.

Constraints

In tropical countries throughout the world, sorghum and pearl millet are generally planted on infertile, marginally productive lands. Large areas of highly weathered, leached soils make most of these countries the least productive agriculturally in the developing world. Predominantly these soils are very acid, deficient in most macro and micro mineral elements and contain toxic levels of soluble Al and sometimes Mn. Acid soils are found both in humid and arid regions of the tropics.

This project addresses, through breeding, three major production limiting constraints of tropical soils; low-input production on infertile soils, phytotoxic levels of Al and Mn, and low P availability. In addition to yield, every breeding project must strive to maintain disease resistance and grain quality as a goal.

Research Approach and Project Output

Success in a crop improvement program depends upon modification of production constraints through improved cultural practices and/or exploitation of the genetic diversity by enhancement of the crop in this particular environment. Sorghum has a large reservoir of genetic diversity and is well adapted to semi-arid and other marginal agricultural production areas of the world; however, it is not known for its acid soil tolerance.

When developing a sorghum breeding program in a new research area, several questions need to be answered. What are the primary constraints? Is there genetic variability for tolerance to the constraints? What is the degree and nature

of the inheritance of the tolerance? What evaluation methods are available and have they been field validated? Is an expensive breeding program warranted or can cultural measures overcome the constraints? When my students and I examined these questions in the 1970's, we concluded that little was known about the genetic variability of sorghum tolerance to acid soils. Soil scientists were also determining the nature and quantity of acid soils in the tropics at this time.

Acid soil stress results from a negative interaction between sorghum genotypes and their environment and not all acid soils are created equal nor are they uniform. The acid soils of Colombia, Brazil, Zambia, Niger and Kenya all have their own peculiarities. Constraints also change due to rainfall, temperature, cation exchange capacity (CEC), natural content of essential elements, level of toxic ions, phosphorus fixation capacity and amount and quality of organic matter. Acid soils in Colombia have a very high Al saturation while those in Zambia have moderate Al saturation plus very high Mn content. Both areas, however, normally receive adequate rainfall during the growing season. The acid soils in Brazil and Kenya can be drought prone during the growing season. The acid soils of Niger have a CEC of 1.0 or less, medium Mn content, low fertility and are very drought prone.

Because of a lack of confidence in the so-called "quick tests" for Al tolerance, a field screening technique was developed at Quilichao, Colombia. The ultisol soil had an Al-saturation level of about 80%, a pH of 4.5, and an effective CEC of about 5. Five hundred kilograms of dolomitic limestone were added to provide fertilizer quantities of calcium and magnesium, and to reduce the Al-saturation level to about 65%. Broadcast applications of N-P-K, zinc and boron were added according to soil test to insure that these elements were not limiting. The procedure was designed to measure Al tolerance and, insofar as possible, not the effect of P or the Al-P interaction. The objective was to establish an Al-toxicity level which was high enough to kill sensitive genotypes, but not too high to prevent tolerant genotypes from producing a reasonable yield of grain. A simple visual rating scale was used to evaluate the exotic sorghum genotypes from the world collection. The world collection was systematically sampled for accessions originally from acid soil areas in Africa.

After screening nearly 6,000 sorghum genotypes, we found that about 8% would tolerate 65% Al saturation and a few of these varieties would produce more than two tons of grain per hectare. Most of these highly tolerant genotypes were identified in the world collection as originating in acid soils areas in Nigeria, Uganda, and Kenya and were classified as Caudatums (Table 1). The Guinea race and the hybrid Guinea-bicolor lines had a higher percentage of acid soil tolerant sorghum entries than those of other races and hybrids evaluated. Several of these lines appear to be from Dr. Hugh Doggett's breeding program at the Serere Research Station in Uganda.

Some early observations at Quilichao, Colombia indicated that most sorghum genotypes would tolerate 40% Al saturation and visual separation of tolerance and susceptibility was impossible with this level of stress. At about 65% Al saturation, susceptible genotypes, such as Tx415 and Tx430 would produce good stands and grow for about three weeks and then every plant in the row would die. The soil at Quilichao was uniform enough that susceptible and tolerant genotypes planted in adjacent rows at regular spacings across the test field would at maturity be tolerant rows and blank rows. The fact that susceptible genotypes would produce perfectly good plant stands in 65% Al saturation plots casts suspicion on seedling primary root length as a screening technique. It also indicated to us that the seed was in some way protecting the primary root from the toxic effects of Al; however, the adventitious root system failed to penetrate the soil and the susceptible genotypes died.Another early observation was that all of the higher yielding, Al-tolerant Caudatums were quite photoperiod sensitive. They were tall and late in Brazil and Zambia. In Niger, they produced tall, late maturity plants and when the rains had finished the plants died without producing any grain. We also found that many of the Al-tolerant genotypes produced large root systems which assisted them in obtaining adequate mineral nutrition in low-input environments and that they were also more drought tolerant than Al-susceptible genotypes.

Several variety and hybrid yield trials in Colombia have compared growth and yield traits at varied Al-saturation levels. Some very Al-tolerant hybrids were observed that produced little grain. Usually, however, hybrids yielded more grain than either parent. Tolerance to Al toxicity of seedling traits and grain yield are not necessarily the same. Shared experiences with sorghum breeders in Brazil confirmed that Al tolerance appeared to be dominant and that tolerance was conditioned by only a few genes. Heterosis for tolerance to these infertile soils was also observed.

Mineral element analyses of Al-tolerant genotypes growing on soils with high levels of Al saturation indicated that there may be more than one mechanism for tolerance to Al toxicity. Some genotypes accumulate Al in their leaves while others allow little Al into the plant. We have not seen a definite advantage of one type of tolerance over the other.

The ICA-INTSORMIL collaborative research has resulted in the release of two Al-tolerant varieties. Sorghica Real 60 and Sorghica Real 40 have consistently produced high grain yields on acid soils in both cropping seasons during the year (Table 2). Both cultivars have good yield stability in acid and fertile soils, are photoperiod sensitive Caudatums, and both probably come from Dr. Hugh Doggett's program in Uganda. It is interesting that no effort was made to evaluate this material on acid soils during the developmental stages. Infertile soils were common at the multiple test sites in Uganda and recently some of these sites have been shown to have pH values in the four to five range.

Table 1. Lines from the world collection of sorghum and country of origin with the highest level of acid soil tolerance in screening trials in Colombia.

Line	Country	Line	Country	Line	Country
IS 2728	Uganda	IS 7373	Nigeria	IS 8888	Uganda
IS 2738	Uganda	IS 7383	Nigeria	IS 8899	Uganda
IS 2742	Uganda	IS 7399	Nigeria	IS 8912	Uganda
IS 2765	Uganda	IS 7402	Nigeria	IS 8924	Kenya
IS 2788	Kenya	IS 7411	Nigeria	IS 8931	Kenya
IS 2965	Ethiopia	IS 7413	Nigeria	IS 8933	Kenya
IS 3025	Ethiopia	IS 7416	Nigeria	IS 8937	Kenya
IS 3032	Ethiopia	IS 7440	Nigeria	IS 8959	Kenya
IS 3071	Sudan	IS 7469	Nigeria	IS 8965	Kenya
IS 3163	South Africa	IS 7547	Nigeria	IS 8981	Kenya
IS 3170	South Africa	IS 7554	Nigeria	IS 8996	Kenya
IS 3413	—	IS 7556	Nigeria	IS 9000	Kenya
IS 3417	—	IS 7566	Nigeria	IS 9109	Kenya
IS 3522	Sudan	IS 7568	Nigeria	IS 9178	Tanzania
IS 3710	Ethiopia	IS 7586	Nigeria	IS 9187	Somalia
IS 3759	Ethiopia	IS 7590	Nigeria	IS 9221	Uganda
IS 6730	Burkina Faso	IS 7596	Nigeria	IS 9227	Sudan
IS 6762	Burkina Faso	IS 7623	Nigeria	IS 9269	Uganda
IS 6792	Burkina Faso	IS 7627	Nigeria	IS 9785	Sudan
IS 6822	Burkina Faso	IS 7630	Nigeria	IS 9828	Sudan
IS 6902	Sudan	IS 7651	Nigeria	IS 9918	Sudan
IS 6944	Sudan	IS 7659	Nigeria	IS 9919	Sudan
IS 7096	Cent. Afr. Rep.	IS 7669	Nigeria	IS 9935	Sudan
IS 7100	Cent. Afr. Rep.	IS 7676	Nigeria	IS 10336	Nigeria
IS 7103	Cent. Afr. Rep.	IS 7688	Nigeria	IS 11296	Ethiopia
IS 7110	Cent. Afr. Rep.	IS 7707	Nigeria	IS 11303	—
IS 7132	Uganda	IS 7721	Nigeria	IS 11306	Ethiopia
IS 7140	Uganda	IS 7755	Nigeria	IS 11323	Ethiopia
IS 7151	Kenya	IS 7793	Nigeria	IS 11366	—
IS 7168	Chad	IS 7809	Nigeria	IS 11377	Ethiopia
IS 7180	Malawi	IS 7827	Nigeria	IS 11380	Ethiopia
IS 7181	Gambia	IS 7829	Nigeria	IS 11382	Ethiopia
IS 7192	Nigeria	IS 7864	Nigeria	IS 11385	Ethiopia
IS 7211	Nigeria	IS 7890	Nigeria	IS 11396	Ethiopia
IS 7243	Nigeria	IS 8577	Kenya	IS 12103	Ethiopia
IS 7252	Nigeria	IS 8583	Gambia	IS 12132	Ethiopia
IS 7267	Nigeria	IS 8603	Uganda	IS 12152	Ethiopia
IS 7268	Nigeria	IS 8619	Uganda	IS 12154	Ethiopia
IS 7274	Nigeria	IS 8628	Uganda	IS 12303	Zimbabwe
IS 7290	Nigeria	IS 8650	Uganda	IS 16319	Cameroon
IS 7291	Nigeria	IS 8858	Kenya	IS 16503	Cameroon
IS 7292	Nigeria	IS 8860	Kenya	IS 16519	Cameroon
IS 7308	Nigeria	IS 8865	Kenya	IS 16597	Cameroon
IS 7318	Nigeria	IS 8875	Uganda	IS 16622	Cameroon
IS 7321	Nigeria	IS 8878	Uganda	IS 16627	Cameroon
IS 7361	Nigeria	IS 8881	Uganda		

Table 2. Plant height and yield of ten sorghum genotypes planted in acid soils with aluminum saturation levels between 40 and 60%. Average data for 12 sites in the Department of Meta, Colombia.

Genotype	Plant height (cm)	Yield (kg ha^{-1}) Semester A	Semester B	Mean
Sorghica Real 60	182	3224	2994	3109
Sorghica Real 40	162	3283	2793	3038
IS 3071	190	2839	2421	2630
PPQ-2	167	2984	2315	2649
IS 3522	183	2538	2143	2340
IS 8577	187	3312	2795	3053
IS 6944	189	2609	2283	2446
5DX61/1/910	178	2428	2123	2275
ICA Nataima	96	534	894	714
Icaima	151	712	2174	1443

Source: ICA, Annual Report, National Cereals Section, June 1991.

Table 3. Plant height, number of days to anthesis, and grain yield for ten sorghum lines evaluated on acid soil at Sete Lagoas, Brazil.

Genotype	Plant height (cm)	Bloom (days)	Grain yield (T ha^{-1})
CMSXS 208	182.7 a	93.4 a	4.63 a
MS 109	159.4 b	80.0 cdf	3.82 ab
CMSXS 209	151.7 bc	84.9 bc	3.37 bc
MS 188-1	161.0 bc	77.9 ef	3.12 bc
CMSXS 189	179.7 a	96.8 a	2.92 bcd
MS 076	135.7 cd	80.2 cdf	2.81 cd
MS 177	148.7 bc	79.2 def	2.61 cde
MS 216	161.7 bcde	80.9 bcde	2.57 cde
BR 007B	93.3 f	78.9 def	0.62 g
TX 623B	105.8 ef	88.6 b	0.33 g
Mean	147.97	84.08	2.68

Pedigrees of the MSU lines are: MS 076 = (NB9040*IS9084)-8-1-3-1; MS 109 = (TX430*IS3071)-44-1-3; MS 177 = (IS12666C*IS7254C)-17-1-1-1-1; MS 188-1 = (IS12666C*7B5113)-68-1-1-1-1-1; and MS 216 = (TX430*IS3071)-101-1-3.

Collaborators working with EMBRAPA at Sete Lagoas, Brazil have evaluated 279 lines developed by this project from segregating populations in which only one parent was acid soil tolerant. After preliminary evaluations, five of the best yielding MSU-104 genotypes were tested further and compared with three local Al-tolerant and two Al-susceptible lines. The Cerrado soil had a pH of 4.6 and an Al-saturation level of 48 and 55% at 0-20 and 20-40 cm soil depth, respectively. The MSU-104 genotypes matured earlier and were shorter than the Al-tolerant material currently available for the Cerrado environment (Table 3). Higher grain yields than those usually obtained in Colombian trials were probably due to the lower level of Al saturation and higher inputs of fertilizer.

Combining ability studies in Colombia, Niger, and Kenya have compared growth and yield traits of Colombian bred inbreds at varied Al-saturation levels in field trials. These studies showed that Al tolerance was conditioned by both additive and non-additive gene action. Hybrids have many advantages over inbred varieties in the infertile-soil environment: hybrid seedlings exhibit more vigor during emergence and early plant growth; hybrids are almost always more stress tolerant and usually yield more grain than the most tolerant parent; and hybrids generally produce more extensive root systems and exploit available soil nutrients and water better than varieties. The value of using the holistic plant breeding approach and measuring the final product, grain, was evident.

Networking Activities

Workshops

Dr. Susana Goggi attended and participated in the 13th Seed Improvement Course. Seed Technology Laboratory, Mississippi State University, June 1-July 11, 1992.

Dr. Susana Goggi instructed in the 36th Seed Improvement Course (T.C. 130-3). Seed Technology Laboratory, Mississippi State University, June 1-July 11, 1992.

The MSU-104 PI attended and participated in the First International Crop Science Congress, Ames, Iowa, July 14-22, 1992.

The MSU-104 PI attended and authored or coauthored two papers at the 8th EARSAM Regional Workshop on

Sorghum and Millet Improvement, Wad Medani, Sudan, October 30–November 5, 1992.

Dr. Susana Goggi attended and participated in a Tetrazolium Testing Workshop. El Malacate, Prov. de Buenos Aires, Argentina, December 22-23, 1992.

The MSU-104 PI and Drs. Susana Goggi and Brian Baldwin attended and participated in the 18th Biennial Grain Sorghum Research and Utilization Conference, Lubbock, Texas, February 28-March 2, 1993.

Dr. Susana Goggi instructed in the 37th Seed Improvement Course (T.C. 130-3). Seed Technology Laboratory, Mississippi State University, May 31-July 31, 1993.

The MSU-104 PI attended and participated in the First Crop Science Conference for Eastern and Southern Africa. Kampala, Uganda, June 14-18, 1993.

Research Investigator Exchanges

The MSU-104 PI along with MIAC, University of Missouri, and KARI staff were involved in the development of the 10-year Strategic Plan for KARI cereal crops for much of Year 14.

Dr. Lynn Reinschmidt, Mississippi State University Agricultural Economist, was escorted through visits with USAID, KARI, and MIAC administrators concerning Kenyan food production and agribusiness. September 18-22, 1992.

Dr. Susana Goggi visited with EMBRAPA scientists at Sete Lagoas, Brazil to discuss acid soil research, field and laboratory germplasm evaluation techniques, and in vitro selection research in the sorghum and maize programs. October 1992.

Dr. Brhane Gebrekidan was assisted by the MSU-104 PI in his INTSORMIL 10-year Strategic Plan visit to Kenya. Most of the KARI sorghum/millet program staff had a chance to visit with Brhane. He was also briefed by KARI and USAID administrators. November 18-25, 1992.

Dr. Darrell Rosenow consulted with MIAC to review sorghum drought tolerant rating procedures and available germplasm. Together with the MSU-104 PI, several KARI Centers and Sub-Centers were visited in the dryland areas of Eastern Kenya. February 6-18, 1993.

The MSU-104 PI was a substitute for the breeding representative on the TC Committee during a meeting at Lubbock, Texas. March 3-5, 1993.

In January-February 1993, the MSU-104 PI traveled to the U.S. where he attended several meetings with Mississippi State University International Programs and Department of Agronomy staff. Some time was also spent visiting with Kenyan graduate students at Mississippi State and by telephone with others at other universities.

Dr. Susana Goggi consulted with DeKalb Plant Genetics on the analysis of possible causes for seed quality problems of specific samples of sorghum seed. A written report and recommendations were presented. April 1993.

Drs. Susana Goggi and Brian Baldwin participated in Dr. Brhane Gebrekidan's 10-year Strategic Plan site visit to Mississippi State University. May 6-8, 1993.

Dr. Goeffry Heinrich consulted with MIAC concerning research in systems agronomy. The MSU-104 PI escorted Dr. Heinrich in visits to KARI Centers and in meetings with KARI and USAID administrators. May 8-12, 1993.

The MSU-104 PI visited several Ugandan research Centers with several ICRISAT and KARI colleagues. June 19-23, 1993.

Germplasm and Research Information Exchange

Hybrid sorghum seed from crosses made in this project and MSU-111 were imported into Kenya and Brazil for evaluation at several locations. The hybrid entries were selected to be useful across several ecological zones.

Publications and Presentations

Publications

Adamou, M., L. M. Gourley, C. E. Watson, S. D. Mclean, and A. S. Goggi. 1992. Evaluation of combining ability of acid soil tolerant sorghum germplasm in Niger. p. 88. In Agron. Abs. November 1-6, 1992. Minneapolis, MN.

Goggi, A. S., J. C. Delouche, and L. M. Gourley. 1992. Morphological aspects of weathering and immaturity in sorghum [*Sorghum bicolor* (L.) Moench] associated with seed specific gravity. In Symposium Abs. 23rd ISTA Congress Symposium, November 2-4, 1992. Buenos Aires, Argentina.

Goggi, A. S., J. C. Delouche, and L. M. Gourley. 1993. Sorghum [*Sorghum bicolor* (L.) Moench] seed internal morphology related to seed specific gravity, weathering, and immaturity. Journal of Seed Technology (in press).

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Breeding Sorghum for Increased Nutritional Value

Project PRF-103
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Dr. Bob Joly, Horticulture Department, Purdue University, W. Lafayette, IN 47907
Dr. Bruce Hamaker, Food Science Department, Purdue University, W Lafayette, IN 47907
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Dr. David Rhodes, Horticulture Department, Purdue University, W. Lafayette, IN.

Summary

The major focus of this project is to develop high yielding sorghum varieties with acceptable food quality and good nutritional value for utilization in developing countries. A great deal of progress has been made in two areas.

We now understand many of the factors necessary for improving the nutritional value of sorghum through local village processing. Sorghum flour is less digestible than most cereal flours unless it is processed using local village procedures that have evolved over hundreds of years. We now understand the scientific reasons why processing is important. This knowledge will help us modify and improve the traditional processing methods and develop improved processing methods for utilization in other countries in the world where sorghum is used as a feed or food grain.

The International Division of the U.S. Census Bureau, in unique agreement with many other agencies, projects that the population of the world will double within the next 40-50 years (Jamison, E. 1989. World Population Profile. Bureau of the Census. Issued September 1989). This means that agricultural scientists will have to learn how to produce as much food, feed and fiber in the next 5 decades as they have learned how to produce during the past 2,000 years. There is virtually no alternative scenario to this view short of a major human calamity. This fact poses an unprecedented challenge to plant and animal scientists around the world. Fortunately, at the same time new and powerful research tools are available from the explosion of knowledge in the biological and agricultural sciences. Crop and livestock yields must increase significantly to avoid a level of human misery in the world which is intolerable to civilized society. Some of this increase will occur on productive land with adequate rainfall, but many of these lands are already stretched to capacity. Much of the increase will have to come from marginal agricultural lands with relatively poor soils and chancy rainfall, which are subject to frequent periods of drought. The goal of the INTSORMIL and McKnight Research Projects is to utilize the best basic information from recent advances in plant biology to understand the mechanisms of drought resistance in crop plants, and to apply this knowledge to the improvement of crop and livestock yields in the U.S. and throughout the world. The model crop used for these studies is sorghum, which has developed mechanisms which have allowed it to evolve in semiarid regions of the world over the centuries. Sorghum is generally grown in those parts of the world where it is too dry to grow corn or other cereals. Even though the drought resistance of grain sorghum has been known for centuries, relatively little effort has been expended in the study of mechanisms of drought resistance in sorghum at the genetic, physiological and molecular levels. The mission of our interdisciplinary program is to combine the resources of the International Sorghum Improvement Program at Purdue University with the expertise of scientists in Stress Physiology and Plant Molecular Biology in a concerted effort toward an understanding of the mechanisms of drought resistance in sorghum and to utilize this information for the improvement of sorghum and other crop species such as maize. An understanding of these mechanisms will provide better opportu-

nities for more efficient screening activities in cereal breeding programs. This research program will serve as an exceptional training ground for graduate students who will assume leadership roles in U.S. and international agricultural research into the twenty-first century.

Drought Tolerant Hybrid Sorghum for Niger. Trials are underway at several locations of a new drought tolerant sorghum hybrid which has proven to be highly productive and well adapted in Niger. The hybrid designated NAD-1 was developed by Issoufou Kapran (Niger Sorghum Breeder/McKnight Ph.D. Graduate Student) in collaboration with INTSORMIL scientists. Results from Experiment Station trials at several locations in Niger have been very encouraging. Mr. Kapran returned to Niger in June 1993 to organize and facilitate distribution of seed for on-farm trials throughout the country and to coordinate plantings of hybrid seed production plots. The grain quality is acceptable for local food preparations and the yields reported from demonstration plots in 1992 were approximately twice the yields of local varieties. Farmer interest has been very high since this is the first sorghum hybrid that has actually reached farmer fields and the head size and grain yield have been impressive to them. Last year's trials at over 100 farmer locations was a critical test of the performance of this hybrid It is important now to develop a seed industry (either private or para-statal) in Niger that is adequate to produce and distribute hybrid sorghum seed. Our experience with a similar situation in Sudan suggests that a workshop would be helpful in Niger which brings in experienced seedsmen from both the U.S. and from developing countries to meet and discuss with scientists and government policy makers in Niger of the necessity of developing a seed industry in Niger. Indigenous seed industries for hybrid sorghum seed production have been successful in India and more recently in Sudan. We propose that a workshop be held in approximately 18 months to 2 years in Niamey, Niger to accomplish this purpose and we will be soliciting financial support to organize and conduct this workshop.

Introduction and Constraints Addressed

Nutritional value of sorghum has long been known to be different from other cereals. This includes the tannin problem, the protein quality problem, the protein digestibility problem, and the local processing methods involved in eliminating these problems in the diets of sorghum consuming people. We have made significant progress in cooperation with Dr. Larry Butler on the tannin problem, and Dr. Sam Mukuru has now proven in studies conducted in our laboratory that high tannin sorghums traditionally grown at high elevations in Eastern Africa are very satisfactory sources of digestible nutrients if the grain is processed adequately by traditional means. Protein quality improvement will be a major breeding objective during the next five years. We have identified good sources of modified quality protein sorghums which are comparable in yield potential and grain quality to quality protein maize as developed by CIMMYT. The basic high lysine gene, P-721 opaque has been combined with sources of vitreous endosperm to give the QPS (Quality Protein Sorghum). The high yield potential has been demonstrated by Emmanuel Monyo and the modified vitreous endosperm characteristics have been recently documented. A major unresolved problem is the environmental stability of these modified endosperm sorghums. A recent breakthrough on QPM in maize by Brian Larkins and Mr. Mauricio Lopez has shown a strong relationship between the gamma-zein fraction and modified vitreous endosperm characteristics. An Elisa technique is being developed which will make selection for vitreous endosperm opaque-2 much more reliable and faster. The same technique will be adapted to sorghum P-721 modified lines in improvement programs. Trials will be conducted at several locations during 1992 to confirm the stability of the vitreous endosperm trait in these QPS lines across temperate and tropical environments. It is interesting to note that the digestibility of P-721 high lysine sorghum is about 10% greater than that of most normal sorghum varieties which should be an additional benefit if it can be confirmed in the QPS lines. The digestibility problem can also be approached at this time by a better understanding of traditional processing technologies. We believe the identification of a low fraction III (cross-linked kafirin fraction) sorghum variety in the World Collection has the potential to provide a genetic and breeding solution to the digestibility problem in sorghum which would be a significant achievement in utilization of sorghum as a food grain and also as a feed grain.

A major priority will be the development of a vitreous endosperm high lysine sorghum variety using germplasm developed from crosses with P-721 opaque. This will be a combined effort with Drs. Bruce Hamaker, Gebisa Ejeta, and Larry Butler. The modified endosperm high lysine sorghum parental materials will be tested in Niger, Sudan, and West Lafayette to verify environmental stability of the vitreous endosperm and the lysine content. An extensive second cycle breeding program will be initiated to further improve the protein quality, vitreous endosperm, and protein digestibility of the new lines.

Another major focus will be to continue to ascertain the nutritional value of thin fermented porridges as used in Eastern and Southern Africa and also to determine what genetic characteristics are necessary in a new variety to successfully prepare these porridges. For example, it is generally known that local varieties have a high diastatic power which is essential for fermentation with either yeast or lactobacillous. Many improved sorghum varieties lack this characteristic and this factor may be responsible for low adoption rate of improved varieties. Joe Mushonga's research on developing rapid assays for diastatic power and studying inheritance of diastatic activity in sorghum cultivars will be continued. Second, Dr. Mukuru has completed his study at Purdue on the digestibility of thin fermented sorghum porridges in Uganda and has found that there is no effect of the tannins on digestibility after the traditional wood ash and fermentation treatments. Another focus of activity will be to pursue the development of cold tolerant

sorghum lines with markedly improved seedling vigor for higher elevations in Eastern Africa and temperate zones. The sources of cold tolerance from Northern China continue to be excellent for early spring seedling vigor. Finally, we have identified a sorghum line in the World Collection (IS 2319) which has a significantly reduced cross-linked kafirin fraction and shows very good digestibility results in rat feeding trials, whether cooked or uncooked. Since we believe this cross-linked kafirin is responsible for many of the digestibility problems in sorghum we are giving this activity a very high priority. Studies include inheritance of the low fraction III trait and incorporation with this genetic characteristic into improved broadly adapted sorghum germplasm.

Drought Research

A major drought occurred across a section of the corn belt, including West Lafayette, Indiana, in 1991. While these droughts were not as extensive as in 1988, it was devastating to those corn growers who had the misfortune to farm within the affected regions. The drought in Eastern and Southern Africa in 1992 was the worst in living memory. Drought continues to be the major source of crop loss throughout the world. The relatively superior performance of grain sorghum under these stress conditions reiterates our hypotheses that sorghum contains some important genes for drought resistance. It therefore seems logical to use sorghum as both a model system and also as a source of genes for stress tolerance. We are now in an era when we can think realistically about identifying, isolating, and transferring genes between crop species. It is our opinion that the best place to seek and identify genes for drought resistance in cereal crops is sorghum. We believe that we have a unique opportunity to improve the drought resistance of maize and other crop species by conducting the kind of research being supported by the McKnight Foundation with INTSORMIL at Purdue University. The implications for the State of Indiana and the cornbelt, as well as for drought prone regions in developing countries, are significant. Our objective, simply put, is to use the best and most current technologies from the biological and agricultural sciences to solve one of the world's most important and heretofore most intractable problems, drought resistance.

The mission of our interdisciplinary program is to combine the resources of the International Sorghum Improvement Program at Purdue University with the expertise of scientists in Stress Physiology and Plant Molecular Biology in a concerted effort toward an understanding of the mechanisms of drought resistance in sorghum and to utilize this information for the improvement of sorghum and other crop species such as maize. An understanding of these mechanisms will provide better opportunities for more efficient screening activities in cereal breeding programs. This research program will serve as an exceptional training ground for graduate students who will assume leadership roles in U.S. and international agricultural research into the twenty-first century.

During the past three years we have initiated a unique graduate training and research program which is designed to foster interdisciplinary research in basic plant sciences focused on a problem of extreme importance to both U.S. and third-world agriculture: drought resistance. We have recruited 11 outstanding graduate students. These students have already earned a reputation (both on and off the Purdue campus) for their interdisciplinary zeal, their group activities, their high quality research, and exceptional grades in ongoing course work. The philosophy that research can transcend discipline boundaries, and must transcend these boundaries if we are to solve difficult and complex agricultural problems, has been rapidly grasped and implemented by our student group. The faculty, Department Heads and Deans view this as a major accomplishment of our training program. Internationalization of research through interdisciplinary activities has recently been identified as a priority at Purdue University. The INTSORMIL/McKnight program at Purdue serves as a model of what can be accomplished in this area. A NEW 6-YEAR McKNIGHT PROGRAM MODELED AFTER THE PURDUE PROGRAM HAS BEEN FUNDED BEGINNING IN 1994 FOR A TOTAL OF 12 MILLION DOLLARS.

Objectives

Identify, develop and evaluate sorghum lines or mutants with improved nutritional quality and superior food grain quality using both chemical and biological methods.

Develop agronomically elite sorghum lines for Niger, Sudan, and Ethiopia with good adaptability, good grain quality, good drought and striga tolerance, and improved yield potential.

Use new tools from molecular biology, genetics and plant physiology to study the mechanisms of drought tolerance in sorghum.

Investigate the potential for developing varieties of sorghum with high nutritional value and good food properties for potential use as nutritional foods for young children, pregnant women and nursing mothers.

Train LDC personnel in plant breeding and genetics.

Research Approach and Project Output

Research Methods

Much of the breeding activities will be conducted in Niger, Sudan, and also with the ICRISAT Southern Africa and East Africa regional centers. Collaboration with Sudan and Niger will continue on *Striga* tolerance and drought tolerance. Considerable time and effort will be spent working with Sudanese and Nigerien scientists on grain quality using pedigree breeding as well as population and hybrid development. A major effort will be made to develop A&B

lines with good grain quality, *Striga* tolerance, drought tolerance which are adapted to Sudan and Niger.

Breeding for good grain quality and high digestibility in elite sorghum cultivars which also have African adaptability, good yield and other needed agronomic traits will be continued. Characteristics such as kernel hardness have now been identified which will facilitate breeding for grain quality. This program also will be carried out jointly with Niger and Sudan. Much of the breeding work will be done in Niger with backup using laboratory facilities at Purdue. Screening and trials will be conducted at 3 locations in Niger as well as in Sudan.

Our approach to investigating the genetic determinants of the exceptional drought resistance of certain sorghum cultivars (P898012 and P954035) will firstly entail constructing hybrids between exceptionally resistant and susceptible (e.g., P721-N) lines and evaluating F2, F3 and subsequent advanced progeny and their backcrosses to the original parents, using traditional plant breeding methods. Secondly, we propose to generate many susceptible revertant lines by mutagenesis of drought resistant P898012 and P954035 sorghum. Seed of these pure line varieties were mutagenized at Purdue in the summer of 1988 and M1 plants were self-pollinated to provide M2 seed to screen for drought sensitive revertants in Mexico under water stress conditions. Stress sensitive revertants will also be obtained by using a controlling element system in sorghum for transposon mutagenesis and tagging. The "candy stripe" sorghum phenotype is analogous to the variegated pericarp controlling element system in maize. Candy stripe sorghum is now being backcrossed to drought resistant sorghum lines to produce a pure line drought resistant sorghum variety which contains the mutable gene system. When this is available, it should be possible to select for genetic events involving transposition of the controlling element away from the pericarp element by selecting seed from fully red sectors on the sorghum panicle. Plants grown from seed having red sectors will then be self crossed and their progeny screened for an alteration in drought resistance. Any drought resistant gene identified can then be cloned using as a probe the candy stripe controlling element we are currently identifying. A genetic map of sorghum is being generated (currently 100 markers) using restriction fragment length polymorphisms (RFLP), and this will be employed to define specific chromosomal regions containing drought resistance genes and genes determining a range of morphological, physiological and biochemical characteristics of putative adaptive significance in terms of sorghum stress resistance.

Training M.S. and Ph.D. LDC students will continue as in the past.

Research Findings

The principal research accomplishments made during the INTSORMIL/McKnight Foundation funding period for this program are as follows. Our approach to investigating the genetic determinants of the exceptional drought resistance of certain sorghum cultivars has been multidisciplinary, international in scope, and multi-faceted. First, we constructed hybrids between exceptionally resistant and susceptible lines and evaluated F_2, F_3 and subsequent advanced progeny and their backcrosses to the original parents, using traditional plant breeding methods. A large number of F_6 recombinant inbred families have been derived from one such cross. These families exhibit an exceptional range of genotypic variation for pre- and post-flowering drought stress resistance, as revealed in recent field evaluations of this germplasm during the drought of 1991 in Indiana.

Second, we developed a sorghum RFLP genetic map and we are now uniquely poised to begin to screen the above recombinant inbred families for RFLPs which are associated with specific drought resistance/susceptibility traits. A major thrust of the proposed research has been to extensively characterize the recombinant inbred families above for morphological, physiological and biochemical traits, and to map the major genes responsible for drought resistance to specific chromosome regions. The concomitant development of sorghum cDNA libraries of constitutive and drought-inducible genes will likely further enhance the sorghum genetic map, and will assist in defining specific genes which are responsive to water deficits.

Third, we generated many susceptible revertant lines by chemical mutagenesis of drought resistant P898012 and P954035 sorghum. Seed of these pure line varieties was mutagenized at Purdue in 1988 and M_1 plants were self-pollinated to provide M_2 seed. These M_2 populations were screened for drought sensitive revertants in Mexico under water stress conditions. In order to provide a focal point for interdisciplinary activities in genetics, physiology and biochemistry, we have identified 38 independently occurring mutants in the epicuticular wax genetic system in sorghum. The latter mutant lines are now providing an exceptional source of genetic material for our multidisciplinary group to investigate the biochemistry and genetics of epicuticular wax synthesis and deposition, and to characterize the contribution of the waxy "bloom" trait not only to drought resistance, but also resistance to fungal pathogens. Biochemical analyses of sorghum sheath waxes indicate that wax loads range from as high as 7.4 mg/dm^2 in wild types to as low as 0.3 mg/dm^2 in certain bloomless mutants. Wild type sheath waxes are predominantly (>90%) comprised of free carboxylic acids of carbon chain length C_{28} and C_{30}. Three bloomless mutants (bm-18, bm-8 and bm-15) resulting from chemical mutagenesis, as well as one bloomless mutant identified in the candystrip population (a putative transposon induced bloomless mutant), exhibit a 60 to 70% reduction in total wax load and accumulate free carboxylic acids of much shorter chain length (predominantly C_{22}, C_{24}, C_{26} and C_{28}). These bloomless mutants appear to prematurely terminate fatty acid chain elongation. In contrast, one sparsebloom mutant (bm-28) accumulates substantially higher amounts of carboxylic acids of chain length C_{32} and C_{34} than the wild type. A tandem mass spectrometry method

for determining the composition of epicuticular wax esters has been developed, and has been used to show that wild type wax esters range in total carbon number from C_{28} to C_{48}; these esters are comprised of carboxylic acids of chain length ranging from C_{14} to C_{24}, condensed with alcohols of chain length C_{14} to C_{28}. Future studies will involve continued characterization of the ester, alkane, aldehyde, alcohol and acid fractions of the various bloomless and sparsebloom mutants.

Fourth, we have characterized a controlling element system in sorghum with the view to exploiting this system for transposon mutagenesis and tagging. The "candy stripe" sorghum variety is similar phenotypically to the variegated pericarp controlling element system in maize. The *Y* gene has been identified as the mutable locus in sorghum. The candy stripe sorghum variety has been backcrossed to the drought resistant sorghum lines to produce a pure line drought resistant sorghum variety which contains the mutable gene system. Now that this is available, it is possible to select for genetic events involving transposition of the controlling element away from the pericarp element by selecting seed from fully red sectors on the sorghum panicle. A total of 100,000 independently occurring excision events are being collected. Plants grown from seed having red sectors will then be self crossed and their progeny screened for drought susceptibility. In principle, any drought resistant gene so identified can then be cloned using the candy stripe controlling element probe which we plan to clone from sorghum. A promising lead came recently from our discovery that one of the epicuticular wax genes in sorghum is linked with waxy endosperms, so we may be able to transposon tag the waxy endosperm gene first and then later tag the epicuticular wax gene more readily because of the mechanics of transposition based on observations in other species. Utilizing the genetic map of sorghum generated using RFLPs, it will be possible to define specific chromosomal regions containing drought resistance genes.

Fifth, we have sought genetic variability for a specific biochemical trait which may play an important role in osmoregulation; the accumulation of glycinebetaine. Six glycinebetaine-deficient sorghum genotypes have been identified by screening of the sorghum world germplasm. Genetic analyses of F_2 and backcross progeny from crosses between glycinebetaine-deficient and glycinebetaine-containing sorghum lines have confirmed that glycinebetaine-deficiency is conditioned to be a recessive allele of a single locus. Tracer studies indicate that glycinebetaine-deficient cultivars are capable of oxidizing $^2H_3$-betaine aldehyde to $^2H_3$-glycinebetaine at the same rate as glycinebetaine-containing cultivars, suggesting that the metabolic lesion is at a step proximal to betaine aldehyde dehydrogenase in the glycinebetaine biosynthetic pathway. A sensitive new method for determining choline and glycinebetaine (by stable isotope dilution plasma desorption mass spectrometry) has been developed, and is being applied to these investigations. Future studies will focus on RFLP mapping this locus, testing whether glycinebetaine-deficiency is associated with an impaired capacity to oxidize choline to betaine aldehyde, and developing near isogenic glycinebetaine-containing and -deficient sorghum lines to determine if this trait affects drought resistance.

Sixth, we have developed a sorghum tissue culture, regeneration and transformation system with the view to exploiting many recent advances in the field of plant biotechnology towards sorghum improvement. A number of genes of putative importance in plant tolerance of abiotic and biotic stresses are currently being cloned from other plant sources in anticipation that it may soon be possible to routinely transform sorghum with such genes and their anitsense equivalents. Specific genes of interest include genes encoding enzymes of proline biosynthesis, genes encoding H^+-translocating ATPases, genes encoding proteins involved in cell membrane-cell wall adhesion, and genes encoding pathogenesis related proteins.

Sorghum Transformation: The INTSORMIL/McKnight research group at Purdue in collaboration with Pioneer Hybrid Seed Company is the first to report the stable and heritable transformation of sorghum. This is a significant accomplishment which will allow new opportunities for sorghum improvement in the future. Transgenic sorghum plants have been obtained after microprojectile bombardment of immature embryos. Southern and polymerase chain reaction analyses indicated the presence of both the selectable marker gene *bar* and the reporter gene *uidA* in T_0 plants. Phosphinothricin aceytltransferase activity (enzyme encoded by the *bar* gene) was detected in extracts of the T_0 plants and these plants were resistant to local application of the herbicide Ignite/Basta. Data from T_1 seedlings of one T_0 plant established a 3:1 segregation ratio for herbicide resistance, indicating that the selectable marker gene is transmitted to progeny and is functioning as a dominant allele. The variety transformed is the drought resistant cultivar P-898012 which is well adapted to the African Sahel. This achievement will allow us to introduce new and useful genes into this important African sorghum variety, and could be the dawn of a new era for sorghum research.

Networking Activities

Workshops

Organizer and participant of "The Third Annual Purdue University McKnight Program Retreat." Presentation entitled "The McKnight Foundation Interdisciplinary Research Project on Mechanisms of Drought Resistance." Turkey Run State Park, IN. April 10-11, 1992.

Organized External Evaluation Review of the Niger INTSORMIL Country Program. October 1993.

Research Investigator Exchanges

INRAN Staff, ICRISAT Staff and INTSORMIL Staff are regularly involved in exchange visits at Purdue, as well as

Pioneer and DeKalb seed company scientists. A partial list follows.

Dr. Osman Ibrahim, ARC/Gezira Research Station, Wad Medani, Sudan

Dr. D.S. Murty, Plant Breeder, ICRISAT, Andhra Pradesh 502 324, India

Dr. Lee House, SADC/ICRISAT Sorghum & Millet Prog, Bulawayo, Zimbabwe

Dr. Vartan Guiragossian, Sorghum Breeder, ICRISAT, Nairobi, Kenya

Dr. Darrell Rosenow, Texas A&M University Agric. & Res. Ctr., Lubbock, TX 79401

Dr. Lloyd Rooney, Soil & Crop Sci, Texas A&M Univ, College Stn,TX 77843

Dr. Bruce Maunder, DeKalb-Pfizer Genetics, Rt 2, Lubbock, TX 79415

Dr. Kay Porter, Pioneer Seed Co., P.O. Box 1506, Plainview, TX 79072

Dr. Gene Dalton, Pioneer Seed Co. Johnston, Iowa

Germplasm and Research Information Exchange

Extensive germplasm has been provided to INRAN/Niger, ARC in Sudan, ICRISAT/SADC Zimbabwe, plus numerous seed lots in response to specific requests by both private and public sector institutions.

Publications and Presentations

Publications

Casas, A.M., A.K. Kononowicz, U.B. Zehr, D.T. Tomes, J.D. Axtell, L.G. Butler, R.A. Bressan and P.M. Hasegawa. 1993. Transgenic sorghum plants via microprojectile bombardment. Proc. Natl. Acad. Sci. USA 90:11212-11216.

Axtell, J.D., P. Peters, and U. Zehr. 1993. Mechanisms of drought resistance in sorghum. ASTA/1992-47th Annual Corn & Sorghum Research Conference Proc. Amer. Seed Trade Assoc. pp. 157-163.

Mertz, E.T., J.D. Axtell, G. Ejeta, and B.R. Hamaker. 1993. Development and recent impact of quality protein maize and sorghum. Proc. of the ICC International Symposium on Cereal Science & Technology: Impact on a changing Africa. 10-14 May 1993. Pretoria, South Africa.

Axtell, J.D., U. Barwale-Zehr, and P. Peters. 1993. Interdisciplinary McKnight Research Project for Sorghum Improvement. International Crop Science I. Chapter 68, pp. 525-527.

Zanta, C.A., X. Yang, J.D. Axtell and J.L. Bennetzen. 1993. The candystripe locus, y-es, determines mutable pigmentation of the sorghum leaf, flower, and pericarp. J. Heredity (In Press).

Premachandra, G.S., D.T. Hahn, J.D. Axtell, and R.J. Joly. 1993. Leaf water relations, gas exchange and water-use efficiency in four bloomless and sparse-bloom mutants of *Sorghum bicolor* L. Canadian J. of Plant Sci. (In Press).

Stromberger, J.A., I.M. Dweikat, J.D. Axtell, D.M. Huber, and C.Y. Tsai. 1993. Genotype variation among maize (Zea mays L.) inbred lines for ammonium assimilation characteristics. A.E.S. J. No. 14065. Crop. Sci. (submitted)

Published abstracts

Barwale-Zehr, U. and J.D. Axtell. 1993. Genetic analysis of mutable phenotype associated with candy stripe sorghum. Agron. Abstr. p. Amer. Soc. of Agron., Cincinnati, OH.

Peters, P.J. and J.D. Axtell. 1993. Characterization and drought reaction of epicuticular wax mutants in Sorghum bicolor. Agron. Abstr. p. Amer. Soc. of Agron., Cincinnati, OH.

Invited Research Lectures-Presentations at Scientific Meetings

First International Crop Science Congress (ICSC). Presiding Chair for Session on "Strategies for Improving Crop Quality: The Next Challenge". July 15, 1992. Iowa State University, Ames, Iowa.

First International Crop Science Congress (ICSC). Paper presented "The INTSORMIL/McKnight Collaborative Research Model for Integrating Biotechnology with Sorghum Improvement" by J.Axtell and U. Barwale Zehr. July 20, 1992. Iowa State University, Ames, Iowa.

47th Corn & Sorghum Industry Research Conference. American Seed Trade Meetings. Presentation on "Mechanisms of Drought Resistance in Sorghum." 12/8-11/92.

Presentation to Dean's Club and Dean's Advisory Council. "McKnight Research Program: Collaborative Research Which Benefits Crop Improvement in Indiana as well as Third World Countries." Nov. 22, 1992.

Development and Enhancement of Sorghum Germplasm with Sustained Tolerance to Drought, Striga, and Grain Mold

Project PRF-107 and PRF-107B
Gebisa Ejeta
Purdue University

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Dr. Abdeljabar T. Babiker, *Striga* Specialist, ARC, Sudan
Dr. Mohamed El Hilu Omer, Sorghum Pathologist, ARC, Sudan
Dr. Omar Fadil, NSA, Sudan
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Summary

Genetic resistance of major biotic and abiotic stresses of sorghum and millets, namely, drought, *Striga* and diseases have been addressed in this project. The thrust of this project (PRF-107) has been in the identification, characterization and elucidation of genetic mechanisms of resistance to these stresses and, whenever feasible, incorporation, through conventional plant breeding methodologies, of key traits into adapted high yielding genotypes. Research efforts in PRF-107 have been totally collaborative both within and outside Purdue University. The strongest and most productive collaboration has been with Dr. Larry Butler (PRF-104B). Significant progress was particularly made in the area of genetic resistance to *Striga* as a result of our collaborative efforts. A unique approach to addressing the *Striga* problem as a series of interactions between the host and parasite with potential for intervention was developed. This approach led to identification of key compounds, development of an effective assay, establishment of mode of inheritance, transfer of a resistance gene to productive cultivars and eventual mapping of the gene on a molecular sorghum genome map. Modest progress has also been made in the area of drought and grain mold resistance. In all areas, superior germplasm have been developed and distributed widely to collaborators in Africa where some have actually been released and used by farmers.

Introduction

This project started in 1984 with the objective of strengthening the international linkages and relevance of sorghum and millet research at Purdue University and at other INTSORMIL institutions. To achieve this objective the PI forged interdisciplinary and inter-institutional partnerships among LDC and U.S. scientists towards the goal of collaborative sorghum and millet research addressing key production and utilization constraints. Specific research thrusts of this project have been in the areas of *Striga* resistance, drought resistance, disease/pest resistance, and nutritional quality of sorghums and millets. In addition, this project also emphasized germplasm development and enhancement as well as conservation and evaluation of germplasm diversity. Beyond research and germplasm development, a significant portion of the PI's efforts have gone into training, networking, and into institutional develop-

ment efforts of research systems and seed production and distribution programs of collaborating national agricultural research services (NARS). The following is an itemized list of the major contributions made by PRF-107 and PRF-107B in collaboration with others.

Objectives

Research

To study the inheritance of traits associated with resistance to drought, *Striga*, pests, and diseases of sorghum and/or millets.

To elucidate mechanisms of resistance to *Striga*, drought and diseases of sorghum and/or millets.

To evaluate and adapt new biotechnological (techniques and) approaches in addressing sorghum and millet constraints for which conventional approaches have not been successful.

Germplasm Development, Conservation, and Diversity

To develop sorghum varieties and hybrids with improved yield potential and broader environmental adaptation.

To develop and enhance sorghum germplasm with increased levels of resistance to drought, *Striga*, diseases, and improved quality characteristics.

To assemble unique sorghum germplasm, and to encourage and facilitate free exchange of germplasm between U.S. and LDC scientists and institutions.

To assess applicability of various statistical and DNA fingerprinting technologies for evaluating genomic similarity or for discerning genetic diversity of sorghum and millet germplasm pools.

Training, Networking, and Institutional Development

To provide graduate and non-graduate education of U.S. and LDC scientists in the area of plant breeding and genetics.

To develop liaison and facilitate effective collaboration between LDC and U.S. sorghum and millet scientists.

To encourage and facilitate positive institutional changes in research, extension and seed programs of collaborating countries involved in sorghum and millet research and development.

Program Approaches

The research efforts of PRF-107 and PRF-107B are entirely interdisciplinary. Much of the on-campus research at Purdue is in close collaboration with Dr. Larry Butler (PRF-104B). Our programs are fully integrated particularly in the areas of pest, disease, and *Striga* resistance, where a concerted effort is underway in elucidating the biochemical and genetic mechanism of resistance to these constraints. Field and laboratory evaluations of sorghum and millet germplasm are coordinated, the results from one often complimenting the other. In addition, there have been collaborative research efforts with colleagues in Africa primarily with Dr. A.G.T. Babiker in Sudan where an integrated approach to *Striga* control has been under investigation.

Our germplasm development and enhancement program utilizes the wealth of sorghum and millet germplasm we have accumulated in the program. Intercrosses are made in specific combinations and populations generated via conventional hybridization techniques, through mutagenesis, or through tissue culture *in vitro*. Conventional progenies derived from these populations are evaluated both in the laboratory and in the field at West Lafayette, Indiana for an array of traits, including high yield potential, grain quality, as well as certain chemical constituents that we have found to correlate well with field resistance to *Striga* or panicle and leaf diseases. We also evaluate our germplasm for tropical adaptation and disease resistance during the off-season at the USDA Tropical Agricultural Research Center at Isabella, Puerto Rico. Selected progenies from relevant populations are then sampled for evaluation of specific adaptation and usefulness to collaborative programs in Sudan, Niger, and more recently Mali. Evaluation of the drought tolerance of our breeding materials have been conducted at Lubbock, Texas in collaboration with Dr. Darrell Rosenow and in a winter nursery at Puerto Vallarta, Mexico. Assistance in field evaluation of nurseries has also been provided by industry colleagues particularly at Pioneer Hi-Bred and DeKalb Plant Genetics.

The training, networking and institutional development efforts of PRF-107 have been provided through graduate education, organization of special workshops and symposia as well as direct and closer interaction with research scientists and program leaders of NARS and associated programs. Much of the effort in this area has been primarily in Sudan and Niger, with limited activity in Mali and some in Southern Africa through SADC/ICRISAT.

Research Approach and Project Output

Striga Resistance

Perhaps the most significant contribution that had come out of our *Striga* research program at Purdue University is the unique approach that we developed in dissecting the complex trait of *Striga* resistance into components based on simpler genetic models. This is based on the knowledge that gaining a better understanding of mechanisms of host plant resistance is vital to crop breeding efforts and that previous efforts on field screening for *Striga* resistance has been slow and difficult, with only modest success. Successful *Striga* parasitism is dependent upon a series of chemical signals

produced by its host. Interruption of one or more of these signals should result in failure to establish parasitism. We therefore made the characterization of specific mechanisms of resistance the focal point of our effort to develop *Striga* resistant crop genotypes. The overall plan is to identify crop genotypes which fail to interact normally at each stage of the parasites interaction with its host.

The most completely characterized mechanism of resistance to *Striga* is unusually low production of host plant root exudate compounds required for germination. We fully exploited low production of germination stimulants in selecting for *Striga* resistance in sorghum. Dr. Butler's students identified and characterized several host root produced chemical signals of two different types (the oily quinine, sorgoleone, and a water soluble analog of strigol) that trigger *Striga* seed germination. We developed simple methods (agar gel assay and a dilution assay) to screen host genotypes (sorghum, millet, maize and cowpeas) for the production of water soluble germination signals. We identified sorghum genotypes that are resistant because they produced limited amounts of the signals. We determined that the capacity to produce unusually low amounts of the germination signal is inherited as a single recessive gene. Using conventional plant breeding approaches, we incorporated this resistant conferring trait into improved sorghum genotypes combining *Striga* resistance with high yield and enhanced grain quality. These improved sorghums have been extensively tested through our international collaborative network for broad adaptation and stability of resistance and are currently pending release. We also generated appropriate populations of sorghum and currently characterizing genes for *Striga* resistance using molecular marker technologies (RFLP, RAPD) and also developing a saturated genetic map of sorghum to facilitate future genetic studies. Basic biochemical work done by Dr. Babiker while on sabbatical leave at Purdue established that the ultimate signal for *Striga* seed germination is ethylene. He also found that various chemical compounds including the cotton defoliant thidiazuron in mixture with herbicides such as 2-4D stimulate ethylene production and may be used to clean up infested fields by induction of suicidal germination.

Although the requirement for a signal to initiate *Striga* germination has long been known, the need for an additional host signal to produce specialized rootlets (haustoria) for attachment to host roots have only emerged recently. A number of compounds have been implicated to function as haustoria initiators in *Striga* but the active signals from host roots have not yet been identified. Yohan Weerasuriya, a Ph.D. student from Sri Lanka, is now developing a quantitative assay for production of this second host-derived developmental signal. Preliminary work has identified maize genotypes which produce low amounts of this signal, but they have not yet been field tested. We observed that the signals required for germination and haustoria formation are inherited and produced independently by host roots.

We have recently shown that once *Striga* is attached to its host roots the seedlings may need an additional host-derived signal to differentiate into shoots. Using *Striga* cells grown in tissue culture we hope to develop an assay for such a signal. In vitro cultivars are also being used to screen extracts of host plants for factors which inhibit elongation and/or proliferation of *Striga* cells, possibly preventing invasion of host roots by the parasite. Furthermore, there are other additional mechanisms including the probable role of chemical regulation of attachment and penetration, a possible involvement of toxins produced by *Striga* that are transported to the host plant metabolic machinery, as well as the root growth habit of host plants and premature haustoria formation as avoidance mechanisms. Our goal is to pyramid as many of the genes contributing to the above listed mechanisms of resistance into a single genotype which should exhibit a more durable and broad-based resistance to *Striga* than is currently available.

Our overall strategy to alleviate the *Striga* problem has been documented in our widely distributed and well received research bulletin entitled "New Approaches to the Control of *Striga*: *Striga* Research at Purdue University."

Drought Resistance

Drought tolerance is also a complex trait influenced by the interactive effects of many genes. Testing and identification of drought tolerant crop germplasm has been difficult. Selection must be made under controlled condition where moisture stress is reliably induced in order to effectively discriminate among genotypes. Although progress has been made in developing drought tolerant crop genotypes through conventional breeding and evaluation of germplasm in drought prone environments, the gains have been slow. The difficulty of selecting for drought tolerance and the need to precisely impose moisture stress have led to identification of genotypes with perhaps enhanced drought tolerance but often with limited yield potential.

A more effective approach to breeding for drought tolerance in sorghum has been one that is based on the observation that drought tolerance (in sorghum) tends to be expressed in a developmentally similar pattern. Experience has shown that precise and repeatable phenotypic effects are observed depending on whether the moisture stress was induced at the early vegetative growth (seedling) stage, or after panicle initiation but prior to anthesis (pre-flowering), and finally from pollination to maturity during the grain filling (post-flowering) stage.

Symptoms of drought stress induction have been identified for each developmental stage. These symptoms can be divided into morphological and yield related symptoms. Pre-flowering drought stress in a susceptible line produces leaf rolling, unusual leaf erectness, delayed flowering, floret abortion, reduced panicle size, reduced seed set, and reduced plant height. In contrast, normal panicle development, good seed set and typical leaf morphology are indicative of a

pre-flowering drought tolerance. Under post-flowering drought conditions, susceptible lines exhibit premature leaf and stalk renascence and reduced seed weight. Tolerance to moisture stress at this stage is manifested by a stay-green phenotype and normal grain filling.

D.T. Rosenow at the Texas A&M Experiment Station in Lubbock has used this approach effectively to identify unique sorghum genotypes with classic phenotypic symptoms. We have both shown these expressions can be used in screening sorghum genotypes in several locations in Africa. The benefit of such an approach in breeding for drought tolerance is that germplasm can be properly catalogued on the basis of the types of drought tolerance mechanism it has accumulated. Because sorghum is native to sub-Saharan Africa, a region characterized by limited water resources, the crop may have evolved with adaptation to the range of environmental conditions including extensive genetic variation for drought resistance. We have capitalized on the genetic diversity for drought tolerance in this crop to use it as a suitable species for studying the genetics, physiology, and biochemistry of drought tolerance, a trait so crucial in most field grown crops.

We have generated a unique set of sorghum germplasm through conventional plant breeding technology following intercrossing and selection under defined moisture stress conditions. Recombinant inbred lines thus produced have been used for characterization using molecular DNA based markers. Our goal is to create extensive, high resolution genetic map of sorghum which should facilitate the identification of quantitative trait loci (QTL) associated with specific drought response at specific developmental stage. We have already identified several QTLs associated with pre and post-flowering stress tolerance. We found that ability to yield under pre- and post-flowering drought are controlled by many separate genetic loci. Tolerance to yield loss under pre-flowering stress is associated with early maturity.

Another approach we had taken in our research on drought tolerance has been the investigation of the possible role of osmoregulatory compounds in providing protection against moisture stress in sorghum. One of the most common osmolytes known to accumulate in many grass and chenopod species is glycinebetaine. In chenopods the accumulation has been thought to be a metabolic response to osmotic stress to protect enzymes during heat and dehydration. A survey of a large collection of landraces of sorghum resulted in six genotypes that have lost the capacity to accumulate glycinebetaine. These null mutants were used in intercrosses with normal sorghum genotypes to create appropriate populations for a study on mode of inheritance for glycinebetaine deficiency. The results showed that betaine deficiency is inherited as a single recessive gene. We also established, in a biochemical feeding study, that glycinebetaine deficient cultivars can synthesize glycinebetaine when supplied with labeled betaine aldehyde. The deficiency, therefore, is not due to a lesion at betaine aldehyde dehydrogenase. The genetic populations generated for the inheritance study have been advanced to evaluate if ability to accumulate glycinebetaine is associated with drought tolerance in sorghum. Preliminary results using random genotypes with contrasting betaine content showed that pre-flowering drought tolerance is positively correlated with levels of glycinebetaine. This will be verified by using recombinant inbred and isogenic lines which we generated for the purpose of verifying the presence or absence of such an association.

Disease Resistance

The major disease investigated in our program has been grain mold, a problem caused by a complex of fungi organism during grain fill and maturation while the crop is still in the field. Grain mold is one of the most important diseases of sorghum around the world. It is particularly important when sorghum is grown in environments where the rains cease after the crop matures providing for a suitable condition for pathogen development. Bird resistant, high tannin sorghums withstand grain mold damage better than low tannin sorghums. This observation led many to assume that tannins, high molecular weight phenols, are responsible for mold resistance in grain sorghum. We screened and characterized a large collection of sorghum germplasm and found that other phenolic compounds and proteins are more significantly correlated with mold resistance. Of particular interest has been the level of flavan-4-ol in low tannin sorghums. We have not yet established whether flavan-4-ol are indicators or are by themselves responsible for reducing mold infection. We also find that hardness of grain is associated with mold resistance among low tannin white sorghum. Genetic studies have shown that flavan-4-ols and related phenols are under simple genetic control and progress from selection can be made if appropriate populations are developed. We now have a random mating sorghum population made up of parents with good level of grain mold resistance. Developmental studies using diverse parental lines have shown that various phenolic compounds accumulate differentially in different genotypes and that this may be associated with timing of initial contact and infection by non-pathogenic and pathogenic fungi respectively. Repeated sampling of sorghum panicles at different post-flowering stages indicated that several fungi (alternaria, aspergillus, Fusarium, curvularia, etc.) can infect the sorghum kernels. However, time of infection, environment, virulence, and population dynamics of the various pathogens, have a more significant effect on the level of kernel damage on sorghum panicles.

We also studied the role of plant pigments and tannins in the reaction of tan and non-tan sorghum lines to leaf diseases. Sorghum plants are known to produce various pigments. These pigments have been suspected to have a role with resistance to leaf diseases and grain deterioration. We developed isogenic pairs of tan and non-tan (red) sorghum lines to compare for phenolic contrast and possible association with leaf diseases. Leaves, stems, sheaths, glumes, and seeds of mature plants were assayed for tannins, pigments,

and precursors of these pigments. We found that red plants accumulate 3-deoxyanthocyanidins, the major pigments in sorghum, but that these were absent in the tan plants. Instead, the tan plants accumulated apigenin. The near-isogenically contrasted genetic stocks, though significantly different in phenol composition, did not show differences in reaction to the leaf diseases, anthracnose (*Colletotrichum graminicola*) and rust (*Puccinia purpurea*). Other sorghum lines which showed marked differences in their phenolic composition also did not show differences in reaction to these pathogens. Our studies showed that among sets of sorghum germplasm we evaluated tannins, pigments, and pigment precursors are not responsible for anthracnose or rust resistance.

Nutritional Quality

Pearl Millet

Nutritional studies on sorghum both *in vitro* and *in vivo* have shown that sorghum gruels have a significantly lower protein digestibility compared with rice, wheat, and maize gruels. We observed that whole grain samples of pearl millets possess protein fractions similar to maize and not with sorghum. The cross-linked kafirin fraction in sorghum, found in large quantities, has been implicated in the reduced digestibility following cooking. We noted that pearl millet lacked large quantities of this endosperm storage and hypothesized that as a consequence pearl millet should have higher *in vitro* digestibility than sorghum. Our studies showed that digestibility values for pearl millet varieties were higher than that of sorghum and comparable to that of maize. In contrast to sorghum, digestibility values of pearl millet and maize did not decrease significantly upon cooking. Protein distribution patterns of uncooked pearl millet and the shifts in the different fractions as a result of cooking also resembled that of maize and not sorghum. The amino acid profile of pearl millet is more favorable than that of normal sorghum and normal maize and is comparable to the small grains, wheat, barley, and rice. On the basis of these findings, we reported that pearl millet is a nutritious and well-digested source of calories and proteins for humans. Our data, therefore, provided a theoretical background for addressing the digestibility problem in coarse grains, particularly sorghum.

Sorghum

In parts of Africa where low-tannin sorghums cannot be grown because of excessive bird damage, bird-resistant high tannin sorghums have to be grown. High tannin sorghums also have resistance to field weathering, but possess some anti-nutritional properties for monogastric animals including humans. In some African countries where high tannin sorghums have been traditionally cultivated, processing technologies that alleviate the anti-nutritional problems have been developed by housewives. The effect of a traditional Ugandan technology, where the grain is treated with wood-ash, followed by soaking in water overnight and germination was tested by Dr. Sam Mukuru, ICRISAT when he spent a sabbatical year at Purdue. His results showed that wood-ash treatment is effective in detoxifying high tannin grain and improves its nutritional quality to the level of low-tannin sorghum. This and other studies previously conducted by the sorghum research group at Purdue have clearly shown that traditional societies have evolved technologies that alleviate nutritional problems associated with utilization of grain sorghum.

Genetic Diversity

Pearl Millet

African pearl millet landraces, while highly drought tolerant, are often of low yield potential. This low productivity is due in part to the harsh climate and poor edaphic environment. Farmers traditionally select within a landrace population but with the recurring drought and increased pest infestation there is a concern that variability among landraces may have decreased continually. Artificial selection by man and natural environmental selection have certainly led to the establishment of landraces with narrow ecological adaptation. Effective utilization of available germplasm in breeding programs is enhanced if the variation is properly characterized and described. Characterization of widely cultivated landraces and knowledge of their heterotic patterns and combining ability would be useful in a breeding program.

We evaluated pearl millet landraces that have been cultivated in countries south of the Sahara (Senegal, Niger, Nigeria, Uganda, and Sudan) for genetic diversity and heterosis in cross combination. We found that the landraces were significantly different for all characters evaluated. Landraces from Niger showed much less variation than the other African millets. Cluster analyses revealed similarities between Niger and Senegal as well as between Niger and Nigeria pearl millet landraces. Flowering time, plant height, stem diameter, spike length, and grain and spike yield seemed to be the major sources of diversity among the cultivars. Heterosis for grain yield ranged 25 to 81%. Hybrids were significantly more tolerant to downy mildew than their better parent. The large heterotic effects and the magnitude of the additive effects were helpful in choosing pearl millet landraces for intercrossing in the development of pearl millet cultivars with improved grain yield for the program in INRAN, Niger. These germplasm have formed the foundation for the breeding program currently run by Dr. Botorou Ouendeba.

Sorghum

Landraces of cultivated sorghums have been extensively collected from many parts of the world. These collections have been stored in germplasm banks at a few national and international research programs. Unfortunately many of these collections have not been properly characterized so that their immediate utility has been limited. As the number

of accessions in the total sorghum collection increases, the demand for time and resources to properly evaluate, characterize, and catalogue these collections continues to overwhelm the capacity of many of these programs. The World Sorghum Collection is known to have many duplicate samples. Many of the samples, particularly early IS entries, may have been misclassified or may not be true-to-type. Most of the collections have not been assessed for diversity or representation, either geographically or botanically. It is the responsibility of the Sorghum Research Community to support efforts towards the proper evaluation, characterization, and cataloging of sorghum germplasm.

A cooperative effort between INTSORMIL, ICRISAT, USAID, and the ARC/Sudan was undertaken recently to properly evaluate and characterize the Sudan sorghum collection. Some 3000 accessions were grown in Wad Medani, Sudan and characterized for major agronomic and botanical characteristics. The collection was later introduced to the U.S. via the APHIS Plant Quarantine Grow-out Station at St. Croix. A more extensive set of characterization data was collected while the accessions were grown out at St. Croix. A smaller Working Collection was also sampled. Studies are underway to develop proper statistical description of diversity in the collection and to evaluate the small Working Collection as a representative of this extensive sorghum collection from Sudan.

Germplasm Development

Since 1984 a wealth of sorghum germplasm has been developed, evaluated, and accumulated under the PRF-107 project. Deliberate intercrosses are made between selected parents and segregating progenies are often evaluated using target environments or assays that were defined and designed specifically for the goal at hand. Sample specimens from these selections are often shared with collaborators to pre-test adaptation and fitness in specific environments. Based on the responses of the test samples a larger set of selections are forwarded to cooperators for extensive testing and are directly in their breeding programs. We have also conducted extensive evaluation in the program in a balanced selection effort where field performance at West Lafayette, Indiana (for yield potential) and at Isabella, Puerto Rico (for tropical adaptation and disease resistance) is complemented by specific laboratory assays such as screening for *Striga* resistance using the agar gel technique. As a result, germplasm developed in our program range from segregating populations, random mating populations to parental lines, experimental hybrids, and elite cultivars that are fit for direct utilization. A major component of our breeding program has involved a generation of food-type (tan plant) sorghum seed parents expected to contribute parental material for commercial hybrids with potential for use both overseas and in the United States.

Training and Networking

This project has contributed to the graduate education of many students. The PI has served as chairman, co-chairman, or member of the graduate committees of over 30 students during the last 10 years. Many of these students have been from developing countries and have returned to serve their home institutions and countries. These students have utilized resources committed through PRF-107 for conducting field and laboratory research for their dissertations. All have utilized germplasm material or data generated through the range of studies conducted in this project. Continued association has been maintained with graduates that now serve at the IARCs (primarily ICRISAT) and NARS (in their respective home countries). Germplasm as well as information have been shared with former students. With some, joint projects have been developed in a collaborative manner. Others have been encouraged to form similar alliances with PIs at other INTSORMIL institutions.

The PI has also interacted with other African sorghum/millet research scientists in Sudan, Niger, Mali, Somalia, Kenya, Uganda, Tanzania, Botswana and Zimbabwe either directly through exchange of visits or through established networks in the various eco-regions. The SAFGRAD/ICRISAT and the SADC/ICRISAT networks have complemented collaborative associations INTSORMIL PIs have forged with LDC scientists and their institutions across the continent of Africa. These associations and meetings have also resulted in informal networks among African scientists across ecological zones. Conferences, symposia, and workshops organized and supported by PRF-107 and other INTSORMIL projects have contributed to many of these developments. Contributions made directly to human capital development through graduate education, conferences, and continual interaction through collaborative research remain to be the key component of technical assistance by this (PRF-107) and other INTSORMIL projects.

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The Enhancement of Sorghum Germplasm for Stability, Productivity, and Utilization

Project TAM-121
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Summary

The objective of TAM-121 is to bring together in a focused manner all those traits which cause the production of higher yielding more stable sorghums with acceptable or superior food quality, and have adequate resistance to biotic and abiotic stresses. Successful crop production systems require cultivars with high yield levels per unit area and these cultivars must have a genetic potential which can be expressed over a wide range of environmental conditions.

One major dominant gene and one major recessive gene were found to control the ability to stay green under drought conditions. A consistent relationship has been shown between high nonstructural carbohydrates in the stem and charcoal rot resistance. Two-gene systems appear to control relative water content, osmotic potential, and heat tolerance. B35, a drought resistant cultivar, lacks the ability to move sucrose from the leaves, etc., and results in osmotic adjustment. RTx430 moves sucrose effectively to the panicle and

relies upon other mechanisms to affect drought resistance. The ability of some sorghums to remain fertile under low temperatures (10°C) is controlled by two pairs of genes. Eight genes have been described which affect the food quality of sorghum grain; pericarp color, presence or absence of a pigmented testa, thickness of pericarp, nature of endosperm, and basic plant color.

More than 14,500 sources of germplasm, inbred lines, and enhanced populations have been distributed to collaborators. These materials have been incorporated into national breeding programs, selected for release to farmers, and used in training programs. In addition, 766 replicated trials have been shared with cooperating scientists throughout the world since this project began. The TAM-121 project has developed and released 68 inbred parental stocks for use domestically and internationally since the INTSORMIL program was initiated. More than 10 countries are known to have released hybrids using materials developed in this project. Paraguay has named at least five hybrids and area planted to sorghum has increased by more than 15-fold.

Training of students in the project has lead to 26 Ph.D.'s from 16 countries and 22 M.Sc.'s from 12 countries. This is probably the greatest contribution of this project.

Introduction

Production of sorghum throughout the world is limited by many and varied risks. Breeding and the incorporation of genetically controlled traits have been considered to be the best avenues for attacking these production constraints. Sorghum originated in Northeastern Africa and is the primary cereal of choice in many parts of the world because of its resistance to high temperature and water stress. In the early stages of this project it was determined that germplasm, which possessed all the possible traits that affect productivity, should be made available to collaborating scientists. Because this project is related to end-product deployment, improved or elite germplasm is the goal.

During the past 35 years, following the introduction of cytoplasmic-genetic male-sterility, and the potential of hybrid seed production, yields have steadily increased under the hybrid system. This has been accomplished by meeting the needs of producers and remaining ahead of yield limiting constraints (diseases, insects, stresses, etc.). Much more progress has been made in some regions of the sorghum world than in others. Those areas where sustainable yield has not changed, are the areas where this project impacts. However, impact of the project in the developed sorghum growing areas has been good also.

When this project began, concentration was divided between Central/South America and several African countries. The broad goal was to insure widespread stability in the characteristics which affect productivity and to distribute this enhanced useful germplasm over a large part of the sorghum growing world, and to gather useful information on those characteristics of stability of production in tropical environments. Furthermore, we were concerned to incorporate adequate and acceptable food quality with the enhanced yield stability germplasm. Without the combination of improved yield potential (with resistance to diseases, stresses, etc.) and acceptable food quality, there could be no real gain.

A sustainable agricultural system is dependent upon an acceptable yield of sorghum in those areas of the world which are constrained by risks associated with unstable productivity and cultivars which are incapable of offering solutions to those constraints where sorghum is considered a staple food resource. The overall objective of this project is to reduce the risks to productivity through enhancement of genetic potential by creating germplasm pools, lines, and hybrids with good food quality, stable performance and potentially high yield, and possessing a high level of resistance to significant diseases, pests, and stress factors while maintaining acceptance and nutritional quality.

Materials from the USDA-TAES Sorghum Conversion Program and breeding materials from other TAES sorghum projects are evaluated for resistance to internationally important diseases and pests in a cooperative program throughout the sorghum growing world. Large nurseries at several locations in Texas which utilize naturally occurring stresses along with artificial inoculations to determine the most useful sources of resistance(s) and economical gene deployment. Screening of advanced and selected items are done in Georgia, Mississippi, Puerto Rico, Arizona, Mexico, Honduras, Venezuela, Brazil, Paraguay, Argentina, Mali, Sudan, and other sites in Africa and Asia.

Basic food quality characteristics are identified in various food systems and then reduced to genetic control mechanisms. These are crossed into the high yield materials and sent for evaluation as a part of the whole system. Those characteristics which add to the quality of tortillas, chapati, ugali, kisra, etc., must be a part of the food system and the production system.

Breeding strategies utilized by TAES sorghum breeders are both qualitative and quantitative in design. Development of RFLP capabilities, tissue culture screening of germplasm, utilization of introduced exotic germplasm in elite line development, as well as characterization of biotic and abiotic stress phenomena, are used to insure the sustainable production of sorghum for grain and forage.

During the years of this project germplasm has been distributed in many countries which have made good use of the material. For example, Mexico has named at least three hybrids for national distribution plus much of the current Mexican sorghum research program uses elite or enhanced materials sent into that program from INTSORMIL. In Guatemala, two hybrids have been named which came from the Texas sorghum project (TAM-121) both have grain quality adequate for food utilization. Paraguay has grown from a country which grew less than 2,000 ha of any

sorghum to a production of more than 28,000 ha today. Sorghums utilized in Paraguay are food types (both varieties and hybrids), grain hybrids for poultry feeds and livestock rations, and hybrids for forage and silage. The most significant thing about the Paraguay project has been the infrastructure building which has taken place. The Mennonite community is now fully capable of producing their own sorghum hybrids, distributing them, and providing extension production information to growers.

The identification of Hageen Dura-1 in the Sudan was an impressive finding. The female ATx623 was used because of its wide adaptation and yield potential, as well as its drought resistance. A sister line ATx622 has been introduced in China and used in hybrids planted on tens of thousands of hectares. The Sorghum Research Institute, Liaoning Province, has used a large quantity of germplasm to introduce yield potential and broaden their use of hybrids. They are capitalizing on the use of A_2/B_2 cytoplasmic-genetic male-sterility introduced from this project because many of the local Kaoliang types restore fertility to the A_2 system plus these combinations have high yield potential.

Large amounts of germplasm have been introduced into programs in South Africa, Zimbabwe, Nigeria, Zambia, Argentina, Honduras, and Mexico which have been incorporated into local programs to add improvement to local types. This material has included pure lines, released materials, F_2 populations, selected breeding materials with specific traits, and other early to intermediate generation materials for onsite selection.

The original concern of this project was to provide elite and enhanced germplasm to collaborators who face constraints of productivity. During the years of this work a very large amount of improved germplasm has been distributed and significant payoff has resulted with the utilization of that material in breeding programs and the release and distribution of numerous improved cultivars and either parents of hybrids or hybrids directly appropriated from the project.

Objectives, Production and Utilization Constraints

Objectives

The overall goal of this project has been to improve the stability of sorghum yields while improving food quality and general productivity. While this is a long term program, it is designed to create a useful series of germplasm pools and cultivars which possess the traits necessary for sustained crop improvement in national and collaborator programs. Our aim has been to develop from these pools enhanced lines, hybrids, and varieties which are best suited to specific conditions in each collaborators area of responsibility. Materials are already coming into widespread use in a number of countries using this approach.

Specific project objectives for the long term have been to:

Provide adequate germplasm diversity which has been genetically enhanced to add potential to existing programs.

Provide increased yield potential and increased stability of production to impact the low economic return received from sorghum in stressful environments.

Provide high quality grain characteristics which can be used for food and feed while insuring high nutritional quality and high yield potential.

Provide a broad array of adequate resistances to pests and stress factors.

Provide graduate training and research leadership enhancement for co-workers in collaborating LDC's and to assist in training programs within collaborating countries.

Constraints

Yield of sorghum throughout the world is constrained by risks associated with unstable productivity and cultivars which are incapable of providing solutions to these constraints. Sorghum is generally grown under less favorable environmental conditions in areas of the world where human nutritional levels are at marginal levels of acceptability. The constraints to productivity which are addressed through this project are genetic limitations to yield, disease resistance, drought, inadequately developed germplasm resources, unimproved food quality, and unavailability of improved seeds.

Sorghum is the primary cereal of choice in several parts of the world because of its resistance to high temperatures and water stresses. In the north of Paraguay, i.e. the Chaco, west and north of Mexico, much of Honduras, El-Salvador, and Guatemala in Meso-America, conditions limit the production of maize. Sorghum fits the need for a cereal grain resource well but the constraints of stability of yield, fodder, and grain (dual-purpose usage) utilization, as well as grain quality adequate for tortilla production must be the focus of research. In West Africa, particularly in Mali, Niger, and Burkina Faso; Southern Africa, and much of Northeastern Africa, temperatures and water stresses also present devastating production problems. Photoperioditic responsiveness must be added to the constraints, since sorghum for grain must mature outside the rainy season. Disease pressures exerted upon the germplasm are similar in many respects but are often different in regions and even small areas of production. In general, insect attack is not as specific. These items, as a part of the total productivity system are constraints which limit successful sorghum growth.

A need for greater genetic diversity is becoming increasingly important as we face both biotic and abiotic erosion of germplasm. Materials from the TAES/USDA Sorghum Conversion Program have been crossed with previously identified elite higher yielding materials and have been re-selected for response to the constraints of stability and

productivity. As these more broad based genetically enhanced lines and hybrids emerge from the project, they are differentially selected for use in Meso-America, South America, Africa or Asia.

Though sorghum is a major food resource commodity in much of the arid and semi-arid regions of the world, very little is known about the genetics of food quality. Even though sorghum has been used for many thousands of years as a food source, selection for quality has been largely subjective and practiced by housewives. It has been said that sorghum will become much more important as a food in the latter part of this century as the best land and water resources are diverted to urban growth. It becomes very important to understand the basic characteristics which impact quality and to explain their genetic control.

There is a continuous erosion of germplasm and a pressure to use new diverse sources of resistance to pests, diseases, and environmental stresses as well as increasing the quality and diversity of end-products, hence there must be preservation and expansion of collections. Adequate evaluations of existing collections, new introductions, and converted lines are necessary to determine usefulness in solving or impacting worldwide sorghum productivity constraints.

Drought is a serious constraint to sorghum production throughout most of the world. Within the sorghum germplasm reserves there exist large differences for reactions to drought (lack of water and related high temperatures) and subsequent performance. Because Texas has a wide range of rainfall and spans both temperate and tropical climatic patterns, it is ideal for both large scale field evaluations of drought resistance phenomena and the validation of laboratory screens of physiologic explanations of drought tolerance. Furthermore, because the environment of Texas represents the climates of world sorghum production regions so well, it is suitable to screen germplasm, incorporate yield and grain quality components as well as disease resistance, etc. The South and Central Texas nursery sites have been critically chosen for screening and breeding sorghums with high levels of resistance to internationally important diseases and adaptation phenomena.

Working with collaborating physiologists, osmoregulation, heat tolerance, leaf wax concentration, and root development patterns have been measured and transferred to elite germplasm. The importance of maintaining green leaf area through nonsenescence, high levels of nonstructural carbohydrates in the stem, and the ability to differentiate a large number of seeds per panicle under stress, coupled with the efficient use of water to fill those seeds, give stability to production.

The TAES/INTSORMIL sorghum research program has and continues to contribute sustainability to the commodity worldwide. The blend of practical field evaluations, with basic research endeavors, identification, and utilization of exotic germplasm with protection traits, strengthens enhancement of utilization traits to make products more useful and economical for the grower and consumer. This research effort in sustainability is focused on increased yield of food energy per unit area, maintenance of increased yield of available protein, and diversification of germplasm to protect production.

Research Approach and Project Output

Research Methods

Germplasm resources which have been collected or shared from international sorghum improvement programs were evaluated during increase or in special nurseries in Texas, Puerto Rico, and Honduras. Those materials which have traits useful to the objectives of the project were routed into either the breeding program or the Sorghum Conversion project. Individual collections from Kenya which possess drought resistance, aphid resistance, and *Striga* resistance were crossed in the greenhouse to elite project materials. Basic breeding strategies were utilized which are both qualitative and quantitative to develop populations of individuals for evaluation and subsequent selection. This project is cooperatively involved in the development of an RFLP map of the sorghum genome. This technology will be useful in the future as a means of locating desired genes for breeding. The project also is involved in the use of RAPD's to assist in the identification and utilization of genes associated with height, maturity, grain quality, and drought. This project uses pedigree breeding, with limited backcrossing, to transfer constraint solutions to elite breeding lines. Development of females in the utilization of hybrid vigor was extended to include A_1, A_2, and A_3 cytoplasmic-genetic male-sterility systems.

Materials from the ongoing improvement program of this project, the Sorghum Conversion Program, and breeding selections from other projects were evaluated for resistance to internationally important diseases and insects. The evaluations were made in critically selected nursery sites and through a cooperative and collaborative special nursery evaluation program. An all disease and insect nursery (ADIN) which consists of 70 entries and two replications includes critically selected materials from several TAES projects; i.e. new sources of resistances, old sources of resistance, and specific race or biotype marker lines. Other nurseries prepared either by the project or cooperatively serve all investigators and collaborating scientists by providing useful germplasm to programs. Primarily, these germplasm evaluations nurseries are used to collect critical data on genetic/environmental responses which can be used in breeding activities.

Large nurseries in several critical locations in Texas use naturally occurring disease, insect, or environmental stresses to provide the base for evaluations. These nurseries and artificial inoculations are used to determine the most useful sources of resistance(s) and methodology for gene

deployment. More than 30,000 selections were evaluated in these nurseries by this project during this reporting period. More than 40,000 selections were made in the nurseries for future evaluations or utilizations. Screenings and critical evaluations of advanced breeding selections were made in Georgia, Puerto Rico, Mexico, Honduras, Venezuela, Brazil, Paraguay, Argentina, Mali, Sudan, Kenya, India, and China, in addition to the Texas based nurseries.

New breeding populations were created in the greenhouse from specific crosses among elite food quality materials, disease resistance sources, nonsenescence types with high sugar levels in their stems, lines with greater green leaf retention, and drought resistance. Many of these materials were crossed to the introductions (27) obtained from Kenya. F_2 evaluations and selections were made in 1992 in the drought and adaptation nurseries of South Texas, College Station, Lubbock, and Chillicothe. More than 200 different F_1 hand emasculated crosses were planted by transplant techniques to produce F_2 seeds for future evaluation and selection.

Evaluations of inbred lines and advanced hybrids were made in multi-location trials to characterize yield of parents, F_1, 3-way, and double-cross hybrids. Trials were carried out in two dryland and two irrigated sites in South and North Texas plus four locations in Kenya.

Both field and laboratory trials were conducted to determine the inheritance, mode of action, and host response of known head smut sources of resistance. A special seed production study was initiated to determine cultivar differences when desiccated prior to seed harvest. This study was conducted in two diverse environments.

Research Findings

This project, 'The Enhancement of Sorghum Germplasm for Stability, Productivity, and Utilization', acts as a delivery vehicle for several projects in the CRSP by bringing together all the critical components to affect sustainability of production. Not only are the basic germplasm resources cooperative in nature but the collaboration with LCD's is cooperative also and includes scientists and graduate students. Large field evaluation nurseries are grown in areas of significant climatic variations and are especially designed to allow for selection of desired recombinations for appropriate yield, stability, drought tolerance, disease resistance, and grain quality. Major emphasis has been placed upon the development of tropically adapted cultivars with high levels of nonsenescence and high yield. Because this project functions in a distinct climatic region critically situated between temperate and tropical environments, it is easy to select and evaluate types for broad and widespread distribution especially into Sahelan tropical areas. The basic breeding goal of this project is to create a base of yield that is both higher and sustainable across varying environmental conditions and to add or enhance mechanisms and traits which increase value and performance. There is significant interaction and exchange of information and germplasm from TAM-122 and TAM-124. The close cooperation and evaluations with TAM-126 insure the inclusion of new sources of food quality and newly identified traits which affect food utilization, plus adding new sources of technology to the important enhancement activity.

In 1992, the environment presented challenges to the breeding program across Texas. Early season was very wet and cool followed by extended periods of cloudy conditions. Summer turned very dry but temperatures were not excessive. Disease expression was relatively high, particularly headsmut and some of the foliar diseases. Expression of tropical and temperate adaptation was less than normal because of the extended cloudy periods. Approximately 6,800 selections from advanced and early generation materials were made in the Corpus Christi, Robstown, and Beeville nurseries. At College Station, more than 11,000 selections were made from various levels of breeding populations for seed number per panicle, green leaf retention, disease resistance, grain quality, tropical adaptation, and yield potential. In the female development program there were 2,065 sets of A/B lines backcrossed to produce 7,970 pairs for further evaluation. Selected advanced females were top crossed to elite tester males for evaluation in F_1 hybrid combinations. Several introductions of potential new female sources were obtained from Australia, Argentina, India, and China, which was backcrossed and seed quantity was increased.

Five sources of *Striga* resistance were obtained from Kenya and increased and crossed to RTx430 and RTx436. SAR24 appears to have resistance to both *Striga asiatica* and *S. hermonthica* and ICSV1006 is a B-line. The other lines with resistance are SRN39, ICSV1007, and ICSV1021BF. Eleven lines were designated to have resistance to aphids. The particular species of aphid was not given but both the lines and segregating progenies with these will be evaluated. Crosses were made to RTx430 and RTx436 to incorporate the resistance into photoperiod insensitive types. The materials obtained with aphid resistance were designated as follows: ENT53, ENT62, WM#177, WM#322, FGYQ336, FGYQ353, (TAM428*SC502-), PGRCLR#69414, PGRCLR#69442, PGRCLR#222878, and PGRCLR #222879. An additional 11 cultivars identified as having drought resistance also were obtained from Kenya. These materials were grown in the quarantine greenhouse and then grown in the winter crossing greenhouse of 1992-93. Each of these 11 cultivars were crossed to RTx430 and RTx436 to incorporate the resistance in short photoperiod insensitive materials possessing elite yield and quality traits. All but one of these lines have white translucent grain and only two have non-tan plant color. These materials looked quite productive in the winter crossing greenhouse. The following are designations of the materials provided and labeled drought resistant: EPSON-2-048, EPSON-1-91, EPSON-1-98, EPSON-1-086, EPSON-2-40, EPSON-2-118, FGYQ#336, ICSV1164BF, IS23496, PGRCLE #69414, and PGRLE#200791.

Experiments were designed to understand the genetic and ontogenic characteristics of resistance to anthracnose (*Colletotrichum graminicola* (Ces.) Wils. in sorghum. This research was carried out by Dr. A. Tenkouano at College Station, Texas; Lafayette, Indiana; and Isabella, Puerto Rico.

Resistant lines SC326-6 and SC599-11E were crossed to susceptible lines BTx623 and B35-6 to derive F_1, F_2, and F_3 progenies, and the disease response of these materials was tested against one avirulent and two virulent isolates of the pathogen. Resistant and susceptible lines did not differ in their ability to respond to infection. However, symptom development varied with plant genotype and age at inoculation. The response of SC326-6 was typically hypersensitive whereas the reaction of SC599-11E was of a slow symptom development type. Contrasting with these resistant responses was the behavior of the susceptible lines, which lost the capacity to restrict lesion growth in older plants.

Three 3-deoxyanthocyanidin phytoalexins were shown to accumulate in resistant lines and their F_1 progenies to significantly greater concentrations than in the susceptible lines or F_1 hybrids in response to attempted infection by the pathogen, regardless of the developmental stage of plants. This response was due to earlier onset and faster rate of synthesis of the phytoalexins in resistant lines compared to susceptible lines. Phytoalexin concentration was considerably lower in plants that had grown beyond the juvenile stage. Of particular interest was the anti-microbial activity of these phytoalexins since they inhibited formation of appressoria by fungal propagules *in vitro*. Earlier availability of these toxic compounds in resistant lines may explain their capacity to restrict infection compared to susceptible lines.

Resistance in SC326-6 was not the same as in SC599-11E, the latter line displayed reversal of its phenotype from resistant to susceptible as plants aged. Reversal of resistance occurred also in SC599-11E derived progenies. In contrast, the phenotype of SC326-6 and its progenies were stable throughout all growth stages. This and the bimodal distribution for anthracnose severity index frequencies suggested that resistance was controlled by dominance at a single multi-allelic locus.

Restriction analysis of DNA from SC326-6, BTx623, and 60 F_2's produced a syntenic group containing the anthracnose resistance locus, which was 23.8 cM and 25.9 cM away from flanking RFLP loci Xtam309 and Xtam1090, respectively.

Sets of experiments were conducted to evaluate the usefulness of horizontal resistance to head smut (*Sporisorium reilianum* (Kuhn) Langdon & Fullerton in sorghum. This research was carried out by Mr. Alejandro Palma C. at College Station, Corpus Christi, and Thrall, Texas.

A set of differentials which contained either spent or current resistance source genes were crossed to produce an array of F_1 hybrids. These parental stocks and their hybrids were evaluated using a syringe inoculation procedure with four different isolates representing different races of the fungus. Entries of the Uniform Head Smut Nursery (UHSN) plus controls were included in field trials at College Station and Corpus Christi.

Results from infection studies suggested that the older race 1, 2 appears to be either disappearing from the soil medium or losing its pathogenicity. This was further suggested when the results of the 1987 to 1992 ratings taken on the UHSN were compared. Results from artificial inoculation showed that the best hybrid combinations for horizontal resistance were obtained when ATx635 was used in crosses, regardless of the different degrees of susceptibility to the isolates of the other parent lines of the hybrids tested.

The horizontal resistance to head smut observed in A/BTx635 and its combinations was expressed as a dominant trait (complete). This cultivar was classified to convey horizontal resistance to races because of factors present in meristematic tissue (condition of nonmeristematic tissue unknown). It appeared that major loci control resistance and a series of polygenes modify that resistance in the host. Because susceptible parents contributed different degrees of susceptibility to their hybrids, dominance or epistasis was inferred. No evidence of additive gene action was observed when several spent genes were pyramided (stacked).

The χ^2 analyses for the F_2 generation derived from ATx635*SC241-14E (R*S) did not fit a 3:1. It was assumed that the horizontal resistance in A/BTx635 is under a polygenic control with complete dominance which should be easily transmitted to its hybrid progenies.

A complex set of very basic studies were carried out to study the effect of the ma_3R mutation on phytochrome, gibberellin metabolism, and photoperiodism in sorghum. This research was carried out by Dr. Kevin Childs, in my co-worker's laboratory (Dr. Page Morgan).

The Ma_3 gene in sorghum regulates photoperiod sensitivity. Cultivars with the ma_3R allele are essentially photoperiod insensitive, are greatly elongated, and contain high concentrations of gibberellins. The hypothesis that the sorghum ma_3R allele results in abnormal phytochrome regulation of growth and maturity was studied.

Phytochrome control of anthocyanin synthesis and R mediated deetiolation was not apparent in ma_3R sorghum. Sorghum contains two phytochromes with apparent molecular weights of 123 and 126kD. ma_3R sorghums did not possess the 123kD phytochrome. The 126kD and 123kD phytochromes were tentatively characterized as phytochromes A and B, respectively.

Gibberellin metabolism was concluded to be more complicated than previously believed. Gibberellin levels were found to vary by both tissue and time of day. The 123kD phytochrome was implicated in the differences seen in gibberellin concentrations between tissues.

The integrity of the biological clock in ma_3R sorghum was tested. Chlorophyll a/b binding protein (CAB) mRNA was found to cycle circadianly in ma_3R and non-ma_3R plants. The periods of CAB mRNA cycling in constant light were different in ma_3R and non-ma_3R plants, but during normal photoperiods, cycling was normal between the genotypes. The biological clock was shown to function properly in ma_3R sorghum, but the mechanism for entrainment was altered in constant light.

Plants were grown under different photoperiods and growth measured. Photoperiods of 23 and 24 hours were found to inhibit elongation of non-ma_3R sorghum. This high irradiance response was not evident in ma_3R sorghum. However, floral initiation was significantly delayed in ma_3R plants by long photoperiods. Sorghum with ma_3R are photoperiod sensitive, but the degree of sensitivity is greatly reduced. Internode elongation occurred in ma_3R plants grown under long photoperiods. Thus, internode elongation was separated from flowering. This suggests that the premise that gibberellins control flowering is not valid.

Sorghum grown in much of Sahelian Africa is sown at the onset of rains as daylengths are increasing. Rains usually are irregular in date of initiation. These plants then grow in a vegetative state for a period of 60 to 90+ days in which they are non-responsive to induction via photoperiod. Once photoperiod decreases past some critical minimum (probably 12:30 to 12:10 hrs) the plants are induced and flowering occurs in about 30 days. Flowering begins with the cessation of rains, grain develops, and subsequently matures in the following dry environmental conditions.

Traditional American type hybrid sorghums have expressed major yield advantages over traditional African varieties but they succumb to severely damaged grain because of too early maturation. These sorghums simply mature too quickly to escape the high humidity environment created by the monsoon rains.

It would be extremely useful to have F_1 hybrids which express 20 to 60 percent heterosis, with superior or acceptable food quality, but which flowered sufficiently late to escape the monsoon rains. In order to accomplish this, there would be a need to create new maturity gene combinations, or use photoperiod sensitive parents and use short-day off-season production to produce hybrid seeds. This would be quite risky.

A 20 entry trial containing inbred lines and F_1 hybrids which differed in photoperiod sensitivity (plus two local checks) were grown in Samanko and Longorola, Mali from June to early July plantings. CSM388, a locally important cultivar, flowered in 82 days after planting (Table 1). Seven entries from the Texas project (TAM-121) flowered from 1 to 14 days later than CSM388 when planted at the beginning of the rainy season. Six of these were F_1 hybrids made using early females crossed to early males, the other was Grassl, a sweet sorghum. These F_1 hybrids combinations utilize a unique maturity gene combination proposed to exist by the late J. Roy Quinby. This is a very significant finding. Even though yield of grain was not acceptable, maturity can be manipulated to create hybrids that will flower at the end of the rainy season. These F_1 hybrids can be produced in Mali, etc., or in a developed country where the technology for hybrid production is in place and then transported to Mali, etc., for sale and/or distribution.

Table 1. Results of different variables for sorghum lines and hybrids with differential responses to photoperiod, Samanko, Mali (planted July 7, 1992).

		Results			
Entry	Cultivar designation	Leaf disease rating	Days to anthesis	Height (m)	Yield (T/ha)
19	A_2Tx632*EBA3	3.0	96	2.77	1.56
20	ATx631*FRM-1	2.0	93	3.08	1.56
12	Grass1	3.0	91	2.72	0.89
18	ATx631*EBA3	3.5	84	3.08	1.33
16	ATx623*EBA3	4.5	83	3.17	1.14
17	ATx629*EBA3	4.5	83	3.12	1.20
15	ATx626*EBA3	3.5	83	3.00	1.97
21*	CSM388	2.5	82	3.87	1.90
22*	Local	2.5	82	3.80	2.48
5	BTx635	-	-	-	-
14	ATx629*Grass1	3.5	80	2.83	2.60
10	Sureño	5.0	79	2.00	1.84
9	Dorado	5.0	77	1.42	1.33
1	A155*R8509	1.5	74	1.97	2.42
11	Rio	3.5	73	2.37	1.27
7	BTx631	2.0	73	1.35	1.27
6	ATxARG-1_1	4.0	72	1.08	0.89
13	ATx623*Rio	2.0	72	2.68	1.96
3	ATx635*Dorado	4.5	71	1.77	1.77
2	ATx635*R8505	3.0	67	1.42	1.46
4	ATx378*RTx430	2.0	64	1.37	1.97
8	FRM-EBA1	4.0	62	1.65	0.70
CV%			2.11	5.45	19.48
X			78.1	2.36	1.56

White grain sorghum hybrids continue to be placed at high levels of importance in this project. There are small overall yield advantages associated with these light colored grain types. While there are advantages with yield, leaf quality, and perhaps disease resistance, there are limitations associated with grain weathering (appearance of the grain only) and discoloration in higher humidity environments. In 1992-93 the IFSAT (International Food Sorghum Adaptation Trial) was grown at 21 locations in the U.S. and inter-

nationally. ATx635, ATxARG1, and ATx631 females are providing high yielding hybrids when crossed to a wide array of good R-lines. Several new combinations were included in the 1992 trial which produced tan plant color and red or red translucent seed color. These hybrids did not appear to discolor or weather nor was the staining of the grain from glumes or insect punctures objectionable. Several hybrids from this trial have been selected by collaborators for further evaluation and possible distribution.

In 1992-93, 28 ITAT's (International Tropical Adaptation Trials) were distributed. This trial contains both parents and hybrids and allows collaborators the opportunity to quickly recognize useful materials. Sustainability of production is a measure of a crop's success over time and across locations. This trial allows us to monitor germplasm usefulness and which unique combinations can be exploited.

Networking Activities

Workshops

SICNA Sorghum Workshop, Manhattan, Kansas and Lincoln, Nebraska. September 9-11, 1992. Participated in review of research activities at these sites.

Research Investigation Exchanges

Dr Graham Hammer, CSIRO, Australia, July 13, 1992.

Ing. Carlos Shaw, Sursem Seeds, Pergamino, Argentina, July 18-19, 1992.

Dr. Paul Menge, Sorghum Crop Consultant, St. Louis Park, MN, July 30, 1992.

Dr. John Scheuring, CIBA-GEIGY, Basle, Switzerland, August 5, 1992.

Dr. John Stenhouse, ICRISAT, Andhra Pradesh, India, August 11-14, 1993

Mr. Dries Booyens, PANNAR Seed Company, Klerksdorp, South Africa, August 25-26, 1992.

Mr. Yami Fushi, Snow Brand Seed Company, Japan, August 28, 1992.

Dr. Keith Andrews, Zamarano, Honduras, March 22, 1993.

Dr. Geraldo de Franca, IPA, Pernambuco, Recife, Brazil, April 10-19, 1993.

Ten students in agriculture - University of Guadalajara, Mexico, May 17, 1993.

Carmine Laserna, Bogota, Colombia, June 4, 1992.

Mr. W. Mose, Ambassador, Zimbabwe, June 21, 1993.

Dr. Vartan Guiragossian, Exec. Consultant, Fundacion Tecnologica de Sinaloa, Mexico, (Study leave).

Mr. Antonio Cristiani, hybrid trials and production, Guatemala

Germplasm and Research Information Exchange

In 1992, 26 sorghums introduced from Kenya which possess resistance to *Striga*, aphids, and drought were increased from quarantine and crossed to elite R-lines from the project. The introductions also were grown in the summer nursery to determine photoperiod sensitivity and relative performance. F_1 hybrids, using these introductions, were grown and F_2 seeds produced for future selection. These materials possess useful combinations of grain color, height, yield, disease and insect resistance, and food quality which are useful to the TAMU/INTSORMIL program.

During this reporting period a large number of breeding lines, germplasm resources including F_2 through advanced generation breeding populations, A, B, and R-lines, converted lines, cytoplasm sources, and experimental hybrids were increased and many distributed to international and domestic collaborators. We distribute over 1,300 different accessions and 94 trials during the 1992-93 period (Table 2). These materials included both old and new materials plus enhanced stocks possessing resistance to various diseases, insects, drought stress, temperature stress, genetic stocks for maturity, height, pericarp, endosperm, and plant colors, tropical adaptation, and other traits. In the 94 trials which were distributed were the International Tropical Adaptation Trials, International Food Sorghum Adaptation Trials, International Sorghum Virus Nursery, Genetics of Pericarp Nursery, and many modified Hybrid Evaluation Trials.

Table 2. Seedstocks distributed from TAM-121, College Station, TX during 1992-1993.

	International		Domestic	
Type of materials	No. of accessions	No. of requests	No. of accessions	No. of requests
Varieties	300	24	102	28
F_2 populations	24	3	—	—
Breeding stocks	633	15	52	18
Hybrid seeds	59	6	45	10
Trials	34	13	60	3
Sum/items distributed	1054	61	259	59

Sorghum advanced breeding selections were made and entered into cooperative international trials including the ADIN, IDIN, GWT, IDMN, IAVN, UHSN, and several drought nurseries.

Developed lectures for presentations in the field nurseries for international and domestic exchanges in Weslaco, Corpus Christi, Beeville, Robstown, College Station, and Thrall, TX. Presented field and laboratory tours for delegates from Egypt, India, Japan, Colombia, Venezuela, Argentina, Paraguay, China, Zimbabwe, Mexico, and Australia.

Table 3. Summary of germplasm, seedstocks, enhanced lines, hybrid stocks, and trials distributed from TAM-121, 1979 to 1993.

Type of materials	International (No. of accessions)	Domestic (No. of accessions)
Varieties	279	627
F_2 populations	570	—
Breeding stocks	7030	5008
Hybrids	680	300
Trials	459	307
Sum/items distributed	9018	6242

Table 4. Summary of releases of inbred lines from TAM-121 during the project life, 1979 - 1993.

No.	Designation	Developer(s)
1	A/BTxARG-1	INTA/TAMU
2	A/BTx635	TAMU/ICRISAT/CENTA
3	A_2/B_2Tx636	TAMU
4	A_2B_2Tx637	TAMU
5	Tx2818-Tx2857 (40)	TAMU
6	Tx2858	TAMU
7	R.Tx436	TAMU
8	R.Tx435	TAMU
9	R.Tx434	TAMU
10	R.Tx433	TAMU
11	R.Tx432	TAMU
12	R.Tx431	TAMU
13	R.Tx430	TAMU
14	A/BTx626	TAMU
15	A/BTx627	TAMU
16	A/BTx628	TAMU
17	A/BTx629	TAMU
18	A/BTx630	TAMU
19	A/BTx631	TAMU
20	A_2/B_2Tx632	TAMU
21	GTPP7R	Georgia/TAMU
22	Tx2816	TAMU
23	Tx2817	TAMU
24	TRPSS	TAMU
25	TP15	TAMU
26	TP24	TAMU
27	GPTM3BR(H)C4 Population	Georgia/USDA/TAMU
28	NES R_3 Population	Nebraska/Georgia/TAMU
29	Tx2786	TAMU

Table 5. List of materials from TAM-121 known to be used in various countries.

No.	Designation	Country
1	Freddy (ATx623*Greenleaf)	Paraguay
2	1844 (1844*TMTx430)	Paraguay
3	CHACO-i (ATx623*Hegari)	Paraguay
4	Alex Red (ATx378*RTx434)	Paraguay
5	Dorado	Paraguay
6	Hageen Dura-1 (ATx623)	Sudan
7	ICTA-777 (Hybrids)	Guatemala
8	ICTA-888 (Hybrids)	Guatemala
9	A/BTx622	People's Republic of China
10	R.Tx430 (Hybrids)	Mexico
11	R.Tx434 (Hybrids)	Mexico
12	A/BTx631 (Hybrids)	South Africa
13	A/BTx631 (Hybrids)	Argentina
14	R.Tx430 (Hybrids)	Guatemala
15	R.Tx430 (Hybrids)	Argentina
16	BJ83 (Hybrids)	Mexico
17	BJ85 (Hybrids)	Mexico

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Germplasm Enhancement for Resistance to Pathogens and Drought and Increased Genetic Diversity

Project TAM-122
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Summary

The objective of this project is to develop sorghum cultivars with enhanced resistance to drought and diseases thereby reducing losses in grain and stover yield. Diseases and insects reduce yields, stability of grain yield and increase production costs. This project emphasizes host plant resistance and pursues its objectives by identifying and developing disease and drought resistant germplasm in genetically diverse backgrounds for use by host country and U.S. scientists. Another component of this project is to collaborate with host country scientists, especially those in Mali, Sudan, and Honduras, in all aspects of their crop improvement programs, including training, thereby strengthening the research capability of the host countries.

This project has contributed to the understanding of drought resistance in sorghum. Two distinctly different responses have been described, pre-flowering and post-flowering. Field screening techniques for both have been described and their success demonstrated. Excellent sources of resistance to both types of moisture stress have been identified and progress has been made in transferring the resistance to higher yielding, well adapted genotypes. The drought responses described in Texas have been shown to be applicable to other countries such as Sudan, Mali, Niger, Kenya, Botswana, and Honduras. The finding of an excellent source of resistance to post-flowering drought in SC35(IS12555C) has been significant. This "stay green" trait provides excellent resistance to premature plant death, and subsequent charcoal rot and lodging.

The disease resistance component has focused on diseases important both to Texas and internationally. Emphasis has been on downy mildew, grain mold/weathering, charcoal rot, head smut and anthracnose. Most of the disease resistant sources currently in use worldwide by private companies, as well as in use by public programs are from sources of resistance identified or developed by or cooperatively with this project.

Numerous germplasm materials containing resistance to drought and diseases and other desirable traits have been developed and distributed to international and domestic programs. This includes resistance to the head bug and *Striga*, two devastating pests of sorghum in Africa. Also, many native landrace cultivars have been collected, introduced, described, put into permanent storage, and evaluated for useful traits. Preservation and utilization of the biological diversity in sorghum is critically important to long term sustainable sorghum production systems.

Research in this project has resulted in the release of 415 germplasm lines, populations, parental lines, and converted exotic lines. The research has resulted in 39 journal articles and 134 articles in printed proceedings or as abstracts. The PI has been a member or co-chaired 35 graduate students, many of them being international students.

Introduction

Drought is the major constraint to sorghum production around the world, especially in semi-arid areas where sorghum production is concentrated. Lack of rainfall results in devastating yield losses in Sub-Saharan Africa and periodically in the Great Plains of the United States. Moisture stress prior to flowering has a major direct effect upon grain yield by reducing panicle size and the number of kernels produced. Post-flowering stress induces premature plant death and often subsequent charcoal rot infestation and lodging, resulting in major yield losses. Although sorghum inherently has good drought tolerance compared to many other crops, there are major differences in response among sorghum cultivars. Improving drought resistance of sorghum contributes to yield stability and enhances the food supply of subsistence farmers in developing countries. It also helps reduce price fluctuations resulting from major variation in production. Improved drought resistance reduces the amount of supplemental irrigation needed in the U.S. where sorghum is irrigated. This contributes to the conservation of water and reduces production costs.

Diseases are important constraints to sorghum production worldwide, with specific diseases often being site specific. They reduce grain yield, reduce the food or processing quality of the grain, and the feed value of the stover. Head smut, downy mildew, grain mold, charcoal rot, and anthracnose can cause severe losses in the U.S. In developing countries, grain mold, charcoal rot, anthracnose, and *Striga* are especially devastating. Host plant resistance is an environmentally and economically sound approach to controlling diseases. Production is stabilized and the need for pesticides is greatly reduced.

The head bug-grain mold-grain quality complex in West Africa is the major constraint to the use of high-yielding, non-Guineense sorghums, either directly or as parents in crosses. Local Guineense cultivars generally suffer only mild head bug damage, whereas the grain of introduced non-Guineense types is often devastated, rendering it unfit for traditional food products. Sources of resistance to head bug are rare, but one good source has been identified and is now a major part of breeding programs in West Africa. Combining that resistance with grain mold resistance along with other desirable food quality traits should permit the successful use of high yielding non-Guineense cultivars or derivatives thereof in Mali and the other traditional Guineense sorghum growing areas of West Africa.

Genetic diversity is essential to insure long term sustainable production. It provides the sources of disease and drought resistance and other desirable traits needed to solve immediate problems, and provides long term stability both in the U.S. and developing countries. Many host country improvement programs lack access to genetic diversity, lack knowledge about diversity and sources of desirable traits, or lack the personnel or expertise to effectively utilize diversity. Our access to genetic diversity through the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program, and experience and access to sorghum from around the world is important. This, along with ability to screen for resistance to drought and diseases in Texas allows us a unique opportunity to upgrade the sorghum breeding and improvement programs of host countries. The nature of our interdisciplinary collaborative program in Texas along with the wide array of elite diverse types in our nurseries permits us to easily generate crosses and early generation breeding materials for distribution and use by host country scientists.

The original source of genetic diversity in sorghum is Africa, and the U.S. sorghum industry is dependent on the continued identification and use of new or improved traits. The INTSORMIL program permits opportunities for direct observation of landrace cultivars in host countries and permits introduction, germplasm exchange, and information exchange, benefitting both the host country and the U.S.

The lack of properly trained researchers is a major constraint to effective agricultural research in host countries. This project has contributed to the training and upgrading of the agricultural research programs in several countries, but especially the IER sorghum breeding and research team in Mali. The Mali program is now generally recognized as the strongest sorghum improvement program in Africa, and compares well with any in the world. Continued collaboration with such a program should greatly enhance and stabilize food production and the agricultural economy of Mali, as well as benefitting neighboring countries of the region.

Objectives, Production and Utilization Constraints

Objectives

Enhance the germplasm of LDC's by developing and distributing early generation breeding germplasm involving genetically improved disease and drought resistance and other desirable traits for use and selection in host countries with emphasis on Honduras, Sudan, Mali, and Niger.

Develop high yielding cultivars for LDC's and the U.S. with genetically enhanced resistance to internationally important diseases with emphasis on downy mildew, charcoal rot, grain mold/weathering, anthracnose, head smut, head blight, viruses, and acremonium wilt.

Develop through breeding and selection, high yielding, agronomically desirable types with superior combination of pre- and post-flowering drought tolerance for use in the U.S. and host countries.

Identify, in basic sorghum germplasm lines, new sources of drought tolerance and resistance to diseases of importance in the U.S. and LDC's.

Collect new sorghum germplasm and evaluate for traits needed in the U.S. and developing countries, and introgress these traits into improved lines.

Constraints

Drought is the major constraint to sorghum and millet production around the world. Large differences have been demonstrated among sorghum cultivars in their reaction to drought and performance under drought stress. Texas has a semiarid environment and high temperatures and is ideal for large scale field screening and breeding for improved drought tolerance. Sorghums with identified high levels of specific types of drought tolerance in Texas, such as pre- or post-flowering drought tolerance, perform as expected regarding drought response in other countries of the world, including Sudan, Mali, and Niger. However, other adaptation traits such as grain quality and disease resistance must be combined with drought resistance to make a new cultivar useful.

Diseases are important worldwide but specific diseases are often region or site specific, and on-site evaluation is necessary to determine severity and possible race differences. Most of the internationally important diseases are present and are serious constraints in Texas, especially downy mildew, charcoal rot, grain mold/weathering, head smut, and head blight. Many other diseases such as anthracnose, leaf blight, rust, zonate, and gray leaf spot are also present in Texas. The Texas environment, particularly South Texas, is ideal for screening and breeding sorghums with high levels of resistance to most internationally important diseases.

In Sudan, the major constraint is drought, and drought related production problems. Moisture-stress related charcoal rot and subsequent lodging is a serious disease problem. Many U.S. sorghums perform quite well in Sudan, but improved drought resistance, local adaptation, and kisra food quality are needed.

Mali and Niger are both drought prone areas. Thus, drought tolerance, including both the pre- and post response, is extremely important to both countries. Foliage diseases such as anthracnose and sooty stripe are important in the central and southern parts of Mali. Long smut is very important in Niger and in the drier northern portion of Mali. High yielding improved introductions often fail in West Africa due to the head bug - grain mold - grain quality complex, stand establishment problems, improper maturity, or lodging, whereas the local sorghums appear well adapted, but are low yielding. Head bugs are a major constraint for the use of non-Guineense type sorghums in much of West Africa. Head bug damage is often compounded by grain mold resulting in a soft and discolored endosperm, rendering it unfit for traditional food products. The early maturity of introduced types also compounds the grain deterioration problem. Therefore, head bug resistance, grain mold/weathering resistance, and proper maturity are essential. In southern Mali, later maturing, photoperiod sensitive sorghums are needed to assure grain maturity after the rainy season. In the drier northern areas of Mali and in Niger where drought stress is severe, earlier, less photosensitive material can be used, and drought tolerant Durra and Feterita sorghums generally perform well.

Striga is a major constraint in Mali, Niger, and Sudan, and soil toxicity problems are important in Mali and Niger. Genetic sources of resistance to *Striga* and soil toxicity problems are used whenever possible in crosses involving disease, drought, and head bug resistance to develop breeding progeny for selection in host countries.

In Honduras, diseases are a major constraint, including downy mildew, foliar diseases, acremonium wilt, and the grain mold/weathering, food quality complex. Drought is also important in Honduras and the Central American Region. Improvement in the photoperiod sensitive, food-type maicillos criollos grown in association with maize on small, hillside farms in southern Honduras (as well as in southeast Guatemala, El Salvador, and northwest Nicaragua) is a unique challenge, and the breeding and selection must be done under the specific daylengths and environment in the host region. Improvement in the nonphotoperiod sensitive combine-type sorghums used over much of Central America can result directly from introduction of Texas adapted cultivars or hybrids.

There is a constant need for new diverse germplasm sources of resistance to pests, diseases, and environmental stress. New collections can provide new sources of desirable traits. Many developing countries are an important source of diverse germplasm in sorghum and millet. The collection, preservation and utilization of genetic diversity in sorghum is tremendously important to long-term, sustainable sorghum improvement programs. The use of such diverse germplasm is critical for producing sufficient food for increasing populations in the future.

Research Approach and Project Output

Research Methods

Introductions from Mali, Sudan, Niger, Honduras, Zimbabwe, Zambia, Botswana, Somalia, Senegal, and ICRISAT with desirable drought or disease resistance, or specific desirable grain or plant traits, are crossed in Texas to appropriate elite U.S. lines and elite breeding materials. Seed of the early generation are sent to host countries, particularly Sudan, Mali, Niger, and Kenya, for selection of appropriate traits and adaptation. Technical assistance is provided, as time and travel permits, in the selection and evaluation and use of such breeding material in the host country.

New breeding material is generated from crosses among various disease resistant sources, agronomically elite lines, and new sources of resistance. Advance generations of breeding lines also are selected each year. Initial screening is done in large disease screening nurseries utilizing natural infection in South Texas, supplemented by artificial inoculation in the field and laboratory screening. Selected advanced materials are then sent to host countries for evaluation and incorporated into various standard replicated trials for extensive evaluation at several locations in Texas and host countries.

New breeding crosses among various sources of drought tolerance (i.e., pre- and post-flowering drought tolerance) and elite, high yielding lines are made. Progeny are selected under field conditions for pre- and post flowering drought tolerance, yield, and adaptation at several locations in West Texas in the Lubbock area and at Chillicothe. The locations vary in their degree and time of moisture and heat stress. Selected advanced materials are sent to host countries for evaluation and use, as well as incorporated into standard replicated trials for extensive evaluation at several location in Texas and host countries.

Converted and partially converted lines from the Sorghum Conversion Program, exotic lines, new introductions, and breeding materials are screened and evaluated in Texas for new sources of resistance to internationally important diseases and resistance to drought.

New sorghum germplasm is collected from several countries, introduced into the U.S. through the quarantine greenhouse, and evaluated in Puerto Rico and Texas for useful traits. Selected cultivars are designated for entry into the cooperative TAES-USDA Sorghum Conversion Program. Cultivars that are not photoperiod sensitive and with known merit are incorporated directly into the regular breeding program. We also work with NARS to assure their country's indigenous sorghum cultivars are preserved in long term permanent storage, as well as evaluated. Assistance is provided in developing smaller working or core collections for the NARS to actively maintain and use in their improvement programs.

Research Output

Drought Resistance

Two very distinct and different responses to drought in sorghum have been identified and explained. These two responses are determined by the stage of growth of the plants when moisture stress occurs, and are called pre-flowering (head differentiation to flowering) and post-flowering (flowering to physiological maturity). Sorghums with resistance at both stages have been identified, but high levels of resistance are not often found in the same line.

Field screening techniques useful to West Texas or other low rainfall areas have been developed for each kind of stress, and visual symptoms indicating either resistance or susceptibility have been described. The timing and intensity of moisture stress is manipulated by irrigation, time of planting, and multiple locations with varying soil types and rainfall patterns. Plant response symptoms to moisture stress are visually rated on a 1 to 5 scale, indicating the relative degree of resistance or susceptibility of each genotype. Rating the panicle development (lack of blasting or abortion) panicle size, and panicle exsertion (normal versus short exsertion or saddle effect) is the best indicator of resistance to pre-flowering stress. For post-flowering stress, a leaf and plant death (LPD) rating made near or soon after maturity is the easiest and most reliable indicator of resistance or susceptibility. Plants with resistance called "stay green" tend to maintain green leaves and fill grain normally, while susceptible plants show premature leaf and plant death (or premature senescense), frequently accompanied by complete lower stalk collapse often with charcoal rot, and stalk lodging. The drought responses and the visual ratings have been shown to be consistent for the same genotype over years, locations, and continents, as long as the stress occurs at similar growth stages.

This empirical approach developed and utilized in breeding for drought resistance has proven to be successful, and has been used in widely differing areas such as Sudan and Australia. It is commonly used by several private companies in the U.S.

Excellent sources of pre-flowering resistance and post-flowering resistance (stay green) have been identified through intensive screening efforts in Texas and Sudan. Table 1 lists many of the best sources of resistance in standard parental lines, local landrace cultivars, or selected breeding or germplasm lines. The converted sorghum lines from the Sorghum Conversion Program have been an unusually good source of resistance with 62 of the best listed in Table 2. Sorghums from Sudan have been another good source of drought resistance.

Many more sorghums possess resistance to pre-flowering drought than to post-flowering stress. The finding of an excellent source of resistance to post-flowering drought in SC35 (IS12555C), a durra from Ethiopia, has been especially significant. This "stay green" trait in SC35 is dominant in nature, thereby very useful in parents of hybrids, and appears to be inherited fairly simply, as one or two genes. Another converted line, SC56 (IS12568C), a Caudatum from Sudan, also possesses the dominant stay green trait. A number of other sources of stay green such as in SC599 appear to be recessive in nature. Lodging resistance to moisture stress type lodging and to overall stalk strength through anatomical stem traits is present in these two lines. This can contribute to stalk strength and lodging resistance both with or without moisture stress.

Progress has been made in transferring drought resistance to higher yielding, well adapted genotypes. The B lines called B1, B2-2(B), and B4 are examples of transferring the

Table 1. Sorghums identified with drought resistance in Sudan and/or U.S.

Designation	Sudan	U.S./[1] Other	Type of[2] drought resistance
Ajabsido/Sudan Fet	X	X,M	Pr
Koro Kollo/Sudan Fet	X	X,M	Pr
P954035	X	X,N	Pr & Po
P898012	X	X	Pr & Po
P37-3	X	X	Pr
P40-1	X	X	Pr
Segaolane/Botswana Kaf	X	X	Pr
El Mota/Niger Cau	X	X,M,N	Pr
Tx7078	X	X	Pr
Tx7000	X	X	Pr
B35	X	X	Po
82BDM499	X	X,M	Pr & Po
SC414-12E	X	X	Pr
(Tx430*Rio)-15	X	X	Pr & Po
(Tx430*R9188)		X	Po
TP4-5	X	X	Pr
TanGbResW	X	X	Pr
Tx2737	X	X	Pr
ICSV1002BF	X		Pr & Po
86EON361	X		Pr
Karper 443	X		Pr
Karper 669	X	X	Pr & Po
Karper 22/22	X		Pr
Karper 22/39	X		Pr
Karper 22/35	X		Pr
NSA440		X	Po
1790E	X	X	Pr & Po
B1778		X	Po
B1887		X	Pr & Po
KS19		X	Po
(P407x559)		X	Po
CSM-63/MaliGuin	X	X	Pr & Po
SS130/Somalia Dur		X	Pr
B1	X	X	Po
B2-2(B)	X	X	Po
B4	X	X	Po
Bagoba/Niger Dur		M,N	Pr
Babadia Fara/Niger Dur		M,N	Pr
Gadiaba/Mali Dur		M	Pr
CE151-262-A1	X	X	Pr
SRN39	X	X,M,N	G
R9188		X	Po

[1] Letter indicates country other than U.S.: M=Mali, N=Niger.
[2] Pr=Pre-flowering; Po=Post-flowering; G=General.

stay green trait from B35 into improved lines. The lines 82BDM499, (Tx430*R9188) and P37-3 are examples of drought resistant improved restorer lines. Hybrids with A1 and A4 have performed well in both the U.S. and Sudan, as well as all of the above mentioned restorers.

Efforts continue to combine pre- and post-flowering resistance into the same genotype or hybrid and to enhance the level of the appropriate type of resistance depending on the needs as determined by rainfall pattern in different regions. An example of technology developed collaboratively with potential impact both in the U.S. and host country is the 10 parental lines, 89001-89010 released cooperatively by Purdue and Texas A&M. These were derived from a cross between elite U.S. lines and introduced drought resistant lines from Sudan, selected in the U.S., and then tested

Table 2. Drought resistant converted sorghums[1].

Designation	Sudan	U.S.	Type of[2] drought resistance
SC23/IS12543C	X	X	Pr & Po
SC33/IS12553C	X	X	Po
SC35/IS12555C	X	X	Po
SC38/IS12558C	X	X	Po
SC48/IS2564C	X		Pr
SC52/IS2501C	X	X	Pr
SC53/IS12567C	X	X	Pr
SC55/IS2451C	X	X	Pr
SC56/IS12568C	X	X	Pr & Po
SC62/IS12572C	X	X	Pr
SC63/IS12573C		X	Pr
SC103/IS2403C	X	X	Pr
SC118/IS2801C	X	X	G
SC141/IS12632C	X		Pr
SC142/IS12633C	X		Pr
SC144/IS12635C	X		Pr
SC146/IS12637C		X	Po
SC170/IS12661C	X	X	Pr
SC202/IS1133C	X		Pr
SC265/IS6705C	X	X	Pr & Po
SC279/IS7419C		X	Pr & Po
SC283/IS7173C		X	Pr & Po
SC284/IS6729C	X		Pr
SC328/IS8263C	X	X	Po
SC329/IS3612C	X		Pr
SC330/IS8187C		X	G
SC334/IS3499C		X	G
SC336/IS3589C	X	X	G
SC337/IS7094C	X		Pr
SC346/IS7440C	X		Pr
SC348/IS7455C	X		Pr
SC367/IS7340C	X		Pr
SC396/IS7447C	X		Pr
SC405/IS3464C		X	G
SC414/IS2508C	X	X	Pr
SC499/IS6439C		X	G
SC502/IS3598C	X	X	Pr
SC5041/IS6895C		X	Pr
SC520/IS7595C	X		Pr
SC563/IS7444C		X	Pr
SC564/IS3909C		X	Pr & Po
SC575/IS3553C		X	G
SC577/IS3072C	X		Pr
SC587/IS3874C		X	G
SC599/IS17459C	X	X	Po
SC609/IS1213C	X		Pr
SC630/IS1269C	X		Pr
SC644/IS8237C		X	G
SC689/IS2729C		X	Po
SC691/IS7088C	X		Pr
SC701/IS3462C	X	X	Pr & Po
SC715/IS6911C		X	G
SC731/IS3587C	X		Pr
SC751/IS3546C		X	G
SC762/IS5437C	X	X	Pr
SC773/IS3389C		X	G
SC781/IS7243C	X		Pr
SC810/IS957C	X		Pr
SC832/IS4585C	X		Pr
SC963/IS2864C		X	G
SC1017/IS11549C		X	Pr & Po
SC1039/IS12171C		X	Pr & Po

[1] Converted (BC4) exotic sorghums released from TAMU-TAES/USDA-ARS cooperative Sorghum Conversion Program.
[2] Pr=Pre-flowering; Po=Post-flowering; G=General (Pre plus possibly Post).

in hybrid combinations in both Sudan and the U.S. The lines P37-3 and P40-1 in Table 1 are of similar origin.

Disease Resistance

Identifying new and/or improved sources of resistance and developing agronomically improved germplasm for distribution and use by both public and private breeders worldwide is a major thrust of this project. Excellent resistance to essentially all important diseases has been identified in this project with many of the sources being lines from the Sorghum Conversion Program. Selected sorghums with excellent resistance to head smut, downy mildew, anthracnose, grain mold/weathering, leaf blight, and *Fusarium* head blight are listed in Table 3.

Much of the resistance to head smut, downy mildew, and anthracnose deployed in the U.S. is from resistant sources identified in this project cooperatively with TAM-124 and TAM-128. Many of these same sources are also used extensively internationally, such as SC326 or derivatives in Brazil for anthracnose and foliar leaf disease resistance, and in Zimbabwe for leaf blight resistance.

Grain mold/weathering is the major disease constraint in sorghum worldwide and high-level resistance is rare for sorghums without a testa. We found high levels of resistance in two white seeded, tan-plant entries (originally from ICRISAT), Sureño (M62650) and VG153 (M62676). These have proven very useful in breeding crosses as the resistance can be readily transferred. Other sorghums with useful resistance are SC748 and the SC170 derivative lines R6078, R4317, and 90EON343. Other cultivars with notable resistance are the red Kafir types from Southern Africa, SC630 and SC650, but their resistance is difficult to recover in crosses. Table 3 lists some of our best identified sources of resistance.

Grain mold is an important part of the head bug-grain mold-grain quality problem of West Africa. It has been shown that grain mold resistance gives a significant incremental increase in apparent head bug resistance. A grain mold resistant breeding line developed in Texas (R6078) was identified by Malian scientists as also having excellent head bug resistance.

The finding of apparently unique source(s) of resistance to head smut in South Texas is of extreme importance, as the highly variable and heterogenous pathogen often over-

Table 3. Selected disease resistant sorghums.

Head Smut[1]	Downy Mildew[2]	Anthracnose[3]	Leaf Blight[4]	Grain/Mold Weathering[5]	Fusarium Head Blight[6]
CS3541	QL3 (India)	SC84 (IS12593C)	SC326-6 (IS3758 der)	SC630 (IS1269C)	B35
IS3541C/SC798-14-E	SC155 (IS12646C)	SC135 (IS12626C)	SC414-12E (IS2508 der)	SC650 (IS2856C)	R9188 (SC599 der)
Sureño	SC167 (IS12658C)	SC137 (IS12628C)	86EON361	SC719 (IS7013C)	SC630 (IS1269C)
Dorado	SC325 (IS2462C)	SC155 (IS12646C)	86EON362	SC748 (IS3552C)	SC650 (IS2856C)
M50009	SC414 (IS2508C)	SC167 (IS12658C)	R4244	SC279 (IS7914C)	IS9530
M90318	SC425 (IS3579C)	SC176 (IS12667C)	SC630-11E (IS1269 der)	Town	Tx436
ICSV1086	SC575 (IS3553C)	SC224 (IS12685C)		Sureño	B1
VG153 (M62676)	SC737 (IS3441C)	SC283 (IS7173C)		VG153 (M62676)	B2-1
CE151-262-A1		SC326-6 (IS3758 der)		IS9530	B2-2 (B)
SRN39		SC414-12E (IS2508 der)		R4317	B4
Malisor 84-7		SC575 (IS3553C)		R6078	
SA281 (Early Hegari)		SC647 (IS2395C)		(M84-7*Sureño)/19023	
FC6601 (Spur Feterita)		SC689 (IS2729C)		(M84-7*VG153)/19178	
PI48770 (Wh. Kafir)		SC701 (IS3462C)		(SC719*SC650)/5844	
SC155 (IS12646C)		SC726 (IS7093C)		90EON343	
SC324 (IS2681C)		SC748 (IS3552C)			
SC325 (IS2462C)		SC991 (IS12219C)			
SC33 (IS12553C)					
BTx635 (BVar)					
Tx2891					
Tx2783					
SC414-12E (IS2508 der)					
82BDM499					
86EON361					
87EON366					
89CC443					

[1] South Texas, virulent race 4 type.
[2] P3, South Texas.
[3] Texas, Georgia, P. Rico, Brazil, India, Zambia.
[4] Texas and Southern Africa.
[5] Overall grain mold & weathering - Texas.
[6] Texas.

comes previously deployed sources of resistance. High levels of resistance were found in BTx635(BVar), a white-seeded, tan-plant, B-line of ICRISAT derivation, and CS3541, and in most other ICRISAT lines, many of which are CS3541 derivatives. Also, many of our breeding lines derived from CS3541 have shown an usually high and stable resistance (Table 3). The fully converted exotic IS3541C (from which CS3541 was derived) was subsequently found to possess excellent resistance. Initial evidence is that the resistance is very stable, resulting from high levels of both specific and non-specific resistance.

Germplasm

The collection, introduction, characterization, storage, evaluation, use, and free exchange of indigenous landrace cultivars and improved germplasm is a major activity of this project. Since project inception, 784 exotic landrace cultivars or improved germplasm lines have been introduced into the U.S. This project also provided a major role in planning, seed acquisition, growout, characterization, and introduction into the U.S. of over 3,100 sorghums of Sudan origin. The Sudanese sorghums have been an unusually useful source of resistance to drought, along with many other traits, IS3541C (head smut), and IS2508C/SC414 (downy mildew) being examples. A few landrace cultivars are collected directly by the PI from farmers' fields as opportunities exist, but many are items with known specific traits or items selected from previous collections by the host country scientists.

One hundred and eighty selected photoperiod sensitive landrace cultivars from the introductions mentioned have been entered into the Sorghum Conversion Program. Some photoperiod insensitive lines are used directly such as CE151, Ajabsido, Koro Kollo, El Mota, and Macia. Many improved lines are introduced to facilitate the crossing and development of breeding progeny specifically for return to collaborating host country scientists as well as for potential use in the U.S. Examples include breeding material developed for head bug resistance (Malisor 84-7 crosses and *Striga* resistance (SRN39 crosses), CE151-262-A1 (sugarcane aphid resistance in Kenya), Ajabsido, El Mota and Segaolane (drought resistance), and Macia (drought and adaptation).

Several introductions have shown excellent potential as food type sorghums for the U.S. and Latin America (Table 4). An example of an introduction from ICRISAT/LASIP in 1980 which resulted in a useful food type commercial cultivar in Honduras is Sureño, a selection from M62650. A recent breeding white tan line introduction from Mali (87EON366*ICSV1086-12-1-SK1-COBK) shows outstanding potential for grain yield and leaf disease resistance in Puerto Rico.

Converted lines from the Sorghum Conversion Program provide an extremely useful source of new germplasm. Most of the new and/or best sources of drought and disease resistance are converted lines (Tables 2 and 3). Three hundred and fifty fully converted lines (BC4) have been released since 1980.

A listing of major collections or introductions into the U.S. during the life of this project are listed below, including the number of items, collaborator, and major reason for introduction:

* Sudan Collection; 3,100; El Hilu, M. Mahmood, O. Ibrahim; Diversity, Drought
* Northern Kordafan (Sudan); 95; Tareke Berhe; Drought
* Miscellaneous over years (Sudan); 30; Several; Diversity, drought
* Somalia; 39, H. Porter; Drought
* Mali; 20; J. Scheuring; Diversity
* Miscellaneous over years (Mali); 130; Several; Diversity, Food type, Grain quality. (Some through ICRISAT).
* Northern Nigeria; 84; Tunde Obilana; Drought, Diversity
* Maicillos Criollos (Honduras & Central America); 100; F. Gomez and D. Meckenstock; Diversity, Unique adaptation.
* ICRISAT/LASIP; 235; T. Hash; Food type, Grain quality

Other Research Results

The importance of the head bug on sorghum in West Africa was first recognized by the PI of this project in Mali in 1981. Further documentation of the distribution and severity of the pest, the finding of an excellent source of resistance in a non-Guinea type, and evidence of the transferability of the trait has provided the impetus and direction for a major multidisciplinary research effort on head bug in Mali. We know that resistance to head bug is inherited as a recessive trait and multigenic in nature. Corneous endosperm alone does not give resistance to head bug.

Sureño, a white-seeded, tan-plant, tan glume cultivar was released in Honduras and is now widely used by small farmers in Southern Honduras. The grain has excellent grain mold/weathering resistance, produces excellent tortillas, and possesses resistance to the maize weevil. It also has a juicy sweet stem and good leaf disease resistance making the stover desirable for livestock feed.

The resistance to *Striga* in SRN39 appears to be expressed in natural field *Striga* infestations in Mali.

The sugarcane aphid was determined to cause severe damage to sorghum in Kenya. A few lines were found with very high levels of resistance (Table 4). It appears that resistance is inherited as a completely dominant trait.

Two dune adapted durra sorghum cultivars from Niger, Bagoba and Babadia Fara, and two durras from Northern Mali, Gadiaba, and Lakahiri were identified as having good genetic tolerance to the soil toxicity problem in the Cinzana area of Mali (Table 4).

A new virulent pathotype of downy mildew (P5) was identified in Honduras, and a testing program initiated. A commonly used source of resistance in the U.S. is susceptible to this new pathotype.

Useful levels of head bug resistance was found in two sorghum lines sent to Mali by INTSORMIL, BTx635 and R6078 (Table 4). BTx635 should be useful in B-line breeding, while R6078 also possesses a high level of grain mold resistance.

Releases

During the life of this project, a total of 415 germplasm lines, populations, parental lines, and converted exotic lines have been released. This includes 350 fully converted (BC4) exotic lines from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program. Important traits in the releases include resistance to head smut, downy mildew, anthracnose, grain mold/weathering, rust, leaf blight, *Fusarium* head blight, charcoal rot, pre-and post-flowering drought, and lodging. Other traits include white-seeded, tan-plant parental lines and populations, A2 and A3 cytoplasm steriles, and tropically adapted males and females. A large number of new germplasm lines (approximately 40) plus some parental female and male lines have been identified as being ready for release. These include sources of essentially all the traits discussed in this project in improved agronomic genotypes.

Networking Activities

Workshops

Planned

International Workshop on Maicillos Criollos and other Sorghums in Middle America, Tegucigalpa, Honduras, December 1987

Participated In

Sorghum in the Eighties International Symposium, November, 1981. Hyderabad, India.

International Symposium on Sorghum Grain Quality, October, 1981. Hyderabad, India.

Table 4. Selected sorghums with various desirable traits.

Mali - Adaptation and[1] breeding potential	Food type potential[2] for U.S. and Latin America	Sugarcane[3] aphid resistant	Mali - Head bug resistance	Mali - Soil toxicity tolerance
Malisor 84-7*	Sureño	TAM428	Malisor 84-7	Bagoba
Malisor 84-5	Dorado	CE151-262-A1	82Sel-Grain-Dur	Babadia Fara
S-34	M90318	R3224(sh)	IS21465	Gadiaba
S-35	Malisor 84-7		BTx635(BVar)	Lakahiri
E36-1	CE151-262-A1		R6078	
ICSV401	VG153 (M62676)			
M36248	Tx436			
CE151-262-A1	BTx635(BVar)			
M50009 (VG-15)	BTxARG-1			
M90318	86EON361			
ICSV1063BF	87EON366			
ICSV1002BF	ICSV1089BF			
ICSV1079BF**	(M84-7*Sureño)/19023			
ICSV1089BF**	(M84-7*VG153)/19178			
Sureño**	(Sureno*VG153)/549			
Dorado**				
VG153(M62676)**				
SRN39				
86EON361				
87EON366				
84C7730				

[1] Based on grain yield, overall grain quality, and performance in breeding crosses.
[2] All are white seeded, tan plant lines with good yield potential.
[3] Data from Kenya.

* High level of head bug resistance
** Moderate level of head bug resistance

Latin American Disease Short Course, April 1981. CIMMYT, Mexico.

Sorghum Downy Mildew Workshop, June, 1982. Corpus Christi, Texas.

Sorghum Breeders Workshop for Latin America, April, 1983. CIMMYT, Mexico.

Sudan Hybrid Sorghum Seed Workshop, November, 1983. Wad Medani, Sudan.

Consultative Group Discussion on Sorghum Root and Stalk Rot Diseases, November, 1983. Bellagio, Italy.

INTSORMIL Graduate Student Workshop, June, 1984 and June 1989. College Station and Corpus Christi, Texas.

Niger Sorghum and Millet Workshop, October, 1985. Niamey, Niger.

Second West African Regional Sorghum Workshop, October, 1985. Bamako, Mali.

International Drought Symposium, May, 1986. Nairobi, Kenya.

Second World Review of Sorghum and Millet Diseases, March, 1988. Harare, Zimbabwe.

Sixth EARSAM Workshop, July, 1988. Mogadishu, Somalia.

Fifth Annual CLAIS Meeting, December, 1988. San Salvador, El Salvador.

International Conference on Dryland Farming, August, 1988. Amarillo, Texas.

Sudan Sorghum and Millet Workshop, Oct.-Nov., 1989, Wad Medani, Sudan.

International Sorghum and Millet CRSP Conference, January, 1989. Scottsdale, Arizona.

Seventh Annual CLAIS Conference, April, 1990. CIMMYT, Mexico.

Seventh EARSAM Regional Workshop on Sorghum and Millet Improvement, June, 1990. Nairobi, Kenya.

International Sorghum and Millet CRSP Conference, July, 1991. Corpus Christi, Texas.

Second Australian Sorghum Conference. February, 1992. Gatton, QLD, Australia.

Molecular Markers in Sorghum and Millet for use in Developing Countries, March-April, 1993. Norwich, U.K.

Research Investigator Exchanges

Traveled to 15 different foreign countries during the life of project to evaluate research, attend conferences, interact with scientists, and coordinate and plan future research. These have included multiple visits to Honduras (13), Mali (11), Sudan (9), Niger (4), and Kenya (3). Other countries visited were Burkina Faso, Somalia, Zimbabwe, Guatemala, El Salvador, Venezuela, Mexico, India, Australia, and Untied Kingdom.

An average of 5 international scientists visited the sorghum breeding program at Lubbock each year of the project. Short-term training programs were provided and directed for Mr. L. M'Ragua and Mr. Ben Kanyenji of Kenya, and Mr. Aboubacar Toure and Mr. Niaba Teme of Mali.

Germplasm and Research Information Exchange

Germplasm Conservation and Use

Numerous exotic cultivars from foreign countries have been introduced into the United States. In some cases, especially from Mali, improved breeding lines have been introduced for use, and for making crosses to return to the host country. Major collections which this project has solely been responsible for introducing, or in some cases cooperated with other INTSORMIL PI's or other persons, has included: Somalia (39), Northern Nigeria (84), Western Kordofan, Sudan (95 + 30), ICRISAT/LASIP (235), Maicillos Criollos from Honduras and other central American countries (100), and Mali (150). Approximately 50 items were introduced from other Africa countries including Niger, Burkina Faso, Ghana, Benin, Cameroon, Mauritania, Kenya, and Ethiopia. This project provided a major role in the planning, acquisition, growout, and classification of over 3,100 sorghums of Sudan origin which were grown out in Sudan in 1991, and seed introduced to the U.S. and grown out under quarantine in St. Croix, Virgin Island the winter of 1993-94.

After introduction, seed is increased in Puerto Rico and seed is available to anyone. Each line is then evaluated for use directly (photoperiod insensitive), or as a candidate for entry into the Sorghum Conversion Program if the cultivar is photoperiod sensitive. Approximately 180 of the recent introductions have been entered into the Conversion Program. Three hundred and fifty fully converted lines (BC4) from the cooperative TAMU-TAES/USDA-DRS, Sorghum Conversion Program have been released and seed distributed since 1980.

Seed Production and Distribution

An estimated 500 sorghum breeding and germplasm lines, including F2 to advanced generation progeny, A, B, and R lines, converted lines, and experimental hybrids are distributed each year to international cooperators, and at least an equal number are distributed annually to domestic

researchers. These contain sources of desirable traits such as disease resistance, pre- and post-flowering drought resistance, grain mold/weathering resistance, and lodging resistance.

Seed is increased annually and many sets of replicated trials containing elite germplasm are packaged and distributed in the U.S. and internationally. These include the ADIN (All Disease and Insect Nursery), IDIN (International Disease and Insect Nursery), GWT (Grain Weathering Test), DLT (Drought Line test), DHT (Drought Hybrid Test), Converted Line Tests (Head Smut Resistant, Downy Mildew Resistant, and Anthracnose Resistant), and the UHSN (Uniform Head Smut Nursery). Countries to which large numbers of germplasm items have been distributed include Mali, Sudan, Niger, Kenya, Honduras, Botswana, Columbia, and Mexico. Others receiving seed include Brazil, Zambia, Zimbabwe, India, Paraguay, China, and ICRISAT (LASIP and Hyderabad).

Assistance Given

Various supplies and small research equipment items have been provided to Mali, Sudan, and Honduras. Also, publications and manuals have been provided. Joint evaluation of germplasm and breeding materials has been done in collaboration with NARS in Mali, Honduras, Sudan, and Kenya. This includes training in disease and drought screening and rating methodology, as well as information on sources of useful germplasm and desirable traits. Similar training is provided annually to host country graduate students in the Texas breeding and disease nurseries in the Lubbock and Corpus Christi areas.

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Germplasm Enhancement through Genetic Manipulation for Increasing Resistance to Insects and Improving Efficient Nutrient Use in Genotypes Adapted to Sustainable Production Systems

Project TAM-123

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Summary

The objectives of this project have been to identify, characterize and utilize the genetic diversity of grain sorghum to develop improved cultivars resistant to selected biotic and abiotic stress factors, and to determine the genetic factors responsible for the resistance and their mechanisms. Insects for which resistance has been identified and utilized include sorghum midge (*Contarinia sorghicola*), biotype C, E, or I greenbug (*Schizaphis graminum*), sugarcane aphid (*Melanaphis sacchari*), and yellow sugarcane aphid (*Sipha flava*).

Sorghum genotype, level of available water and soil chemical properties (nutrient levels, acidity, toxicity, etc.) interact to affect crop yield along with the efficient use of water and nutrients. This interaction must be quantified in order for sufficient knowledge to be available for development of appropriate agronomic solutions to insure stability and sustainability of sorghum production in West Africa.

The data presented here and that of others clearly shows the potential synergistic effects of interactions between soil fertility, available water and sorghum genotypes. It has also shown a number of important responses of sorghum to drought, soil fertility and applied inputs to be under separate genetic control. Thus, there is great potential for exploitation of available germplasm resources for development of multiple stress tolerant sorghums to take advantage of synergistic interactions for a wide range of climatic and input conditions.

A joint project between INTSORMIL and TropSoils (Soil Management CRSP) was initiated in Mali in 1992 utilizing these results.

This project has been part of a collaborative effort with entomologists, especially TAM-125, to characterize, understand and utilize genetic resistance to manage insect pests. The research has resulted in the release of 12 germplasm lines resistant to biotype C greenbug, 11 germplasm lines resistant to biotype E greenbug, and 37 germplasm lines resistant to sorghum midge. Additionally, the project has cooperated in the release of 250 converted exotic sorghum genotypes. Results of this research have been documented in 73 publications, abstracts, or reports, and 26 invited or submitted presentations. The principal investigators have served on 12 graduate committees related to project activities.

Introduction

Sorghum production and yield stability is constrained by numerous biotic and abiotic stresses. Insects pose a production risk in all areas of sorghum production, the severity of damage depending on the insect and local environment. To reduce the impact of stress research is needed to develop crop genotypes with enhanced environmental fitness suitable for use in more sustainable production systems. Genetic resistance to multiple stresses in a single genotype will further reduce environmental risk and contribute to improved productivity in LDC and DC production systems. This is particularly important as local production ecosystems (relative to cultivars and technology) experience induced change with natural balance between cultivars and biotic stresses also being changed and insect damage becoming increasingly severe.

To meet the demands of increased food production in an economically profitable, environmentally sustainable production system genetic resistance can be utilized at no additional cost to the producer. This requires a multi-disciplinary research program to integrate resistance hybrids into the management system. Cultivars resistant to insects will readily integrate with other required inputs as part of an integrated, ecologically sound production and stress control strategy with large potential benefits in subsistence and mechanized agriculture. Host plant resistance to insects is a continual effort in response to a dynamic evolving production agroecosystem.

Among the major constraints to sorghum production in Sahelian Africa are: soil acidity, extremely deficient levels of N and P, spatially variable soil toxicity and limited available water. These factors frequently interact with food shortages being the result. Solutions to these problems must meet site specific needs of soil, rainfall, resources, labor and capital.

Objectives, Production and Utilization Constraints

Objectives

Obtain and evaluate germplasm for resistance to arthropod pests. Determine the resistance source or mechanisms most useful to sorghum improvement.

Determine the inheritance of insect resistance.

Develop and release high yielding, agronomically improved sorghum resistant to selected insects including the sorghum midge.

Identify and define potential sources of more efficient plant nutrient extraction and/or utilization in sorghum.

Develop agronomically elite sorghum with improved nutrient use efficiencies.

Develop new methods for determining nutrient use efficiencies and study responsible mechanisms when appropriate.

Determine the effects of nutrient use efficiency on water use efficiency in sorghum.

Develop analytical procedures for determining chemical and physical properties of Sahelian soils and diagnostic techniques to use in predicting crop response and need for fertilizers or corrective amendments.

Identify and define sorghum genotypes with varying levels or tolerance to drought and chemical stress of Sahelian soils and determine how each trait is inherited.

Constraints

Sorghum production and yield stability is constrained by numerous biotic and abiotic stresses. Insects pose a production risk in all areas of sorghum production, the severity of damage depending on the insect and local environment. To reduce the impact of stress, research is needed to develop crop genotypes with enhanced environmental fitness suitable for use in more sustainable production systems. Genetic resistance to multiple stresses in a single genotype will further reduce environmental risk and contribute to improved productivity in LDC and DC production systems. This is particularly important as local production ecosystems (relative to cultivars and technology) experience induced change with natural balance between cultivars and biotic stresses also being changed and insect damage becoming increasingly severe.

Sorghum midge, *Contarinia sorghicola*, is the only cosmopolitan sorghum insect pest and is among the sorghum species destructive insect pests. As LDC programs cross exotic germplasm with improved agronomic traits to indigenous genotypes, progeny and eventually cultivars will be

developed which are more photoperiod insensitive and midge damage will become increasingly severe. Depending on the environment numerous other insects, including aphids, head bugs, and borers will damage grain sorghum. For all of these insects genetic resistance exists and can be integrated into the production system in an ecologically safe, economically inexpensive, and environmentally sustainable manner. Cultivars resistant to insects will readily integrate with other required inputs as part of an integrated, ecologically sound production and stress control strategy with large potential benefits in subsistence and mechanized agriculture. Host plant resistance to insects is a continual effort in response to a dynamic evolving production agroecosystem.

It has long been assumed that water was the first limiting factor to plant growth in much of the semi-arid tropics. However, Stroosnijder and his associates from the University of Wageningen have shown conclusively that due to a lack of nutrients, principally N and P, usable water is left on the soil profile even by native range plants. We have determined that on Aflisols in Texas (same soil family as many in SAT areas of Africa) usable water is left in soil zones of low nutrient supply. Consequently, increasing grain production under simultaneous low soil water supply and low soil fertility is important as well as conditions of low soil fertility with adequate water.

Research Approach and Project Output

Research Approach

The research approach of this project is to conduct collaborative research in LDC's on specific problems. On-site research is supported by participation in graduate education, germplasm exchange and evaluation, site visits, and research conducted at various nursery locations in Texas. Collaborative research has focused on evaluation of sorghum lines and hybrids resistant to sorghum midge in Central America. This project had input in developing a collaborative research program in Southern Africa on plant resistance to the sugarcane aphid. For the United States greenbug and yellow sugarcane resistant sources have been identified and are being used in developing elite resistant sorghums. Through collaborative ties with other projects genetic inheritance and resistance mechanisms are determined. Methodology has been developed to quantify the response of sorghum genotypes to high and low soil fertility levels, to identify response of specific genotypes to fertilizer, and to evaluate the effect of water and/or nutrient use efficiency on grain yield.

Germplasm is evaluated for resistance to insects of economic importance in the collaborative breeding/entomology program in field nurseries or greenhouse facilities, depending on the insect mode on infestation. Sources of germplasm for evaluation are elite accessions from other programs (including ICRISAT), introductions, and partially or fully converted exotic genotypes from the sorghum conversion program.

New sources of resistance are crossed to elite material in the breeding program and to other germplasm lines with superior trait(s). Studies to determine the genetics of resistance and the resistance mechanism are conducted when possible. Advanced elite materials are evaluated at diverse locations for stability of resistance, adaptation, and reaction to additional stress factors. Based upon data collected, crosses are made among elite lines to produce additional germplasm for subsequent evaluation. Improved adaptation, other stress resistance (disease resistance and/or drought tolerance), and additional favorable traits are incorporated into insect resistant germplasm whenever possible.

Elite lines and hybrids are provided to LDC cooperators for evaluation in indigenous environments. The germplasm is evaluated under the local production system (fertilizer, tillage, plant population, etc.) and agronomic and yield data collected.

For insects important in LDC's but not in the U.S., an array of germplasm is provided to the LDC cooperator. The germplasm is evaluated for resistance to the specific insect by the cooperator. Based upon experimental results crosses are made to produce relevant populations for inheritance and entomological studies. These populations are provided to the cooperator for further evaluation.

Diverse cultivars of grain sorghum from the breeding programs at Lubbock, and introductions from LDC's are screened for N, P, and Fe use efficiencies in nutrient culture in greenhouse studies at Lubbock and field nurseries in Mali, West Africa and at Beeville and Lubbock, Texas. Priority is given to lines that have shown promise in previous tests including nurseries in LDC's. Lines from the sorghum conversion program are also evaluated. Genotypes relatively different in N and/or P nutrient use efficiency are grown in a greenhouse in soil deficient in the respective nutrient. Water use are determined and water use efficiency defined as dry weight production per unit of available water. Water use efficiency for selected genotypes differing in N use efficiency is determined in an N deficient soil under field conditions based on grain and forage yields, available water, and water used. Water use will be determined by neutron probe. Particular attention is given to determination of soil chemical and physical characteristics for nurseries in Mali.

Project Output

1993 Accomplishments

Research to broaden the genetic base of the midge resistance breeding program, to incorporate additional sources of resistance into elite lines, to identify new superior R-lines, and to identify new A-lines with excellent resistance and yield potential continued. Seventy-six converted exotic sorghum lines were evaluated for resistance to sorghum midge.

While some lines expressed resistance under moderate infestation none of the lines were resistant under high infestation levels. Combined results from two years of trials led to the conclusion that none of the lines contained useable sources of resistance.

Elite advanced lines were evaluated in a midge line test for resistance to sorghum midge and agronomic desirability. Of the seventy-five experimental entries twenty-four were selected for further evaluation and testing. Nineteen of the lines are B-lines (A1 cytoplasm) and are being sterilized to develop new seed parents. Partial results which show the superior lines are presented in Table 1. The experimental entries designated as 'MB' represent potential new B-lines (the A-line counterpart is used as the female seed parent in hybrid production), and each possess excellent resistance to sorghum midge. Their usefulness as female seed parents is currently being investigated. A major constraint to production and use of sorghum midge resistant hybrids has been to lack of superior A-lines which possess excellent resistance and yield potential under pest infestation, and excellent yield potential in the absence of the pest. If the lines possess the needed characteristics they would represent a significant advance in A-line breeding material and could make a potentially major contribution to use of sorghum midge resistant hybrids.

Experimental hybrids (forty-four) representing new hybrid combinations were evaluated (Table 2). Included in the test were new R-lines and A-lines being evaluated in hybrid combination for the first time. When compared to the standard sorghum midge resistant hybrid, ATx2755 x Tx2767, most experimental hybrids expressed significantly better yield potential and pest resistance under high population density at Corpus Christi. While the differences were not as large under moderate density (at College Station) the experimental lines still express better yield potential and resistance than previously available hybrids.

Research was conducted to develop new germplasm resistant to biotype E greenbug. Advanced hybrid trials were conducted to test new R- and A-lines in hybrid combination. Superior lines will be tested in 1994 to select superior germplasm for release. Initial selections were made in breeding populations to develop biotype I resistant lines. A large number of crosses were made to introgress the resistance gene(s) into an array of elite germplasm. Research continued to introgress genes for resistance to yellow sugarcane into elite adapted material. Evaluation of F_4 generation progeny resulted in identification of six progeny which express a useful level of resistance. The germplasm is currently undergoing further crossing with adapted germplasm to develop elite resistant lines.

Table 1. Mean midge damage rating and desirability of selected entries in the 1993 Texas Midge Line Test.

	Midge damage rating†			Desirability‡		
	$\bar{x}$	CC §	CS	$\bar{x}$	CC	CS
Tx3042	8.5	8.0	9.0	3.2	3.3	3.1
Tx623	8.0	8.7	7.3	2.6	2.5	2.7
Tx430	7.8	9.0	6.7	2.4	2.4	2.5
Tx378	7.2	8.7	5.7	3.0	2.8	3.2
Tx2801	6.3	9.0	3.7	2.5	2.5	2.5
TAM2566	5.5	5.0	6.0	3.1	3.1	3.2
MB104-B91NF6	4.3	5.7	3.0	2.7	2.6	2.8
MB110-B92NF3	3.8	5.7	2.0	2.5	2.5	2.5
MB104-B92NF7	3.8	4.0	3.7	2.7	2.6	2.7
MB104-B92NF8	3.8	5.0	2.7	2.7	2.5	2.8
MB104-B92NF9	3.7	4.0	3.3	2.6	2.5	2.6
MB104-B93NF1	3.7	5.0	2.3	2.5	2.4	2.6
Tx2878	3.2	5.3	1.0	2.5	2.5	2.5
MR114-90M11	3.2	4.0	2.3	2.6	2.6	2.5
MR112B-92M4	3.2	4.0	2.3	2.6	2.6	2.7
Tx2882	3.0	4.7	1.3	2.4	2.4	2.3
MR127-92M5	3.0	5.0	1.0	2.5	2.4	2.5
Tx2782	2.8	3.3	2.3	3.1	3.2	3.1
Tx2880	2.5	3.6	1.3	2.6	2.5	2.7
MR112B-9992M2	2.5	4.0	1.0	2.7	2.6	2.7
$\bar{x}$	4.4	2.9	6.1	2.6	2.7	2.6
$LSD_{.05}$	1.1	0.2	1.0	0.2	1.1	0.3

† Rated on scale of 1 = 0-10% blasted seed, 2 = 11-20% blasted seed, ..., 9 = 81% blasted seed.

‡ Rated on scale of 1 = most desirable to 5 = least desirable.

§ CC = Corpus Christi, TX; CS = College Station, TX.

Table 2. Mean grain yield and midge damage rating of the 1993 Midge Hybrid Test.

Hybrid	Yield/A (in Lbs)			Midge damage rating †		
	$\bar{x}$	CC‡	CS	$\bar{x}$	CC‡	CS
ATx2755*MR127-92M5	4819	3419	6218	3.2	3.7	2.7
ATx2755*Tx2880	4395	2380	6409	3.7	5.0	2.3
A91NF8(MB104)*Tx2767	4334	1663	7004	3.8	6.0	1.7
A9NF8(MB104)*Tx2882	4262	2809	5715	3.3	4.3	2.3
A9NF3(MB110)*Tx2880	4256	2300	6212	3.0	4.7	1.3
A9NF8(MB104)*Tx2880	4206	2642	5771	3.5	4.7	2.3
A91NF6(MB104)*Tx2767	4041	1938	6144	3.5	5.0	2.0
A92NF7(MB104)*Tx2880	4018	2244	5793	3.7	5.3	2.0
A91NF8(MB104)*Tx2882	3803	2049	5557	3.5	5.0	2.0
ATx2755*MR112-92M1	3735	1984	5485	4.0	6.0	2.0
A92NF3(MB110)*Tx2882	3721	1698	5744	3.7	5.3	2.0
A91NF6(MB104)*Tx2880	3697	2310	5084	3.5	4.3	2.7
ATx2755*MR112B-92M4	3646	2682	4610	3.5	4.0	3.0
A91NF8(MB104)*Tx2880	3625	2127	5122	3.8	5.0	2.7
A92NF6(MB104)*Tx2880	3614	1935	5293	4.2	5.7	2.7
A92NF9(MB104)*Tx2767	3510	1954	5067	3.7	5.3	2.7
A92NF6(MB104)*Tx2767	3440	1431	5449	4.5	6.7	2.3
A92NF(MB104)*Tx2882	3428	1924	4931	2.5	3.3	1.7
ATx2755*Tx2767	2993	542	5443	4.8	7.7	2.0
ATx2801*Tx2767	2390	165	4616	5.7	8.7	2.7
ATx2801*Tx2872	1495	482	2509	5.3	8.0	2.7
ATx399*RTx430	1243	592	1894	8.3	8.3	8.3
ATx2755*RTx430	1238	85	2391	7.6	9.0	5.5
ATx2752*RTx430	599	164	1252	8.2	9.0	7.0
ATx3042*Tx2737	303	243	363	9.0	9.0	9.0
$\bar{x}$	2958	143	4499	4.7	6.2	3.1
$LSD_{.05}$	1147	842	1727	1.4	1.6	1.3

† Rated on scale of 1 = 0-10% blasted seed, 2 = 11-20% blasted seed, ..., 9 = 81% blasted seed.

‡ CC = Corpus Christi, TX; CS = College Station, TX.

Twenty-one breeding lines and three hybrids were evaluated for nitrogen use efficiency at low and high levels of available nitrogen and for responsiveness to fertilizer nitrogen application. Significant differences in grain yield were found. No relationship was found between grain yield and either high or low levels of available nitrogen and responsiveness to nitrogen application.

Ten lines in the same test were used to evaluate a chlorophyll meter for utilization in determining nitrogen status of sorghum breeding lines. Previous research using a single sorghum hybrid, showed meter readings linearly related to nitrogen fertilizer treatment, Figure 1. Readings were made on two plants at pre-boot and after heading on the top most mature leaf and the lowest live leaf. Leaf readings were taken near the ligules, mid-leaf and at the leaf tip. The conclusion at this point is that the chlorophyll meter will be of little use where more than one genotype is being measured. There were significant differences in meter readings between genotypes at each nitrogen level and leaf position. There was no clear advantage or consistent differences in readings due to reading location on the leaf.

A 46 entry paired plot screening nursery for soil toxicity was established, jointly with TropSoils, on the Cinzana Experiment Station at a previously selected site. Bagoba was used as the resistant check and Malisor 84-5 was used as the susceptible check. This nursery was evaluated on October 14, 1993. A Gadiaba selection made on the Cinzana Station was rated higher than the resistant check. It was concluded that this technique of paired planting coupled with appropriate soil analyses would be useful in screening for tolerance to the soil toxicity problem. Soil samples have been taken. Analyses will be performed when the samples are transported to Lubbock, at which time an effort will be made to determine what characteristics makes the response of sorghums to these semi-arid acid soils different from their response to humid acid soils.

Fifteen-Year Accomplishments

Resistance to Insects

In addition to developing and distributing tests for resistance to specific insects this project contributed entries and

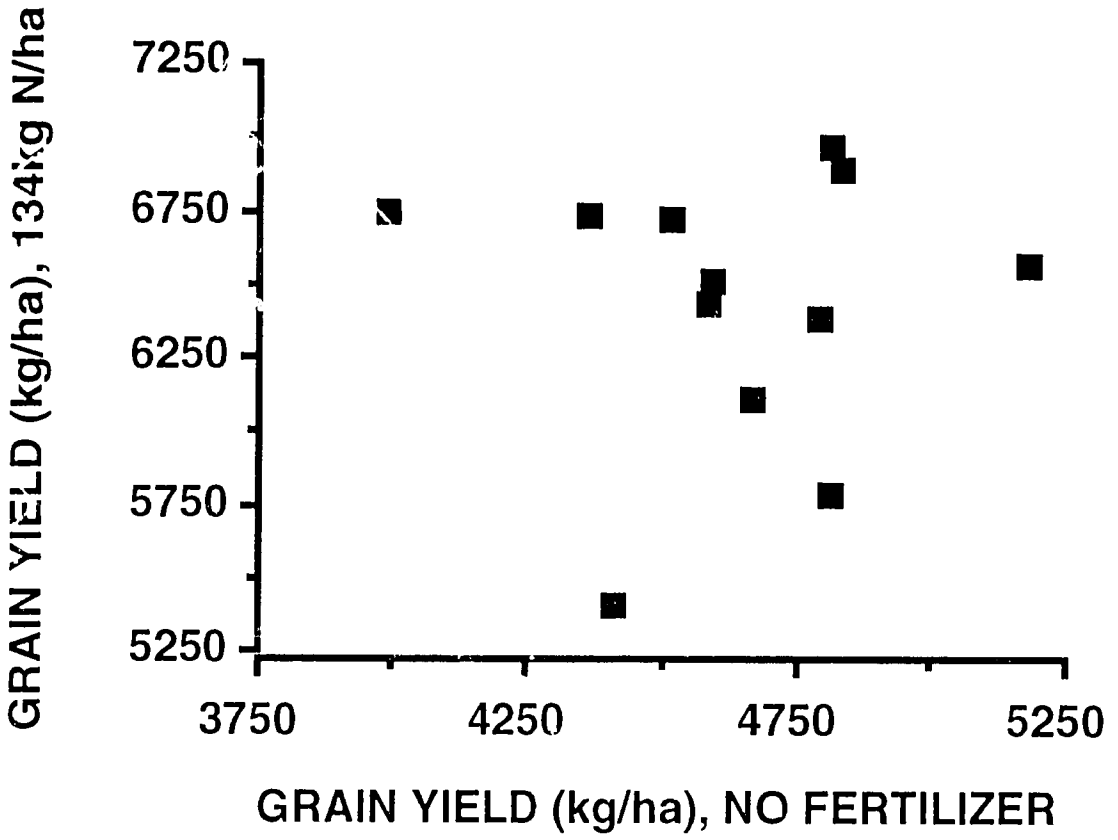

Figure 1. Relationship between grain yields of 12 sorghum genotypes grown at two soil N levels. No fertilizer applied and 134 kg N/ha.

germplasm to the ADIN (All Disease and Insect Nursery), ITVAN (International Tall Variety Adaptation Nursery), TAT (Tropical Adaptation Test), IFSAT (International Food Sorghum Adaptation Test), EON (Elite Observation Nursery), and BON (B-line Observation Nursery). The ADIN, ITVAN, TAT, and OFFSET are evaluated at many locations domestically and internationally. Additionally, a number of F_2 breeding populations, advanced lines, and hybrids were developed and sent to LDC cooperators.

Twelve germplasm lines, designated Tx2789-Tx2800, resistant to biotype C greenbug were released in 1983. Four of the lines were A/B pairs (Tx2789 - Tx2892) and eight were R-lines (Tx2793 - Tx2800).

Eleven germplasm lines resistant to biotype E greenbug were released. Tx2783, released in 1981, is an R-line which is also resistant to biotype C greenbug. Tx2859 through Tx2868 were released in 1989. The commercial seed industry has used Tx2783 and its derivatives extensively as a pollinator in hybrids, and is also using Tx2864 as a pollinator.

Tx2782, derived from AF-28, was released in 1981 for resistance to sorghum midge. Tx2782 has consistently superior resistance wherever evaluated.

Thirty-seven improved germplasm lines resistant to sorghum midge were released. Tx2801 through Tx2815, released in 1983, contain resistance derived from lines in addition to SC175-9. Three A/B pairs (Tx2801 - Tx2815) and twelve R-lines (Tx2804 - Tx2815) were included in the release. Twenty-two R-lines, designated Tx2869 - Tx2890, were released in 1989. The resistance is derived from either TAM2566 (SC175-9) or SC423-14.

Cooperated in the release of three hundred fifty converted exotic sorghum lines. The releases were made in three groups: two hundred forty lines in 1986, fifty in 1992, and an additional sixty in 1992.

Provided four hundred sixty-four sorghum lines to Dr. Chris Manthe, Department of Agriculture entomologist in Botswana, to determine resistance to sugarcane aphid. Inheritance of resistance and resistance mechanisms were also studied. The best resistance sources were TAM428 and IS12661C. Other resistance sources were IS12609C, IS12610C, and IS12664C. A differential response for some lines was noted between aphids from Botswana and Zimbabwe. Resistance was determined to be inherited by a single, dominant gene.

During the duration of this project thousands of lines have been evaluated under field conditions for resistance to sorghum midge. Included were lines from other programs, introductions from LDC's or ICRISAT, and three hundred forty eight converted exotic sorghums from the sorghum conversion program. From the converted exotic sorghum

genotypes evaluated sixteen were identified as potential resistance sources. Several of these lines have been used in the crossing and selection program to broaden the genetic base from TAM2566 (SC175-9) and AF-28.

Thousands of sorghum genotypes have been evaluated for resistance to biotype C or E greenbug. Several of the lines released by this project have been utilized extensively in commercial industry. The estimated net social benefit to the United States in breeding for resistance to greenbug has been estimated at $113 million.

When a new greenbug biotype, designated biotype I, was identified additional resistance sources were needed and subsequently identified. The new sources, PI550607 and PI550610, are being introgressed in elite breeding material. Germplasm resistant to biotype I will be made available to sorghum producers as rapidly as possible.

Two plant introductions, PI457709 and PI453951, were confirmed as resistant to yellow sugarcane aphid. These lines are the first germplasm identified with genetic resistance. Breeding populations are being developed to incorporate the resistance into elite adapted lines.

Nutrient Use Efficiency

Concepts at Beginning of Project:

Sorghums that perform best at high soil fertility levels will perform best at low soil fertility levels.

Agronomic nitrogen use efficiency is defined at the product of uptake efficiency and metabolic N use efficiency.

$$G_w/N_s = (G_w/N_t)\ (N_t/N_s)$$

where: G_w = grain weight

N_t = N in above ground plant tissue
N_s = N in soil available to crop

Breeding plants tolerant to adverse soil conditions that are spatially variable over small distances cannot be accomplished in field plots.

A knowledge of soil properties is not necessary to successfully conduct a plant breeding program.

Fertilizer affects water use efficiency of crops by increasing leaf area index, thereby reducing soil evaporation, which increases water available for transpiration. The increased water available for transpiration is utilized for increased yield.

Water use efficiency of crops is affected by soil fertility only if the deficiency is sufficiently severe to result in a 50% or greater reduction in yield.

Materials and Methods

Various sorghum cultivars and breeding lines were studied in greenhouse, lysimeter and field trials in the U.S. and West Africa.

Treatments consisted of appropriate levels of fertilizer, water or other soil amendments, alone or in combination, depending upon the specific information sought.

Soil physical and chemical properties were determined using standard procedures.

Soil moisture levels were determined by weighing or neutron probe.

Transpiration for field plots was estimated using a mechanistic model developed by Lascano et al., 1989. SSSAJ. 1113-1121.

Water use efficiency was calculated based on evapotranspiration (ET) or transpiration (T) depending upon the study.

Nitrogen use efficiency was defined as: $G_w/N_s = (G_w/N_t)(N_t/N_p)(N_p/N_s)$

where: G_w/N_s = units of grain produced per unit of N supply.

G_w/N_t = units of grain produced per unit of N in the aerial plant tissue. Metabolic N use efficiency.

N_t/N_p = units of N in the aerial portion of the plant per unit of N in the whole plant. Translocation efficiency.

N_p/N_s = units of N in the whole plant per unit of N supply in the soil. Uptake efficiency.

Results and Discussion

Results have consistently shown that grain yields at high and low fertility (Fig. 1 and Fig. 2), as well as, yield responses to fertilizer (Fig. 3) are to some degree independent of one another.

Therefore, it is incorrect to assume that selection of sorghums under adequate soil nutrient conditions will result in sorghums that perform well under nutrient stress.

Sorghum performance at low nutrient levels, yield potential under good conditions and responsiveness to applied fertilizer appear to each be under separate genetic control.

Soil fertility level has only small effects on evapotranspiration (ET) regardless of sorghum genotype, whereas, water level has significant effects (Fig. 4).

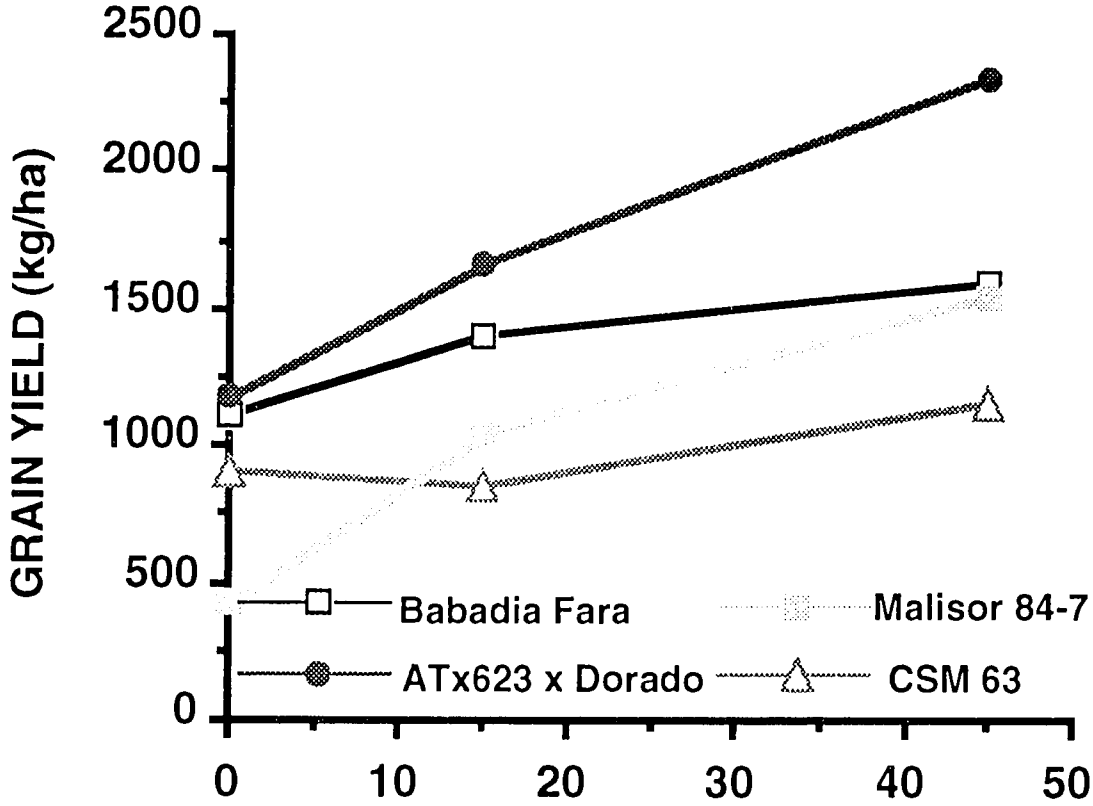

Figure 2. Grain yield of four sorghum cultivars as affected by fertilizer phosphorus. Cinzana, Mali.

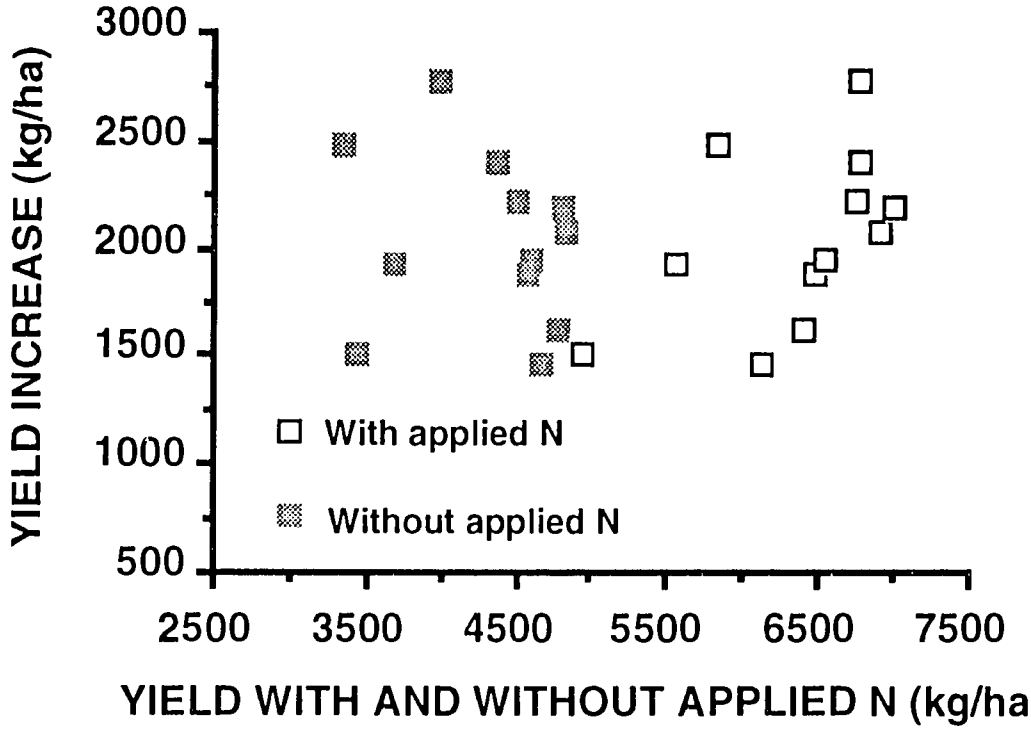

Figure 3. Relationship between grain yield increase of 12 sorghum genotypes and their yield with and without the application of 134 kg N/ha.

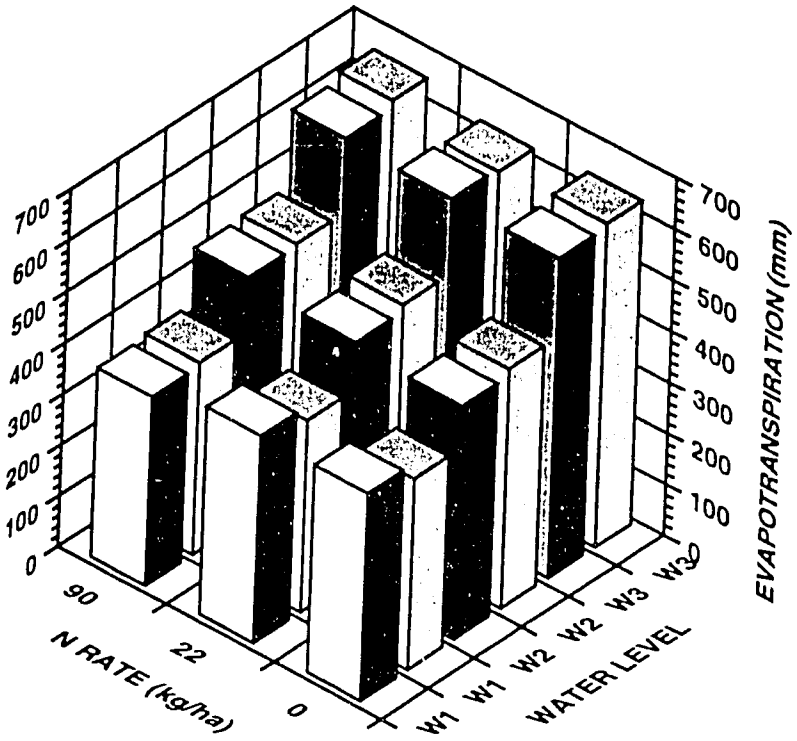

Figure 4. Evapotranspiration as affected by N fertilizer rate, water level and sorghum genotype. W1 = Beginning with full profile + rainfall. W2 = 50% of ET applied weekly. W3 = 100% of ET applied weekly.

Grain yield of sorghum is affected by N rate, water level and genotype (Fig. 5).

As a consequence of small effects of N rate on ET and significant effects on grain yield, water use efficiency (WUE) based on ET is significantly affected by N rate (Fig. 6).

Sorghum genotype and water level interact with N rate to influence WUE based on ET, resulting, in the highest WUE occurring at the moderate water level and high N rate (Fig. 6).

Percentage increases in WUE are linearly and positively related to percentage increases in yield due to soil fertility, even at small percentages of increased yield (Fig. 7).

Thus, it is not necessary to have large increases in yield to derive benefit from fertilizer in improving WUE based on ET.

While soil fertility has small effects on ET of field grown sorghum (Fig. 4), it results in proportional changes in E and T (Fig. 8). Increasing soil fertility increases T and decreases E. The decrease in E is probably due to increased leaf area index.

The increased yield due to fertilizer application is proportionally different per unit of T than under lesser fertility conditions, resulting in increased transpirational WUE (Fig. 9).

Consequently, increases in evapotranspirational WUE in field grown sorghum, due to fertilizer and where ET is little changed, are not only a result of reductions in E, but are also a result of increases in transpirational WUE.

Transpirational WUE has been consistently found to be related to harvest index in lysimeter trials (Fig. 10). This might be a useful screening tool for plant breeders, but needs to be tested under field conditions.

Sorghum grain produced per unit of N in aerial plant tissue (metabolic N use efficiency, G_w/N_t) has been found to be affected by an interaction between genotype and N rate (Fig. 11).

N content of the aerial plant tissue per unit of N in the whole sorghum plant (translocation efficiency, N_t/N_p) has also been found to be affected by an interaction between N rate and genotype (Fig. 12). As with G_wN_t, differences between genotypes tended to disappear at higher N levels.

N content of the total sorghum plant per unit of N supply (uptake efficiency, N_p/N_s) has also been found to be affected by the interaction of N rate and sorghum genotype (Fig. 13). As with G_w/N_t and N_t/N_p, differences between genotypes were greatest at lowest levels of fertility.

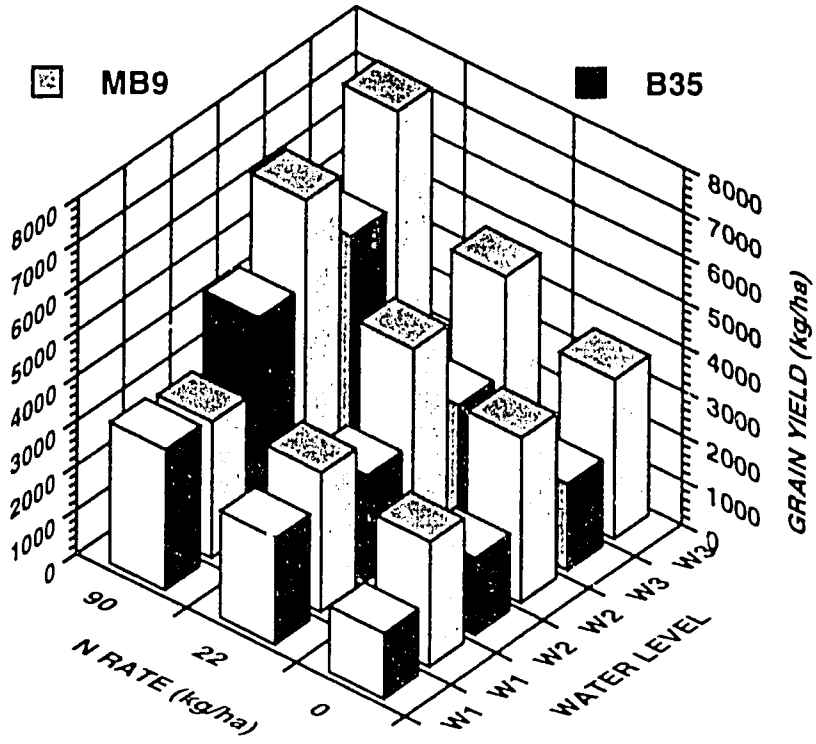

Figure 5. Grain yield as affected by N fertilizer rate, water level and sorghum genotype. W1 = Beginning with full profile + rainfall. W2 = 50% of ET applied weekly. W3 = 100% of ET applied weekly.

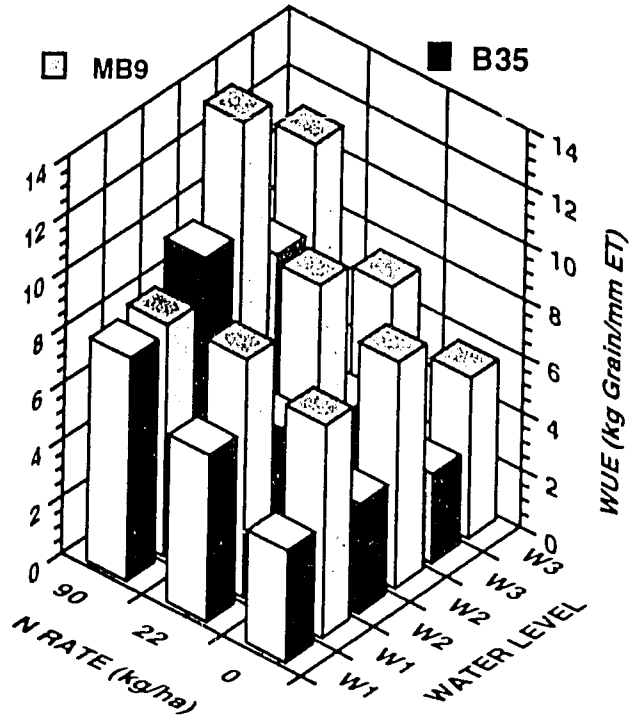

Figure 6. Water use efficiency (ET) as affected by N fertilizer rate, water level and sorghum genotype. W1 = Beginning with full profile + rainfall. W2 = 50% of ET applied weekly. W3 = 100% of ET applied weekly.

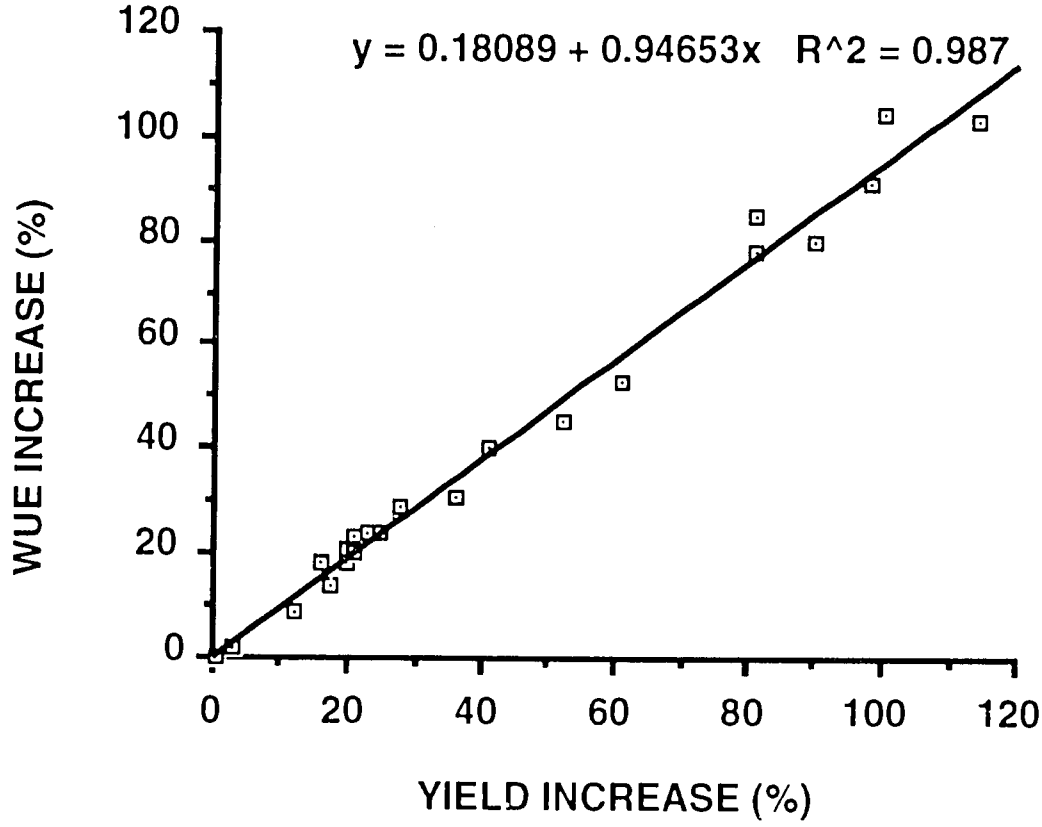

Figure 7. Relationship between percent increase in water use efficiency (ET) and percent increase in yield as a result of fertilizer N application. Data for two sorghum genotypes (MB9 & B35) grown for two years at three water levels and three N levels.

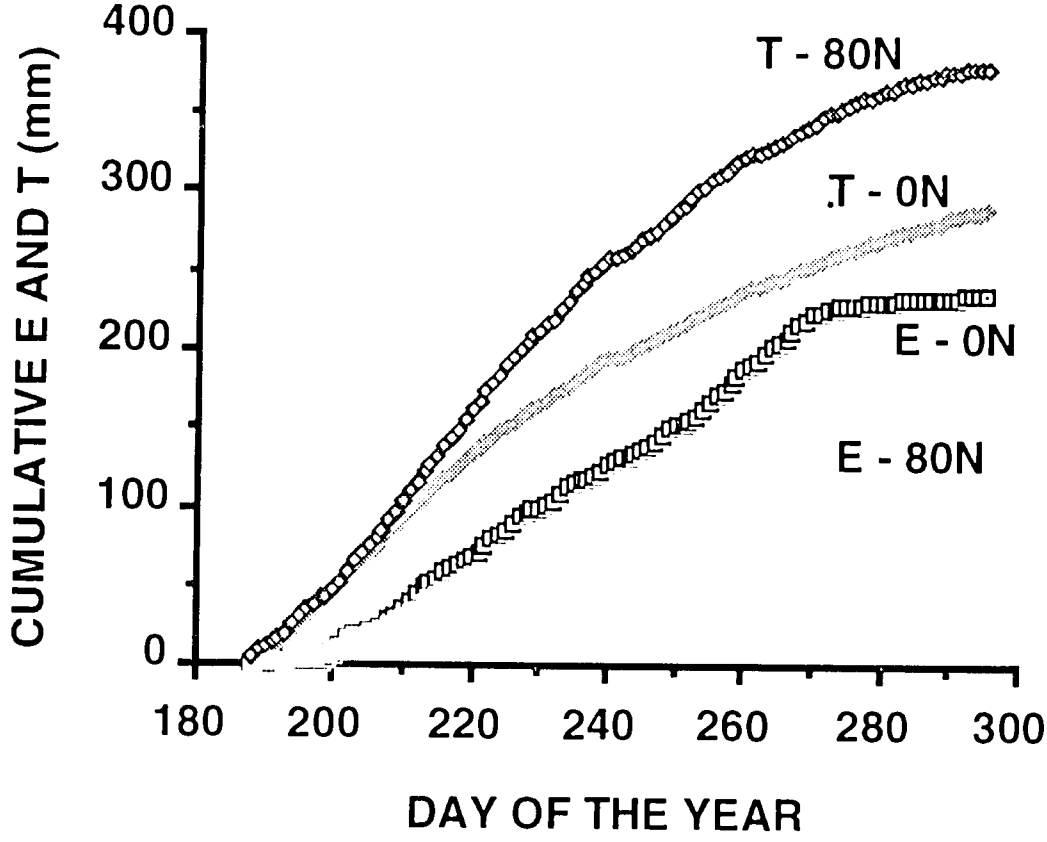

Figure 8. Simulated cumulative E and T for grain sorghum grown at two N levels and with adequate water (100% of ET applied weekly).

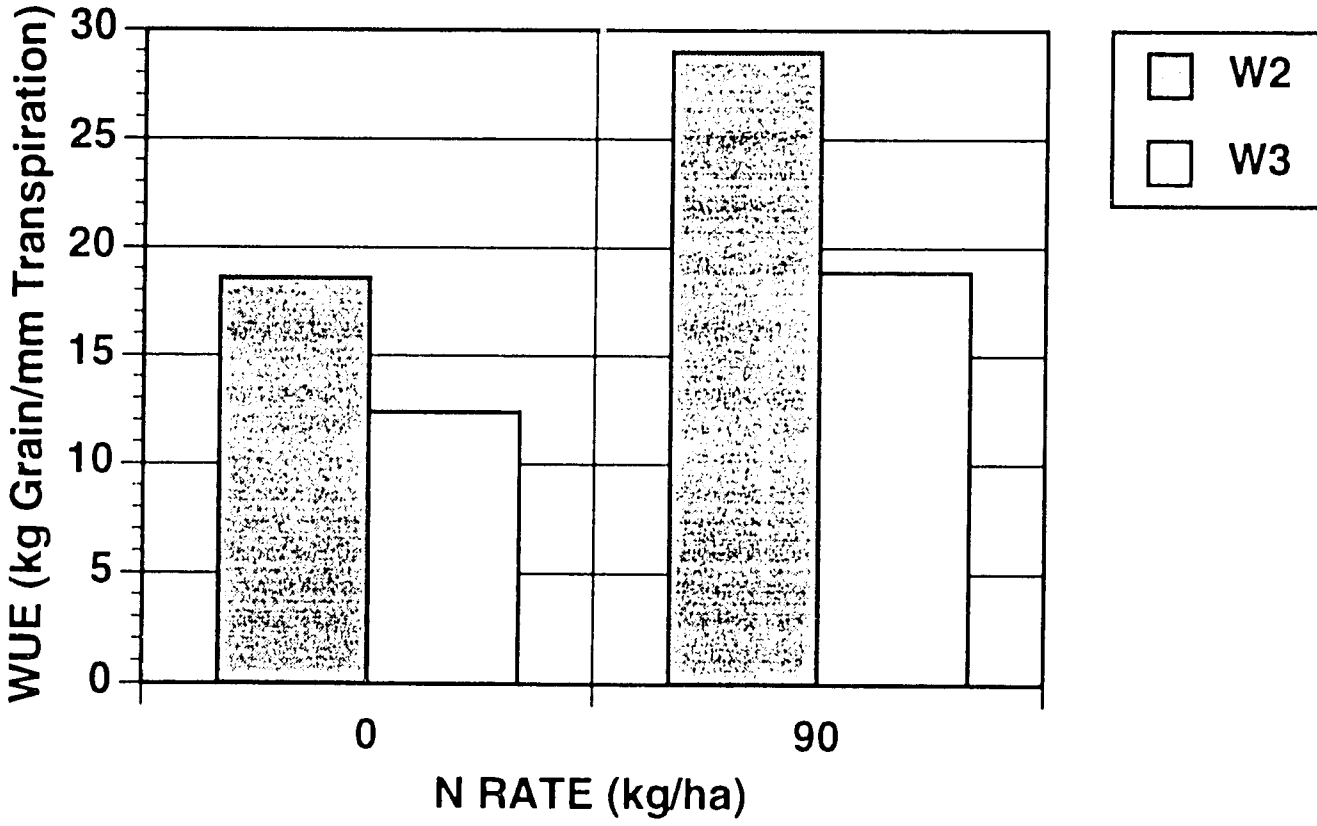

Figure 9. Transpirational water use efficiency of field grown sorghum as affected by water and N levels. W2 = 50% and W3 = 100% of ET applied weekly

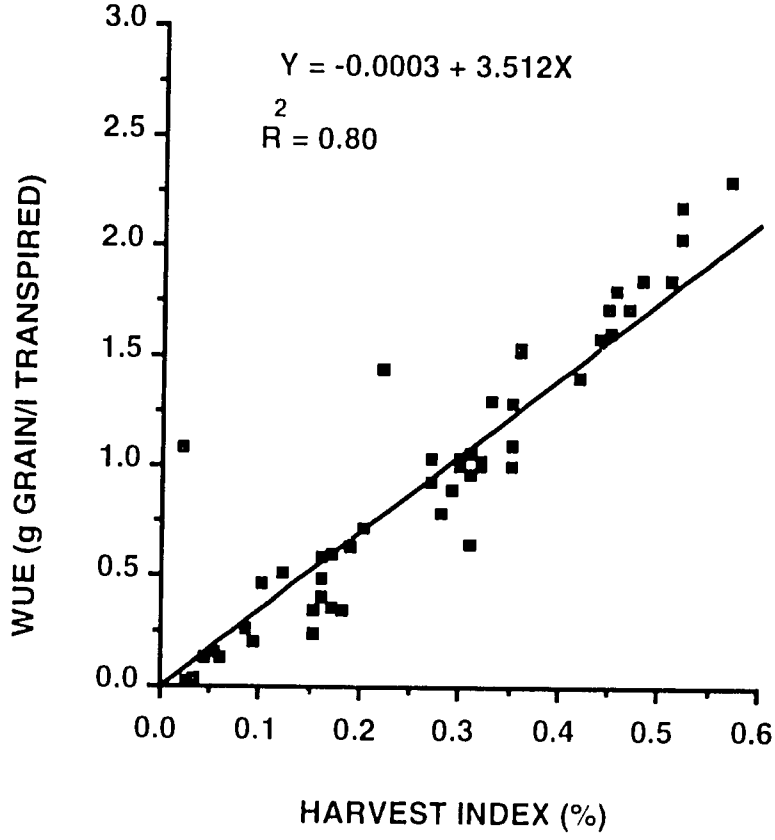

Figure 10. Relationship between transpirational water use efficiency and harvest index. Data from two studies which together used four sorghum genotypes, two water levels, four P rates, and three N rates.

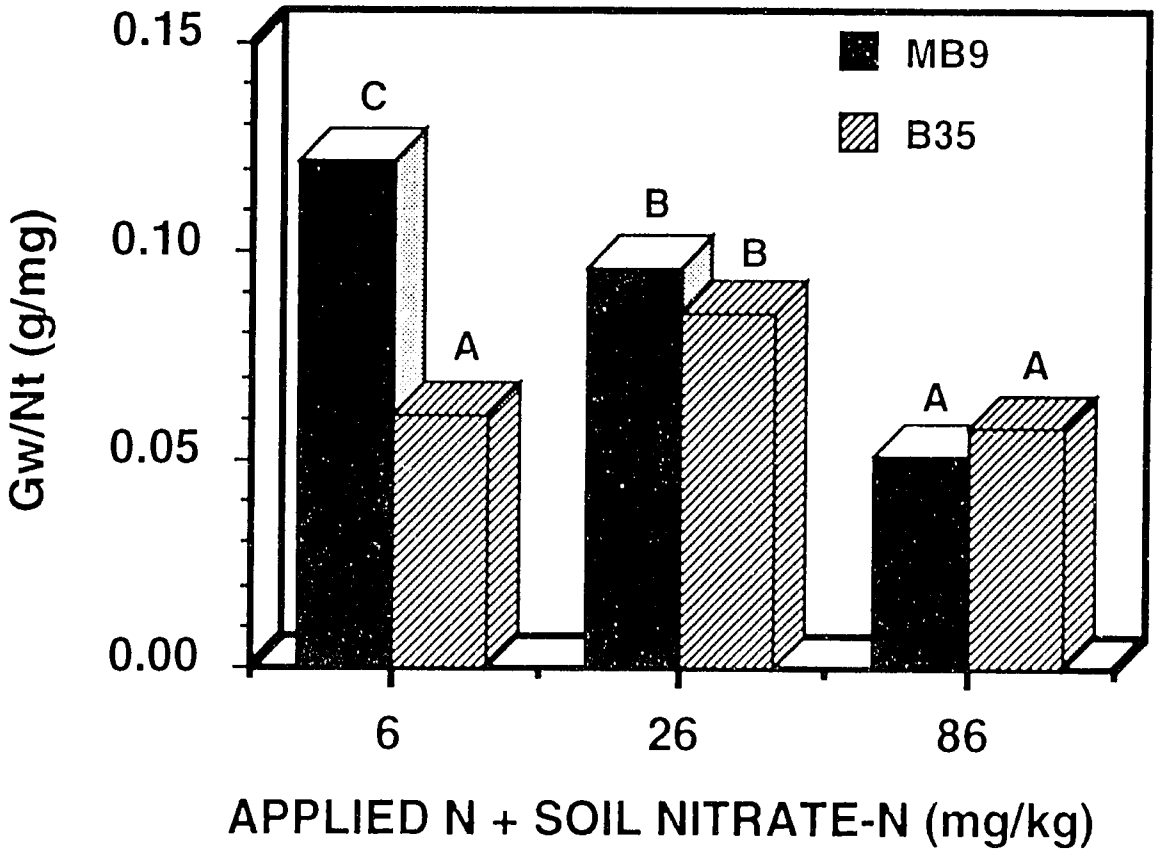

Figure 11. Effect of applied + residual soil nitrate - N on the ratio of grain weight to N in the above soil plant tissue of two grain sorghum genotypes.

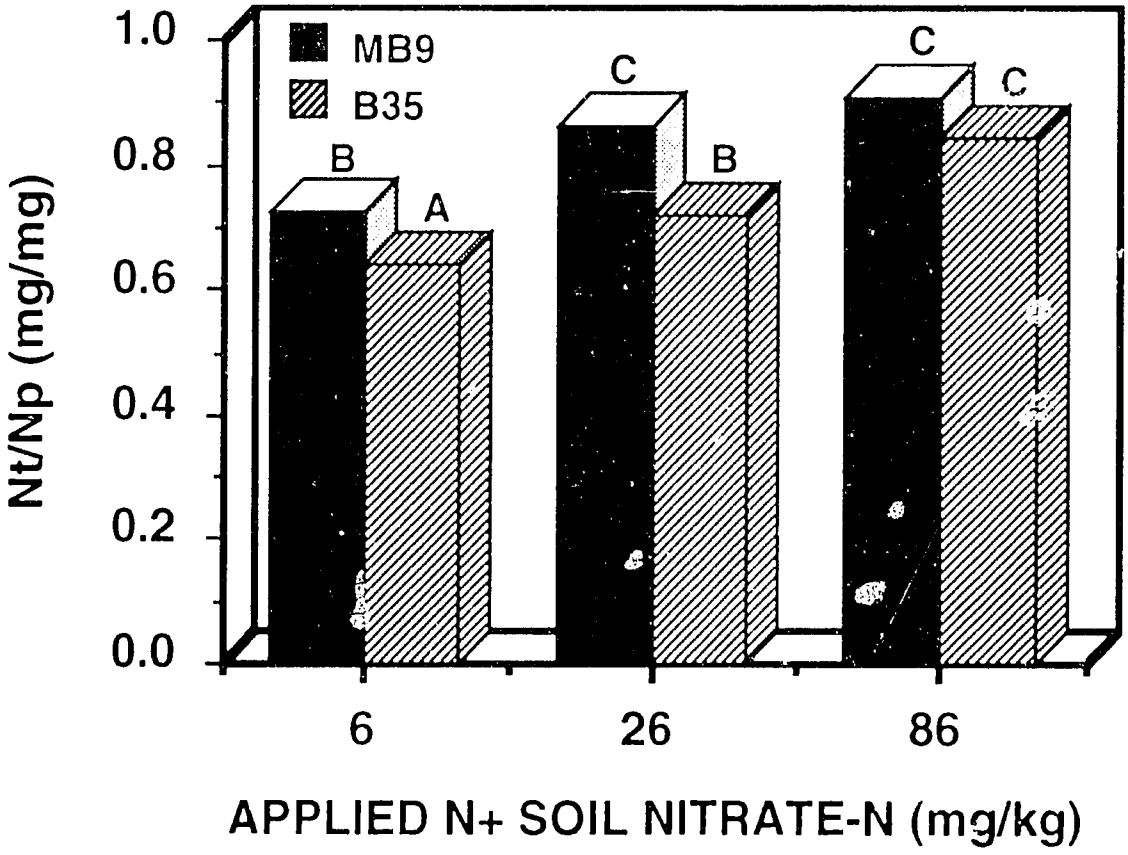

Figure 12. Effect of applied + residual soil nitrate-N on the ratio of N in the above soil tissue to total plant N content for two grain sorghum genotypes.

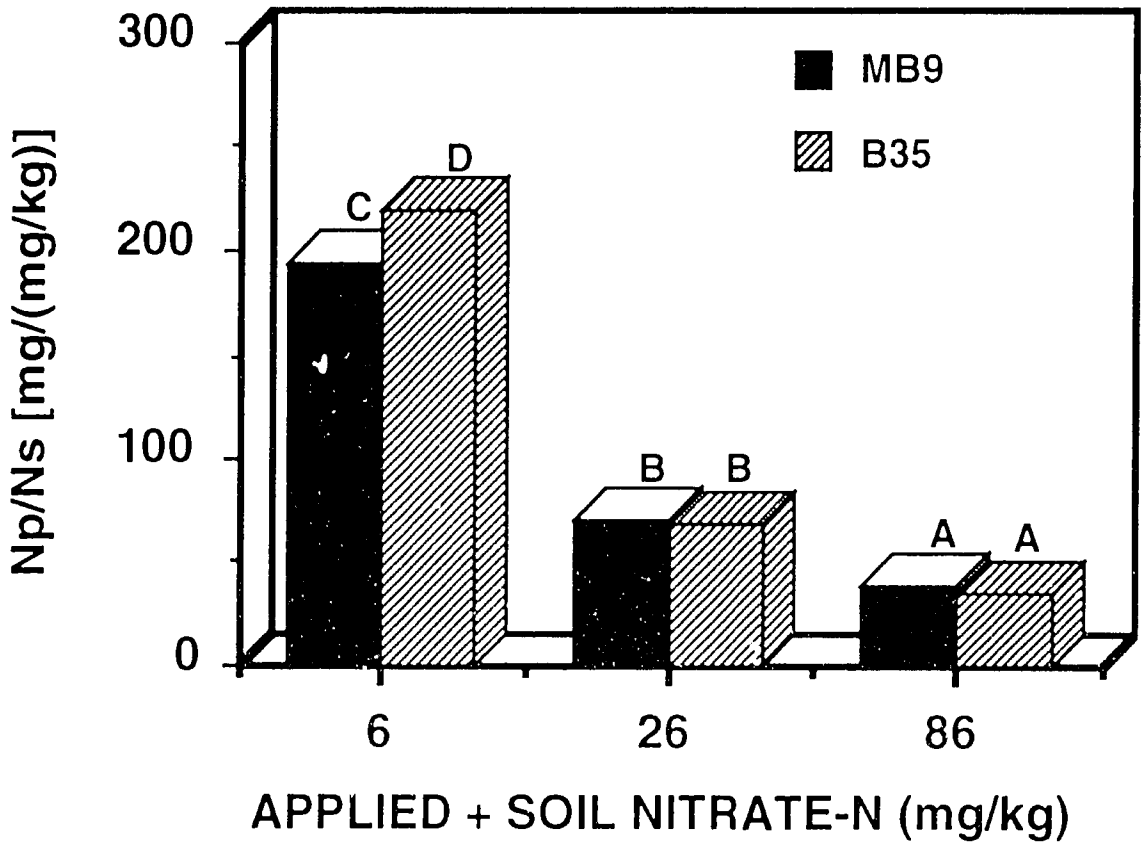

Figure 13. Effect of the rate of soil available N (applied + residual soil nitrate-N) on the ratio of total plant N to soil available N for two grain sorghum genotypes.

Grain produced per unit of N supply (N use efficiency, G_w/N_s) decreased with increasing N supply and, as a consequence of the reactions of its components, was significantly affected by the interaction of N rate and genotype (Fig. 14).

All of the components for the proposed definition of N use efficiency given in the Materials and Methods were affected by N rate and sorghum genotype. Therefore, these should be considered a minimum for expressing this trait.

Transpirational WUE and G_w/N_s were found to be linearly and negatively related for sorghum (Fig. 15). This is because unlike transpirational WUE, G_w/N_s decreased with each additional increment of applied N. However, the rate of decrease in G_w/N_s with increasing transpirational WUE was different between genotypes.

The observed difference in the rate of decrease in G_w/N_s with increasing transpirational WUE may be related to high values of each under both low and high levels of fertility. That is, genotypes that exhibit the highest levels of transpirational WUE and G_w/N_s under both low and high fertility may have the least decrease in G_w/N_s when transpirational WUE increases with increasing soil fertility.

Networking Activities

Workshops

G.C. Peterson. 1983. Sorghum Breeding Workshop for Latin America, 10-16 April 1983, CIMMYT, El Batan, Mexico.

G.C. Peterson. 1984. International Sorghum Entomology Workshop, 15-21 July 1984, Texas A&M University, College Station, TX.

G.C. Peterson. 1985. La Produccion de la Semilla de Sorgo en America Latina, 14-17 Oct. 1985, CIMMYT, El Batan, D.F., Mexico.

G.C. Peterson. 1987. Proc. of the Maicillos Criollos and other sorghums in Middle America Production, Utilization, and Improvement Workshop, 7-11 Dec. 1987, Tegucigalpa, Honduras.

G.C. Peterson. 1991. International Sorghum Millet CRSP Conference - Participant and led part of field tour discussion, 8-12 July 1991, Corpus Christi, TX.

G.C. Peterson and A.B. Onken. 1993. Participated in workshop on Adaptation of Plants to Soil Stresses, 1-4 Aug. 1993, Lincoln, NE.

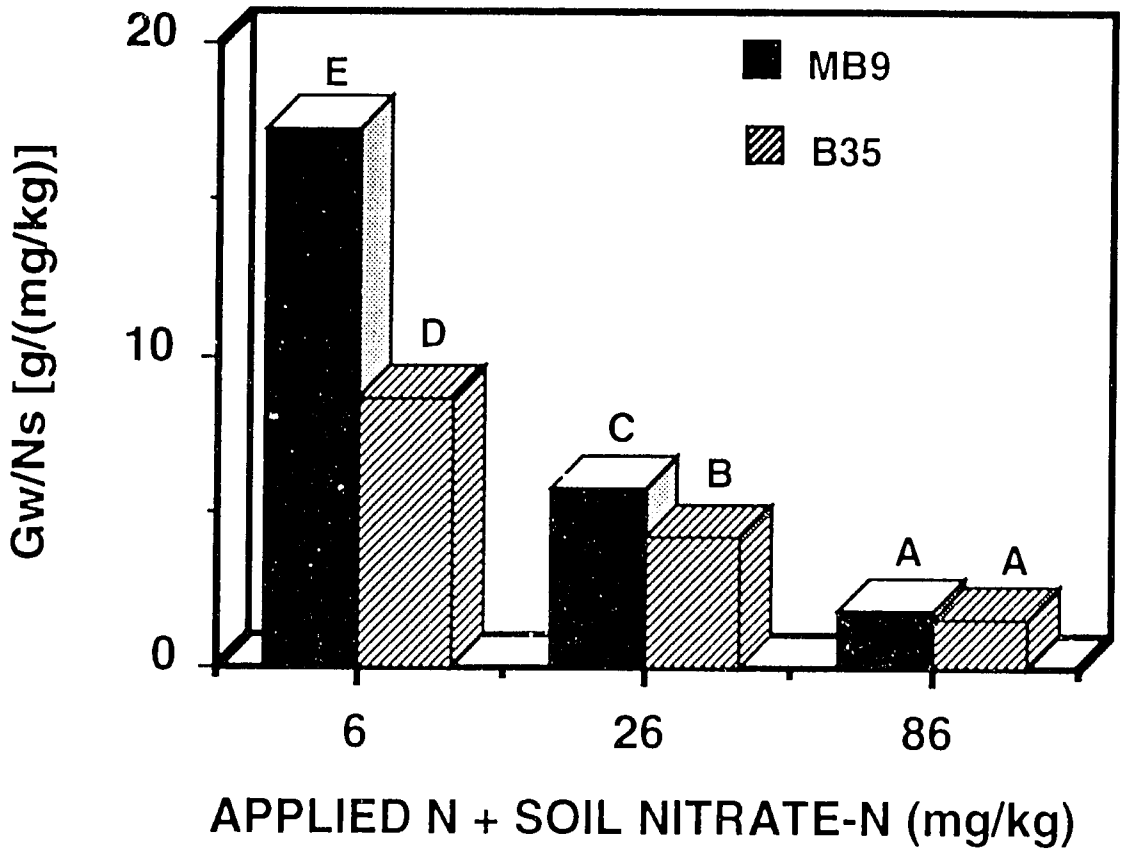

Figure 14. Effect of the rate of soil available N (applied + residual soil nitrate-N) on the ratio of grain weight to soil available N (Gw/Ns = Nitrogen use efficiency) for two grain sorghum genotypes.

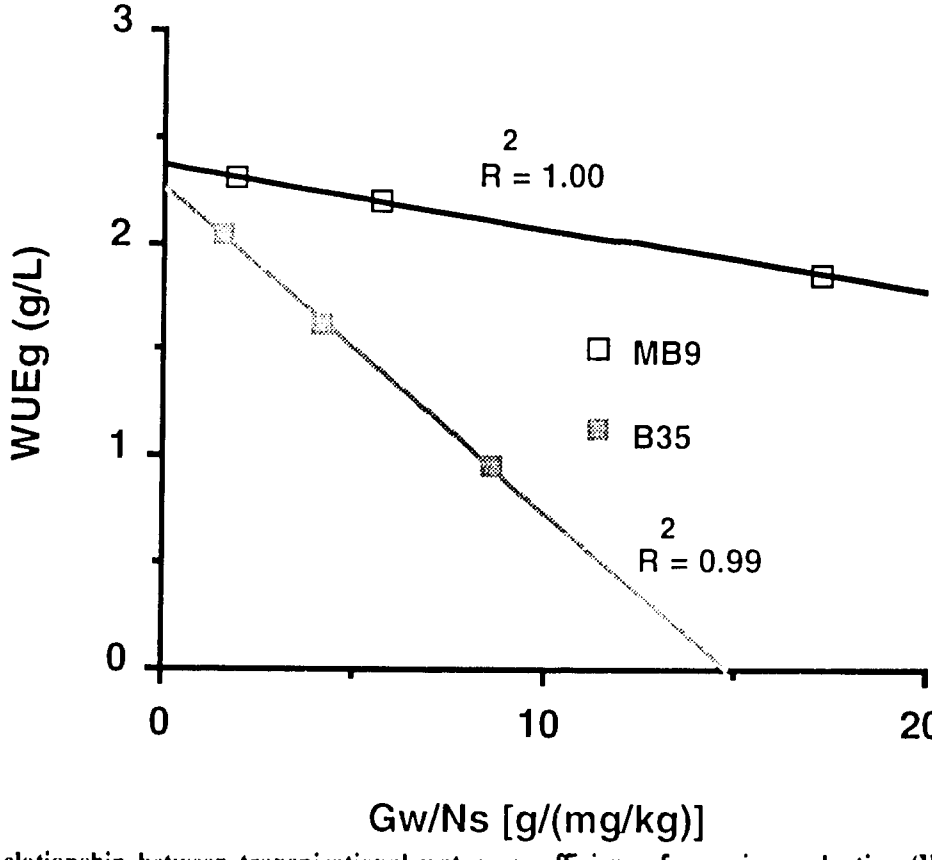

Figure 15. Relationship between transpirational water use efficiency for grain production (WUEg) and N use efficiency for grain production (Gw/Ns) of two grain sorghum genotypes.

G.C. Peterson. 1993. International Consultative Workshop on Panicle Insect Pests of Sorghum and Pearl Millet, 4-7 Oct 1993, Niamey, Niger

Research Investigator Exchanges

G.C. Peterson and A.B. Onken, Mali, 12-24 Oct. 1992. Evaluated cooperative IER/INTSORMIL research at Sotuba, Cinzana, Semanko. Developed cooperative research plans for joint IER/INTSORMIL/TROPSOILS research on adaptation of sorghum genotypes to areas of soil toxicity/stress. Evaluated the plant breeding and entomology (resistance to head bugs) programs.

G.C. Peterson, Honduras, 29 Nov. - 4 Dec. 1992. Participated in review of collaborative SRN/EAP/INTSORMIL research program by the INTSORMIL External Evaluation Panel. Collaborative research was reviewed at Zamarano, Rapaco, Choluteca, and Comayagua. Discussed collaborative research program activities with representatives of the Ministry of Natural Resources (SRN), USAID/Honduras, and Pan American School (EAP).

G.C. Peterson, Niger, 1-8 Oct. 1993. Participated in and presented paper at the International Consultative Workshop on Panicle Insect Pests of Sorghum and Pearl Millet, Niamey, Niger.

G.C. Peterson and A.B. Onken, Mali, 8-16 Oct. 1993. Participated in review of collaborative IER/INTSORMIL research program by the INTSORMIL External Evaluation Panel. Collaborative research was reviewed at Sotuba, Samanko, and Cinzana. Evaluated field research in the joint INTSORMIL/TROPSOILS soil toxicity/stress and planned future collaborative activities.

Other Cooperators

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Dr. R.R. Duncan, University of Georgia, Georgia Station, Griffin, GA 30223-1797

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Dr. J. Dahlberg, Tropical Agriculture Research Station,USDA-ARS, P.O. Box 70, Mayaguez, PR 00681-3435

Dr. C.S. Manthe, Ministry of Agriculture, Dep. of Agricultural Research, Private Bag 033, Gaborone, Botswana

Germplasm Exchange and Conservation

During the life of this project thousands of germplasm samples have been distributed domestically and internationally to public scientists and private seed companies. Countries to which seed has been distributed include, but is not limited to: Mexico, El Salvador, Columbia, Venezuela, Brazil, Argentina, Paraguay, Uruguay, India, Australia, India, Korea, Taiwan, China, Spain, South Africa, Botswana, Zimbabwe, Egypt, Mali, Niger, Sudan, and Kenya. Most private seed companies with sorghum programs have requested, and received, germplasm developed by this project.

G.C. Peterson participated in classification and description of the Sudan sorghum collection when it was grown at Wad Medani, Sudan, and at the USDA Quarantine Center, St. Croix prior to introduction of the collection into the U.S. plant germplasm system.

Impact of Technology Developed

This project has developed numerous germplasm lines resistant to biotype C and/or E greenbug which have been distributed to private seed companies for use in their breeding programs. Lines developed by this project which have been extensively used directly in the production of hybrids include ATx2752, Tx2737, Tx2783, Tx2864, and Tx2862. It has been estimated that the net social benefit to the United States from the resistance to greenbug breeding program is at least $113 million.

Germplasm resistant to sorghum midge which has been developed by this project has served as the foundation for many similar breeding programs throughout the world. Lines used, or which could be used, directly in sorghum hybrids include ATx2755, Tx2767, Tx2880, and Tx2882. New A-lines currently in advanced testing have the potential to significantly increase use of midge resistance hybrids.

Assistance Given

A.B. Onken - Provided a computer and printer with software to Inter-CRSP project in Mali.

G.C. Peterson - Provided a CD-ROM for computer listed above.

Publications and Presentations

Abstracts

Peterson, G.C. 1992. Characterization of converted exotic sorghum cultivars for resistance to sorghum midge. Agronomy Abstracts, Nov. 1-6, 1992, Minneapolis MN. p. 204.

Peterson, G.C. 1993. Sources of midge resistance of selected converted exotic sorghum cultivars. 18th Biennial Grain Sorghum Research and Utilization Conference. Feb. 28-Mar. 2, 1993. Lubbock, TX p. 37.

Peterson, G.C., J. Dahlberg, D.K. Mulitze, D.T. Rosenow, and F.R. Miller. 1993. Multi-location nearest neighbor analysis of sorghum data using Agrobase/4™. Agronomy Abstracts. Nov. 7-12, 1993. Cincinnati, OH p. 192.

Dahlberg, J., G.C. Peterson, and D.K. Mulitze. 1993. Sorghum pedigree management using Agrobase/4™. Agronomy Abstracts. Nov. 7-12, 1993. Cincinnati, OH p. 69.

Newsletter

Peterson, G. C. and G.L. Teetes. 1992. Sources of resistance to sorghum midge. Annual Plant Resistance to Insects Newsletter 18: 52.

Refereed Journal

Teetes, G.L., R.M. Anderson, and G.C. Peterson. 1993. Exploitation of sorghum nonpreference resistance to sorghum midge (Diptera: Cecidomyiidae) using mixed plantings of resistant and susceptible sorghum hybrids. J. Econ. Entomol. (accepted for publication).

Presentations

Peterson, G.C. 1992. Characterization of converted exotic sorghum cultivars for resistance to sorghum midge. Annual meeting of the American Society of Agronomy/Crop Science Society of America/Soil Science Society of America. Nov. 1-6, 1992, Minneapolis MN.

Peterson, G.C. 1993. Sources of midge resistance of selected converted exotic sorghum cultivars. 18th Biennial Grain Sorghum Research and Utilization Conference. Feb. 28–Mar. 2, 1993. Lubbock, TX.

Peterson, G.C., J. Dahlberg, D.K. Muhtze, D.T. Rosenow, and F.R. Miller. 1993. Multi-location nearest neighbor analysis of sorghum data using Agrobase/4™. Annual meeting of the American Society of Agronomy/Crop Science Society of America/Soil Science Society of America. Nov. 7-12, 1993. Cincinnati, OH.

Dahlberg, J., G.C. Peterson, and D.K. Muhtze. 1993. Sorghum pedigree management using Agrobase/4™. Annual meeting of the American Society of Agronomy/Crop Science Society of America/Soil Science Society of America. Nov. 7-12, 1993. Cincinnati, OH.

Breeding Sorghum for Stability of Performance Using Tropical Germplasm

Project UNL-115
David J. Andrews
University of Nebraska

Collaborating Scientists

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Mr. Peter Setimela, Sorghum Breeder, Department of Agricultural Research, P.O. Box 0033, Sebele, Botswana
Dr. Tunde Obilana, Sorghum Breeder, SADC/ICRISAT, Southern Africa Regional Sorghum and Millet Research Program, P. O. Box 776, Bulawayo, Zimbabwe
Mr. Gilles Trouche, Sorghum Breeder, CNRA, B.P. 51, Bambey, Senegal
Drs. J. W. Stenhouse and Belum Reddy, Sorghum Breeders, ICRISAT/India
Dr. Fred W. Miller, Sorghum Breeder, TAM-121, Texas A&M University, College Station, TX
Dr. D. W. Rosenow, Sorghum Breeder, TAM-122, Texas A&M Agricultural Experiment Station, Route 3, Box 219, Lubbock, TX
Dr. Paula Bramel-Cox, Sorghum Breeder, Kansas State University, Manhattan, KS
Dr. J. D. Eastin, Physiologist, UNL-116, University of Nebraska, Lincoln, NE
Dr. J. W. Maranville, Physiologist, UNL-114, University of Nebraska, Lincoln, NE

Project Highlights 1984–1993

This project originally focused on quantifying the use of recurrent selection to improve sorghum for yield and grain protein quality. Several authoritative publications were produced, populations established and collaboration with the Botswana sorghum breeding program initiated. With the change in PIs in 1984 objectives were revised to give major emphasis to the introgression of high yield tropical food quality material into U.S. parental stocks and using the resulting variability in two directions; a) as base material for incorporation in developing country programs and, b) to produce new parental lines to increase diversity, especially for grain quality, in sorghum for the U.S. midwest.

While this new diversity was being generated and selected, existing program material was exploited, which led to the release of one medium maturity seed parent, N122, and two early maturing seed parents, N123 and N124, all white grained. Two of these three have found commercial applications. A collaborative breeding program was established in Botswana to meet objectives set by the Department of Agricultural Research. Selection over six years of mostly extreme drought conditions has produced 11 seed parents which are now being evaluated in hybrid tests. The SADC/ICRISAT program at Bulawayo has assisted with winter nursery space for the Botswana program.

UNL-115 has also been involved introducing and testing INTSORMIL sorghums in Senegal, both in the dryland program and, at the request of the Government, in irrigated conditions. In both environments several INTSORMIL seed parents were able to produce substantially higher yielding acceptable hybrids, using existing adapted Senegalese male parents.

Several germplasms were released in the U.S., which have variously been useful as base material for new seed parents, as sources of chinch-bug resistance and unique sources of resistance to the newest race, I of the greenbug. A recent seed parent release N148, is the first to result from the introgression program started in 1984.

Methodology research in Project UNL-115 has focused on how best to select for combining ability for grain yield (essential for breeding hybrid parents), and seedling vigor—a characteristic needed especially for variable farming conditions in developing countries. Chibwe Chungu, from Zambia, found in her M.S. thesis little difference between lines, F_1s, and populations as testers to evaluate combining ability. If so, there is a theoretical advantage of using F_1 tester to select for combining ability in early generations to improve efficiencies in parental breeding programs. This line of research is being continued by Fabien Jeutong from Cameroon. Louis Mazhani, from Botswana, in his Ph.D. dissertation compared the stability of performance individuals and blends of lines, parents, hybrids, and sorghum populations in Botswana. In general, blends were more stable and sometimes higher yielding than the average of the individual components, of which many were better than the local variety Segaolane. Among the blends hybrids were best, though one single hybrid was also high yielding and stable.

Anthony Assibi, from Ghana, in his M.S. thesis showed 4-fold difference in seedling dry weights among a range of

germplasms. A very high correlation was found between seedling dry weight and a simple nondestructive visual score. F_1's and F_2 populations of crosses between high x high, low x low and high x low seedling vigor parents showed good evidence for gain through breeding in this trait, even from high x high crosses. Some lines had a much higher parental worth than others.

Charles Wortmann, from the U.S., concluded from his Ph.D. study on seedling cool tolerance that seedling emergence and seedling growth in cool conditions were largely independent. Additive gene effects predominated, however, while heterosis was generally positive for seedling vigor, it could be either way for emergence. Selection for improvement of both traits would be effective in some populations.

Germplasm was supplied to many countries, including Botswana, China, South Korea, India, Nigeria, Senegal, Sudan, Kenya, Zambia, Zimbabwe. The project has provided advanced degree training to students from Botswana, Cameroon, Ghana, Zambia and the U.S. and short-term training to scientists from Egypt, South Korea and Senegal.

Summary

Most sorghum is grown for food in low resource semi-arid conditions in Africa and Asia where there are many environmental constraints to production, the principal of which are low nutrient levels, a variable and uncertain moisture supply and many severe pests and diseases. Actual production is the interaction of these constraints on the genetic yield potential (the comparative yielding ability) of the cultivar. The tolerance of the genotype to the sum of these constraints constitutes adaptation. Good adaptation alone, however, is not enough, since yield potential has to be raised to increase production. Though some constraints are more common than others, there are different combinations of constraints in different regions, and hence there are different areas of adaptation which need to be bred for separately. Many cultivars from ICRISAT's breeding programs, while they have raised yield potentials in many low input dryland agriculture (LIDA) regions, have not, in general, involved much of the high yield potential available in U.S. combine sorghum parents. In turn the genetic base of hybrid parents in the U.S. is very narrow in terms of the total range of genetic diversity available. There is a fertile breeding area, therefore, that this project seeks to exploit, of crossing higher yielding adapted food quality tropical sorghums and U.S. parents.

On the one hand, the resulting segregating populations are selected *in situ* in collaborative LIDA breeding programs to the benefit of developing countries, and on the other, selections are made from the same crosses for adaptation and combining ability to broaden the genetic diversity in parental lines in the U.S.

This project works principally with the breeding programs in Senegal and Botswana (but has also provided material to China, India, Mexico, Nigeria, South Africa, Zambia, and Zimbabwe), as well as in the Midwest of the U.S.

In Senegal, hybrids made from INTSORMIL parents continued to perform well in tests in the Senegal River Valley, where alternatives are needed for the existing rice monoculture.

In Botswana, development of adapted drought-tolerant seed parents continued at Sebele and in the winter nursery provided by SADC/ICRISAT in Zimbabwe, where testcross seed was also produced.

In U.S. multilocation tests in Kansas and Nebraska showed yields of hybrids made with several new tan-plant seed parents equalled or exceeded commercial hybrid checks. Research on determining the most efficient way to assess combining ability early in the selection process continued. Work on seedling vigor identified non-destructive methodology, located several good sources, and using crosses showed that there is good potential for improving this trait through breeding.

Objectives, Production and Utilization Constraints

Objectives

Objectives have changed little from the previous year as this is a long-term breeding project. A principal aim of this project is to introduce and utilize newly bred high yielding tropical food quality sorghums which have so far not been widely used in U.S. breeding programs. Utilization will be mainly through selection of progeny from crosses with superior U.S. lines. Conversely, through the same crosses high yield traits from U.S. sorghums are made available for selection in developing countries. Appropriate parts of this variability in early generations will be used to support breeding projects in developing countries, and in the U.S. to develop new varieties and parental lines.

Constraints

Constraints to sorghum production are both genetic and physical factors in the growing environment and the effects of inelastic markets. Many existing landrace varieties, though they are well adapted to low moisture and fertility situations and to numerous pests and diseases, are not efficient in converting dry matter they produce into grain. Their harvest index (HI) efficiency is poor. There are breeding stocks such as U.S. hybrid parent lines, which are twice as efficient in this process but they generally perform poorly in African conditions because they have little adaptation or pest/disease resistance. A combination of traits conferring adaptation and grain production efficiency is required through breeding, as well as further improvement in the basic breeding stocks (particularly seed parents) for grain yield potential per se. Combinations (lines/plants) with good adaptation and seed qualities can only be identified *in situ*

in developing countries. Thus, segregating material generated from crosses with stocks known to perform well in the region concerned, in crosses with selected high HI lines, are supplied for selection in collaborative projects.

Research Approach and Project Output

Research Methods

The most widely adapted high yielding lines and seed parents from the ICRISAT sorghum food quality breeding program in India and Mexico, and the Botswana and Zambia NARS and the IRAT West African sorghum breeding programs were introduced and crossed with U.S. B- and R-lines. New lines are being produced by pedigree selection during which criteria for agronomic value and evident food quality grain are used. After F_3 evaluation, remnant seed of F_3 and the preceding F_2s of crosses between appropriately adapted exotic lines are provided to host-country breeders to initiate collaborative selection programs. At F4/F5, selections with per se worth are tested for drought/heat stress resistance and for combining ability through test crosses. Those which act as non-restorers will be considered for producing new seed parents. Well adapted partial inbreds/lines are released as germplasm stocks/parental lines for use in the U.S. The introductions are also tested for per se performance and in hybrid combinations for possible dissemination in international nurseries together with hybrids made with lines derived from the exotic x U.S. crossing program.

The research program provides opportunities and material for post-graduate student thesis problems. Currently, students are researching combining ability methodology and per se and parental effects on seedling vigor. Both selection and testing in the UNL-115 project is conducted without added fertilizer (about 50 kg N/ha is available from the preceding soybean crop), since most LDCs use little chemical fertilizer on dryland cereals but can use rotations with legumes.

Research Findings

Fifty-eight new F_1s were grown, with emphasis on utilizing tropical, large seeded germplasm from West Africa and Zambia with good evident food grain quality. One thousand and two hundred F_2 to F_6 lines were evaluated for potential use in host-country programs and the U.S. Seed parent development was continued on 80 lines and 140 were increased and testcrossed.

Seed parents both for the U.S. and collaborative programs were evaluated in testcross nurseries, initial and advanced tests, and in collaboration with Kansas State University in multilocation tests.

The project has reached the stage where the development of the first generation of new seed parents has been completed and their evaluation in hybrid combination has commenced. Among 28 hybrids using new seed parents tested at Mead, four exceeded the yields of all check hybrids (Table 1). Through the cooperation of Dr. Paula Bramel-Cox, seven UNL-115 hybrids were entered into multilocation tests in Kansas with the objective of testing them under drought and heat stress. Rainfall in 1992, however, was exceptionally high and no drought stress occurred. A hybrid with 90M363A, a tropically derived seed parent, was on average, best in test across locations (Table 2), while the hybrid with 90M524A, derived from cool-tolerant x tropical sources also did well, as it has done in Nebraska tests.

Later maturing more tropically adapted seed parents were tested in both dwarf and semi-dwarf hybrid tests. Seventeen seed parents were identified for tests in Senegal, Botswana, Nigeria, and Zambia.

Mr. Assibi Mahama from Ghana concluded his M.S. research on trait correlations and parental effects on seedling vigor at normal temperatures (20-25°C). Using 25 diverse lines, including Naga White from Ghana and Shanqui Red from China, correlations between seed weight, germination and seedling weight, were found to be significant but low (<0.31 or less). Seedling height or a visual vigor rating were highly correlated (>0.79 or more) with seedling weight showing that these can be reliably used as nondestructive estimators in breeding programs. Greenhouse observations correlated well with observations on the same genotypes in the field. Parents, F_1's and F_2's of crosses including reciprocals between two high and two low seedling vigor lines were studied. GCA effects for seedling weight were two to three times larger than SCA effects and mid-parent F_1 heterosis ranged from 29% in the high x high cross to 74% in the low x low cross. F_1 heterosis for seedling weight over high parents ranged from 17 to 39%. Mean F_2 heterosis was about 25% of the F_1 level (less than expected), and there were no significant maternal effects. Shanqui Red was the best line per se and the best parent. The results showed there

Table 1. Advanced sorghum hybrid test 92-11 (data on 11 of 30 entries, including checks). Mead 1992.

Hybrid	Days bloom	Height (cm)	Grain Yield (kg/ha)
90M811A x Tx2737	84	112	9890
N122A x Tx2737	76	128	9870
90M524A x Tx8505	85	127	9410
90M524A x Tx2721	76	122	8770
N122A x Tx2721	79	123	8650
90M863A x Tx2737	77	127	8370
90M373A x Tx2721	83	127	8230
Pioneer 8358 (check)	82	123	8140
90M773A x Tx2737	77	118	8000
DK46 (check)	78	138	7070
N122A x Tx430 (check)	75	132	6950
Mean (30 entries)	80	130	7770
LSD (0.05)	3.1	10.0	1850

Table 2. 1992 joint sorghum hybrid test at four Kansas locations (grain yields of seven UNL-115 entries, plus checks).

Hybrid	Yield kg/ha	Rank by location				Mean rank
		Manh.	Gar. D.	Gar. I	Hess.	
90M363A x Tx2721	11860	1	3	2	1	1.75
90M524A x Tx2721	9820	4	7	12	30	13.25
DK46 (check)	9390	13	17	25	10	16.25
90M677A x Tx2721	9200	56	20	28	2	26.5
N122A x Tx430	8930	35	25	21	9	22.5
90M689A x Tx8505	8600	60	55	1	16	33
90M373A x Tx2721	8520	23	26	55	13	29.25
Pioneer 8446 (check)	8410	14	41	35	41	32.75
90M373A x Tx2737	7990	59	58	7	12	34
Mean (64 entries)	8380	32	32	30(1)	32	22.8(2)
LSD (0.05)	2860	--	--	--	--	--

(1) Only 60 entries at this location
(2) Overall average ranking of UNL-115 entries.

Table 3. Two year (1991 and 1992) mean grain yields of top three sorghum hybrids in irrigated test No. 1, Senegal River Valley.

Hybrid	Mean yield kg/ha	% of check
A155 x RTX2817	6560	115
A155 x RTX8505 (RTx436)	6260	110
A1 x RTX8505 (RTx436)	6090	107
612A x 75-14 (check)	5700	100

Table 4. Two year (1991 and 1992) mean grain yields of top two sorghum hybrids in irrigated test No. 2, Senegal River Valley.

Hybrid	Mean yield kg/ha	% of check
A1 x 75-14	7360	110
ATX631 x 75-14	6890	103
612A x 75-14 (check)	6670	100

is a wide range in seedling vigor in sorghums and that breeding for improved seedling vigor could be effective.

Fabien Jeutong from Cameroon commenced his thesis study comparing inbred, F_1, 4-way and population testers for their comparative worth in early generation evaluation of combining ability in parental lines.

Networking Activities

Botswana

Selection for adapted drought tolerant food quality varieties and seed parents was continued by Peter Setimela at Sebele, Botswana. Backcrossing continued on selected seed parents and 220 testcrosses from the winter nursery were evaluated. Low rainfall again permitted selection for drought tolerance. The best lines and seed parents were identified for increase in the 1993 winter nursery and production of hybrid seed.

Senegal

Sorghum tests conducted by Gilles Trouche, ISRA/CIRAD, with INTSORMIL lines continued for a second season under irrigation in the Senegal River Valley. Seed parents and restorers from projects TAM-121 and TAM-122 gave hybrids which produced up to 15% more than the local check hybrid (Table 3). Similarly, two seed parents, A1 and ATX631, showed better combining ability with the existing pollinator 75-14 than the standard seed parent (Table 4).

Germplasm Exchange

4 sorghum parents were sent to Botswana

32 seedparents were sent both to Nigeria and Zambia

2 seed parents to China

27 lines to India

8 lines were supplied within the U.S. and 16 received

Publications

Andrews, D. J., P. J. Bramel-Cox, and G. E. Wilde. 1993. New sources of resistance to greenbug, biotype I, in sorghum. Crop Sci. 33:198-199.

Marinesco, O., C. Chungu, P. J. Bramel-Cox, E. Igartua, D. J. Andrews, and M. D. Witt. 1992. Comparison of the effectiveness of different types of testers to identify parent lines for improved hybrids in grain sorghum. Agron. Abstr. 105.

Breeding Pearl Millet for Stability Performance Using Tropical Germplasm

Project UNL-118

David J. Andrews

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Project Highlights 1985-93

Project UNL-118, which commenced in 1985, has assisted country programs in developing and breeding adapted pearl millet *in situ*, researched several breeding methodologies of wide application, particularly for developing country breeding programs, produced a broad range of breeding stocks for the U.S., and trained students in breeding research relevant to their future tasks.

The recognition of important problems and the sequence of research undertaken in response by the project is outlined below.

The basis for any collaborative breeding program in a developing country is the supply and introgression of new and useful germplasm into adapted material existing in that country's breeding program. This involves the host country breeder and the INTSORMIL PI in the joint planning and execution of the breeding program. In pearl millet, the most needed attribute in new germplasm for developing country programs is higher grain yield. Therefore, a basic objective of UNL-118 has been to generate a diverse base of higher yielding germplasm, both for use in introgression in developing countries and for use in making varieties and hybrid parents in the U.S.As demonstrated in Senegal in 1991 and 1992, higher yield levels have been obtained in INTSORMIL pearl millet germplasm. In response to a request by the Government of Senegal, tests conducted in high yield conditions in the Senegal River Valley, in collaboration with Mr. A. Fofana, showed that early dwarf U.S. pearl millet hybrids maturing in 85 days could out-yield local varieties by 20-30%, which took another 10 days to mature. The parental lines of these hybrids and similar stocks with demonstrated high yield potential form the source material used in crosses with locally adapted varieties to introgress yield and wider genetic diversity for selection *in situ* in developing country programs. Previous research has shown that 3-way crosses [(exotic parent x adapted No. 1) x adapted No. 2] gave better results than simple exotic x adapted crosses. Five synthetic varieties produced this way averaged 40% more yield than adapted variety checks in dryland tests in Senegal in 1993 and were equal or better in resistance to downy mildew. A similar approach was used for Mali where new synthetics are being tested by Karim Traore.

Parents for synthetic varieties are often chosen only on the basis of genetic diversity and per se values. Though rapid, this is not the most effective way. The classic method, a full diallel, is too resource consuming. Ph.D. research by Rowland Chirwa, from Malawi, showed that evaluating potential parents for synthetics either through testerosses to an unrelated tester, or by a particular type of partial diallel (a central circulant design) were equally effective in identi-

fying the best combining parents. However, the partial diallel also allowed prediction of yields of the resulting synthetics.

West African land race varieties contain recessive wild type genes, when homozygous, produce vigorous plants called 'shibras', whose grains shatter and are lost before harvest. Shibras are usually regarded as deleterious. Karim Traore, from Mali, using a recessive seedling marker, virescent, studied in his M.S. thesis an analogous situation and showed that while recessive virescent plants yielded less, the heterozygous plants in some populations were more vigorous than normal plants. Though the virescent and shibra genes are unrelated, these results suggest that the wild type genes, having survived in cultivated populations, may in a heterozygous state, have a positive role in the performance of traditional West African farmer varieties.

Mass selection is a form of recurrent selection well suited to pearl millet breeding programs in developing countries which seek to produce better varieties. Several modifications to increase the effectiveness of mass selection were used on the Nebraska dwarf millet population (NDMP). One modification involves the use of wider spacing to maximize the genetic expression of single plants. However, for this to have applicability there has to be a good correlation between performance at wide and normal (high) plant populations. This was researched over three years using NDMP S_1 progeny, and the correlation for yield found to be $r=0.64^*$, sufficiently good to recommend the method (AR 1989, p. 82).

In breeding pearl millet for combine harvesting, post-senescence resistance to plant lodging is essential, as in combine grain sorghum. Ferdinand Muuka, from Zambia, in his M.S. thesis examined selection criteria and surveyed genetic resistance to lodging in pearl millet. He noted that 60% of the cause of fallen heads is due to peduncle lodging, the remainder being basal. Crosses with elephant grass (*Pennisetum purpureum*) had the potential to contribute basal stem strength but not peduncle strength. Greater resistance to longitudinal crushing and transverse breaking of stem sections contributed to resistance to stem lodging. However, reduced plant height, upright tillers, wider diameter stems and peduncles were all correlated with resistance, suggesting, besides thickening of the stem rind, the phenotypic characteristics needed for lodging resistance. Lines with good combining ability for lodging resistance were identified. No pearl millet hybrids are yet grown in Africa but they are now widely grown by subsistence farmers in India, where they were the catalyst that led to a 30% increase in national yields and the involvement of commercial capital in breeding and producing seed of superior hybrids.

Hybrids could supply in Africa, as they have done in India, the quantum increases in yield to provide the impact needed to make them acceptable to subsistence farmers. However, there are technical problems to be solved before hybrids can succeed in Africa. These involve durability of resistance to downy mildew, and secondly, increased susceptibility to ergot, which is associated with the use of the A_1 type of cytoplasmic male sterility (cms) conventionally needed to make the hybrids. Ergot is more generally severe in Africa than India where epidemics are sporadic. Topcross (line x variety) hybrids are both more durably disease resistant and stable than the single (line x line) hybrids which initially caused instability in India. Topcross hybrids are very appropriate for Africa since well adapted varieties can be used directly as male parents. Research in UNL-118 was, therefore, directed to alternative ways of making hybrids for Africa through; a) utilizing the natural flowering behavior of pearl millet and, b) using a different male sterility system.

When pearl millet heads bloom they first become completely female fertile for one to five days before anthers emerge on the same heads. This offers an opportunity to produce hybrid seed without cms on a field scale, by using another line (or better, a variety) which provides profuse pollen to fertilize the heads on the 'female' parent, during the time before they shed their own pollen. Hybrids made this way are designated 'prohybrids' (after protogyny - the female fertile phase) to distinguish them from cms hybrids. Barnabas Kiula, from Tanzania, in his M.S. research, used made up mixtures of hybrid and parental line seed of four different hybrids to investigate the consequences of several levels of female self pollination, which is the critical issue in the production of such prohybrids. He showed that, provided the hybrid plants were taller and more vigorous than the female parent, even the presence of 20% selfed seed had a low and non-significant effect on the hybrid performance. Topcross hybrids made with local African varieties used as male parents on adapted dwarf female lines or populations would produce hybrids that would completely dominate any female plants. A 20% level of selfing in prohybrid seed production would be excessive. Prior research by IRAT in Niger indicated that such hybrids could be made with only 5% selfing. Prohybrids would have several major advantages including a wide choice of parents, no male sterility problems, as common with A_1 cms hybrids, and a relatively short development time.

A further possibility is the use of a different cytoplasmic male sterile system. The A_4 cms system, discovered by Wayne Hanna at Tifton, Georgia in 1989, uses cytoplasm from wild pearl millet from Senegal. Initially this system was not exploited because of an apparent lack of restorer genes. However, a careful survey of the advanced breeding material developed in UNL-118 identified nine good sources of A_4 male fertility restoration in dwarf backgrounds agronomically suitable for making hybrids. These were intermated and released. Further searches have located restorer genes in African breeders populations. The A_4 system has several major advantages including much stronger restoration of male fertility, and it may replace the A_1 system. Its utility in an ergot endemic environment will be examined in Senegal.

The Ph.D. thesis dissertation of Mr. Figuhr Muza, from Zimbabwe, conducted in Zimbabwe with the assistance of Dr. S.C. Gupta of the SADC/ICRISAT SMIP, on the use of mutagens in finger millet, resulted in the discovery of apparent recessive genetic male sterility. Progress in breeding this crop has been slow because of the extreme difficulty of making crosses. This new male sterility has application to all finger millet breeding programs to greatly increase the generation of new variability.

The project has developed a wide germplasm base of breeding stocks adapted to the US midwest/high plains area. Started as an M.S. thesis project of Mr. Figuhr Muza in conjunction with Mississippi State, the Pearl Millet Regional Grain test for the U.S. coordinated by UNL-118, is now in its sixth year and has been grown in seven states from Georgia to Oregon. This testing program is providing a unique data source on the adaptation and potential of pearl millet for grain in the U.S.

UNL-118 has supplied and received germplasm from many countries including Senegal, Mali, Niger, Sudan, Yemen, Kenya, Malawi, Zambia, Zimbabwe, Honduras, Colombia and India. Students trained in the project have come from Malawi, Mali, Senegal, Zambia, Zimbabwe and the U.S.

Summary

Pearl millet is the only cereal adapted to the driest and hottest of the lowland crop cultivation zones in Africa and Asia, principally in the sandy regions of West Africa and northwest India. Though pearl millet will grow well in more humid areas with better soils, it is in these harsh climates, where it is the major food cereal, where improvements to production are primarily needed. Physical constraints to production are low and erratic rainfall with frequent drought periods, and low soil nutrient status. Principal among many biotic constraints are downy mildew and ergot diseases. Actual production is a result of the interaction of these production constraints on the yielding ability of the cultivar. Where the physical constraints (drought, low soil nutrients) are strong, agronomic interventions will have large effects on production, however, these are often too expensive, or otherwise unacceptable, to low resource farmers. Seed of new cultivars of higher yielding ability is a cost effective technology, even without agronomic support, but more effective with and encourages the use of better agronomic practices. Seed of new pearl millet cultivars, both varieties and hybrids, have been widely accepted, by low-resource farmers in India even without changes of agronomic practices.

The goals of this project are several. To develop parental material of higher yielding ability that can be used in collaborative breeding programs in developing countries, and to develop new varieties and hybrids in the U.S. To research ways of improving breeding populations and the best ways of making varieties and hybrids for developing country breeding programs, and in the U.S., to produce the adapted plant type needed to grow pearl millet as a combine feed crop. And, finally, to provide students from the on-going research, thesis topics which are relevant to the problems they will face in their research programs at home.

Pearl millet research continued in Senegal and Botswana. In Botswana, 92BS6-2, a pearl millet variety made from Botswana Serere 6A, was entered in multilocation tests for a second year. Based on prior collaborative research with INTSORMIL, seed was produced in Senegal of hybrid KS2068A x 086, for the Senegal River Valley. The Ph.D. dissertation research of Dr. Figuhr Muza in Zimbabwe on finger millet in collaboration with Dr. S. C. Gupta at SADC/ICRISAT Bulawayo, showed that both chemical EMS and radiation (x-rays) in each of three cultivars produced a number of agronomically useful mutants substantiated by head to row grow outs, including apparent male sterility. Opportunities for breeding finger millet will greatly increase if tests now being conducted show this sterility to be stable and heritable.

In the U.S. research continued on producing segregating populations for selection in West Africa, providing data on production of protogyny hybrids for use in low-resource agriculture and developing hybrid parent lines in the A_4 cytoplasmic male sterility system which has several major advantages over the A_1 system, and may also be useful in developing agriculture. Recurrent selection continued on a Nebraska population in conjunction with ARS, Tifton, GA, and the 1992 pearl millet regional test was expanded to nine locations and included an experimental commercial hybrid.

Objectives, Production, and Utilization Constraints

Objectives

The objectives of the breeding program, with slight modifications remain as in previous years:

To establish a diverse base of agronomically elite inbred and semi-inbred lines from crosses between U.S. parents and introduced tropically adapted stocks and from prior program material. The establishment of such a base of diversity with yield potential is fundamental to practical collaboration on genetic improvement in LDCs in the long-term where populations from specific crosses between superior UNL-118 lines and collaborating country stocks will be selected in that country. It also permits hypotheses to be tested about the relative potential of various types of varieties and hybrids and parental breeding procedures and also enables the identification of parents to make hybrids adapted to the U.S.

A type of modified mass selection (recurrent restricted phenotypic selection) is being tested on an UNL-118 population cooperatively with Glenn Burton, Tifton, GA. Besides information, improved lines and varieties will result from this process.

Training LDC personnel in plant breeding and genetics is an important objective. Both of the above breeding approaches provide opportunities and material for post-graduate student theses.

Constraints

Constraints to pearl millet production are both genetic and physical factors in the growing environment and the effects of fragile markets. Many existing landrace varieties, though they are well adapted to low moisture and fertility situations and to numerous pests and diseases, are not efficient in converting the dry matter they produce into grain. Their biomass production may be good but their harvest index (HI) efficiency is poor. There are breeding stocks which are twice as efficient in this process but they generally perform poorly in African conditions because they have little adaptation or pest/disease resistance. A combination of traits conferring adaptation, growth rate, and grain production efficiency is required through breeding, as well as further improvement in basic breeding stocks (particularly seed parents) for grain yield potential per se. Combinations (lines/plants) with good adaptation qualities can only be identified *in situ* in developing countries. Thus, segregating material generated from crosses with stocks known to perform well in the region concerned, to selected high HI lines, are developed for selection in collaborative projects.

The selection criteria used in developing improved basic breeding stocks are numerous and involve morphological and physiological traits and estimates of genetic combining ability for performance. Principal morphological traits involve determinants of seed number/m^2 and seed size. Performance data under moisture stress and lower soil fertility are needed. Both specific and general combining ability estimates are needed. These are principally thought of in the context of hybrid parent development (for pollen and seed parents, respectively), but these estimates are also of use in identifying parents for varieties (synthetics), and possibly for indicating parental worth, which is important in generating collaborative material for selection.

Hybrids use growth resources, particularly when they are in short supply, most efficiently. While varieties in pearl millet are heterotic, higher yields are given by hybrids, even those where the best variety is used as a parent. Increased yields at the small farmer level, often without other inputs, has been the reason why pearl millet hybrids have been successful in Asia, and provided they are of a stable and durable type, they can also perform in subsistence agriculture in Africa. The project, therefore, has been examining aspects of topcross hybrid development and production with this use in mind.

Research Approach and Project Output

Research Methods

Inbreds and partial inbreds produced from crosses with existing and new introductions are selected for suitability as parental material for varieties, parent lines (particularly seed parents), for hybrids and as parents to cross with host-country (HC) material—to supply both hybrids and segregating populations for selection in collaborative HC programs. The first of such crosses was made in 1987. Producing satisfactory inbreds in pearl millet is a relatively protracted process. Unless parents previously selected for good seed set are used, considerable attrition during selection may be expected.

As more inbreds become available in the program, ways of making hybrids other than using A_1 cytoplasmic male sterile (cms) seed parents are being explored. This is because the development of A_1 seed parents both delays and restricts the development of hybrids to a small percentage of the total useful hybrid combinations possible among the inbreds and varieties being produced in a breeding program. When pearl millet flowers, the period of protogyny, when the head is only female fertile, prior to anther dehiscence, provides a natural opportunity to make hybrid seed with any line or variety shedding pollen at that time. Since some self-pollination in the female "seed" parent lines is possible with this method of making hybrid seed, the effect of controlled amounts of this on hybrid performance has been measured. In developing countries, where such protogyny hybrids (pro-hybrids, as they are termed) may be most useful, the use of tall pollinators on dwarf or semidwarf female lines will minimize the effects of any self pollination in the female parent through the unequal competition between hybrid and inbred plants. Pro-hybrids will also avoid the additional sensitivity to ergot commonly associated with hybrids made with A_1 cms seed parents.

Since pearl millet is a cross-pollinating crop, population improvement is a relevant breeding approach, particularly for LDC conditions where selection is needed simultaneously for many adaptive traits and heterozygosity must be maintained. Research into the utilization of recurrent selection is being conducted (using the NTPC population) and ways of using products of recurrent selection relevant to LDC conditions have been tested. Equally transferable will be the methods and operational techniques being developed.

Research Findings

Research in the U.S.

Germplasm enhancement continued both through pedigree breeding and recurrent selection, lines were evaluated both in hybrid combinations and for variety production. Two types of hybrids were investigated and the fifth year of the regional grain yield test coordinated.

Pedigree Breeding

Two hundred and four new exotic x adapted and adapted x adapted F_1s were grown and 660 F_2 to F_6 lines evaluated. New introductions were made from Niger and ICRISAT/India. Selection emphasis continued on per se performance and lodging resistance for material intended for the U.S. The continued presence of chinch bugs enabled further selection to be made for resistance to this pest. Screening was continued for propachlor and atrazine herbicide tolerance in a separate inbred nursery and in three isolations composed of random-mating progeny derived from crosses of herbicide tolerant lines.

The development of good combining seed parents based on the A_1 cytoplasmic male sterility (cms) system continued and yield testing confirmed the usefulness of seed parents 293A, 378A, and 413A, and further new seed parents were identified (Table 1).

Table 1. Pearl millet new A1 hybrid test—lodging, height, and grain yields of 5 of 64 hybrids in Mead test 92-62.

Hybrid	Height (cm)	Lodging (%)	Yield (kg/ha)
90M57242A x 086	94	3	3990
90P0433A x 183	120	10	3580
90M57043A x NPM 2	107	7	3460
90M57242A x 60015	94	8	3208
68A x N-MLS	122	32	2970
Mean (64 entries)	107	20	2750
LSD (0.05)	119	14.6	1050

The A_4 Cytoplasmic Male Sterility (cms) System

Significant advances were made in utilizing the A_4 (monodii) cms system which acts independently of the A_1 system. Following the identification of a number of agronomically good restorers, work on developing seed parents and determining the worth of the restorers on the A_4 cms system was increased. Unlike the A_1 system, almost all lines are maintainers in the A_4 system (which means most good lines can be converted to seed parents). Evaluations in 1992 confirmed that male sterility and male fertility in this system are more clearly expressed with fewer intermediate phenotypes. Since sources of male fertility restoration are now available and because there is a much wider choice of potential seed parents, the use of this system is going to allow more rapid and effective breeding of hybrids in pearl millet. The indication that the environmental stability of fertility restoration, and hence seed set is more consistent in A_4 hybrids will be further examined.

Preliminary assessments of new A_4 restorers (termed Rm) were made by means of a partial diallel (Table 2) and by crosses to an established tester (Table 3). These tests indicated that there was variability in combining ability between lines and five were equal to an existing good combiner, KS2068A. A population made from the nine initial R_4 lines was random-mated a second time. Seven further R_4 lines have now been identified.

Table 2. Pearl millet Rm (A_4) part diallel - - plant height and grain yield mean of two locations, Mead trial 92-68-2.

Rm cross	Height (cm)	Yield (kg/ha)
7 x 5	116	3948
1 x 6	104	3130
1 x 2	86	2930
9 x 6	102	2810
9 x 4	102	2800
7 x 4	103	2750
8 x 5	103	2360
2 x 8	95	2120
LSD (0.05)	15	930

Table 3. Pearl millet Rm (A4) tester trial—plant height and grain yield of six out of ten hybrids, Mead 92-68-1.

Hybrid	Height (cm)	Yield (kg/ha)
5Rm x 58016	111	2780
6Rm x 58016	105	2780
2Rm x 58016	95	2780
4Rm x 58016	116	2760
7Rm x 58016	93	2740
68A x 58016	107	2630
LSD (0.05)	10.5	844

Protogyny Hybrids

Barnabas Kiula completed his M.S. thesis on the effect that potential levels of selfing in female parents would have on the performance of hybrids made by protogyny. The use of protogyny to make hybrids in pearl millet has several advantages for low resource agriculture, including ease of development. The effects of mixing 0, 20, 40, and 60% of female parent seed into hybrid seed were examined in four different hybrids in experiments conducted over two to four years. In three of the four hybrids, the presence of 20%, and in one case up to 60%, of selfed female parent seed caused negligible yield reductions compared to 100% hybrid. In the topcross hybrid (line x variety) 68 x MLS the presence of 20% inbred line 68 caused a non-significant 1.7% reduction on hybrid yield, and that mixture still yielded 30% more than the variety (MLS) (Table 4). It is evident that the relative competitiveness of the parental line and the hybrid plants determines the yield of any mixture. Major factors are relative plant canopy components, such as leaf numbers and area (tillering), rate of growth and height. The hybrid which

Table 4. Comparison of actual and expected grain yields in topcross hybrid 68 x MLS (four year mean).

Treatments				Grain yields		Reduction from 100 hybrid		
No.	Hyb	68B	MLS	Actual	Expected	Actual	Expected	Comp.[2]
	- - - seed percentages - - -			- - - kg/ha - - -		- - - % - - -		- %
1	100	0	0	3810	3810	0.0	0.0	0.0
2	80	20	0	3740	3460	1.7	9.1	9.2
3	60	40	0	3200	3120	15.9	18.1	2.6
4	40	60	0	2880	2770	24.3	27.2	3.8
5	0	100	0	2080	2080	45.3	45.3	0.0
6	0	0	100	2870	2870	24.7	24.7	0.0
LSD (0.05)				313				

[1] Expected yields = sum of percent of hybrid and parent yields according to mixture.
[2] Comp. = compensation = [1 - (actual - expected)/actual] x 100.

Table 5. Mean grain yields, regression coefficients (b), deviation mean squares (s^2_d), and coefficient determination (r^2) of dwarf pearl millet populations and their topcross hybrids grown in seven Nebraska environments.

Genotype	Populations				Topcross hybrids			
	Grain yield	b	s^2_d	r^2	Grain yield	b	s^2_d	r^2
	kg ha^{-1}		x100		kg ha^{-1}		x100	
EDS	2140	1.14	70	0.87	2750	1.08	1540	0.67
MLS	2150	1.08	0	0.96	2600	1.18	2170	0.67
MLS-P	2210	1.43	0	0.96	3050*	- -	- -	- -
NPM-1	2090	0.91	0	0.86	2590	1.35	3290	0.67
NPM-2	2200	1.40	0	0.95	2980	1.35	1940	0.74
DVP	1770	1.10	90	0.86	1940	1.26	410	0.81
SVP	2060	0.99	80	0.83	2650	1.23	1230	0.74
LVP	1810	1.00	980	0.74	2480	1.55	0	0.90
CLP	2240	1.02	770	0.76	2220	0.91	1170	0.62
SSP	2120	1.28	660	0.84	2399	1.48	2540	0.74
LP	2160	0.69	770	0.59	2660	1.13	0	0.84
Sidney	1900	1.10	310	0.83	2630	1.12	220	0.79
Mean	2070				2540			
LSD (0.05)	330				420			

* Not tested in three 1990 environments.

was affected was very dwarf and showed the least differences in height and growth habit from the female parent.

This research indicates that varieties which are of normal height in African agriculture would be the best genotypes and phenotypes for use as male parents for adapted topcross protogyny hybrids.

Recurrent Selection

Recurrent selection in population NTPC continued in collaboration with Dr. Glenn Burton, Tifton, GA. Eighty-one progeny in the second cycle of recurrent restricted phenotypic selection were evaluated at Mead in 1992. The selection differential for grain yield between the mean of the 20% of progenies retained and the mean of all progenies was again 30% showing no indication of decrease in genetic variability because of previous selection. As with the previous cycle of progeny evaluation, head number showed the strongest correlation (0.79) with grain yield but plant height (0.45), days to bloom (-0.41), and head lodging (0.25) all showed significant correlations with yield. Recurrent restricted phenotypic selection has been successful in other graminae and because of its relative simplicity, would be appropriate for developing country breeding programs.

Comparison of Populations

A number of different random-mating populations have been developed. In order to decide which would be the best to use in a recurrent selection program, the populations were examined per se and in tester (topcross) combinations over seven environments (year x location number). Results in Table 5 indicate that the populations had relatively similar yield levels per se, but that their combining abilities (with the single tester used) varied considerably. Average heterosis was 23% but two of the higher yielding varieties, MLS-P and CLP, showed 38 and -1% heterosis, respectively. As expected, the topcrosses showed higher b_1 values, indicating they responded better to improving environments, but the populations were slightly more predictable in their response to environmental change.

Regional Test

This was planted at nine locations in the U.S. in 1992 by collaborators in eight states. Yields were not obtained from three locations due to an unusually cool weather, hail or early frost. For the first time an experimental commercial hybrid was entered in the test. Average location yields varied from 1060 kg/ha at Sidney, Nebraska, to 5490 kg/ha at Plainview, Texas. The same four pearl millet hybrids have now been grown over three sites (Tifton, GA; Hays, KS; and Mead, NE) for three years. The overall average yield was 3180 kg/ha. The best hybrid was different for each location but averaged between 3900-3930 kg/ha.

Networking Activities

Senegal

The genotype testing program could not be conducted on the Senegal River Valley in the 1992/93 off-season through lack of staff funding, however, seed of hybrid KS2068A x 086 identified from previous tests, was increased. Evaluation of Senegalese varieties for their male sterility/fertility reaction to A_4 cytoplasm was commenced (the original source of A_4 cytoplasm was a wild *Pennisetum glaucum* subspecies from Senegal).

Five synthetic varieties bred in the Senegal pearl millet breeding program which involved introgressed INTSORMIL germplasm were tested at two locations by Mr. A. Fofana. The results (Table 6) show that four of the five new synthetics, which had good downy mildew resistance, yielded an average of 40% more than the mean of the three check varieties.

Zimbabwe

Dr. Figuhr Muza, from Zimbabwe, completed part of his Ph.D. dissertation on mutagenesis in finger millet. Six levels (including zero as a control) of chemical ethyl methanesulphonate (EMS) and radiation (X-rays) mutagens were given to seed of three finger millet inbred cultivars of diverse origins. These three inbreds were evaluated prior to treatment and made up of only true-to-type plants. The treatments were carried through to the M_3 generation by bagged head-to-row descent (even though finger millet is a virtual 100% chasmogamous inbreeder). Variant plants that were different from any variability noted in the untreated plot detected in the M_2 populations were head-rowed to the M_3, as well as a random sampling of 125 plants from each untreated control plot.

A total of 14 variant phenotypes including height, maturity, and head structure attributes were identified in the M_2 generation and verified in the M_3. The highest frequency of these phenotypic variants occurred in two out of the three varieties with the 1.0% EMS treatment (not the maximum of 1.5%) and with the 50 kR x-rays (the highest level given), on all varieties. While potentially useful variants for dwarf habit, early maturity and thick- and long-fingered heads were found, possibly the most significant was male sterility. While crosses of various types are yet to be evaluated to confirm the type of sterility, it is probable that this is genetic male sterility under recessive control. If this is so, and its expression proves relatively independent of background genotype and environment (which is not the case with Gulu E—the only other known male sterile source), then this discovery would be widely useful in the breeding of finger millet where crossing is very difficult.

Germplasm Exchange

Three varieties were supplied to Yemen, one variety to CIAT-Colombia, and one to Honduras. Six lines were sent to ICRISAT, Sahelien Center, Niger, and 17 to ICRISAT Center, Hyderabad. Three varieties were supplied within the U.S., and 23 received from ARS, Tifton, GA, and KSU, Hays, Kansas.

Table 6. Pearl millet synthetics grain test. Means of Bambey Nioro locations, Senegal 1993.

Synthetic	Days to bloom	Ht. (cm)	Downy Mildew %	Grain Yield (kg/ha)
*ISMI 9301	43	206	6.2	1850
*ISMI 9302	45	197	29.1	1340
*ISMI 9303	45	206	9.7	1840
*ISMI 9304	43	214	7.8	2040
*ISMI 9305	46	202	13.6	1680
ISMI 9306	46	207	8.6	1410
ISMI 9203	48	231	14.4	1650
Souna-3 (check)	49	214	28.0	1040
IBV 8001 (check)	45	214	18.8	1270
IBV 8004 (check)	44	202	20.6	1450
Mean	45	209	22.6	1541
LSD (0.05)	2.0	NS	9.4	380

*Parentage includes INTSORMIL germplasm.

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Crop Utilization and Marketing

Chemical and Physical Aspects of Food and Nutritional Quality of Sorghum and Millet

Projects PRF-112 (1992-present) and PRF-103B (prior to 1992)
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Summary

This report covers the project directed by Allen Kirleis until 1992, followed by the present project directed by Bruce Hamaker. Since the inception of this project the approach has been to address two general areas: 1) to understand the fundamental properties of grain components as they relate to grain quality so that various traits can be improved through genetics or processing, and 2) to assist the national programs in Niger and Sudan with practical solutions to their problems. Significant progress has been made. A laboratory manual was developed and distributed describing procedures for assays important to grain quality laboratories in West Africa. Laboratory tests for porridge quality were identified that best correlate to consumers in Niger. Grain hardness tests, which are important indicators of end-use quality, were evaluated and suitable methods that are rapid and simple were put in place. New processed foods from sorghum in Sudan were evaluated for nutritional quality and research was conducted that will improve quality and help efforts to commercialize *kisra*, the staple Sudanese fermented flat bread.

We now have a far better understanding of the structural and chemical composition of the components of the sorghum kernel, and the interactions between them, that affect important end-use characteristics such as protein digestibility, pasting properties, and kernel hardness. Sorghum digestibility in humans was shown by nutritionists to be low compared to other cereal grains, and from this project we now have a clear concept of why the storage proteins, or kafirins, are difficult to digest. Addition of a reducing agent to break disulfide bonds between proteins markedly increased digestibility, and while this is not presently a practical means of increasing digestibility of the grain in developing countries, it has given a clearer picture as to what the constraints are in sorghum regarding digestibility. Presently, a high molecular weight non-kafirin endosperm protein that inversely correlates to reduced digestibility is being evaluated as a possible means of increasing digestibility through breeding or genetic manipulation. Much effort has been given to microstructural and chemical studies of kafirin, the storage protein that makes up nearly 80% of the total endosperm protein. This project developed a new nomenclature for kafirin and, using antibodies made to individual classes of kafirin, determined the organization of the storage bodies which contain kafirin by immunolocation studies using transmission electron microscopy. Studies were also conducted on the interactions between sorghum starch and protein that affect the pasting properties of cooked sorghum flour. It was found that high amounts of kafirin decrease the gelatinization potential of the starch granules thereby making a thinner porridges. Porridge texture was found to be the most important attribute when different sorghum cultivars were evaluated using sensory panels in Niger.

Since this project began many individuals have been trained for short and long term periods on up-to-date laboratory procedures and on research projects related to grain utilization problems in Africa. This impacts the national programs and has permitted strong collaborative ties to develop.

Introduction

Research in the sorghum and millet utilization area addresses a variety of constraints that affect the producer, cereal processor, and consumer. If newly released grains are not of acceptable quality to the consumer they will not be grown in large quantities by farmers. Moreover, to expand the use of sorghum and millet in the semiarid tropics new varieties or hybrids with superior quality traits are required to produce competitive processed products. Processing not only provides a market for excess grain, but also stimulates the economy by generating income in rural and urban areas and can have the effect of reducing cereal imports. In some parts of Africa sorghum is now being used industrially to a

much larger extent than was previously seen. Nutritional considerations are important to the vulnerable groups who consume these grains as their principal source of energy and protein. Improvements in digestibility and protein quality of sorghum would impact these groups as well as favorably impact processing industries looking to use sorghum in their cereal-based products. In order to find increased markets for sorghum, especially in processed foods for urban markets, it is important that sorghum not have the reputation of being nutritionally inferior.

This project has focused on improving sorghum quality through fundamental and applied studies. We now have a far better understanding of the chemical makeup and properties of the storage proteins of sorghum and how they are organized in the endosperm. This has led to knowledge of how their digestibility can be increased and how they may affect grain hardness. By determining the mechanisms involved it is then possible to more directly manipulate attributes either genetically or through processing. In the future it will be even more necessary to understand grain components and their relationship to quality attributes as molecular biology techniques will be employed to alter grain traits.

With the exception of the Horn of Africa region foods made from sorghum and millet are generally not popular in urban areas where other cereal grains are available and often affordable. Along with the sharp increase in urban populations in the developing world comes a need and opportunity to improve sorghum and millet quality to create a market for increased grain production, a central goal of the project. Improvements in quality attributes of sorghum such as texture, flavor, and color could make the grain more useable. As sorghum and millet become used more in processed foods it is also necessary to identify types that are best used for specific purposes, such as composite flour breads, cookies, crackers, etc.

Objectives, Production and Utilization Constraints

Objectives

Develop an understanding of traditional village sorghum food processing and preparation procedures and determine the grain characteristics that influence the functional and organoleptic properties of traditional food products.

Develop laboratory screening methods for use in developing country breeding programs to evaluate and improve the food quality characteristics of sorghum grain.

Determine the relationships among the physical, structural, and chemical components of grain that affect the food and nutritional quality of sorghum.

Determine the biochemical basis for the poor protein digestibility of sorghum grain and cooked sorghum preparations.

Constraints

Research on the food and nutritional quality of sorghum and millet grain is important to improving the agricultural systems of developing countries of the semi-arid tropics. Factors affecting milling properties, food quality, and nutritional value of sorghum and millet critically affects other efforts to improve the crop. If the grain is not acceptable to consumers, then grain yield and other agronomic improvements to the crop are lost. In addition, the breeding of grains that have superior quality traits will more likely give rise to processed food products that can be successfully and competitively marketed. This is especially true for sorghum which is perceived in some areas to have poor quality characteristics. Processing grain, even in minor ways, adds value to the grain and can generate income within farming communities. Ultimately, a good quality grain that can be used in a composite flour or alone to produce a good processed product can result in decreased need for grain imports. One of the main goals of this project is to improve food and nutritional quality of sorghum and millet through a better understanding of the structural and chemical interactions that govern quality. This can then be applied to develop useful methodologies for improving quality. Another future goal is to aid in the commercialization of processed products made from sorghum and millet so that small businesses or cooperatives can successfully market them.

Research Approach and Project Output

Since the inception of this project a great deal of progress has been made toward solving the protein digestibility problem of sorghum and understanding the role of sorghum endosperm proteins in different quality issues. Factors affecting quality of traditional foods tuwo (Niger) and kisra (Sudan) were identified. Various new varieties and hybrids of sorghum were evaluated for quality and acceptability in Niger and Sudan. Kisra starter cultures were characterized microbiologically and a culture was developed for commercialization. More recently (project PRF-112) we have continued work on sorghum kafirins and other endosperm proteins, as well as initiated a new project in the food product area involving sorghum and millet.

Sorghum Protein Digestibility

The most recent concern related to low digestibility of sorghum grain originated from a report from Dr. George Graham (*J. Nutr.*, 111:1928, 1981) that showed Peruvian children who had recovered from a malnourished state, on average only digested 46% of sorghum proteins and excreted 21% of energy consumed. Other cereal grains tested in the same unit were much more digestible. Because tannin-free sorghums were used in the study it was apparent that other factors in the grain were responsible for the low digestibility. Studies were initiated in cooperation with Dr. Axtell to identify methods of increasing digestibility and to

understand the basis of the problem so that it could be corrected through breeding efforts.

Sorghum is now increasingly being used in industrial processes in Africa to make baked goods and other products. Obtaining maximum digestibility, as well as improving protein quality, could become very important as the upward trend in commercial processing of sorghum continues. The following is a brief summary of our findings on sorghum digestibility.

Initial *in vitro* studies at Purdue showed that protein digestibility decreased due to cooking and that digestibility was significantly lower than for other cereals either uncooked or cooked. Subsequent digestibility studies using animal models also showed digestibility to decrease upon cooking, though the decrease was less pronounced. Processing sorghum in certain ways was found to effectively increase digestibility. A traditional fermented product, Sudanese *nasha*, and high temperature, low moisture extruded gruel made from decorticated sorghum were found to be highly digestible in children both in protein and energy (starch). From chemical studies sorghum had previously been shown to have a higher amount of "crosslinked" prolamins compared to other cereals. These storage proteins, also called kafirins, when fractionated using the Landry-Moureaux scheme based on differences in protein solubility were mostly soluble in aqueous alcohol plus reducing agent to cleave disulfide bonds. This suggested that a high degree of disulfide bonding might decrease digestibility through formation of protein complexes resistant to enzymatic degradation. Accordingly, addition of a variety of reducing agents, both toxic and non-toxic, increased sorghum protein digestibility of the cooked gruel to the level of the uncooked, and of the uncooked to the level of other cereal grains. This discovery still shows promise as a practical means of increasing digestibility through processing if a suitable edible, and inexpensive, reducing agent can be found. Better, however, would be to correct this problem through breeding or molecular biology techniques. Therefore, studies were continued on the structure and function of kafirin proteins, as well as other non-kafirin endosperm proteins, to understand the specific chemical basis of low digestibility in sorghum. It is interesting to note that Dr. Waniska, Texas A&M University, found that starch digestibility increased after breaking proteins up with enzymes. There appears to be a dependent relationship between protein and starch (or energy) digestibility as *in vivo* studies have also shown that when digestibility increases it occurs in both components.

Using sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE) to visualize protein digestion over time, kafirins were found to be the last class of proteins to be digested. After cooking these proteins became less digestible and less aqueous alcohol soluble. From recent studies we now believe that the majority of kafirins are relatively easy to digest by proteases, but a highly disulfide bound protein coating on the protein bodies restricts both proteolytic enzymes and extraction of the kafirin-contained inside. Native, unreduced kafirin extracted and mixed with a starch carrier was highly digestible. Recent unpublished work shows that the major kafirin (α– kafirin) in this fraction is no different from the α-kafirin contained in the "crosslinked" kafirin fraction in terms of the amount of disulfide bonding occurring between proteins. Thus, kafirin contained inside the protein bodies is not difficult to digest.

High molecular weight non-kafirin proteins were identified that may cause the low digestibility of sorghum. These proteins which consist of one major band and two minor bands on SDS-PAGE were the last proteins to be digested prior to kafirin digestion. The major HMW band was significantly correlated in amount with digestibility of uncooked flour ($r=0.79$, $P<0.01$). These proteins have a strong tendency to form disulfide-bound insoluble complexes while in solution, despite the fact that their cysteine content is relatively low and similar to other non-kafirin proteins. In the developing seed they are soluble in non-reducing solvents up to approximately 40 days after half bloom, then become insoluble, or form disulfide-bound complexes, at the same time as protein digestibility decreases substantially. We hypothesize that these HMW proteins may be located at the surface of the protein body adjacent to γ-kafirin proteins that are rich in cysteine residues (approx. 7 mol%), and form enzyme resistant complexes with this kafirin thereby restricting access to the kafirin-containing interior of the body. The major HMW protein has now been isolated using 2-dimensional gel electrophoresis and N-terminal sequence obtained. We are presently making antibodies to this protein for immunolocation studies and to develop an ELISA assay that can be used to more accurately quantitate the amount of this protein in various sorghum varieties. This hopefully will be suitable to be used in screening early generations of breeding stock to select for highly digestible lines.

Sorghum protein was highly digestible in earlier stages of seed development, and in fact was well digested even after all proteins have been synthesized. A large digestibility drop occurred in uncooked and cooked sorghum during seed drydown, and analysis of developing seeds in two different years where drydown occurred at different rates showed digestibility decreased concomitantly with moisture content. This presumably is related to the higher likelyhood of oxidation reactions occurring with removal of water. Disulfide bond formation is an oxidation reaction. Also related to environment, substantial variation was recently seen in digestibility in one genotype over seven years. Uncooked *in vitro* digestibility ranged from 69 to 89% and cooked digestibility ranged from 47 to 73%. There was no trend in digestibility from older to newer flour, and it was concluded that differences in environmental conditions, most likely during drydown, affected digestibility of sorghum.

In the past year we screened 25 sorghum genotypes for uncooked and cooked *in vitro* protein digestibility and found wide variability in digestibility as well as the drop due to

cooking. Two experimental lines from Dr. Axtell's breeding program had percent digestibilities in the high 80s with little reduction after cooking. These values were higher than most maize inbreds tested. On the low side there were sorghum varieties with percent digestibilities in the 50-60s. Using a three enzyme pH-stat procedure a time course of digestion was obtained based on the amount of NaOH titrated for sorghum varieties with high and low digestibility. Differences in protein digestibility could be attributed to differences in the ability of enzymes to digest protein bodies.

Kafirin Nomenclature and Immunolocation of Subclasses

A new kafirin nomenclature based on that of maize zeins was developed that has facilitated a more in-depth study of kafirins, their function, and location. Kafirins have traditionally been fractionated and quantitated based on their solubility in aqueous alcohol and aqueous alcohol plus reducing agent. These fractions are referred to as "true" and "crosslinked" kafirins, however, do not to differ appreciably from each other. In the new nomenclature kafirin polypeptides were classified on the basis of their relative differences in solubility, molecular mass, and from antibody reactions to corresponding zein antibodies. Polypeptides were classified as either α-, ß-, or γ-kafirins. α-Kafirins correspond to the 25 and 23 kDa polypeptides on a SDS-PAGE gel. They are electrophoretically similar to α-zeins from maize, have similar extractability (40-90% alcohol), and react with α-zein antiserum. The ß-kafirins correspond to the 20, 18, and 16 kDa components. They are similar to ß-zein in molecular weight, extractability (10-60% alcohol), and react with ß-zein antiserum. Finally, the γ-kafirin corresponds to the 28 kDa component on SDS-PAGE. It is extractable in 10-80% alcohol in the presence of reducing agent and reacts with γ-zein antiserum. Obviously there are many similarities between the storage proteins of sorghum and maize.

Polyclonal antibodies were then raised against the α-, ß-, and γ-kafirins and used to develop an ELISA assay to quantitate these proteins from various sources, and to determine their location in the sorghum endosperm. Peripheral and central endosperm regions were studied in developing seed (20 DAHB). Locational studies were conducted by exposing thin sections of sorghum endosperm to antisera to kafirins, followed by incubation with anti-rabbit antibodies with attached colloidal gold, then viewed on a transmission electron microscope. The localization of γ-kafirin was of particular interest due to its high cysteine content. Individual localization of the three types of kafirins showed their organization in the protein body. Transmission electron microscopy showed that protein bodies in the peripheral endosperm were spheroid with concentric rings and a few darkly stained inclusions. In contrast, protein bodies of the central endosperm were irregularly shaped with a higher proportion of dark staining material. Light staining regions were primarily composed of α-kafirin which was shown using ELISA to make up about 80% of the total kafirin. The darkly stained inclusions were predominately ß- and γ-kafirins. γ-Kafirin was also found at the periphery of the protein body. Due to the high content of cysteine in these proteins they are likely found as disulfide-bound polymers. Central endosperm protein bodies had a higher proportion of ß- and γ-kafirins, a finding later quantitated and shown by ELISA. It seems quite possible that the concentration of γ-kafirin at the periphery of the protein body negatively affects the digestibility of the interior contents, though the fact that maize protein bodies contain the analogous -zein at the same location does not in itself explain the difference in digestibility between the two cereal grains. These studies have furthered our knowledge of sorghum storage proteins, not only related to the digestibility problem, but also to other properties such as endosperm hardness and flour functionality. It is important that the chemistry and structure of the major endosperm proteins is well understood in order to change quality traits through genetics or processing. Now that molecular biologists are beginning to be able to manipulate genes in cereals, it is of particular importance that structure, location, and function of grain components is known.

Quantitation of Kafirin

We recently showed that kafirin content in sorghum endosperm is significantly higher than previously reported. The standard method for extracting and quantitating kafirin comes from the Landry-Moureaux fractionation procedure that is used to separate sorghum proteins into five classes based on solubility differences. Total kafirin is determined as the amount of protein extracted in 60% t-butanol plus reducing agent. Reports from the literature place kafirin content in a range from about 40 to 60 % for normal sorghum types. We found by using ELISA quantitation of kafirin proteins that approximately 30% of the total kafirin content is unextractable in the above solvent and that about 60% of the γ-kafirin was not extracted. Using a new extraction procedure developed for maize proteins, we quantitated kafirin and non-kafirin by first extracting virtually all protein in an alkali buffer with detergent and reducing agent, followed by addition of t-butanol to 60% of total volume to precipitate non-kafirins and to keep kafirins in solution. SDS-PAGE analysis of the two protein fractions showed them to be pure and not cross-contaminated with the other protein type. Kafirin content of 14 cultivars and one hybrid that were decorticated ranged from 68 to 81% of total protein. The significantly higher values than the new method could help explain why sorghum grain behaves differently both in functional and nutritional aspects when compared to maize. Using the same method zein content was lower. Because they are free to interact with other components of the grain, non-kafirin proteins contribute most to flour functionality. They also contain protein of much better quality than the kafirins. Instead of non-kafirins comprising about 50% of total protein, we have shown that they may only amount to as little as 20%, thus undoubtably affecting quality.

Sorghum Grain Hardness

The degree of grain hardness is an important criteria for choosing a sorghum cultivar or hybrid for a particular food application and is an important consideration in grain milling. For example, sorghums with intermediate to hard endosperm texture produce the best West African thick porridges, while sorghums with soft to intermediate texture are best for the East African fermented breads. Therefore, endosperm texture is an important trait in breeding of food sorghums. An understanding of the factors responsible aid in breeding for texture as well as further the development of sorghums for specific food applications. Over the project period a number of studies were conducted to attempt to determine the factors responsible for grain hardness in sorghum.

A number of different hardness tests were evaluated in a study on 15 sorghum varieties. Particle size index and pearling index were shown to provide a rapid and sensitive measure of hardness. Percent floaters, percent vitreousness, and kernel density also ranked varieties in the same order. The abrasive-milling performance of sorghum was related to all hardness parameters investigated.

A study using scanning electron microscopy was conducted to observe the differences in soft, intermediate, and hard varieties of sorghum during seed development. Grain of NSA 740 (soft), P721N (intermediate), and SC283-14 (hard) was grown and collected at 5 day intervals beginning five days after flowering and continuing to 40 days or physiological maturity. Samples were prepared by critical point drying for viewing on the scanning electron microscope. Although the developmental sequence does not differ between hard and soft varieties, the location and rate of occurrence of particular structures do. The first visual indication of protein development is the formation in the exterior endosperm of beaded strand structures which are immature protein bodies. This is followed by appearance of the structures in the interior endosperm. Soft and hard varieties differed in rates of development as early as at 15 DAHB. At this stage the hard variety had beaded strands present throughout the interior and exterior regions of the endosperm. However, the intermediate and soft varieties each showed less development of the beaded strands and in the soft variety they were only found in the exterior endosperm. This trend continued as the grains developed. By physiological maturity, the interior and exterior endosperm of the hard variety had gone through the complete developmental sequence from beaded strands to protein bodies encased in matrix. It appears that the softer grains have a large proportion of floury endosperm as a result of the inner portions not reaching maturity.

These materials were also examined by transmission electron microscopy and light microscopy. As viewed in a light microscope differences between the soft and hard variety were mainly in cell size and packing density. In general, cell size was smaller and starch and protein bodies were tighter packed in the hard variety compared to the soft. Viewed by the transmission electron microscope it was shown that the cells which will form vitreous endosperm have a dense cytoplasm. The cytoplasm later during seed drydown forms the protein matrix. Vitreous endosperm cells also appeared to have a higher concentration of mitochondria and endoplasmic reticulum than the floury cells indicating higher metabolic and synthetic activity. The major difference between vitreous and opaque endosperm regions in sorghum is the presence or absence of a continuous matrix. A continuous matrix apparently occurs during development due to the small cell size, tightly packed contents, and higher protein synthesis in the cells of the vitreous endosperm.

Chemical tests were also done to elucidate the proteins or class of proteins that are responsible for grain hardness. Vitreous and floury endosperm were obtained from soft (Zanab elsha), intermediate (P721N), and hard (Mshimbha) varieties and proteins were fractionated using the Landry-Moureaux scheme. Proteins were sequentially extracted using different solvents and quantitated to obtain values for albumins/globulins, kafirins, and glutelins. Vitreous endosperm had a much higher protein concentration than floury endosperm averaging about 11% compared to about 6.5%. This increase was due to a much higher kafirin content in vitreous endosperm. Kafirin content of the vitreous endosperm varied with hardness of the grain. Floury endosperm has elevated amounts of albumin and globulin proteins. Elevated kafirin content may be responsible for a harder, vitreous endosperm.

The above materials were also analyzed for individual kafirins using SDS-PAGE and ELISA. Both techniques showed that the kafirin fraction of floury endosperm has a higher percentage of ß- and γ-kafirin and a lower percentage of α-kafirin compared to the kafirin fraction of the vitreous endosperm. This suggests that composition of the protein bodies from the two endosperm fractions differ possibly due to differences in stages of protein body development.

Sorghum Porridge Quality

Cooperative studies with scientists in Niger have focused both on evaluating porridge quality of new varieties and hybrids, and fundamental studies on kernel components related to texture. In Niger the commonly consumed thick porridge is called tuwo which is similar to tô of Mali. At early stages of a breeding program objective laboratory tests are required to screen and select breeding lines to plant the next season. A number of laboratory tests have been developed to measure such porridge attributes as stickiness and firmness. Before a new variety is released to farmers, it is important that its food quality be evaluated by people through tasting and cooking tests. In one study two new varieties and a newly developed hybrid were evaluated for food quality at four locations in Niger using taste panels. All three sorghums were rated better than a local check for color, texture, and overall acceptance.

A study was conducted by a Nigerien graduate student to relate objective methods of testing tuwo quality with subjective panel scores obtained in Niger. Although consumer test panels are a valuable method for evaluating new sorghum lines, this method is expensive, time consuming, and limits the number of lines that can be tested. Because texture is a principal factor of consumer acceptance, a study was set up to determine the validity of using a variety of laboratory texture tests by correlating results to panel scores taken in two locations in Niger. A total of 16 varieties varying in grain hardness and endosperm color were grown in Niger in the 1990 crop season. The two panel groups composed of 27 and 30 members evaluated the appearance, aroma, color, taste, firmness, cohesiveness, stickiness, and overall texture of tuwo by completing a questionnaire. The attributes were evaluated along with the acceptability of the products using an anchored 0 to 100 point scale. The linear correlations of overall acceptance with attributes and the slopes of the regression lines made it possible to rank the sensory attributes in terms of the impact on acceptance. The study showed that texture (cohesiveness, stickiness, and melting) is the most important attribute affecting acceptability. Small changes in these textural qualities greatly affected the acceptability of tuwo. A comparison was made with laboratory methods to measure texture - alkali gel consistency test, Precision penetrometer, and a compression test using an Instron Universal Tester. Except for the gel consistency test, the instrumental methods correlated significantly with consumer ratings for both Nigerien locations. The test value best correlated ($r=-0.79$, $P<0.01$) with sensory ratings of texture was the slope of the compression curve of the Instron test.

Further work using the Instron showed that the apparent deformability modulus, a firmness measure in universal engineering units, could reliably be used as a measure of comparing porridge firmness, provided that factors such as flour concentration and time of testing are carefully controlled. At medium flour-water ratio, percent vitreousness and apparent amylose content showed correlation coefficients with apparent deforability modulus of $r=0.771$ and $r=0.801$, respectively (significant at the 0.05 probability level).

Fundamental studies were also conducted to investigate the factors that determine porridge texture. In one investigation the relationship between protein and starch gelatinization was studied in nine sorghums differing in endosperm texture. Tests used were alkali and acid gel consistency, and an enzymatic measure of degree of gelatinization. Grains containing more kafirin had higher gel consistency values and lower starch gelatinization. It was also found that the rate of gel firming during storage was greater for the hard than for the intermediate and soft endosperm grains. The addition of a reducing agent (2-mercaptoethanol) to cleave disulfide bonds before cooking decreased gel consistency and increased degree of gelatinization particularly of the hard endosperm sorghums. It was concluded that compactness of the disulfide-bound protein matrix surrounding the starch granules influences starch gelatinization in sorghum. This may explain why hard endosperm sorghums produce thinner porridges that are more sticky, and soft sorghums produce thick porridges. Starch granules in the former do not gelatinize as fully as granules in the latter. It may be possible to manipulate the texture of sorghum-based products in the processing step by using oxidizing or reducing agents.

Another study showed that three non-kafirin proteins form large disulfide-bound polymers during the cooking process. This was determined by extracting cooked proteins in a strong dissociating solvent without a reducing agent, separating the mixture by size exclusion chromatography, and analyzing the proteins in the high molecular weight peak by SDS-PAGE with a reducing agent. These proteins could affect texture either by forming extensible polymers or by inhibiting starch granule gelatinization. This work is now being continued to see if differences in amounts of these proteins could explain varietal differences in texture.

Sorghum Kisra Quality

Kisra is a fermented, thin pancake-like bread eaten as a staple in Sudan. There is a trend towards commercialization of kisra in urban areas and studies were conducted in cooperation with Sudanese investigators to 1) find a standardized predictive test for consistency of kisra batter to be used in commercial operations and to predict kisra making quality of different sorghums, and 2) characterize the changes occurring during the fermentation process and develop a starter culture that could be used commercially. A critical step in the kisra making process is the thinning of the thick fermented batter so that it can easily be spread on the hot griddle to make the pancake. The thinness of the batter determines the ease of spreading, thickness of the kisra sheet, and the ease of removing the baked kisra from the griddle. This step is a subjective one necessarily made by an experienced kisra maker. An objective test was developed using a Bostwick consistometer, an inexpensive and simple fluid viscosity tester. Bostwick readings were found to increase linearly for batters with water/flour ratios from 1.40-1.67. A water/flour ratio of 1.45 was used to compare the behavior of fermented and unfermented suspensions of five Sudanese sorghum flours. All flours exhibited an increase in Bostwick consistency (became more fluid) after fermentation, however, those with the lowest unfermented values increased more after fermentation than samples with higher Bostwick values.

The fermentation process was studied and it was found that in a naturally fermented flour (microbes found in the flour, cultivar - Dabar) bacterial population increased with fermentation time and reached a plateau at 18 hours. The microflora of the sorghum flour obtained from Sudan consisted of lactic acid, coliforms, and other acid producing bacteria and yeasts/molds. Lactic acid content increased to 0.8% causing a pH drop from 5.95 to 3.73. In flour that was fermented by adding a backslop from a previously fermented sorghum, the bacterial population increased with time and fermentation plateaued at nine hours. The bacterial

population consisted mainly of lactic acid bacteria. Yeast and mold counts were low, and coliform growth was suppressed by the other organisms. At the end of 9 hours the lactic acid content was 1.5% and pH was 3.73. The end products produced from the sorghum flour fermentation were lactic acid, acetic acid, proprionic acid, isobutyric acid, ethanol, propyl acetate, and 2-furan-methanol. By the end of the fermentation using an inoculum from previous fermentation, simple sugars were not detectable. Starter cultures developed in the laboratory from combinations of lactic acid bacteria with different proportions of hetero- to homolactics or combinations of lactic acid bacteria and yeasts did not produce the same amount or types of end products that were produced during natural fermentation of sorghum flour. Sensory trials remain key to selecting proper combinations of microorganisms for an optimal kisra. A suitable culture and objective testing methods would permit larger scale kisra bakeries to operate to produce good, consistent quality product that could compete with large wheat bread operations.

Laboratory Manual

A manual titled Sorghum Quality Laboratory Manual for Use in West Africa by J.M. Shull, M. Oumarou, A.W. Kirleis, and J.W. Clark was published and distributed in both French and English. The manual is a comprehensive listing of the procedures of methods most useful for evaluating the inherited qualitative properties of sorghum that contribute to its processing and food quality. The manual was distributed to scientists and US AID missions in Africa, Asia, and South and Central America.

Publications and Presentations

Journal Articles and Abstracts

Aboubacar, A., Oumarou, M., and Kirleis, A.W. 1992. Relationship between consumer ratings and laboratory measurements of grain sorghum tuwo quality parameters. Cereal Foods World 37:551. (Abst.)

Hamaker, B.R., Mertz, E.T., and Axtell, J.D. 1994. Effect of extrusion on sorghum kafirin solubility. Cereal Chem. In press.

Hamaker, B.R., Huang, C.P., and Mohamed, A.A. 1994. Kafirin and non-kafirin content of sorghum grain. Cereal Chem. In press.

Hamaker, B.R. and Oria, M.P. 1993. Potential relationship of a HMW protein to protein digestibility of sorghum. Cereal Foods World 38:624. (Abst.)

Mohamed, A.A., Hamaker, B.R., and Aboubacar, A. 1993. Effects of flour-to-water ratio and time of testing on sorghum porridge firmness as determined by a uniaxial compression test. Cereal Chem. 70:739-743.

Mohamed, A.A., Aboubacar, A., Hamaker, B.R. 1993. Effects of flour/water ratio and time of testing on sorghum porridge firmness determined by a compression test. Institute of Food Technologists annual meeting, 232. (Abst.)

Oria, M.P., Hamaker, B.R., and Shull, J.M. 1993. Protein digestibility of developing sorghum and its relation to α-, β-, and γ-kafirin content. Institute of Food Technologists annual meeting, p. 70. (Abst.)

Oria, M.P., Hamaker, B.R., and Shull, J.M. 1993. Resistance of sorghum α-, β-, and γ-kafirins to pepsin digestion. Cereal Foods World 38:624. (Abst.)

Watterson, J.J., Shull, J.M., and Kirleis, A.W. 1993. Quantitation of α-, β-, and γ-kafirins in vitreous and opaque endosperm of *Sorghum bicolor*. Cereal Chem. 70:452-457.

Presentations

Hamaker, B.R. 1993. "Relationship of specific sorghum endosperm proteins to in vitro protein digestibility." 18th Biennial Grain Sorghum Research and Utilization Conference, held at Lubbock, Texas, February 28-March 2.

The above abstracts are titles of presentations that were made at the annual meetings for the American Association of Cereal Chemists and Institute of Food Technologists.

Networking Activities

B. Hamaker traveled to Niger in December 1992 to meet with A. Aboubacar and M. Oumarou to develop work plans for cooperative studies on sorghum and millet couscous, composite flour products using new Nigerien sorghums, and quality evaluation of breeding lines.

B. Hamaker traveled to Lubbock, Texas to participate in the 18th Biennial Grain Sorghum Research Utilization Conference, February 28-March 2, 1993.

B. Hamaker traveled to Cameroon in October 1993 as part of a group (Project SUSTAIN) to make recommendations to the USAID mission regarding food processing and marketing projects and met with IRA food scientists and the IITA food technologist. From there he went to Niger to participate in the EEP review and to meet with collaborators.

Visitors to the Purdue Cereal Lab with whom future cooperative projects were discussed included Dr. Ralph Waniska (Texas A&M University), Dr. D.S. Murty (ICRISAT), and Dr. S. Subramanian (ICRISAT).

Laboratory supplies were sent to Mr. Moussa Oumarou, INRAN, Niger.

Utilization and Quality of Sorghum and Millet

Project TAM-126

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Summary

The α- and ß-amylase activities of 23 sorghum cultivars varied significantly. Dorado a white food type sorghum had the best malt and lowest dry matter losses during malting. In addition it produced high levels of enzymes after only two days germination.

The rapid viscosity analyzer can be used to measure the level of amylase activity in sorghum malt quickly and efficiently. None of the simple physical measurements of grain or malt were highly correlated with malt properties.

Waxy sorghum hybrids produced steam flakes with the most durability, largest diameter, lowest bulk density and most attractive appearance. The white food type sorghums produced good flakes with excellent appearance. Tempering the grain to 17.5% moisture improved flaking efficiency significantly. ß-mercaptoethanol and sodium bisulfite added during tempering greatly improved flake quality while a commercial grain conditioner did not improve flaking efficiency.

JOWAR crunch, a low fat (10%) snack, was produced from new, white, tan food sorghums. Waxy sorghum made excellent JOWAR granola and granola bars because of its unique flake tenderness. JOWAR noodles, bread from sorghum-cassava blends and other products were successfully produced.

Honduras farmers are growing Sureño and improved Maicillos because the grain produces lighter colored tortillas.

In Mali, the variety Malisor 84-7 with white grain and tan plant color has produced excellent new foods. White tan plant photosensitive sorghum cultivars are needed in Mali for value added processing. Local varieties cannot be used because they are discolored.

Objectives, Production, and Utilization Constraints

Objectives

Develop new food products from sorghum and millet using appropriate technology for use in less developed areas.

Develop simple, practical laboratory methods for use in breeding programs to assess important grain quality characteristics.

Determine physical, chemical and structural factors that affect the food and nutritional quality of sorghum; seek ways of modifying the properties or improving methods of processing.

Determine the factors that affect resistance to grain molds and field deterioration in sorghum and devise laboratory procedures to detect genotypes with resistance.

Constraints

Factors affecting food quality, processing properties, and nutritional value of sorghum/millet critically affect the potential impact of other attempts to improve the crops. If the grain cannot be processed and consumed for food, then the agronomic and breeding research has been wasted. This project relates quality to measurable characteristics that can be used to select for sorghum and millet with acceptable traditional and industrial utilization attributes. It has defined quality attributes and incorporates those desirable properties into new cultivars at early stages in the breeding and improvement programs. The project also seeks to find more efficient ways of processing sorghums and millets into new foods with better acceptabilities that can generate income for village entrepreneurs.

Research Approach and Project Output

Sorghum and millet grains grown locally and from various areas of the world were analyzed for physical, chemical, structural, processing and food properties. Some of these findings are summarized.

Sorghum Malting Quality

Malting Quality of Sorghum Cultivars

Sorghum malt is used to produce a wide variety of foods and beverages in Africa and other areas. Malt quality can be improved by optimizing the malting properties of the sorghum varieties and developing improved malting procedures. We conducted several studies to determine the effect of different steeping and germination times and sorghum cultivars on the dry matter losses, enzyme activities, extract levels, density changes and composition of sorghum malt.

Five-day malts of five sorghum cultivars were subjected to extensive analysis to compare the malt quality produced from the grains. In addition the changes in carbohydrates were determined for the five cultivars. The varieties included a soft floury brown, a waxy endosperm type, a very hard food type, and two improved intermediate texture food sorghums that have been released for production in Honduras. The malt from Dorado, a white food sorghum grown in Central America, had the best overall enzyme levels and lowest dry matter losses. Malisor 84-7, a hard food sorghum developed in Mali, and the waxy sorghum had the poorest malt and greatest dry matter losses. The soft brown, high tannin sorghum had intermediate malt properties. The high quality of Dorado for malt was significant because white sorghums are thought to have poor malting potential.

Eighteen hours steeping and five days germination gave optimum enzyme levels, extracts and dry matter losses. Sound, whole sorghum contained small amounts of both α- and ß-amylases. Some cultivars like Dorado had significant amylase activities after 2 days germination. However, each variety varied significantly in the rate of enzyme development and dry-matter losses. Some varieties such as Malisor 84-7 had vigorous root and shoot growth with large dry matter losses but very low enzyme levels.

The malting properties of 16 sorghum varieties grown at Lubbock were investigated using the standard procedure typical of pneumatic malting. Total dry matter losses ranged from 8-19% The α-amylase activity in the malt ranged from 25 to 183 U/g compared to commercial barley malt with 189 U/g. ß-amylase ranged from 11 to 41 U/g. The soft floury sorghums had the best overall malt properties. However, there were white food sorghums with good overall malting properties. There are economically significant differences among cultivars in germination time required to reach optimum levels of enzyme activity. Hard sorghum grains appeared to have poor malting characteristics. Sorghums with bright red pericarp and soft endosperm were generally among the best. Thus, it appears likely that certain varieties can be found that have significant economic advantages for malt extracts for non-alcoholic beverages and weaning foods.

We had difficulty obtaining consistent results on grains grown at College Station and Corpus Christi because the samples molded during malting. Evaluation of malting potential must be done on clean bright grain otherwise the results are confounded. Weathered or even slightly molded grain cannot be evaluated effectively for malting potential.

Sorghum loses 15 to 30% of its dry matter during malting. Starch is converted to lower molecular weight molecules, dextrins, oligosaccharides and simple sugars which are metabolized during growth of the germinating seed. The respiration losses increase with germination time, so, varieties that modify and develop enzymes quickly are desirable. That is why soft, floury sorghums have an advantage for malting over hard endosperm types. The malting process tends to eliminate the adverse properties of the condensed tannins which is why brown sorghum is used for traditional village malting.

Methods of Malt Evaluation

The colorimetric methods to measure specifically α- and ß-amylases proved to be very accurate, precise, quick and cost effective under our situation.

The rapid viscosity analyzer (RVA) was a quick way (10 min) to measure the amylase activity of sorghum malts by recording the decrease in viscosity of a standard corn starch slurry treated with malt extract. The decrease in viscosity was highly correlated to α-amylase activity measured with the specific colorimetric procedure.

Prediction of Malt Quality

The use of simple techniques to predict malt quality from measurements on the grain or the malts has been only partially successful. None of the analytical and physical measurements of viable raw grain were good predictors of malt quality. There is an association of soft, floury texture with improved malting properties. However, not all soft, floury types have improved malt potential. Some white food sorghums have excellent malting properties which were not predicted from grain properties. More research to define attributes of sorghums with improved malt properties is necessary.

The CSIR in South Africa and the Southern African commercial malting and brewing industry have developed some standard methods for evaluating malt quality that are currently being revised and shared with collaborators around the world. Incorporation of this information into sorghum improvement programs will lead to improved sorghum cultivars for malting with potential for food use as well. The future of sorghum utilization in Southern Africa and possibly Nigeria is linked to improved understanding of malt quality and development of cultivars with optimum properties for malt.

Sorghum Processing Quality for Food and Feed

Steam Flaking of Sorghum

The Texas Sorghum Producers Board has funded research in our laboratory and at Texas Tech University to determine the factors affecting the steam flaking properties of sorghum. Large quantities of sorghum is processed into cattle feed by steam flaking the grain, similar to the flaking process used to produce breakfast cereals. The goal of the research is to determine if some varieties process better than others.

Seven commercial and new food types of sorghums were steam flaked in replicated trials and the flakes were evaluated for physical and chemical properties and in vitro digestibility.

The sorghums had statistically different flaking properties, i.e., flake diameters, resistance to breakage, hardness, and appearance. The waxy endosperm flakes were the most thoroughly processed and had the largest diameter, the most durability and excellent appearance. The food type sorghum was similar in flaking characteristics to the two commercial sorghum hybrids; the major difference between them was the improved appearance of the food type sorghum flakes. The waxy sorghum flakes tended to have slightly greater *in vitro* digestibilities than the other sorghum flakes.

The energy to process the sorghum was similar for most of the hybrids; however, it took more to process the very hard endosperm sorghum than it did for the others. The waxy sorghum appeared to be more easily processed into large diameter, low bulk density, durable, translucent flakes than the other sorghums.

Tempering sorghum prior to steaming reduced energy consumption and produced flakes with significantly lower breakage values. The effect of tempering was more pronounced for the waxy than the other sorghums.

The effect of various conditioners and chemicals on grain structure after tempering and steaming varied. The regular commercial conditioning agent did not alter the structure of tempered, steamed sorghum kernels while the use of chemicals that break disulfide bonds (sodium bisulfite, ß-mercaptoethanol) caused significant changes in sorghum kernel structure. The protein matrix was partially dissolved, which should facilitate steam flaking and improve digestibility.

The experiments this past year showed clearly that sorghum hybrids have significant differences among them that affect their flaking properties. However, the results must be repeated to confirm that the differences are real. Thus, grain of the same hybrids has been increased at Halfway, Texas for additional processing trials using the Texas Tech laboratory steam flaking procedure developed this past year. Additional equipment to more precisely monitor the amount of energy consumed is being acquired. The effect of tempering and steaming times on moisture uptake of different hybrids will be determined.

Tortilla Quality

Sorghum varieties with improved food quality for use in tortillas are being grown by farmers in Honduras. Farmers in Southern Honduras grow the variety Sureño because it produces lighter colored tortillas and has a sweet stalk for forage. Two improved Maicillo cultivars are preferred for tortillas. All samples from the advanced Maicillo nurseries grown in Honduras are evaluated for tortilla quality here in the Cereal Quality Laboratory at Texas A&M. The data are used by Dr. F. Gomez, Sorghum Breeder, Pan American Agricultural University, Zamorano, Honduras to select for tortilla quality.

A black seeded sorghum cultivar from the Sudan produced tortillas and tortilla chips with a very dark blue color and an interesting taste. Special sorghums could be used to produce specialty products similar to blue maize products.

Pearl millet tortillas and tortilla chips had excellent flavor and color. Pearl millet has good potential for commercial food products.

JOWAR Granola and Breakfast Foods

Two food-grade sorghum hybrids, ATx631*Tx436 (non waxy), and B.BON 34 (waxy), were micronized and evaluated for use in ready-to-eat breakfast cereals (RTE-BC). Whole and decorticated grains were exposed to infra-red burners and flaked between corrugated rollers. Whole grain

waxy flakes had the lowest density, best flavor, texture, and the most starch gelatinization. Decorticated waxy flakes were extremely thin and fragile. Based on flake characteristics, whole waxy and decorticated nonwaxy flakes were used for granolas. Whole nonwaxy flakes (27.4% amylose) were used for the preparation of a flaked cereal with reduced rate of starch hydrolysis.

Granolas were prepared by mixing, baking, and cooling sorghum flakes, wheat bran, sesame, sunflower seeds, raisins, sorghum molasses, oil, fructose and water. A control granola was prepared with rolled oats instead of sorghum flakes. All granolas were crisp, sweet with a nutty flavor. Decorticated nonwaxy granola had the hardest texture and remained crisp in milk for the longest time. Whole waxy granola was preferred ($p<0.05$ N=36) by a sensory panel over the decorticated nonwaxy granola.

A flaked cereal was prepared by mixing, extruding, flaking and baking ground, whole nonwaxy flakes with high amylose starch, mono and diglycerides, sugar, salt and water. Flaked cereal with the highest amylose content had the slowest rate of hydrolysis and the least starch gelatinization.

Acceptable RTE-BC were produced from food-grade sorghums with different endosperm types using different technologies. Waxy sorghum produced the best flakes for granola. Non-waxy sorghum produced the best flaked cereal with a relatively slow rate of hydrolysis.

Noodles

A system for the production of noodles from sorghum (100%) was developed. A dough ball of sorghum flour (100 g):water (65-70 ml) was cooked in excess water for 30 minutes before being extruded into noodles. The extruded noodles were surface gelatinized by dipping them in boiling water for 10-15 seconds after which they were dipped in cold water for 10-15 seconds before being dried in a forced-air oven for at least 18 hours.

Grains of four sorghum cultivars were decorticated by tangential abrasion and the decorticated grain was milled into flour using modified wheat roller milling procedures. The four sorghum cultivars represented a soft, hard and an intermediate texture sorghum plus a waxy endosperm. In addition, sorghums with tan plant color and straw colored glumes were compared to one with purple plant color. The sorghums with an intermediate to hard endosperm texture and tan plant color had the highest milling yields, and the lightest flour color. The intermediate to hard endosperm texture flours produced non-sticky freshly extruded noodles with good handling properties. They produced relatively hard dried noodles which absorbed less water during cooking. The noodles had dry-matter losses during cooking comparable to rice noodles and they were not sticky. The soft sorghum produced unacceptable noodles. They were sticky and had poor color and high dry matter losses during cooking.

Flours with finer particle size produced stronger, smoother, and lighter colored noodles with reduced dry-matter losses compared to coarse flours.

The 100% sorghum noodles, especially those from Dorado, a white tan sorghum from Central America, had acceptable flavor and texture. The taste panel was composed of people who were used to consuming wheat noodles. However, they still liked the sorghum noodles even though the texture was different from wheat noodles. Thus, sorghum could be used to produce desirable noodles at a relatively low cost. The variety of sorghum is critically important.

JOWAR Crunch

Traditional alkaline-cooking was modified to produce JOWAR crunch, a new snack from special food sorghums. JOWAR is a name given to special white food-type sorghums. JOWAR (from Dorado) was boiled (96°C, for 30 and 60 min) or autoclaved (120 C for 30 and 60 min) in water (1:5) containing CaO (1.5% based on JOWAR weight). After cooking, the JOWAR was washed, drained and dried to produce "pellets" which consisted of dehulled individual kernels. The pellets were dense, and could be stored for a long time. JOWAR crunch was produced by deep fat frying the pellets.

Factors affecting the quality and yield of JOWAR crunch included the extent of cooking, the moisture content of the pellets and the oil temperature during frying. Pellets with higher moisture contents (≥ 8%) yielded acceptable products when fried at a lower temperatures. Shorter cooking times produced JOWAR crunch with higher densities and lower fat contents than pellets cooked for longer times or at higher pressures. Fat content of JOWAR crunch ranged from 10-19 which compares to 23% for tortilla chips. JOWAR crunch prepared from pellets with 60 min cooking time and 8% moisture content had optimum yield (96%) and a crunchy texture. The addition of seasonings to JOWAR crunch yielded delicious snacks with a relatively low fat content.

Sorghum Cassava Starch Yeast Bread

A low specific volume (3.3 - 4.0 cm^3/g) yeast-leavened bread was prepared from blends containing sorghum flour (70%), gelatinized cassava (20%) and raw cassava starch (10%) or sorghum flour (75%) and gelatinized cassava starch (25%).

The cassava starch (20 or 25%) in 90% water (based on 100g of table flour) was brought to boil and held for 4 minutes. The gelatinized starch paste was cooled to 30°C and mixed with sorghum flour, sugar (8%), dry yeast (2%), salt (2%) and raw cassava starch (if used) to develop batter

which was scaled, fermented and baked at 192°C for 20 minutes. The gelatinized starch enhanced batter cohesiveness and viscosity. Sorghum-cassava bread had greater loaf volume (520-550 cm^3) and significantly better crumb structure than the bread produced with sorghum alone (390 cm^3).

Light flours free of black specks and with fine particle size distribution were produced from decorticated sorghum grains using roller mills. Dorado flour (25% amylose) produced the best bread. ATx630*Tx435 flour (17% amylose) produced bread with less loaf volume and a sticky crumb. Waxy flour (2% amylose) produced unacceptable bread with wet, sticky crumb and low loaf volume. Freshly baked Dorado sorghum-cassava starch breads had acceptable texture and flavor, but they staled rapidly. Apparently, amylose plays a critically important role in the breadmaking quality of sorghum flours used in cassava starch blends.

Dough additives, shortening and succinylated monoglycerides (SMG) increased loaf volume, 6.5 and 9.0% respectively, and improved crumb structure. A combination of 1% shortening and 1% SMG enhanced loaf volume and crumb softness, but caused a rancid off-flavor. Glycerol, sodium stearoyl-2-lactylate, xanthan gum, gluten and glycerol monostearate did not increase bread volume and had no effects on crumb properties at practical levels.

Nonwheat, yeast-leavened bread can be made with fine sorghum flour when gelatinized cassava starch is used to provide a continuous network to disperse the sorghum flour. The bread can be sliced and consumed similar to 100% wheat bread, although it stales rapidly. This baking procedure could be useful to produce a convenient, tasty bread in tropical countries where wheat flour is unavailable or expensive.

Grain Molds

Sorghum grain molding is a serious problem resulting in substantial losses in yield and quality. Two major fungi associated with fungal deterioration of sorghum grain are *F. moniliforme* and *C. lunata*. Several agronomic, physiological and biochemical characteristics of the grain have been identified that correlate positively with resistance to molding. However, none of the properties alone convey effective mold resistance to cultivars.

Recently, antifungal proteins have been found in sorghum. Various isozymes of chitinase (29 kDa) and sormatin (22 kDa) have been identified in different sorghum cultivars. The intensity of these bands varies among cultivars. Chitinase and β-1,3 glucanases could play a role in the defense mechanism of plants because of their ability to digest chitin and β-glucans, which are major cell wall components of fungi. Sormatin acts by permeabilizing fungal plasma membranes. Sormatin and the endosperm proteins are reported to inhibit the growth of *F. moniliforme in vitro*. Their effects on *C. lunata* or other common sorghum grain molding fungi are unknown. We initiated research to study the role of anti fungal proteins in resistance of sorghums to molding.

Preliminary results indicate that sormatin levels increased during maturation in four different cultivars (Malisor 84-7, SC103-12E, SC326-6 and 91BE7151). Sormatin levels were also different among the cultivars. Sormatin may increase during germination. Differences were also observed in levels of chitinase and a 30 kDa endosperm protein in mature seeds of BTx378, Malisor 84-7, Sureño and Tx430 x 2817. The extent of grain molding was inversely correlated with the level of 30 kDa endosperm proteins. A positive correlation existed between chitinase levels and grain molding.

Further experiments are required to clarify the role and mode of action of antifungal proteins during growth and development of the sorghum kernel and to relate it to mold infection and proliferation. Research in this area will be expanded in a two year research project funded by Pioneer Hybrid Seed Company. This new approach may lead to significant improvement in grain mold resistance of sorghum.

Collaborative Sorghum Improvement Research

This project cooperates closely with other members of the sorghum program to incorporate the best quality characteristics into sorghum. Samples from the breeding nurseries and from the food quality tests grown at different locations are tested for kernel characteristics and for processing properties such as decortication and tortilla processing. The alkaline cooking tests are especially sensitive and pick up off colors and aromas.

From this research, Texas A&M has released several inbreds that produce white, tan-plant sorghum hybrids which have excellent food and feed processing quality. For example, recent work in Mexico has confirmed that the new food sorghums gave 65% yield of grits compared to 50% yield of grits from existing commercial sorghum hybrids. In addition, the color of the grits from the white food sorghums was significantly improved. These sorghums produce excellent quality grain when grown under dry conditions. Because of reduced anthocyanin pigments, the grain can withstand some humidity during and past maturation. However, these sorghums need more resistance to molds and weathering to be grown in the hot humid areas of the world.

Networking

Travel

L.W. Rooney traveled to Mali to confer with personnel in the Food Technology laboratory on sorghum and millet quality evaluations and development of new food products. The laboratory is undergoing some changes in personnel and needs additional help to achieve its objectives. Increased emphasis on developing improved local sorghums with

photosensitivity, tan plant and straw glume color by the plant breeders will provide grain for processing into high quality products. Research on parboiling, weaning foods from cowpeas and millet, instant masa flours and quality evaluation of breeders samples continues.

L.W. Rooney, Marta Gomez and Laura Cruz y Celis presented information on sorghum and maize quality/ technology to participants at the Latin American and Mexican Symposium on Food Science and Technology in Mexico City, Mexico. Two-hundred scientists from Mexico and Central America participated in the conference.

L.W. Rooney participated (partial expenses from INTSORMIL) in the International Cereal Chemistry Congress in Pretoria, S. Africa where he and Professor Taylor, University of Pretoria, organized a two day sorghum symposium as part of the conference. L. Rooney presented seminars and discussed sorghum food quality personnel at the Summer Grains Research Center in Potchefstrom and several food companies that process sorghum into foods. A significant amount of sorghum is milled and sold for porridge in South Africa. Many of the new food type hybrids can be grown in South Africa.

Dr. H.D. Almeida-Dominguez, Institute of Technology of Merida, Mexico, received funding from the International Foundation for Science for research on Utilization of white sorghums for food in southeast Mexico. The Texas A&M Cereal Quality Lab is a collaborator. The objective of the study is to determine the milling and malting quality of grain from 102 sorghum lines grown in Merida, Yucatan. A student from Merida spent three weeks conducting analyses on sorghum malt in the Cereal Quality laboratory. Some chemicals and supplies have been sent to Merida.

Cooperation with the University of Sonora continues, with publication of papers resulting from our previous research.

Dr. R. Waniska traveled to India (partially funded by INTSORMIL) where he conferred with ICRISAT scientists working with sorghum and millet quality. He also conferred with scientists working on cereal chemistry at the Central Food Technology Research Institute at Mysore. He presented seminars on tortilla and other sorghum food systems. Information on anti-fungal proteins in sorghum was obtained from Dr. A. Chandrashekar and students. These ideas will be evaluated in subsequent trials evaluating mold resistance of sorghums.

L.W. Rooney has a cooperative project with Dr. S. Serna-Saldivar, Professor, Food Science, Monterrey Institute of Technology (ITESM), Monterrey, Mexico to evaluate the usefulness of the new improved food sorghum hybrids in milling and as adjuncts in brewing. Cerveceria de Cuauhtemoc, in Monterrey, has financially supported the project and are conducting milling and brewing trials on grits from white food type sorghums. Results are promising. Dr. Serna-Saldivar and three ITESM MS students conducted sorghum and maize analyses for two weeks in the cereal quality lab.

L.W. Rooney traveled to Rio de Janeiro, Brazil (no expense to INTSORMIL), to provide assistance to EMBRAPA on food science and technology research on corn and sorghum. Seminars were presented to the Brazilian Dry Maize Millers Association, to staff of the EMBRAPA maize and sorghum research center in Sete Lagoas and to the food technology research center staff.

North America

Several papers were presented at the annual American Association of Cereal Chemists conference in Minneapolis, Minnesota, and the Institute of Food Technologists Food Exposition in Chicago, Illinois. L.W. Rooney presented sorghum quality/ utilization discussions to Texas Sorghum Producers Board Members and other farm groups.

Several members of the cereal quality lab presented posters and papers at the 18th Biennial Grain Sorghum Research and Utilization Conference in Lubbock, Texas.

Training

One Ph.D. and two M.S. students completed their studies and returned to Mexico, Botswana and Tanzania. Five other students are nearing completion of M.S. degrees.

L.W. Rooney currently serves as chairman of the Sorghum and Millet Working Group of the International Association for Cereal Science and Technology.

Accomplishments of the Project over 15 Years

This project has collaborated with many scientists in a large number of countries and with colleagues from different United States universities. The productivity has been outstanding because of the many unselfish collaborators we have had. A partial list of some accomplishments is presented. We acknowledge that nearly all of them have had significant input from our collaborators and could not have been accomplished without the interdisciplinary efforts so typical of INTSORMIL.

Sorghum and Millet Food Quality

Traditional foods from sorghum and millet were classified into seven major categories based on processes by local consumers.

Laboratory procedures for producing each major food class were standardized and used to determine the critical attributes of grain quality.

The processing and food quality of new sorghum varieties affect their acceptance. Poor food quality caused several new varieties to fail.

Sorghum kernels with thick pericarp and hard endosperm have the best dry milling properties for hand dehulling and thick porridge production.

Simple, practical laboratory tests to evaluate food quality of sorghum and millet were devised and utilized to improve processing and food quality. For example, an alkali test to estimate color of sorghum lines has been used to select for tortilla quality.

Varieties with good processing properties have been identified and selected by breeders based upon quality tests devised in this project.

The genetics of sorghum kernel characteristics have been documented and related to their structure and functionality in the major food systems.

Kernel size and shape affect the milling properties of sorghum and millet. Harder, white, spherical sorghum kernels have the best dry milling properties. Souna pearl millets with long,slender kernels have poor milling properties.

Grain molds and weathering affect the quality of sorghum significantly. In West Africa, head bugs attack the grain of improved types and together with molds reduce food quality. Such grain has soft kernels that are destroyed during decortication. The flour produced often produces poor quality thick porridge. Photosensitive sorghums are required in these areas.

In Mali, a food technology laboratory was developed, equipped and personnel trained to conduct post harvest technology research on cereals and oilseeds and legumes. It evaluates breeders samples for milling and food quality.

In Honduras and Mexico, sorghums with vastly improved properties for tortilla production were identified. Methods of evaluating tortilla quality were developed. These test have been used to select for sorghum with improved tortilla quality in Honduras.

New Food Products and Processes

Major food products have been produced using sorghum and millet grains. Ready to eat granolas, noodles, snacks, nonwheat breads, instant porridge, couscous, parboiled rice like products have demonstrated the usefulness of improved food quality cultivars.

Waxy sorghum grain has excellent potential for use in breakfast foods such as granola because of its unique expansion properties.

The laboratory in Mali produced a mixture of 25% peanuts and 75% pearl millet flour for use as a weaning food for young children. The product was successfully used in several villages. Currently some local entrepreneurs are attempting to commercialize the product.

Parboiled sorghum and millet was evaluated in Mali and found to have excellent potential when new cultivars with white tan plant color were used. The local sorghums produced off color products that could not compete for markets with wheat and rice.

Cereals soaked in alkali for a short time prior to milling produced flours with good storage stability. Corn flour was improved the most by the process. The laboratory in Mali evaluated the technology in several village trials. This treatment permits marketing of processed sorghum and millet flours.

Sorghum can be used to produce acceptable tortilla chips and other alkaline cooked products. It is critical to use white, tan plant sorghum kernels. These types have excellent milling properties also.

Millet with a white seed makes superior parboiled and decorticated products. White millet has excellent potential for use in snack foods and other products because of its strong flavor and light color.

The importance of head bugs, molds and weathering on grain quality was documented in Mali which has lead to a concerted effort to develop local photosensitive types with tan plant and glume color to provide high quality grain for value added processing by local processors. This is a key finding that will lead to availability of sorghum for use in foods of high quality to compete for markets with rice.

Contributions to U.S. Agriculture

Cooperated in the development of several white, tan plant, high-yielding sorghum hybrids adapted to the U.S. and Mexico that produce high yields of grain with value added quality characteristics.

New sorghum hybrids with improved quality for food and feed processing allow U.S. sorghum to compete more effectively for International markets.

Mexican breweries utilize sorghum in brewing and are planning to use U.S. white sorghum because it has improved milling properties. Trials are underway currently with white, waxy sorghums.

Information on the tannin content of U.S. sorghums has allowed U.S. producers to gain a better market share of the world sorghum market. Information generated on tannins was published and used to document the superiority of U.S. sorghum over competing grains.

Information on the improved nutritional value and processing properties of current sorghums has been documented and used by U.S. sorghum producers in marketing and promotion programs to obtain new and retain old domestic and international customers.

Information generated on sorghum processing for tortilla and alkaline foods has been applied to corn products produced in the U.S. These techniques to evaluate corn quality are used by the U.S. food industry. They would not have been developed without INTSORMIL support.

Fundamental information on the genetics and quality of sorghum has been used by the sorghum industry.

Prototypes of food products from sorghum and millet demonstrate the potential of the crops for use directly in human foods.

The wide array of germplasm provides potential sorghum types with unique components for industrial product development.

Fundamental information on sorghum and millet structure, chemistry and nutritional quality has provided a basis for improved utilization efficiency, domestically and internationally.

The project has provided training to many domestic and international students who have significant leadership in the food industry in the United States and many other countries. Over the long term, these young scientists are the most important products from these concerted research efforts.

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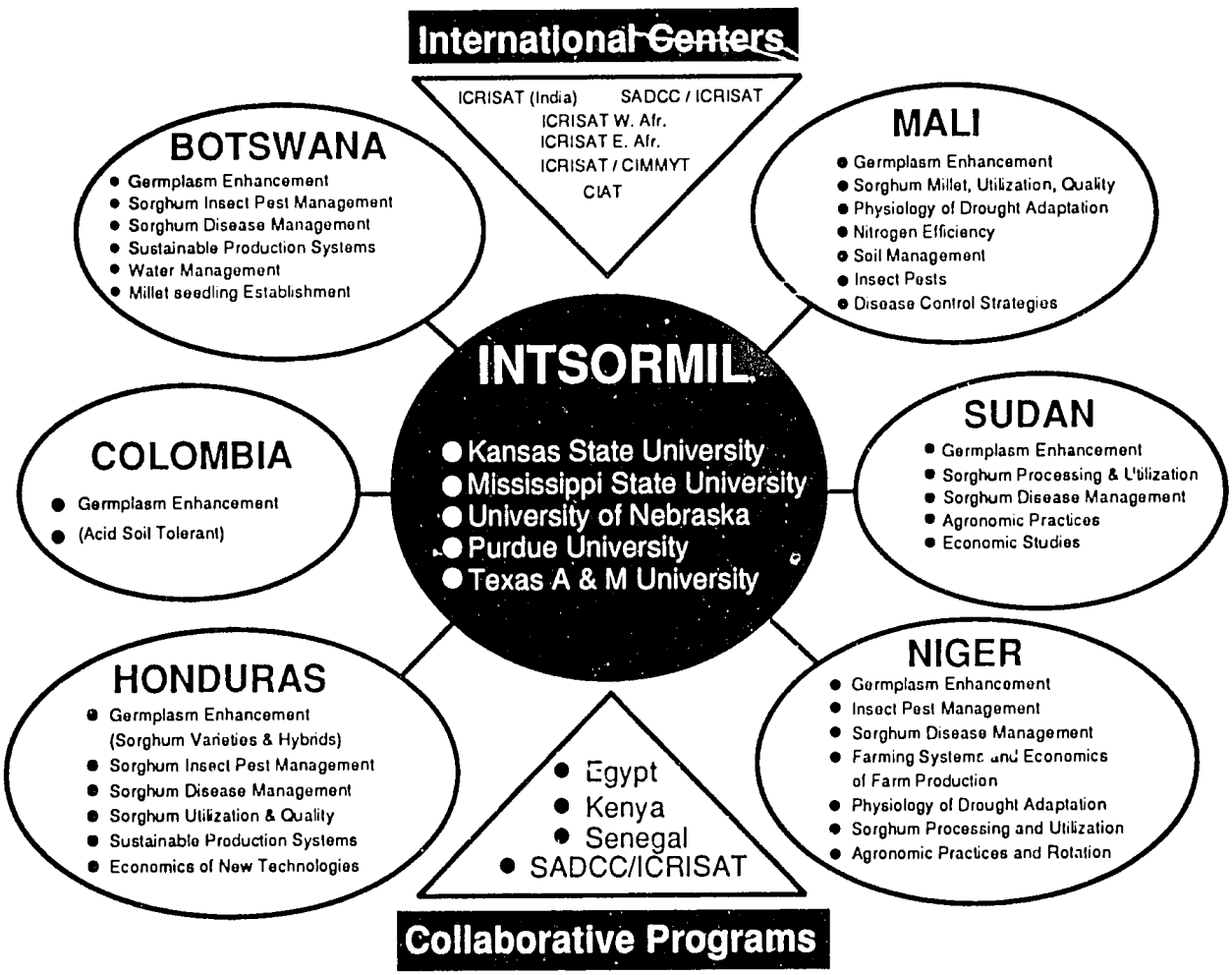
Host Country Program Enhancement

INTSORMIL Collaborative Sites



Botswana

M.D. Clegg
University of Nebraska

Coordinators

Dr. Chris Manthe, Entomologist, Botswana (Host Country Coordinator), Gaborone, Botswana
Dr. M.D. Clegg, Department of Agronomy, University of Nebraska, Lincoln, NE 68583 (U.S. Coordinator)

Collaborative Program

Organization

The Botswana project initially operated under an MOU between the Government of Botswana (GOB), USAID/Botswana and the provisions in Grant AID/DSAN/XII-G-0149 to the University of Nebraska, the Management Entity (ME). Funding of the project was provided by the Government of Botswana (GOB), the University of Nebraska (KSU-107) and USAID/Botswana ATIP Project. The INTSORMIL technical assistance positions were associated with the Agricultural Technology Improvement Project (ATIP). A Memorandum of Agreement between the GOB, USAID/Botswana and the INTSORMIL ME was extended for two years to continue agronomy/soil research after ATIP was completed in 1990.

The Botswana program model essentially consisted of two related components: an INTSORMIL researcher stationed in the country and scientist to scientist collaboration. Dr. Douglas Carter assumed the position of the cereal agronomist in 1984. A second position in the area of soil physics (Dr. Naraine Persaud) was added in 1987. Administratively these positions were considered a part of the Department of Agricultural Research (DAR), under the direction the Chief Arable Research Officer. Emphasis of the program was soil water management research. The technical objective of the project was to continue and expand the on-farm and on-station research on tillage and fertilizer practices across the various rainfall and soil conditions in Botswana. Also, a junior agronomist position (Wayne Youngquist) was filled in 1984 to maintain the research of Lucas Gakale, who was on leave at the University of Nebraska for study towards a Ph.D.

Scientist to Scientist Collaboration

Collaboration and/or contact with various scientists in the areas of agronomy, plant breeding, plant pathology, entomology, and food quality are detailed in the various individual projects.

Financial Inputs

GOB provided office and laboratory space, land, technicians, and other research support costs. USAID/Botswana provided housing, supplemental furniture and other normal allowances and entitlements available to USAID contract employees and similarly allowances and entitlements at the completion of the assignment. INTSORMIL provided salaries and benefits. USAID funded its responsibilities through the Botswana Agricultural Improvement Project, the GOB through its normal budgetary sources and ME of INTSORMIL at the University of Nebraska. The ME was responsible to USAID for fiscal matters and research progress. These resources allowed the Botswana program to undertake comprehensive and collaborative research on dryland sorghum/millet production. With the expiration of the project no research funding was designated for program use.

Collaboration with Other Organizations

Water harvesting research was conducted in collaboration with the SACCAR Land and Water Management project and ATIP. Collaborative activities in entomology, pathology, and plant breeding are with ICRISAT in Bulawayo, Zimbabwe. This activity has led to the establishment of a grain sorghum winter nursery in the Zambezi Valley, Mzarabani, Zimbabwe. Collaboration occurred with the ODA Land and Water Management project on rainfall runoff, with IBSNAT on DSSAT software, Department of Meteorological Services on agroclimatic data and FAO sponsored Soil Survey and Mapping Services on site selection and characterization.

The Planning Process

Each year research by the DAR scientists is reviewed at their annual planning meeting in September or October. The work plans are circulated among the scientists for review and then presented at this meeting. Other collaborative research program scientists and/or administrators of DAR are also involved in the planning process.

In 1990, a review by ISNAR of Botswana's Agricultural System recommended that DAR establish commodity, factor and systems based programs, interdisciplinary in nature and oriented towards production of farmers. The priority programs recommended and established are: 1. Cereals, 2. Grain legumes, 3. Oil seed, 4. Horticulture, 5. Soil and water management and 6. Crop based production systems, (including agroforestry).

Sorghum/Millet Constraints Researched

Production Constraints

Sorghum is an important crop in Botswana. Grain sorghum is used as food and the stalks are used as feed for livestock. Even in dry years 70% of the land planted is harvested. However, in the last decade of the 80's, farmers' yields have averaged only 161 kg ha^{-1}. These low yields partially reflect hectares that are planted but are not harvested. Farming is subsidized by other enterprises, mainly cattle.

The low, irregular, and low-efficiency rainfall pattern, sandveld and hardveld soils with low moisture retention, low N and P content, broadly graded sand fractions, and unstable surface contribute to the low yield of sorghum and millet. Broadly graded sand fraction and unstable surface are properties which result in a high bulk density and a massive hard structure when dry, and surface sealing and crust formation. This tends to impede rain infiltration and root penetration. Moisture conservation and redistribution technologies, fertility improvement, residue incorporation, and weed control are urgently needed to improve soil structure and water infiltration and availability for promoting crop establishment and improved grain and stover yields.

Research Methodology

Because of the diverse nature of research being conducted it is not possible to outline specific research procedures. These will be included in the various individual reports.

Research Progress

Factors effecting the utilization of sorghum flour for production of noodles were studied using techniques that might be used at the village level. The noodles were made without wheat flour. Noodles could be produced with acceptable texture.

Planting date influenced the incidence of several diseases. Early plantings had almost no sorghum downy mildew and lower levels of leaf blight. Virus symptoms were also present on a large number of materials but the incidence and severity was variable. It was noted in a large farmers field that there was some very late occurrence of sooty stripe and leaf blight.

Pearl millet research is continuing. A pearl millet variety from Botswana Serere 6A, was entered in multilocation tests for the second year of evaluation. Selection for adapted drought tolerant food quality varieties and seed parents are continuing. Backcrossing continued on selected seed parents and 220 testcrosses from the winter nursery were evaluated. Low rainfall permitted selection for drought tolerance. The best lines and seed parents identified in 1993 are being increased in the winter nursery and also being used in making hybrids.

Mutual Research Benefits

Presently, food types of sorghum and millet are being utilized in the U.S. These types offer better grain quality. Techniques in plant breeding and soil fertility developed in the U.S. are being utilized for improving agricultural production in Botswana. Emphasis on sustainable agriculture will lead to improvements in crop production management for the mutual benefit of the U.S., Botswana and southern Africa.

Value added to sorghum can be obtained with studies of sorghum flour use in products such as noodles and improved malting characteristics of the grain. Progress is also being made so the sorghum flour and malting characteristics can be applied in breeding and selection programs.

Institution Building

During the initial years an irrigation system, pickup truck, Neutron probe for soil moisture, computer and software, cone planter units, tensiometers, micrologger and accessory equipment, Metler balance, an infrared thermometer, etc. were provided by INTSORMIL.

Since 1980, many of the major agricultural research administrative positions have been staffed with national scientists. SADC/ICRISAT/INTSORMIL and USAID/Botswana have contributed to educating many of them. The earlier trained scientists continue to move into administrative positions and now even to teaching responsibilities in the Botswana College of Agriculture.

INTSORMIL PIs continue to maintain collaborative contacts with national scientists. Professor Andrews in Plant Breeding; Dr. Clegg, Agronomy and Dr. Odvody, Plant Pathology are examples.

Within the DAR, various staffed regional research stations are being implemented. Botswana funding is available to establish stations at Kgalagadi and Francistown regions and to improve existing research facilities at Maun, Pandamatenga and Sebele.

Networking

A multidisciplinary working group of DAR researchers, ALDEP, field managers, the SADC/ODA Land and Water Management Project, and the FAO/UNDP supported Soil Mapping and Advisory Services jointly planned and implemented the field research. Dr. Naraine Persaud initially chaired this group.

The INTSORMIL researchers worked directly with the DAR. Information is distributed in other southern African areas through SACCAR and ICRISAT. Collaborative re-

search continues to be published as reports, bulletins and journal articles. These include: The Bulletin of Agricultural Research, Botswana; Agrinews, Ministry of Agriculture, Botswana; Experimental Agriculture, printed in Great Britain.

There have been many trained students returning to the southern Africa region. Thus, there is an opportunity for the organization of a support group to keep them in the mainstream of current research. Electronic mail linked through national programs and universities can be an excellent vehicle for this purpose.

General Comments

The greatest impact that can be derived from INTSORMIL is the training of students. In Botswana there is a small number of trained personnel. Many students that have been trained to do research have been assigned administrative roles and now some are taking positions in the Botswana College of Agriculture. Some also have moved into the private sector. A positive development is that students with a B.Sc. in Agriculture are being trained and are being hired into the available research positions. However, these scientists can benefit from a program in which there is the assistance from Technical Advisors to aid them in developing and implementing programs. This should be supported by INTSORMIL, DAR, and other donor agencies.

Botswana is a country that is marginal for cultivated agriculture. Water and nutrients are very limited. Management for improved water use and water harvesting and for improved fertility must be continued. This is very important as cultivars are available or are being developed that yield better with more favorable growing conditions.

Research Accomplishments

Agronomy

Drought has prevailed over the duration of the project. However, manure/crop residues were effective in increasing rainfall intake. Manure by itself was quite effective, but combined with residues, intake was even greater. Short season hybrids may have a place in sorghum production. Segaolane, an improved variety, still has good yield ability because it is well adapted to Botswana.

Management practices on rain runoff showed if additional water could be diverted to a site, better yields resulted. Practices associated with better water availability must be coupled with the proper plant population and pest control. In the event excess water occurs, the system must be designed to release water without erosion. The National Tillage Trials showed early tillage frequently improved soil water storage. This coupled with fertilizer (15 kg P ha^{-1}) generally increased yield. Due to low yield, addition of P was not economical where soil P was greater than 5 mg kg^{-1}. Nitrogen was not influential unless the rain was uniformly distributed over the season. Results from the studies of this project have been fully documented in journals, extension publications, and presented and disseminated locally in Botswana. All the data have been computerized and archived in an easily accessible DBASE3 database. The data have already been used for model validation and requested for by BCA students for use in term papers.

Entomology and Pathology

Identification of resistance to the sugarcane aphid and identification of predators that will attack it have been found. These should aid control of this pest. Sorghum nurseries in Texas A&M, SADC/ICRISAT, and SADC programs show that good anthracnose resistance is available in introduced and improved local germplasm.

Sorghum/Pearl Millet Breeding

The SADC/ICRISAT regional program are involved as the sorghum and pearl millet breeders there are providing off-season generation advance and seed increase of the Botswana/INTSORMIL selections. Lines and advanced lines were evaluated and those with potential are being utilized as parental lines. A seed parent from Segaolane has been developed. Variability on both the female and male sides is being used to develop adapted hybrids for Botswana. The pearl millet breeding program has made selections from a Serere 6A population. An advanced improved line from this population is being tested for its potential as a new variety.

Food Science and Technology

It is possible to produce noodles from only sorghum flour using small, low technology equipment. Thus, the use of sorghum can be diversified.

Soil Fertility

Soil from 14 sites across the major grain producing regions of Botswana were collected. These soils were analyzed for N, Ca, Mg, K, S, P, Mn, Cu, Fe, and Zn. These samples are being used to establish baseline critical levels for the elements listed. This information is critical to allow more precise interpretation of soil data fertilizer recommendations.

Other Southern African Students

Research by other students in southern Africa has relevance to utilization by the entire region. Students have completed research in the areas of plant breeding, agronomy and soil fertility, food technology, entomology, plant pathology, agricultural economics, statistics, microclimatology, etc. Although, there have been a substantial number of students trained, many have progressed into administration, teaching or joined the private sector. Thus, training must be continued.

Egypt

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Plant Pathology

Objectives

Determine whether aerial infestation with a spore/hyphal fragment suspension, toothpick infestation, or soil infestation is the most effective method for assaying sorghum resistance to *Acremonium strictum*.

To identify sorghum germplasm with tolerance to Pokkah Boeng and Fusarium stalk rot.

To characterize genetic diversity within the pathogen population and to identify pathogenic strains to be used in breeding challenges and nonpathogenic strains to be used in a biological control program.

Methods and Materials

Toothpick inoculation: Wooden toothpicks were boiled in water to leach out fungal growth inhibitors in several changes of water. Toothpicks were placed in a test tube containing media and then inoculated with an agar disc from the fungal culture. The tubes are incubated at room temperature for fungal growth. Sorghum plants (55-60 days) are inoculated by puncturing the stalk with a sharp metal nail and then inserting the infested toothpick.

Soil infestation: Fungal inoculum will be produced on sterilized grain sorghum kernels in 500 ml milk bottles. *A. strictum* will be added to the bottles and then incubated at 30 C for three to four weeks. The inoculum is added to Nile silt at the rate of 5-7 g/kg soil and then placed into 25 cm diameter clay pots. Disease ratings are made 90 days after sowing.

Aerial inoculation: An aqueous conidial suspension is made with 10-day-old *A. strictum* cultures. Leaves of one-month-old plants will be clipped with scissors, sprayed with inoculum, and then covered with a plastic bag for 24 hours.

Eighty-six accessions from the Sorghum Section, Field Crops Research Institute were examined for stalk rot due to natural infestation at two locations (Shandaweel and Gemmeiza). A limited number of lines (7) were evaluated for resistance to *Acremonium strictum* using the toothpick infestation method.

Results

An extensive survey throughout all sorghum production regions in Egypt was conducted in September, 1991. The major diseases of sorghum identified during this survey included: sorghum downy mildew, *Acremonium* wilt, pok-

kah boeng, maize dwarf mosaic virus, long smut, and covered kernel smut.

The following table reports on results from an experiment that was conducted during 1992 with only infested soil containing *A. strictum*. In 1993, all treatments will be evaluated with 3-5 cultivars.

Cultivars	% Plants Infected
Giza 3	60
Giza 15	40
Giza 114	50
Giza 123	30
Local 169	80
CS 3541	25

Vegetative Compatibility Groups (VCG) are very useful techniques for detecting different strains within the same genus and species of fungi. Nearly 120 Egyptian isolates (59 from maize and 60 from sorghum) have been analyzed and 58 different VCG's have been identified. Twenty-one of these groups have more than one strain; 13 can be found at more than one location, and 7 of these 13 were found on both maize and sorghum. This pattern is very different than observed on maize and grain sorghum in the United States. This will likely be a very important parameter for breeding for resistance to fusarium stalk and root rot in maize and sorghum. Contamination of seed and feed grains with fumonisin mycotoxins is also an important aspect of the VCG strain variability within *Fusarium moniliforme*. Some VCG's have negligible amounts and other strains produce fumonisin at unacceptable levels for food products.

Physiology/Production

Objectives

1. Develop water control irrigation systems which permit control and measurement of water applied to research plots for water and nutrient use efficiency investigations.

2. Determine the influence of water level and nutrient level on water use efficiency (WUE) and nutrient use efficiency (NUE).

3. Evaluate short, white seeded, tan plant selections at Shandaweel for general adaptability in preparation for later stress screening tests when sprinkler systems become available.

Research Methods and Approach by Objectives

1. Little is known about WUE in sorghum and other crops in sorghum based cropping systems because of inadequate water application control and measurement. Therefore, considerable time has been spent in designing a flexible recycling irrigation system suitable for small plot work. The system will be field tested in April, 1993.

2. Objective 2 will be addressed in 1993.

3. Six hundred plus lines from a stress resistant population were grown out to assess their general adaptability.

Research Results

Research results in general are meager due to delays in receiving equipment funding but should progress satisfactorily from this point on. Irrigation equipment for cultural NUE and WUE experiments is available and should be used effectively in the summer of 1993. A LICOR 6200 is in place and training on it will commence in early 1993. Proper water stress screening systems are not yet readily available. 1993 should be a productive year.

An appropriate water delivery system to accurately deliver and measure water volumes for 15' x 20' plots was developed.

Three water levels (250, 350 and 450 mm/feddan) were used at four nitrogen application levels (0, 60, 80, and 100 kg N/feddan) to partially evaluate water, nitrogen and interaction effects. Yield data for sorghum after clover and barley are given in Table 1.

The clover effect at 0 N addition improves with each added water level. Respective yield increases from clover at 250, 350 and 450 mm of water are 1.9, 2.6 and 4.0 ard/fed. The respective N equivalents attributable to clover at 250, 350 and 450 mm are roughly 60, 70 and 80 kg N/fed. The influence of water level on the efficiency of nitrogen extraction after clover is clear. Also, the yield increases from added N at the 450 mm water level after clover are fairly linear through 80 kg of N and remain substantial at 100 kg N which suggests that both higher water and N levels need to be tested.

The yield response to successive water level increases averaged across all fertility levels is 50 to 145% higher after clover. The data in Table 1 could be scrutinized in detail regarding water and nitrogen level effects on water use efficiency. More years of data are needed to reach sound conclusions. Suffice it to say that the value of legumes in sorghum based cropping systems appears increasingly attractive as nitrogen fertilizer costs increase. These kinds of tests need to be run at several locations. Stress screening of different legumes, particularly forage cowpea or other forage legumes, in the more marginal areas would appear to be valuable.

Evaluate white seeded, tan plant germplasm at Shandaweel.

An effort is being made to broaden the germplasm base being utilized in Egyptian breeding programs. Since light colored seeds are desired, 930 sorghum derivatives from a preanthesis stress resistant tan plant population were sent from Nebraska (Eastin). The population, which was derived

Table 1. Comparative water and nitrogen yield responses (ard./fed.) by sorghum after barley and Egyptian clover.

	Nitrogen level (kg/fed)				
H_2O level (mm)	0	60	80	100	Mean
			after barley		
250	7.3	9.5	10.8	11.7	9.8
350	8.5	10.8	12.5	13.6	11.3
450	9.3	11.5	13.3	15.5	12.4
Mean	8.4	10.6	12.2	13.6	11.2
			after clover		
250	9.2	11.6	12.2	12.5	11.4
350	11.1	12.3	14.6	16.2	13.6
450	13.3	15.5	17.2	18.8	16.2
Mean	11.2	13.1	14.7	15.7	13.7

from TP24 (a Texas population synthesized by D.T. Rosenow and F.R. Miller) through a stress screening methodology testing exercise in Western Kansas. Some 233 of the 930 samples were selected as being well enough adapted for further characterization and testing (a higher proportion than expected). One of the main problems with this germplasm source is susceptibility to smuts, particularly long smut.

Mr. Mohamed El-Bakary spent three months in Nebraska partially designing an approach to broaden Egypt's germplasm base in a manner to insure relatively high numbers of genetic recombinations amongst new materials and the current well adapted Egyptian germplasm base. Basically he is crossing several proven lines to six or more population steriles (ms_3), growing out the progeny and allowing the next generation to randomly mate two or three times to provide a truly Egyptian adapted population. The population can be used for direct selection and the introduction of various elite germplasm sources into an adapted Egyptian background. Target areas will be both the high and marginal production areas.

International Food Sorghum Adaptation Trial (IFSAT)

Dr. F.R. Miller sent a 40 entry trial which contained ATx 623 x Derado as a check which yielded 3528 kg ha^{-1}. ATx 631 and ATx 635 Derado hybrids were superior suggesting good adaptation for TX 631 and 635. Continued running of this test will be one good baseline indicator for Egyptian breeder progress.

Honduras/Project TAM-131

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Escuela Agricola Panamericana (EAP), Honduras
Texas A&M University
Mississippi State University
Purdue University
University of Nebraska

Summary

Honduras is the INTSORMIL prime site in Central America and collaborative research has been conducted there since 1981. During this time, INTSORMIL has helped Honduras develop, without doubt, the most innovative and productive National Sorghum Project (NSP) in Central America, and perhaps the most viable national research project within the basic grains dimension. Much of this success is attributed to INTSORMIL's training of local scientists and the resulting collaborative interdisciplinary research that takes place in Honduras.

Two significant capacity enhancement accomplishments that have facilitated this progress have been privatization of the NSP in the Panamerican Agricultural School (EAP) in 1991 and linking technology transfer to NGOs and the private seed industry. Furthermore, the combination of better trained local scientist and the fiscal agility of the EAP has enabled our Honduran counterparts to compete for competitive research grants and carry them to term. These developments have strengthened the long-term stability and overall effectiveness of the sorghum program in Honduras.

In light of this progress, INTSORMIL has graduated the Honduran NSP by retiring its long-term technical advisor, Dan Meckenstock, as of June 30, 1993. This marks a milestone in INTSORMIL's accomplishments in Honduras and reinforces the methodology of this CRSP.

Sorghum's Importance in Central America

Sorghum is produced in the semiarid region of Central America. This region ranges along the Pacific side of the isthmus from southeastern Guatemala through El Salvador and southern Honduras, south to Lake Nicaragua. Typically, sorghum is a poor man's crop grown on marginal land, but large scale commercial production is increasing as better adapted hybrids and local grain markets are develop by the private sector.

Sorghum production in Central America has witnessed a net increase of some 50,000 ha since 1981. About 350,000 ha were planted to sorghum in Central America in 1989 according to the FAO yearbook (Vol. 43). Since 1981, Guatemala and Honduras have increased sorghum production by about 35,000 ha each whereas Costa Rica has reduced production from 20,000 ha to practically nothing. The two largest sorghum producing countries in Central America remain El Salvador (123,000 ha) and Honduras (90,000 ha). Changes in macro economic policy to better reflect real prices, improve markets and intensify production coupled with better adapted hybrids have encouraged Honduran farmers with larger land holdings to plant sorghum instead of maize.

In spite of this trend towards hybrids, tropical landrace sorghum populations, called maicillo criollo, are the predominant sorghum in Central America. They are tall, late maturing (photoperiod sensitive), have white seed and are generally intercropped with maize by resource poor farmers on marginal land. Some 67% (235,000 ha) of the sorghum acreage in Central America is planted to maicillo criollos. Commercial hybrids and improved varieties, which are produced on better land by larger scale farmers making up the difference.

Maicillo is adapted to traditional maize intercropping systems and is used as a hedge against drought in these systems by subsistence farmers. About 40% of the maicillo grain substitutes maize in tortillas. An inverse relationship between economic well being and utilization of sorghum for food exists with landless peasant households utilizing sorghum in the greatest proportion of their diet.

Collaborative Program

Organization, Management and Implementation of the Country Program

"Dynamic" is the best description of the INTSORMIL program in Honduras. Over the years, INTSORMIL has adjusted its program by identifying new collaborative institutions and organizations to work with and shifting technical thrusts to meet new expectations.

Activities began in Honduras with the signing of two MOUs in 1981. These were with the Honduran Institute of Anthropology and History (HIAH), March 18, 1981, and the Ministry of Natural Resources (MNR), June 1, 1981. Two years later, the MOU with MNR was replaced with an automatically renewable MOA (Acuerdo #0152, February 8, 1983) which was approved by the President of Honduras and remains in force today. The agreements with the MNR established the placement of an INTSORMIL long-term technical advisor in Honduras to facilitate a comprehensive sorghum breeding program, backstop student research in-country, and provide continuity to the overall program. The MOU with the HIAH remained active through 1987.

Although joint research activities also began with the Honduran Integrated Pest Management Project (MIPH) at the EAP in 1982, INTSORMIL's relationship with the EAP was not formalized with an MOU until October 18, 1988—after it relocated its technical advisor there in October 1985. The EAP is the premier private non-profit agricultural college in the tropics. All collaborative research in Honduras today is conducted through the NSP and MIPH projects at the EAP. The MOU with the EAP is still in effect.

Another important agreement pertaining to sorghum research in Honduras is the MOA (Acuerdo # 3524-91, December 9, 1991) between the MNR and EAP. This document was approved by the President of Honduras and completes the EAP-MNR-INTSORMIL agreement triad. It privatizes the NSP in the EAP and provides a mechanism for continued GOH financial support and access to government owned experiment stations. This restructuring, which evolved over the decade as better alternatives were sought for conducting research, is consistent with USAID/H mission strategy for privatizing the agricultural services of the MNR. It also has produced the strongest example of cooperation between the MNR and EAP and serves as a model for privatizing other agricultural services. This arrangement is one instance of leading by example and has been followed to privatize the National Rice Project in the Honduran Foundation for Agricultural Research (FHIA).

Throughout its collaboration with INTSORMIL, the NSP has functioned as a small core of sorghum researchers within the means of the GOH. It has consisted of a Head (breeder) and two to three technicians (agronomists) stationed at strategic experiment stations (Figure 1). INTSORMIL has collaborated with the NSP to enhance its interdisciplinary dimension and amplify its research output. Much of this output has been contributed by INTSORMIL graduate students, many of whom have been Hondurans, conducting research in Honduras. The direction of student research by INTSORMIL PIs has ensured quality scientific

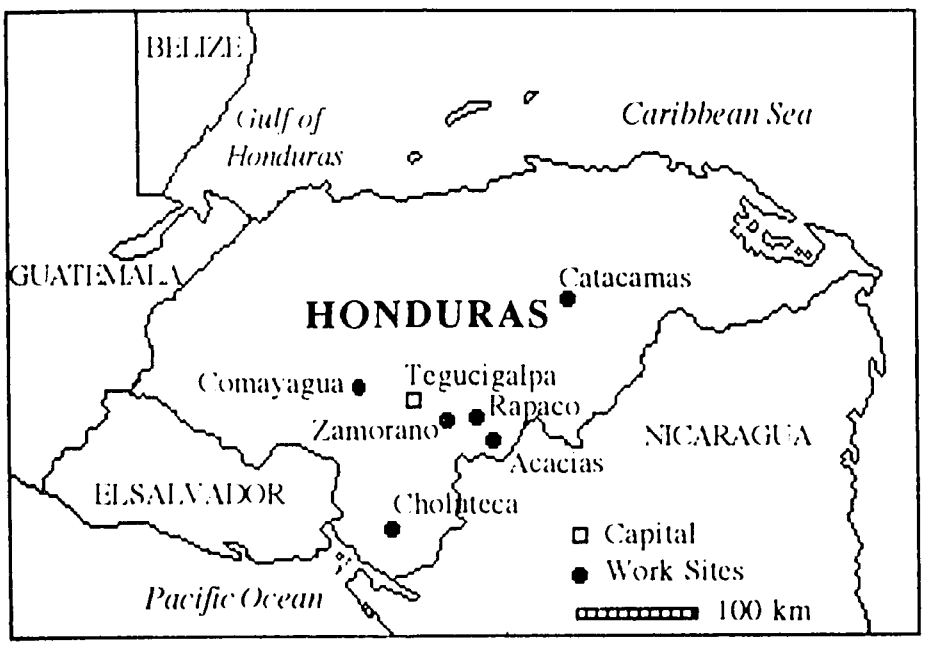

Figure 1. Sorghum work sites in Honduras.

work and a close association with the NSP. It also has enabled the NSP to carry out a comprehensive interdisciplinary program that anticipates problems and moves to solve them before they develop into a crisis.

The responsibility of the interdisciplinary support is shared among several U.S. universities and serves as a paradigm for other CRSPs. A total of thirteen INTSORMIL projects, representing six land grant universities, have backstopped the NSP's interdisciplinary program throughout the collaborative period (Table 1). No other country has benefited from this level of collaborative support within INTSORMIL or other CRSPs for that matter. Presently, nine INTSORMIL projects, representing three universities, are collaborating with Honduran scientists (Table 1).

Table 1. INTSORMIL projects and disciplines that have been active in Honduras.

Project	PI	Discipline	Active
KSU-101	W. Stegmeier	Millet Breeding	1985–1987
MSU-3	M. Futrell	Nutrition	1981–1984
MSU-105	H. Pitre	IPM	1983–present
PRF-105	J. Sanders	Economics	1987–1989
TAM-121	F. Miller	Yield Enhancement	1982–present
TAM-122	D. Rosenow	Drought Tolerance	1981–present
TAM-123	G. Peterson	Midge Resistance	1982–present
TAM-124	R. Frederiksen	Disease Resistance	1983–present
TAM-125	F. Gilstrap	Biological Control	1982–present
TAM-126	L. Rooney	Cereal Quality	1982–present
TAM-131	D. Meckenstock	Maicillo Enhancement	1981–present
UK-2	B. and K. DeWalt	Socioeconomics	1981–1983
UNL-113	M. Clegg	Shade Tolerance	1989–present

The flux of projects in Honduras is indicative of INTSORMIL's ability to adjust to needs. The first wave of collaboration in Honduras focused on socioeconomic baseline studies and sorghum enhancement. The socioeconomic and nutrition studies were carried out by University of Kentucky (UK-2) and Mississippi State University (MSU-3) projects under agreements with MNR and HIAH. These studies documented: land tenure and land use (with emphasis on predominant farming systems); indigenous knowledge of crop management; farmer perceptions of production constraints and their solution; diet and nutritional status of rural communities in sorghum growing areas of Southern Honduras; and gender analysis of labor and time allocation of women in production, consumption and marketing of agricultural products. Together, these base line studies identified many constraints that other INTSORMIL projects would address.

In conjunction with the socioeconomic studies, a breeding effort (TAM-131) was started to help NSP upgrade local sorghum cultivars. This project began working to enhance local varieties called 'maicillo' for traditional maize intercropping systems. It added a conservation of tropical landrace sorghum component in 1988. Other INTSORMIL breeding projects also began assisting the NSP through infusion of sorghum germplasm. These introductions resulted in the release of the food-type hybrid 'Catracho' in 1984 (TAM-121), the food-type variety 'Sureño' in 1985 (TAM-122; Crop Sci. 33:213), and a sorghum-sudangrass forage hybrid, 'Ganadero', in 1993 (TAM-121 and TAM-124). These releases fulfilled short-term goals and served to maintain support for the program while the long-term breeding effort with maicillo moved forward.

Other INTSORMIL projects also began assisting the NSP in areas of integrated pest management, sorghum grain quality for tortillas, disease resistance, shade tolerance and determining the economic impact of released sorghum cultivars. Some of these conducted landmark studies like TAM-124's inventory of sorghum diseases in Honduras and their importance (Ceiba 28:101-113) and MSU-105's inventory and population dynamics of soil insect pests in intercropped sorghum and maize (Turrialba 40:172-183). This latter study received international recognition by winning the outstanding research award at the Central American Cooperative Program for Improvement of Food Crops and Animals (PCCMCA) meeting in Honduras in 1989.

A significant outcome of the survey of sorghum diseases is that it led to the detection of the most virulent pathotype, P5, of *Peronosclerospora sorghi*, which causes sorghum downy mildew (SDM), reported in the Americas (Ceiba 28:79-100). The NSP has capitalized on this pathogen by establishing the International Sorghum Downy Mildew Nursery at Comayagua with TAM-124 advising its management. More recently, the European Economic Community (EEC) has helped the NSP defray operating costs of the nursery through its Regional Program to Strengthen Agronomic Research on Basic Grains in Central America (PRIAG). This nursery has greatly improved the ability of Central American breeders and seed companies to develop and provide sorghum cultivars resistant to SDM. To date, resistance found at Comayagua has held throughout Central America where less virulent pathotypes predominate. This nursery is an excellent example how the NSP has led the way in preempting a SDM epidemic in Central America.

The integrated pest management dimension of the NSP has been assisted by two INTSORMIL projects. TAM-125 has conducted a long-term effort towards the biological control of stem borers and fall armyworm through three graduate students (all M.S. degrees) and MSU-105 has conducted a long-term effort in the control of fall armyworm and the "*langosta*" lepidopterous pest complex through five graduate students, (two Ph.Ds. and five M.S. degrees). MIPH has collaborated with laboratory facilities and some student stipends while in country and the NSP has provided logistical support for experiments on-farm in Southern Honduras. Controlling the langosta, of which the fall armyworm is a component, is a complex problem involving the ecology of four insect larval species that prefer diverse habitats (Florida Entomologist 74:287-296). Both MSU-105 and TAM-125 technical thrusts are still ongoing.

Because of sorghum's importance as food, TAM-126 plays an important role in helping the NSP release acceptable food-type cultivars. Much of Sureño's popularity with small farmers is due to its outstanding tortilla quality. TAM-126 has provided systematic screening of advanced maicillo hybrids and varieties for tortilla quality to ensure that new releases meet the same acceptability standards as Sureño.

As the Honduran program developed and needs changed, other projects became involved. The Purdue University socioeconomic project (PRF-105) followed up the Catracho and Sureño releases in 1988 to determine their economic impact on small farmers in Southern Honduras. This study (Qtrly. J. Int. Agric. 31:55-72) confirmed that improved sorghum germplasm maximizes the soil conservation interventions being disseminated by the Land Use and Productivity Enhancement (LUPE) project. In addition to highlighting the synergism between these two USAID projects (i.e., INTSORMIL and LUPE), the economic study recognized the importance of price policy in reducing the risk of adopting new technologies.

As progress was made in maicillo enhancement, it became clear that shade tolerance was a competitive advantage of maicillo over other sorghum cultivars in maize intercropping systems. To characterize the physiological response of maicillo to shade, UNL-113 began assisting the NSP in 1989. The ramifications of shade tolerance greatly enhances sorghum's role in sustainable development and this research is still ongoing.

Financial Inputs

The primary source of funds that provide for collaborative research in Honduras comes from USAID through the INTSORMIL grant and PL480 local currency. From the onset, INTSORMIL has provided a country budget which has oscillated between 115,000 to 135,000 dollars per year through TAM-131 (Table 2). This budget provides the technical advisor and support for equipment, supplies, communications, and international travel. This funding will be reduced in 1994 since the technical advisor has been retired. Other INTSORMIL projects also contribute through training, germplasm, and laboratory analysis in the U.S. Their monetary contributions are not shown in Table 2.

In addition, the GOH and USAID/H have provided local currency through the Title I PL480 program to the NSP for in-country costs since 1983. These funds are currently administered by the EAP and cover the lion's share of in-country expenses, including local salaries and wages. Present PL480 funding is 479,000 lempiras per year, but level ceiling funding and gradual devaluation of the lempira has eroded this base.

Recently, the American Ambassador to Honduras announced that United States' aid to Honduras would be reduced over the next five years. In light of this waning financial assistance, measures are being taken to reduce the NSP reliance on PL480 local currency. The EAP has hired (July 1993) our primary collaborator, Dr. Gómez, which has allowed the transfer of his salary from PL480 soft funds to EAP core funds. Although Dr. Gómez now divides his time between teaching and research, this positioning ensures his long-term collaboration. The GOH has indicated that it will begin matching PL480 contributions for all CRSPs with national funds in 1994. Last, special projects are being developed by our Honduran counterparts to create new funding sources. These projects have focused on commercial hybrid performance testing, contract screening of sorghum lines and hybrids for resistance to pathotype 5 of *P. sorghi*, and competitive research grants.

The timely privatization of the NSP has created incentives to secure additional funding and therefore has placed the NSP in a better position to meet this challenge. Since privatization in 1991, the NSP has begun to developed special projects that now make a significant contribution to the overall program (Table 2, "Other" column). Although INTSORMIL's technical thrusts focus on "fighting hunger through research", changes in donor interests have led the NSP to expand into other activities like developing forage sorghum and broomcorn cultivars. Unlike maicillo enhancement, which carries a social and moral argument for feeding the poor and contributes to an often undocumented impact at the farm gate, commercial hybrids (both forage and grain) and broomcorn directly impact commercial markets and are readily appreciated by policy makers. It has been necessary to develop a full-service NSP that deals with several kinds of sorghum (fiber, food, forage) in order to sustain the maicillo work which is an unique dimension to sorghum research in the world and has a long-term payoff.

INTSORMIL's partnership with the EAP also creates an opportunity to access international donors that do not fund U.S. universities. For example, the NSP has received two mini-grants from the EEC, one to operate the international SDM nursery in Comayagua and the other to manage

Table 2. Summary of direct financial support for sorghum research in Honduras.

Year	TAM-131† ($)	GOH-A.I.D. ($)	GOH-A.I.D. (L.)	Other ($)
93–94	115,000	66,528	479,000	>21,000
92–93	115,000	82,586	479,000	18,110
91–92	135,000	88,700	479,000	490
90–91	120,000	90,377	479,000	1,500
89–90	120,000	75,013	397,571	500
88–89	120,000	197,000	394,000	900
87–88	120,000	165,500	331,000	300
86–87	135,000	124,950	249,900	500
85–86	124,875	127,500	255,000	0
84–85	133,000	0	0	0
83–84	135,000	30,000	60,000	0
82–83	115,000	0	0	0
81–82‡	95,000	0	0	0
Total	$1,582,875	$1,048,158	L.3,124,471	$43,300

†TAM-131 is the INTSORMIL country budget designated for Honduras.
‡10 month period.

maicillo nurseries in Choluteca. Although this money is administered by the EAP, it contributes to program objectives and enhances the capacity of the NSP. The strategy behind these kinds of indirect institutional linkages is to increase INTSORMIL's effectiveness and impact while minimizing the level of USAID support.

Collaboration with International Centers and Other Organizations

INTSORMIL has enjoyed a close association with the ICRISAT Latin American Sorghum Improvement Project (LASIP) working out of CIMMYT in Mexico. Since 1981, INTSORMIL has cosponsored nine workshops with ICRISAT in Central America and Mexico. In addition, this interaction has provided access to valuable germplasm for the breeding program in Honduras as well as enhancing networking opportunities in Central America through the Commission of Latin American Sorghum Investigators (CLAIS), an ICRISAT initiative. For example, Sureño came to Honduras from India after first passing through the ICRISAT program in Mexico and then TAM-122 in Texas.

With the closing of the ICRISAT-LASIP program in Mexico in December 1993, the INTSORMIL prime site in Honduras is the only international sorghum research program in Central America for National Agricultural Research Systems (NARS) to draw upon. INTSORMIL and ICRISAT are presently considering alternatives to sustain their synergistic relationship in Latin America, with donor funding to establish and maintain a sorghum network in Latin America being the primary constraint. No closure has been achieved on this network.

Presently, INTSORMIL works through its Honduran trained counterparts and the NSP to provide sorghum research leadership in Central America. This puts our Honduran counterparts at the forefront as role models while conferring leadership responsibility. For example, Dr. Gomez has just completed a two year term (1990-1991) as the elected president of the Council of Latin American Sorghum Researcher (CLAIS). Presently, he serves as the EAP's representative to the National Council of PRIAG which is sponsored by the EEC and administered by the Inter-American Institute for Cooperation on Agriculture (IICA). As a senior scientist, he has provided valuable council to PRIAG in establishing their research grants program. Other leadership activities include diffusion of germplasm and exchange of ideas. The NSP is presently funneling demonstration plots and other germplasm to the Swiss development program COSUDE working with the CHINORTE project in Chinandega, Nicaragua; the Center of Agricultural Technology (CENTA) in El Salvador; and the Institute of Agricultural Science and Technology (ICTA) in Guatemala. In addition, the recent Honduran modernization of state law calls for the creation of the Honduran Council of Science and Technology which will advise the President of Honduras on policies that stimulate development of science and technology. Dr. Gomez presently sets on this council as the representative for private Honduran universities.

Development of Collaborative Research Workplans

INTSORMIL primarily responds to local needs. To determine these, it has conducted several baseline studies mentioned above. In addition, INTSORMIL has helped the NSP develop activities that allow farmers to participate in the development of technology. These include conducting student research on-farm, carrying out enhanced maicillo demonstration plots on-farm, and conducting commercial hybrid performance tests in strategic sorghum producing valleys. These activities serve as a two-way-street in which farmers learn about new cultivars and management practices and we learn about farmers needs and expectations. This impromptu dialog has helped guide research on controlling the langosta complex and enhancement of maicillo for alley cropping systems. It also has identified anthracnose as a potential threat to the expanding commercial sorghum hybrid industry in Honduras. Although most local landraces are resistant to anthracnose, many introduced hybrids do not possess adequate levels of resistance to this disease.

In addition, the EAP-MNR-INTSORMIL program is the only USAID supported project integrated into MNR's objectives for national food security. The recent modernization of agriculture law in Honduras creates a new Agricultural Science and Technology Division (DICTA) in the MNR. The MNR has expressed interest in integrating the MNR-EAP-INTSORMIL sorghum program into DICTA as its sorghum research component. Although GOH core funding for DICTA is a constraint, USAID/H's initiative to match core funds with local currency is an incentive for the GOH to move forward.

Sorghum/Millet Constraints Researched

Constraints to Sorghum Production and Utilization

Emphasis is placed on improving sorghum production and bolstering the economic well-being of small farmers who derive their livelihood from agricultural activities on steep hillside slopes. Needs of larger farmers situated in lowland valleys are addressed through the commercial hybrid performance test. Specific production and utilization constraints being addressed include genetically enhancing the yield potential of local cultivars, controlling the langosta complex of lepidopterous defoliators, guarding against sorghum downy mildew, and improving sorghum grain quality for tortillas. Nested within yield limitations are two additional constraints associated with traditional farming systems—sensitivity to photoperiod and shade tolerance. Because these two constraints restrict the use of introduced conventional, temperately adapted sorghum types, emphasis has been shifted from the Green Revolution approach to development (a fast track based on the introduction and release of early maturing short stature cultivars with high yield potential) towards conservation and enhancement of

local landrace populations. Although our conservation and enhancement approach requires time to develop new cultivars and, therefore, proceeds at a slower pace, it is consistent with farmer's needs and more sensitive to environmental concerns like conservation of biodiversity.

Low Yield Potential. National sorghum yield in Honduras is about one metric ton per hectare. In part, this is a reflection of the adverse environment in which sorghum is grown, but more importantly, this is the result of the preponderant use of landrace populations which have inherently low but stable yield. The inability of maicillo to respond to improved management practices, such as soil and water conservation interventions, with increased grain yield is the primary constraint to sorghum production. Given that higher yields provide farmers economic incentive to adopt better management practices, cultivars with greater yield potential are essential before they will implement sustainable practices without assistance. Linking crop improvement to sustainable farming systems provides the economic incentive to move towards sustainable development. This point is often overlooked as attention shifts from agriculture to the environment. INTSORMIL projects most active with this constraint include TAM-121, TAM-122, TAM-123, and TAM-131.

Traditional Farming Systems. Maicillo is an old world crop that has adapted to neotropical slash and burn agroecosystems. About 90 percent of the sorghum planted in Honduras and El Salvador is a late maturing sorghum (maicillo) that is intercropped with early maturing maize. The success of maicillo in traditional maize intercropping systems is attributed to its ability to withstand shading coupled with its sensitivity to photoperiod. While maicillo's shade tolerance allows it to subsist under the maize canopy, its photoperiod sensitivity extends its vegetative phase throughout the growth and development of the associated maize crop. Thus, the reproductive phases of maize and sorghum, when demand for nutrients are highest, are staggered. In contrast, introduced sorghum cultivars—which are not sensitive to photoperiod and, therefore, early maturing—enter their reproductive phase at the same time as maize. The resulting increased competition for available water and nutrients jeopardizes the production of both crops. This is where the Green Revolution approach—introduction of short stature early maturing cultivars—breaks down. Maicillo's shade tolerance opens the door to developing the role of sorghum in more sustainable systems like alley cropping with leguminous trees. INTSORMIL projects most active with this constraint include TAM-131 and UNL-113.

Insect Pests. An early season lepidopterous pest complex, called the Langosta in Central American, is an occasional constraint to sorghum and maize production. The fall armyworm (*Spodoptera frugiperda*), along with other lepidopterous larvae—*S. eridania, Metaponpneumata rogenhoferi, and Mocis latipes*—make-up this complex. Farmers fear the langosta most at the beginning of the planting season, when seedling fields are attacked with little or no warning. These ostensibly random attacks appear to come in waves and are most damaging when large larvae (late instar) migrate from surrounding non-crop vegetation (weeds) into seedling fields. Under these circumstances, an unaware farmer can loose his entire crop overnight. This loss is most devastating to those who do not have seed to replant. Understanding the complex, its species diversity, density, time of occurrence, and origin, is necessary to develop an adequate control strategy. INTSORMIL projects most active with this constraint are MSU-105, TAM-125, and TAM-131.

Sorghum Downy Mildew. SDM is a recently introduced disease (first observed in Honduras in 1972) that is now endemic in the region. Not only is maicillo susceptible to SDM, but the threat of this disease is heightened by the existence of the most virulent pathotype (P5) of *Peronosclerospora sorghi* reported in the Americas. This pathogen was discovered at Las Playitas Experiment Station, Comayagua, Honduras in 1986. Because maicillo and most sources of resistance in the United States are susceptible to P5, the pathogen threatens the stability of sorghum production in Honduras. Monitoring local hot spots for changes in virulence and the introduction and deployment of resistant genes offers the best alternative for control. INTSORMIL projects most active with this constraint are TAM-124, and TAM-131.

Grain Quality. Although maize is the preferred staple, roughly 40 percent of maicillo's grain production extends or substitutes maize in tortillas in subsistence diets. Acceptable sorghum tortilla making quality is essential for the success of any sorghum cultivar intended for small farmer use. Traditionally, the preferred sorghum for tortillas has had small, corneous kernels with white or cream pericarp color. Advanced breeding materials are rigorously screened to meet local tortilla standards with the assistance of TAM-126. In the process, we have been able to improve tortilla color beyond that of local cultivars by changing plant color to tan, a recessive trait (*pp qq*) not found in maicillo. INTSORMIL projects most active with this constraint are TAM-126 and TAM-131.

Research Methods and Results

Looking back, sorghum research in Honduras has been a long-term multidisciplinary effort that integrates agronomy, breeding, cereal quality, conservation, entomology, pathology, physiology, and socioeconomic disciplines. This approach has been very fruitful. Short term breeding goals have led to the release of four sorghum cultivars (Tortillero, Catracho, Sureño, and Ganadero) while long term improvement goals have established the only sorghum breeding program in the world working with photoperiod sensitivity. The entomology work, much of which is conducted on-farm, has led to the identification of the langosta complex and its natural enemies. The *in situ* conservation of maicillo, which is farmer oriented, has effectively utilized the INTSORMIL scientist network to identify many useful maicillo traits that contribute to acid soil tolerance, drought toler-

ance, antibiosis to fall armyworm, resistance to multiple diseases (e.g., anthracnose, ladder spot, and rust), and shade tolerance. Additional information on these topics are presented in the individual project reports in this Annual Report (see Table 1 for listing of projects that have worked in Honduras).

Student research has played an essential role in conducting our interdisciplinary program. Most students have fulfilled program objectives in disciplines such as quality, entomology, pathology, physiology, and socioeconomic. Some students have presented their research at the PCCMCA meetings in Central America and have earned the recognition of their peers for conducting outstanding research (Table 3).

Of the four sorghum cultivars the NSP has released, two—Sureño (1985) and Ganadero (1994)—have met spectacular success. Sureño is the first variety released by the MNR that has found its way into informal seed markets. Consequently, not only has it sustained its survival but continues to increase its hectare share with all classes of farmers. Sureño's popularity grows from its dual purpose use for forage and grain, outstanding grain quality for making tortillas, and high yield potential. Several projects, including ICRISAT, COSUDE, NSP, TAM-122, TAM-124, TAM-126, and TAM-131 all played a role in qualifying Sureño for release.

A farm level study to determine the economic impact of Sureño and Catracho, was conducted by Miguel López (PRF-105) in 1988. He found that the improved variety Sureño, when coupled with improved agronomic practices, increased grain yield over maicillo by 68%. Similarly, the hybrid Catracho increased grain yield over maicillo by 113%. This translates into an increase in farm family income from $1.60 to $2.70 per day ha^{-1} with Sureño and $4.40 per day ha^{-1} with Catracho. It is these kinds of strategies, like coupling improved cultivars with soil and water conservation practices, that provide the incentives necessary to move farmers towards sustainable development.

In 1991, Ing. David Erazo (NSP) conducted a follow-up study of the 32 farmers who tried Sureño in 1988 with Miguel. He found that Sureño, on average, had substituted 28% of the maicillo acreage. Interestingly, this acreage percentage increased as the proportion of sorghum grain used in household diets rose. In other words, Sureño was preferred over maicillo for tortillas. From a development perspective, Sureño's adoption (28%) seems low. But from a conservation perspective, this degree of maicillo displacement by a single variety is high. Other cultivars with preferences similar to Sureño's are being developed in the maicillo background. This will help diversity the new cultivar base. Because of Sureño's broad acceptance, we have sent a sample of its seed to the National Seed Storage Laboratory in Fort Collins, Colorado for safe keeping where it bears PI 561472 & NSSL 259979.51 numbers. It was registered in *Crop Science* (33:213) by MNR-INTSORMIL-ICRISAT so that other programs can learn of its existence and for historical reference.

More recently, the NSP has developed a forage sorghum hybrid 'Ganadero' with pedigree ATx623*Tx2784. This hybrid has rapidly become a favorite with farmers and has done much to boost sorghum forage acreage in Honduras. The development and release of Ganadero is an excellent example how the NSP has contributed to USAID/H's intensification of land use objective. Since the EAP began using Ganadero to meet its annual production goal of 2,000 tons of silage, it has significantly reduced the amount of land allocated to meet its production goal from 91 ha of maize to 64 ha of Ganadero. Much of the land that Ganadero has freed up, has been put into seed production. Sureño and Ganadero now dominate basic seed and certified seed production at the EAP.

Research Benefits

The NSP has assisted the privatization of the national seed industry (a USAID/H objective) by providing new and improved cultivars for private seed companies and by conducting a hybrid sorghum performance tests. Presently, four Honduran seed companies produce certified seed of Ganadero. Since 1989, the EAP alone has produced over 67 metric tons of Ganadero certified seed.

The nationwide commercial hybrid testing program, initiated by the NSP in 1989, has been key in upgrading commercial hybrids available to farmers. It is also the only published listing of any cultivar performance in Honduras. Since initiating the performance test, we estimate from seed import records that hybrid sorghum acreage has increased by 10,000 hectares, with much of this seed being supplied by international seed companies. Furthermore, this increased use of hybrids has begun to boost national sorghum

Table 3. Outstanding research awards won at Central American PCCMCA meetings.

Year	Name	Project	Research title
1987	L. Fernández	NSP	Virulence of *Peronosclerospora sorghi* in Honduras.
1987	F. Gómez	NSP	Food quality of 14 sorghum cultivars.
1988	F. Gómez	NSP	Maicillo classification.
1989	L. Lastres	TAM-125	Fireants as predators of fall armyworm.
1989	C. Trabanino	MSU-105	Soil insect pests of sorghum and maize.
1989	M. López	PRF-105	Impact of new sorghum cultivars and soil conservation interventions in Southern Honduras.
1993	F. Gómez	NSP	Control of sorghum downy mildew in Honduras.

yield above the historical yield plateau of one ton per hectare (Figure 2). At the present rate of commercial hybrid expansion, the sorghum industry in Honduras will grow to a 10 million-dollar industry by 1996. This is another example how the NSP has facilitated the increased production of feed grains to assist the USAID mission goal of intensifying land use. Because of the production potential and profitability of sorghum hybrids, the GOH is now considering policy to make loans available for sorghum production. Not only is this consistent with the USAID mission objective of improving small holder farmer access to institutional credit, but it is the first time credit for sorghum production has won support in the face of other basic grains like maize, beans, and rice. These changes toward sorghum are being driven by productivity.

Institution Building

Support for Host Country

Over 100,000 dollars worth of equipment and items were turned over to the EAP when the technical advisor was retired. Among the big ticket items were: two electronic scales, a forced air oven, a laser printer, a micro-logger, three personal computers, three pick-up trucks, two plot threshers, a remote telephone system, and a rolling cultivator. Other items include a 35 mm camera and slide projector, an assortment of computer software and accessories, a dehumidifier, a megaphone, some office furniture and equipment, an overhead projector, and a small seed blower.

The Impact of Training

Sustainable development is a dynamic process that requires continual renewal of intellectual resources to meet new challenges that continually arise. The development of human capital is an integral part of INTSORMIL's program in Honduras. Since 1981, INTSORMIL PIs have directed 20 graduate students for a total of 22 advanced degrees in which research was related to Honduras. All but three of these students conducted their research in Honduras. Two have research ongoing in Honduras. Eight of these graduates are Hondurans and have received a cumulative four Ph.D. and six M.S. degrees.

It is through training that Honduras is enabled to assume responsibility for its development as well as make a contribution to the region. Of the four Ph.D. degrees conferred, F. Gómez heads the NSP in Honduras, M. López is an economist with CIMMYT in Mexico, M. Castro is an entomologist with Standard Fruit in Honduras, and H. Portillo is an entomologist with BASF Inc. in Mississippi.

Presently, four INTSORMIL trained Hondurans are employed by the EAP. In addition to Dr. Gómez, three M.S. level professionals—L. Lastres, J. López, and C. Trabanino—work with the Department of Plant Protection and Biological Control Center. Another, A. Palma, works with the Catholic Relief Service PVO and uses the NSP as a resource in his program. INTSORMIL's relationship with the EAP has played a strategic role in identifying excellent students for advanced degree training in the United States. Most of the Hondurans who have received advanced degrees in the INTSORMIL program have been EAP graduates, one has been a CURLA graduate.

The problem-solving kinds of research that students do has been essential for developing our comprehensive program. Identification of the langosta lepidopterous insect complex and soil arthropod pests on sorghum and maize, discovery of shade tolerance and maicillo antibiosis to fall armyworm, determination of the economic impact of Sureño and Catracho on hillside farms in the South, assessment of sorghum loss to disease, and biological control of fall armyworm and stem borers (*Diatraea* sp.) are all initiatives that were undertaken by graduate students.

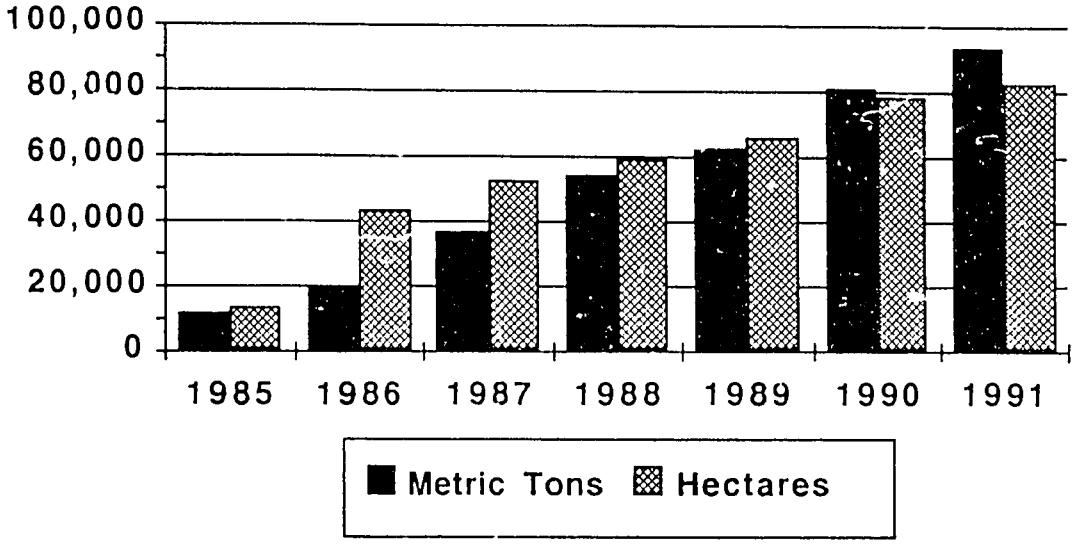

Figure 2. Expanding use of hybrids are increasing sorghum's productivity in Honduras.

Scientist Exchange

Over the years, an excellent scientist-scientist rapport has developed through a mix of PI visits to Honduras and collaborative scientist visits to the United States. In general, annual PI visits to Honduras have revolved around advising graduate students off to a good start in the Spring and assisting evaluation of nurseries in the Fall. PIs have also participated in the external evaluation of in-country activities, three such reviews have been undertaken since 1981.

On the flip side, collaborative scientist have been invited to INTSORMIL laboratories to learn new procedures and to participate in scientific meetings, including INTSORMIL PI Conferences, TC and EZC committee meetings.

July 8-12, 1991 - Dr. Gómez and two Ministry of Natural Resources representatives attended the INTSORMIL PI conference in Corpus Christi, Texas.

February 3 to May 29, 1992 - Mr. José Monroy, EAP/MIPH, received short-term training (four months) at Texas A&M University by TAM-125 in culturing and conducting research on natural enemies.

February 19-23, 1992 - Dr. Gomez attended the INTSORMIL External Review at College Station.

May 11-14, 1992 - Dr. Gómez attended a special INTSORMIL PI meeting with an ICRISAT representative at TAMU to plan the future of the CLAIS network.

February 28 to March 2, 1993 - Dr. Gómez attended the 18th Biennial Grain Sorghum Research and Utilization Conference (SICNA) held at Lubbock, Texas.

March 3, 1993 - Dr. Gómez attended the joint TC/EZC committee meeting that followed the SICNA Conference at Lubbock, Texas.

March 4-8, 1993 - Dr. Gomez visited Texas A&M University at College Station to plan collaborative research with INTSORMIL PIs.

December 20-21, 1993 - Dr. Gómez attended the joint TC/EZC meeting at Kansas City.

Human Resource Development Strategy

INTSORMIL's association with the EAP provides an eloquent method for selecting outstanding students to pursue graduate studies in the United States. The fourth year program (Ingeniero Agronomo degree) at the EAP, which requires independent research and a thesis, provides our collaborators an excellent opportunity to identify capable and interested students. Although some graduate assistantships have been made available by individual INTSORMIL projects, this preference for quality students has enabled INTSORMIL to access other scholarships funds like Fullbright-Laspau and OAS.

Networking

Over the years, the NSP has established an elaborate network of collaborators in Honduras that includes both GOH and NGO organizations (Table 4). Numerous other on-farm collaborators and sites are used to validate new sorghum cultivars and other technologies. This multi-location testing is essential for developing cultivars with broad adaptation and resistance to multiple diseases and has paid off handsomely in the release of Sureño and Ganadero.

Research Accomplishments

As to be expected, research results have been numerous in Honduras:

Project KSU-101 has provided male sterile lines of pearl millet to support tropical pasture and forage research in the Animal Science Department at the EAP. Dr. Raul Santillán, has used this germplasm to develop interspecific forage hybrids with elephant grass (*P. purpureum*). Plans are now underway to release a pearl millet x elephant grass hybrid in the near term. Although elephant grass produces about 40 t/ha of dry matter per year, its wide spread adoption as pasture has been constrained by vegetative propagation. The traditional practice of establishing elephant grass pasture requires about 2 tons of fresh cut stems per hectare, which are not always available when needed. The innovative aspects of this research is that pearl millet-elephant grass hybrids allow pastures to be established by seed. Advantages to developing such interspecific hybrids is that seed is combine harvested from the pearl millet female parent, it can be stored until needed, it is easier to transport than live stem cuttings, it can be planted with conventional grain drills, and about 10 pounds of seed is sufficient to plant a hectare. Although the interspecific hybrid produces about 30 t/ha of dry matter per year, its digestibility (66%) is better than that of elephant grass (60%). Because the hybrid is sterile (its triploid like seedless watermelon and bananas) and has no rhizomes, it does not become a noxious weed when it comes time to convert the pasture back into crop land.

Project MSU-3 conducted some of the early nutritional and anthropometric base line studies. Although subsistence farms produced the minimum recommended amounts of calories and protein in southern Honduras, diets were deficient in vitamin A, riboflavin, and ascorbic acid. Women and children were most affected by these deficiencies with 65 to 68 percent of the children suffering some degree of malnutrition—29 to 30 percent having second and third degree severe malnutrition. Lower transferrin levels and parasites were more common in malnourished children.

Project MSU-105 has conducted the only inventory of soil arthropod pests of sorghum and maize in southern

Table 4. NGOs and PVOs collaborating with the EAP-MNR-INTSORMIL program in Honduras.

Acronym	Name	Sponsor	Collaborator	Location	Technology
ARD	Associates in Rural Development	USAID	David Leonard	Tegucigalpa	Enhanced maicillo and varieties
CEDA	Center for Agricultural Development	Japan/GOH	Napoleon Reyes	Comayagua	Commercial hybids and SDM nursery
CENTA		GOES	René Clará	Sand Andrés, El Salvador	Enhanced maicillo and varieties
CORASUR	Consolidated Agrarian Reform in the South	Belgium/GOH	Mauricio Garcia	Choluteca	On-farm demonstration plots
DRI-Yoro	Integrated Rural Development	Swiss/GOH	Miguel Sosa	Yoro	Enhanced maicillo and broomcorn
ENA	Escuela Nacional de Agricultura	GOH	David Lafnez	Catacamas	Commercial hybrids and anthracnose nursery
F.E. Foundation	Friederich Ebert Foundation	W. German Social Democrats	Ricardo Rivera	Colon	Commericial hybrids
L.L. Ag School	Luis Landa Ag School		Juan A. Avila	Nacaome	Enhanced maicillo, on-farm demos
LUPE	Land Use and Productivity Enhancement Project	USAID	Javier Mayorga A. Zelaya	Choluteca, Sabanagrande	Enhanced maicillo and varieties, on-farm demos
PER-INFOP	Rural Small Business Development Program	Dutch Gov't.	Eliud Tejada	Sabanagrande	Enhanced maicillo, varieties and broomcorn
Chinorte Program	COSUDE Cooperación Suiza al desarrollo	Swiss Gov't.	Carlo Foletii	Chinandega, Nicaragua	Enhanced maicillo, on-farm demos
Lempira Project	Lempira Rural Development Project	FAO	Luis Welchez	Mapulaca	Enhanced maicillo, on-farm demos
PDR	Rural Development Program	GTZ	Alonzo Moreno	El Zamorano	Enhanced maicillo, on-farm demos
	Polivalente Institute Julia Zelaya	GOH/Min. Educ.	Ruben Zuniga	Monjaras, Choluteca	Enhanced maicillo, on-farm demos
	Hermandad de Honduras		Jose Pineda	San Marcos de Ocotepeque	
	Christian Development Commission	PVO	Luis Espinoza	San Marcos de Ocotepeque	Enhanced maicillo, on-farm demos
CEDEN	Evangelist Committee on National Emergency	PVO	Luis Sarmiento	Choluteca	Enhanced maicillo, on-farm demos
Mennonites	Mennonite Social Action Commission	PVO	Francisco Machado	Choluteca	Enhanced maicillo, on farm demos
World Vision	World Vision	US-PVO		Nacaome	Enhanced maicillo, on farm demos
PROAPACH	Choluteca Support Project	United Nations	Rodolfo Bulnes	Choluteca	Enhanced maicillo, on farm demos
San José Obrero		US-PVO	Alex Madrid	Choluteca	Enhanced maicillo, on farm demos
World Neighbors	World Neighbors	US-PVO	Jose Sauceda	Choluteca	Enhanced maicillo, on farm demos

Honduras, identified antibiosis to fall armyworm in local landrace sorghum populations, and identified four lepidopterous insect species in the Langosta complex that attacks sorghum and maize. Present research focuses on characterization of two of the lesser know species in the Langosta complex with respect to occurrence, host plant relationships, biology (including diapause), ecology, behavior, and population dynamics.

Project PRF-105 impact analysis of the MNR/INTSORMIL released hybrid 'Catracho' shows that sorghum yields are increased 113 percent over traditional cultivars. This translates into an increase in farm family income from $1.60 per day ha^{-1} to $4.40. Increasing household income is a mission objective.

Project PRF-105 impact analysis show that the MNR/INTSORMIL released variety 'Sureño' increases sorghum yields 68 percent over traditional cultivars. This translates into an increase in farm family income from $1.60 per day ha^{-1} to $2.70. Increasing household income is a mission objective.

Project TAM-121 has provided elite lines for the development to two Honduran hybrids, Catracho and Ganadero, and is working on the release of a tropicalized commercial hybrid with high yield potential.

Project TAM-122 has provide valuable sources of disease resistance and drought tolerance that is being incorporated into the maicillos criollos and has been instrumental in the flow of germplasm between Honduras and Western Africa.

Project TAM-123 has provided valuable sources of midge resistance that are being tested in combine hybrids for Olancho. As production area increases and sorghum moves into wetter areas, the importance of this project increases.

Project TAM-124 has conducted the only nationwide inventory of sorghum diseases and loss assessment in Honduras. It provides valuable technical assistance in the management of the International Sorghum Downy Mildew Nursery in Comayagua and works with the Plant Protection Department at the EAP in the control of anthracnose and sorghum downy mildew.

Project TAM-125 has identified three effective native predators of fall armyworm—fire ants, earwigs and wasps—and is developing a IPM strategy, along with the EAP and MSU-105, to bring fall armyworm under control.

Project TAM-126 has assisted in the selection of three food type sorghum cultivars, as well as, screening enhanced maicillo cultivars for tortilla quality. This project is essential for success in Honduras, because if the grain cannot be processed and consumed for food, then the breeding research has been wasted. Both cultivars that LUPE promotes have been selected with help from the TAM-126 laboratory.

Project TAM-131—in conjunction with TAM-121, TAM-122, and TAM-126—has formally released three food type sorghum cultivars and one forage hybrid in Honduras. sorghum seed production dominates the basic seed unit at the EAP.

Project UNL-113 provides the basic research needed to identify and characterize shade tolerance in sorghum. Considering that small farmers produce about 80 percent of the sorghum in Honduras and most of this is intercropped with maize, interaction with this program is essential for increasing the yield potential of local varieties. Shade tolerant sorghum is essential for agroforestry systems like those being promoted by LUPE.

Mali

D.T. Rosenow and Aboubacar Touré

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Collaborative Program

The program in Mali is a coordinated effort among INTSORMIL and the IER. The vital collaboration continues to provide efficient use of resources. In Mali, each Malian scientist develops research plans cooperatively with an INTSORMIL counterpart which provides for effective research planning, communication and coordination. Major INT-

SORMIL collaborators travel to Mali annually during the critical period of the crop year to consult, review progress and plan future activities with their Malian counterparts. Individual INTSORMIL investigators transfer funds to Malian counterparts to provide additional support to accomplish the research.

Memorandum of Agreement

A Memorandum of Agreement to allow transfer of funds was signed in Mali on October 10, 1984. The Amendment to the MOA, 1992-93 work plan and budget, was developed jointly by the country coordinators and approved by IER and INTSORMIL in July of 1992.

Production and Utilization Constraints

Yield level and stability in sorghum/millet production is of major importance in Mali where food production is marginal relative to the rapidly growing population. Low and unstable yields are the result of complex interactions of low soil fertility (particularly nitrogen and phosphorus), drought stress, diseases, insect infestations, *Striga*, and availability of improved cultivars. Grain prices which cycle between high and low yield-level years are a deterrent to adoption of improved technology, thus milling properties become critical to maintaining prices in surplus grain production years. Transformation of sorghum and millet grain into new shelf-stable foods and industrial products is required to encourage local production of grains and to enhance agribusiness activities of food processing and poultry feeding which stabilizes prices. Head bugs and associated molds adversely affect sorghum yield and grain quality, and are a major constraint to the development of improved high yielding sorghum cultivars. *Striga* is a major constraint for both sorghum and millet. Other major millet constraints are phosphorus and nitrogen deficiency, water stress and millet head miner infestations.

Efforts are concentrated to strengthen research on breeding, crop physiology, soil and water relationships, entomology, pathology, and food processing and technology. An effort to develop new food products from cereals and legumes is emphasized. Selection for enhanced drought resistance is a major concern. Major activities involve the introduction and use of new genetic materials in breeding programs to develop cultivars to increase or stabilize grain yields with desirable food quality.

New Opportunities

The Malian program has continued work on millet entomology, breeding, quality and cropping systems. Work to develop *Striga* resistant sorghums and photosensitive late maturing sorghums to escape the head bugs and molds was expanded. InterCRSP activities with TROPSOILS were initiated for breeding and selection of sorghums for improved soil nutrient efficiency and toxicities during the 1992 cropping season. A Malian Ph.D. soil scientist will return to Mali in 1994 to collaborate in this program.

Research Progress

- Germplasm Enhancement

Breeding Nurseries

Major progress was made in the objective to develop white-seeded, tan-plant guinea sorghum cultivars. F4 progenies from crosses involving Bimbiri Soumale, Tiemarifing, and CSM388 looked very good at both Sotuba and Cinzana and some will be advanced to the preliminary yield trial. Also, they will be backcrossed once to further enhance the guinea traits. These progenies are white-seeded, tan-plant, juicy-stem, with good guinea plant, grain, glume, and panicle characteristics. They also appear to have excellent yield potential. Dirivatives of Bimbiri Soumale, a southern Mali guinea with extremely long panicles, appeared especially promising, and may be a useful type to utilize in breeding guinea derivative cultivars for West Africa. The cross, Bimbiri Soumale x Introduced Zerazera, gave the best progeny. Early generation breeding progenies (214 F2, 508 F3, and 181 F4) were evaluated across a range of environments from north to south and 584 white grain single plant selections in the F2 and 489 in the F3 were made. Improved maicillo varieties from the INTSORMIL program in Honduras were tested for adaptation at Longorola (Southern Mali). Some of the materials showed the correct maturity, however, the grain quality was poor. Crosses were made between some selected improved maicillo varieties and improved malisor food types to develop photoperiod sensitive improved food sorghums. Some unique late maturing genotypes were evaluated for flowering date in southern Mali to determine potential usefulness to the area. Over 200 B and R lines from Texas A&M were observed for adaptation at Sotuba, eight B lines and four R lines were selected and used to make 38 crosses with diverse improved lines from Mali and ICRISAT.

Evaluation of Advanced Varieties

Sixty-one advanced varieties were evaluated in two separate trials, based on maturity groups at different locations in Mali. Among the early varieties 6 were evaluated for 3 years and showed a grain yield between 2.7 t/ha (87-CZ-F4-455-1) and 2.3 t/ha (88-BE-F4-287). Three varieties among the medium-maturing group showed an average grain yield between 2.41 and 2.02 t/ha over 3 years. Two varieties 87-LO-F4-92 (Malisor 92-1) and 87-SB-F4-54-2 (Malisor 92-2) with 3t/ha and 2.5 t/ha respectively were selected and will be included in the on-farm testing in 1993.

International Sorghum Tropical Adaptation Trial (ITAT)

We evaluated eight B lines, seven R lines, and 38 hybrids at Bamako Mali in 1992. The head bug-grain mold complex and leaf diseases were very severe and reduced the perform-

Table 1. Visual ratings in the advanced nursery trial grown at Sotuba, Mali in 1992.

Treatments	Visual rating[a]	Glume covering[b]	Panicle shape[c]	200 seed weight (g)
Malisor 84-7	1.25 C	3	C	3.65 BCD
87-SB-F4-54-2	1.68 BC	6	C	3.70 BCD
IS-16-357	2.37 A	3	L	4.40 B
IS-21468	1.50 BC	2	L	3.19 CB
IS-21525	1.62 BC	5	L	4.09 BC
IS-27477	1.56 BC	5	L	6.32 A
R-6078	2.06 AB	4	C	3.64 BCD
BVar1/BTx635	1.50 BC	5	C	2.74 D
82-Sel-Grain-Dur	1.50 BC	2	L	6.24 A
p. 0.05	HS			HS
CV	15.86			12.14
Mean	1.67			4.22

a Visual rating of head bug damage to grain: 1 = no damage, 5 = destroyed.
b 1 = completely covered, 10 = not covered.
c L = loose, C = compact.

Table 2. Summary of visual ratings in the advanced nursery trial grown at Sotuba, Mali in 1991 and 1992..

	Visual rating[a] (head bug)		Visual rating[a] (grain mold)		200 head weight (g)	
Treatments	1991	1992	1991	1992	1991	1992
Malisor 84-7	1.00 D	1.25 C	2.13 BC	1.18	3.46 D	3.65 BCD
87-SB-F4-54-2	2.63 BC	1.68 BC	2.50 AB	1.25	4.10 BC	3.70 BCD
IS-16-357	4.50 A	2.37 A	2.63 AB	1.00	3.67 BCD	4.40 B
IS-21468	3.13 B	1.50 C	1.25 C	1.00	3.21 D	3.19 CD
IS-21525	2.25 C	1.62 BC	3.25 A	1.00	4.17 AB	4.09 BC
IS-27477	4.00 A	1.56 BC	1.00 AB	1.12	4.67 A	6.32 A
R-6078	4.13 A	2.06 AB	2.38 AB	1.12	3.60 CD	3.64 BCD
BVar1/BTx635	2.00 C	1.50 BC	2.75 AB	1.12	3.48 D	2.74 D
82-Sel-Grain-Dur	2.25 D	1.50 BC	3.13 AD	1.00	3.23 D	6.24 A
p. 0.05	HS	HS	HS	HS	HS	HS
CV	17.12	15.56	24.03	19.80	9.4	12.14
Mean	2.76	1.67	2.55	1.09	3.73	4.22

aa 1 = no damage, 5 = severe damage.

ance of most of the entries. The top yielding hybrids were ATx631 * GR127-90M-48 with 2.66 t/ha and A1 * 86EON361 with 2.60 t/ha. The lowest yields were obtained from R8503 and R9032.

International Food Sorghum Adaptation Trial (IFSAT)

The 40 entry IFSAT was planted at Cinzana to obtain information on yield and adaptation. The top performer yielding entries were hybrids obtained from crosses of 87EON366, Dorado, RTx2816, and GR127-90M-47. The yields ranked between 2.59 t/ha (ATx635 * 87EON366) and 1.0 t/ha (ATx631 * R8511 and ATxARG-1 * R8511). Unfortunately the trial suffered from the combination of head bug damage and leaf diseases, which reduced grain yield of some entries as well as grain quality.

- Entomology

Advanced Screening Trial for Head Bug Resistance

This trial was planted at Sotuba and contained 9 entries, including Malisor 84-7 as check (Table 1). Most of the entries showed good level of resistance to head bug attack. The visual rating indicated that 82 Sel-Grain-Dur, BVar1/BTx635 and IS 21465 did not show significant difference with Malisor 84-7 in head bug damage evaluation. 82 Sel-Grain-Dur, in addition to the good level of resistance to head bug, seems to have a vitreous grain and a better level of resistance to anthracnose compared to Malisor 84-7.

- Preliminary Screening Trial for Head Bug Resistance

To obtain new sources of head bug resistance, a nursery of 51 breeding lines in 2 replications was planted at Sotuba in 1991 and 1992. Most of the varieties was progenies of Malisor 84-7. The results indicated that 5 entries from Texas out of the 51 entries showed a level of resistance to head bug comparable to that of Malisor 84-7. Thus varieties will be screened in the advanced screening trial in 1993.

- Simple Screening Method for Head Bug Resistance

Studies were conducted at Sotuba in 1991 and 1992 to determine a simple screening method for head bug resistance by comparing the use of the insecticide diazinon, mesh case protection, pollinating bag protection, and natural in-

Table 3. Summary of visual rating of the best five entries in the preliminary screening nursery (Sotuba 1991 and 1992).

Treatments	Visual rating[a] (head bug)		Visual rating[a] (grain mold)		200 seed weight (g)	
	1991	1992	1991	1992	1991	1992
TX1	1.25	2.00	1.75	1.25	20.57	20.7
TX2	2.50	1.62	1.25	1.00	17.97	15.7
TX5	1.75	2.00	1.25	1.00	19.53	17.45
TX6	1.75	2.00	2.00	1.50	17.75	20.45
TX9	1.25	2.1	1.50	1.0	18.90	20.15
Malisor	1.50	1.75	1.0	1.0	18.60	17.1

[a] 1 = no damage, 5 = severe damage.

Table 4. Comparison of different methods of protection to head bug damage.

Treatments	Visual rating[a] (head bug)		Visual rating[a] (grain mold)		1000 seed weight (g)	
	1991	1992	1991	1992	1991	1992
Insecticide	1.95 B	1.35 B	2.05 B	1.00	31.55A	20.65 BC
Cage	1.00 C	1.00 C	2.17 B	1.05	30.68 A	20.12 A
Pollinating bag	1.00 C	1.00 C	2.07 B	1.00	30.71 A	24.39 AB
Natural infestation	4.05 A	2.40 A	3.65 A	1.00	31.07 A	19.51 C
p. 0.05	HS	HS	HS	NS	HS	S
CV	9.43	7.42	17.48	7.27	8.24	10.34
Mean	2.00	1.43	2.48	1.02	31.00	22.60

[a] 1 = no damage, 5 = severe damage.

festation. The pollinating bag method appeared especially promising.

The head bud damage was more severe in 1991 than in 1992. This is mainly due to the variation in the population size of *Eurystylus marginatus*. The results showed that Diazinon did not protect as well as the cage and pollinating bag protection. Further studies should be done to evaluate other insecticides for head bug protection.

- Phytopathology

Anthracnose

Two years of screening (1991 and 1992) resulted in the identification of resistant varieties using the technique of susceptibles in alternate plots. The result indicated that 848109, MAS157, 90L1341, M500902 and CSM388 are the most resistant to anthracnose.

Sooty Stripe

A trial of 100 varieties was tested in 1991 and 1992 at Sotuba for screening for sooty stripe resistance. The results indicated that 7 varieties showed a good level of resistance: CSM388, SC326-6, SSW036, S47, MR849 and MR923-2.

Grain Mold

In 1992, 40 varieties were screened for grain mold damage using the protected and non-protected technique developed in the head bug/grain mold complex study. Six lines possess useful grain mold resistance : VG153, SC630-11E, 90L19037, 91CW5299, 91BE2149, 91CW4406.

Covered smut

During 1992 season, two fungicides, Apron plus 50DS and vitavax, were tested for efficacy in covered smut. The results indicated that seeds treated with the chemicals reduced significantly the attack of *Sporisorium sorghi*.

- Agronomy/Physiology

Long term cropping system and nitrogen rates interaction study

The cereal/legume rotation was continued at Cinzana. Increases in pearl millet grain yield and biomass production due to previous cowpea crops was equivalent to that obtained with application of 30 to 40 kg/ha N. The increase in sorghum grain yield due to nitrogen application was 26% and 82% at 40 Kg N and 80 Kg N/ha levels. This indicates that application of nitrogen fertilizer is essential for maximum sorghum grain yield when phosphorus fertilization is not a limiting factor.

In previous peanut cropping alone (at 0 N level), 86% and 117% yield increase occurred when 40 kg and 0 kg of N were applied as urea on previous peanut plots. The results on efficiency of sorghum cowpea intercropping suggest that the efficiency of sorghum peanut intercropping is a function of soil fertility level, especially soil nitrogen status. In 1992, the increase in pearl millet yield due to nitrogen application alone ranged from 15% to 45% when 20 kg and 40 kg/ha of

N were applied as urea. It was observed that at 0 N level, previous cowpea effects on pearl millet yield results in 33% yield increase. This effect may be equivalent to the effect of 30 kg N/ha applied as urea.

Crop Residue Management Study In Cereal/Legume Rotation

In 1992, at Samanko, there was no interaction between cropping systems and crop residue application. Previous peanut crop effect was significant on sorghum grain yield (about 39% increase). Sorghum residue application did not increase sorghum grain yield (P = 0.05). At Cinzana, no interaction occurred between cropping systems and residue application.

Nutrient Use Efficiency in Sorghum

Four genotypes (CSM388, Tiemarifing, S34, and Malisor 84-7) were compared at five nitrogen levels (0, 40, 80, 120, and 160 kg/ha) at Sotuba and N'Tarla in 1992. Nitrogen use efficiency for genotypes was measured as the ratio of increment of a given treatment grain yield compared to the check grain yield, to the difference of nitrogen applied on that given treatment and the nitrogen applied on the check. Data in Table 5 suggests a decrease of N use efficiency of Tiemarifing with respect to N rate. This tendency was not evident with CSM388, Malisor 84-7, and S34.

Table 5. Nitrogen use efficiency of the four genotypes, N'Tarla, 1992.

	40 N	80 N	120 N	160 N
Tiemarifing	19.42	12.57	5.95	6.78
CSM388	6.65	10.33	8.76	5.94
Malisor 84-7	8.97	1.88	4.43	3.65
S34	24.57	3.68	3.84	5.43

An experiment was implemented to select diverse progenies which show good response in sandy soils of the Cinzana station with nutrient deficiencies/toxicities. The progenies were F2 from some crosses made in Texas. The best progenies were consistently from crosses made with Babadia Fara, Bagoba and Gadiaba. Those F2 individuals will be tested in F3 progenies in 1993.

Seedling Screening for Resistance to Drought and High Temperature

Thirty-five entries were tested in a charcoal pit at Cinzana for drought and high temperature resistance. After emergence, plants were counted at 3, 7 and 15 days after planting. The results showed that CSM219, Bagoba and 89-CZ-CS-F5-15AF were the most resistant. The three varieties had the highest number of surviving plants at 15 days after planting.

Plant Population and Fertility Effects on Leaf Area, Relative Water Content, and Yield of Sorghum

Two varieties, CSM63 and ICSV401, were used at Bema for this study. The plant populations were 31.25 plants/ha (P1) and 62,500 plants/ha (P2). The high plant population reduced the leaf area of the two varieties (P1 = 491 cm^2, P2 = 422 cm^2 for CSM63 and P1 = 348 cm^2, P2 = 305 cm^2 for ICSV 401). The grain yield recorded with ICSV401 showed with the plant population P1, a yield of 1183 kg/ha with no fertilizer and 1975 kg/ha with fertilizer and for P2 a yield of 1467 kg/ha with no fertilizer and 2567 kg/ha with fertilizer.

- Grain Quality Studies

In the food technology laboratory research, evaluation was made mainly on materials from the preliminary and the advanced yield trials. A total of 93 lines from different locations was evaluated for kernel characteristics, physical properties, decortication yield, and the properties of fresh and stored tô. For potential new cultivars, a mini-tô-test was performed on the flour by comparing with local cultivars for porridge texture and keeping properties. A larger sample from advanced materials was milled and cooked into tô to evaluate texture and keeping properties.

Research Accomplishments for Life of Project

INTSORMIL has been in Mali informally since November of 1979. A formal Memorandum of Understanding was signed with IER in 1984. The program has interacted with ICRISAT-WASIP,TROPSOILS, IER, and Ciba-Geigy. USAID-Mali has supported the program with moral and financial support over the years. The most significant overall accomplishment has been a major improvement in the capability of IER to conduct sorghum/millet research in Mali. IER is now recognized as having the best overall sorghum/millet research program in Sub-Saharan Africa. Some accomplishments for the life of the project are:

Training

- INTSORMIL has provided graduate training for 15 key Malian scientists (Table 6).
- Short term training has been provided in the USA for Malian PI's in physiology, breeding, soil fertility, food technology and entomology.
- INTSORMIL trainees are now in key governmental or research positions in Mali: Dr. Moussa Traoré - Currently Permanent Advisor to the Minister of Agriculture - Previously, INTSORMIL Country Coordinator and Dr. Aboubacar Touré - Currently Sorghum Team Leader and INTSORMIL Country Coordinator.

Table 6. Malian scientists trained by INTSORMIL PIs.

Name	Year graduated	Degree sought	Discipline
Moussa Dossolo Traoré	85	PhD	Physiology
Sidi Bekaye Coulibaly	91	MS	Physiology
Siriba Dione	91	MS	Physiology
Abdoul W. Touré	92	MS	Agronomy
Adama Coulibaly	92	MS	Agronomy
Osman Coulibaly	*	PhD	AgriEconomics
Karim Traoré	90	MS	Millet Breeding
Minamba Bagayoko	90	MS	Agronomy
Aboubacar Touré	92	PhD	Sorghum Breeding
Abdoul A. Sow	**	PhD	Soils
Mamadou Doumbia	**	PhD	Soil Fertility
Assa Kanté	87	MS	Food Technology
Mamourou Diourté	88	MS	Pathology
Mamourou Diourté	*	PhD	Pathology
Abdoulaye Traoré	*	PhD	Agronomy
Naimoye Yaro Diarisso	*	PhD	Entomology

* Currently studying.
**Currently studying, MS completed in Soils, supported by TropSoils.

Infrastructure

- Designed and equipped food technology laboratory at Sotuba.
- Built and equipped physiology laboratory at Cinzana.
- Provided computers/word processors for DIAL-COM and laboratories.
- Short-term technical assistance on soil fertility/agronomy, entomology, pathology, physiology, food technology.
- Physical and chemical analysis of soil profiles of Cinzana Station.
- Established and installed sprinkler systems to initiate screening procedures for drought tolerance at Cinzana.

Germplasm Enhancement

- Elite sorghums from all over the world have been incorporated into Malian breeding programs.
- Testing in Texas and Mali has demonstrated the drought response in Mali is similar to that in West Texas.
- Elite U.S. pearl millet lines crossed to Malian pearl millets have been introduced into Mali.
- Seven improved sorghum lines from the Malian program have been released.
- These Malisor lines (84-1 to 84-7) have different maturities and characteristics for the various regions of Mali.
- Malisor 84-7 has shown some advantages in multiple cropping systems.
- Malisor 84-7 has been identified to possess excellent tolerance to head bugs which can be genetically transferred to its progeny.
- CSM388 and CSM-219, improved local photosensitive Malian sorghum cultivars through mass selection, are currently grown by farmers on a significant area.
- Genetic tolerance to soil toxicity problems has been demonstrated, and tolerant varieties identified (Bagoba, Babadia Fara, and Gadiaba).
- New breeding progeny to develop white-seeded, tan-plant guinea cultivars looks very promising for yield and other traits.
- A program in *Striga* has been initiated using host plant resistance.
- Malian breeding lines show excellent potential for use in the U.S. to improve overall grain quality of food type sorghums.
- The first focused improvement program to develop sorghum with resistance to the head bug/grain mold complex was established in Mali.

Utilization

- Sorghum and millet postharvest technology systems in Mali were documented in 1979 and subsequent years.
- Strategies for evaluating the quality of cereals, especially sorghum, for thick porridge (tô) were devised.
- Equipment for the new Food Technology Laboratory was provided.
- Personnel were given short term training programs in the U.S.
- Mini tests for evaluating milling and tô properties were developed.
- Sorghum dehulling properties were defined by combined village trials and laboratory research in Mali.
- Sorghums with hard endosperm and thick pericarp were definitely required for efficient traditional hand pounding.
- Pearl millet quality is affected most by variation in kernel size and shape which significantly affects dehulling properties.
- Pearl millets with long, thin kernels (souna types), have drastically reduced yields of decorticated grain.
- Tô quality of millet cultivars does not vary as much as it does among sorghums.
- The combination of cowpea and millet flour (1:3) significantly improved the nutritional status of young children.
- This technology has been transferred to villages, especially in the Cinzana area.

Plant Protection

- The adverse effect of head bugs on the grain/food quality of introduced sorghums across the guinea type sorghum growing area of West Africa was first recognized and documented in Mali.
- Head bugs and molds combine to cause devastating losses in grain yield and quality of most introduced types.
- Inheritance of head bug resistance is quantitative and primary recessive.
- Head bug damage reduces sorghum milling yields.
- The damaged grain is difficult to dehull because the endosperm is partially degraded and the kernel disintegrates when pounded.
- The resulting tô has unacceptable texture, color and keeping properties.
- Parboiling can convert sorghum and millet into acceptable shelf-stable products.
- Parboiling improves dehulling yields, especially for soft grains.
- The cooked milled products can be eaten like rice.
- Good quality sorghum (white, without stained kernels) is required to produce good quality shelf-stable food products.
- The development of photosensitive sorghums with tan plant and straw color glumes is required to produce high-quality, value-added products.
- Research on *Striga* has been initiated.
- An easy, efficient method of screening for head bug resistance using bagged vs. non-bagged heads has been developed.

Agronomy/Physiology

- A method of screening large numbers of sorghum and millet lines for early generation selection for seedling stage drought resistance using a charcoal pit has been adapted and is used.
- Factors affecting the "soil toxicity problems" in Mali have been partially determined through joint INTSORMIL/TROPSOILS collaboration.
- Some Durra varieties from Niger and northern Mali show tolerance to soil toxicity.
- A soil crust breaker designed at ICRISAT has effectively enhanced the stand establishment of sorghum and millet. Millet and sorghum genotypes vary in ability to emerge through soil crusts.
- The poor seedling emergence of many improved sorghums is caused by inferior seed quality caused by head bug/mold damage.
- Crop rotation of sorghum or pearl millet with either cowpea or peanut increases grain yield by 18 to 56% which is equivalent to the application of 20 to 40 kg/ha of nitrogen fertilizer application.

- Optimal yields of continuously cropped sorghum requires 40 kg/ha nitrogen fertilizer and continuously cropped pearl millet 20 kg/ha.

- Nitrogen fertilizer responses are greatest when adequate water is available for plant growth, thus production practices must improve for both in order to have a major impact in yield. Nitrogen management strategies have been developed for sorghum and are now being disseminated to local farmers.

- Nitrogen use efficiency (NUE) of improved cultivars have been better than local cultivars at higher N rates, while local cultivars had better NUE at zero and very low N rates.

- Abscisic acid (ABA), accumulation of solutes in cells and proline accumulation have all been found to be associated with stress tolerance.

Niger

Ouendeba Botorou and John D. Axtell
INRAN/Niger and Purdue University

Coordinators

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Collaborative program

Organization

This is an interdisciplinary, multi-institutional collaborative research program which involves INRAN and U.S./INTSORMIL institutions.

Financial Inputs

A major sorghum and millet workshop was sponsored in 1985. This workshop demonstrated the quality research and collaboration that had taken place not only between INTSORMIL and leading INRAN scientists but also between the TROPSOILS CRSP, ICRISAT Sahelian Center, the USAID/Purdue/INRAN National Cereals Research project, the International Fertilizer Development Center (IFDC), and the Interstate Committee to Combat Drought in the Sahel (CILSS). This workshop provided significant interaction between scientists and other workshop participants and served as a model of cooperation and collaboration on resolving constraints to improved production and utilization of sorghum and millet. USAID provided core funding and local support for this workshop.

An Inter-CRSP PID was prepared by USAID with INRAN and INTSORMIL inputs, and submitted to the Agricultural Officer at USAID. Due to USAID budgetary constraints, this PID was not funded.

Collaboration with Other Organizations

The ICRISAT Sahelian Center has been actively involved in millet entomology and millet breeding research. Participants include Drs. Frank Gilstrap, Ousmane Youm, Ouendeba Botorou and Anand Kumar. Dr. Wayne Hanna in Georgia has also been an active collaborator in this millet program. In the past 14 years, there have also been other organizations and International Centers who collaborated with our program in Niger. These include TROPSOILS, the Agricultural Research Corporation (ARC) in Wad Medani, Sudan, the Educational and Agricultural Research Institute (IN.E.RA.) in Burkina Faso, and the Purdue/Niger Applied Agricultural Research (NAAR) project.

The Planning Process

There are several interdisciplinary activities involved in this program. These include sorghum and millet breeding, agronomy, pathology, physiology, food quality and economics. U.S. INTSORMIL Principal Investigators develop research plans and budget with INRAN collaborators on an annual basis. Each plan is then translated into French and submitted to Dr. Mamadou Ouattara, INRAN Director General, for his approval.

Sorghum/Millet Constraints Researched

Production and Utilization Constraints

Drought, insect pests, long smut and *Striga* are the major constraints in Niger. Extremely high soil temperature leads to difficult problems in crop establisiment. Sand blasting of young seedlings is also a complicating factor. Plant breeding for tolerance to these major constraints is one of the most feasible solutions. New cultivars must be acceptable for tuwo preparation. For example, the variety L-30 has been the highest yielding sorghum variety in the Sahelian trials for the past 10 years, but is not accepted by farmers because of poor food grain quality. A number of useful collaborative research activities have been developed in Niger between INTSORMIL principal investigators and INRAN scientists.

Research Methods

The collaborative research program in Niger includes sorghum and millet breeding, agronomy, pathology, physiology, food quality and economics. Research methods appropriate for each of these disciplines are employed for this research program.

Research Progress

The sorghum and pearl millet breeding programs are only two examples of research progress findings. The INRAN sorghum breeding program has made significant progress in its own organization and in the results obtained over the years. INTSORMIL is recognized within INRAN as a great contributor to all of that success. Among other things,

INTSORMIL researchers have provided professional assistance in the field and in academic training to many INRAN workers. The improved sorghum varieties SRN-39, NAD-1 (in pre-extension) and SEPON-82 (adopted by a large number of farmers) are clear examples of what this collaboration has yielded to farmers in Niger. This needs to be continued and strengthened. Genetic materials, with overall adaptation, are still needed and may come from the kind of productive exchange we have had thus far. Presently, there is a good number of improved lines which need further tests and improvement for traits like stand establishment, lodging resistance, or resistance to *Striga*.

A major study of pearl millet breeding strategies for Niger was conducted by Dr. Ouendeba Botorou with the following conclusions: the results of the diversity and diallel cross studies indicate clearly that knowledge of the degree of similarity or dissimilarity among landraces is not sufficient when choosing the best parent for crosses. The population crosses Ex-Bornu x P3Kolo gave the highest grain yield and a good level of heterosis even though the cluster analysis showed that the two cultivars had similarities for most of the traits measured. This is the best study of its kind on millet in Africa.

Mutual Research Benefits

Extensive use of drought tolerant materials from Sahelian countries, including Niger, have been used extensively by the private and public sectors in the U.S.

Institution Building

INRAN and INTSORMIL are both approximately 15 years old at this time. In a sense, both institutions have grown up together. When INTSORMIL first began collaborative research relationships with INRAN there were relatively few highly trained Ph.D. level scientists in their organization. Over the past 15 years this situation has changed dramatically within INRAN. INRAN has matured and grown significantly as a research organization over the past 15 years. INTSORMIL has played some part through training and through collaborative research efforts in the institutional development of INRAN. INTSORMIL scientists have also grown during this period in terms of their collaborative research capabilities in sorghum and millet research and technology. The collaborative research relationship now is an effective system for delivering excellent research and for the application of this research for the benefit of farmers in Niger and in the United States. INRAN now has excellent leadership, excellent scientific direction and excellent scientists, either fully trained or in the final stages of their Ph.D. training programs. They now have a critical mass of excellence in research capability for the agricultural sciences. When one looks at progress in institutional developments over a longer time frame, it is easy to be optimistic about the future of INRAN/INTSORMIL collaborative research.

Research Supplies and Support

In support of this collaborative program, two vehicles (Toyota Corolla and Toyota Land Cruiser) were purchased for use by INRAN/INTSORMIL collaborators. In addition, four Yamaha dirt bikes were purchased for use at Kolo and Maradi stations. Other capital equipment purchased have included: a Mettler balance, mini-dehuller, infrared thermometer, multimeter, top loading balance, stage micrometer, sterilizer and Labconco Purifier. To assist the host country coordinator a desktop and laptop computer were purchased as well as a printer. Over the past 14 years, minor equipment and supplies have been purchased and shipped to Niger from funds held at Purdue on behalf of the host-country program.

Training of Host Country Researchers

Dr. Ouendeba Botorou was trained in pearl millet breeding at Purdue University and has returned to INRAN to serve as senior scientist in the pearl millet breeding program as well as Cereals director and INRAN/INTSORMIL coordinator.

Dr. Moussa Adamou received his Ph.D. at Mississippi State and returned to lead the sorghum breeding program in Kolo.

Dr. Ousmane Youm received his Ph.D. at Texas A&M University in entomology and is now principal entomologist at the ICRISAT Sahelian Center.

Dr. Dale Hess received his Ph.D. at Purdue University in sorghum breeding and returned to the ICRISAT Sahelian Center in Niger as millet pathologist.

Mr. Issoufou Kolo received his M.S. in pathology at Purdue University and has returned to Niger as INRAN sorghum pathologist.

Mr. Issoufou Kapran received his M.S. at Purdue University in sorghum breeding and returned to INRAN as the sorghum breeder for the Maradi station. He is currently back in the U.S. for Ph.D. training.

Mr. Cherif Ari received his M.S. at Purdue University in millet/sorghum agronomy, and is stationed at Maradi.

Mr. Adam Aboubacar received his M.S. at Purdue University in food science and is currently working on his Ph.D.

Mr. Seini Sirifi received his B.S. from Purdue University and his M.S. at Nebraska in 1993 in millet/sorghum agronomy and is now stationed at Kollo.

Networking

INRAN is the responsible organization for agriculture in Niger. INRAN as a national institute collaborates with other

national institutes in sharing germplasm and research results. These include IN.E.R.A. in Burkina Faso, IER in Mali and ARC in Sudan. Increasing collaboration with the ICRISAT Sahelian Center in Niamey will expedite transfer of research results across the Sahelian zone.

A Sorghum Quality Laboratory Manual was developed in collaboration with the Cereal Technology Laboratory in Niger and the Food Technology Unit in Mali. This manual has been widely distributed throughout W. African countries.

Research Accomplishments

During the 93 crop season eight collaborative projects were implemented by INRAN scientists working on millet and sorghum. The projects cover aspects of breeding, agronomy, entomology, pathology, food quality, and socioeconomics. An increasingly important outreach to farmers, NGOs, and extension organizations played a part in these activities.

Millet breeding - Ouendeba Botorou

More than 500 late maturing collections made in 1992 were evaluated at the INRAN stations of Bengou and Tara, in southern Niger. The study aims at characterizing late maturing dwarf millets but ultimately the objective is to develop late maturing, highly productive varieties for southern Niger where the rainfall is higher. The high variability observed on characteristics such as flowering, height of stalks, head length, disease reaction, chibra and head yield indicates the possibility of making significant progress in the improvement of these characteristics. The improvement of late maturing millet varieties can have a regional importance since this type of millet is extensively grown in the Soudanian zone of Burkina Faso, Mali, Ivory Coast and many other countries of the region. A much ambitious breeding program can be implemented to make use of the available genetic resources and select for adapted and productive types.

Evaluation of new crosses

P3KOLO x EXBORNU: the objective of the cross is to develop good yielding varieties adapted to the region. F1s were selected on the basis of their earliness (55-67 days to heading) and head length (26-62 cm) in 92, and their stalk height and head length measured in 93. Selfed heads will be used to select plants with high potential in 94 for the development of productive populations or varieties.

<u>1992-93 crosses</u>

Two hundred and forty individual crosses between CIVT, K0191, K0192, GRP1 were evaluated for agronomic characteristics, and reactions to insects, diseases and *Striga* (five exceptional crosses selected). This material will be evaluated as F2 in 94.

Seed production: Isolations were used for the second recombination of ExBornu x Mansori (Kollo) and the first recombination of late maturing varieties (Bengou, Tara).

U.S. collaborators include W. Hanna (Tifton, Georgia), G. Ejeta (Purdue) and D. Andrews (Nebraska); the latter has visited Niger in October 93 to discuss the future collaboration with Niger millet breeders.

Millet agronomy - Cherif Ari

An experiment in its second year was conducted at Maradi and Konni to test the effects of phosphorous on water use by millet genotypes. Results show no significant difference in the responses of the three varieties (DGP1, GRP1, CIVT) to any level of phosphorus fertilizer (100 kg/ha, 150 kg/ha, 200 kg/ha of SSP). At Maradi, variety CIVT was best yielder (1437 kg/ha) while it was surpassed by GRP1 at Konni (2573 kg/ha). Other data recorded are: incident solar radiation, leaf area, P content of leaf and stem, foliar index. They will be analyzed and interpreted in relation with yield data.

Sorghum breeding - Moussa Adamou/Kollo

The long-term objective is to improve sorghum for the sandy acid soils. A trial was conducted at five different locations with 20 entries, of which 4 are known tolerant and 5 know susceptible to aluminum toxicity. Data collected include flowering, plant height and grain yield.

Two tolerant varieties (AT1-36-42, AT1-52-2-1) were comparable in earliness with one non-tolerant (Wheatland) and the early locals Mota Maradi, Mota Galmi, and IRAT-204.

There were highly significant differences for plant height, which could be due to rainfall, planting data or soil conditions. Exotics were generally the shortest.

Highest yields were obtained from the locals Babadia Fara, Mota Maradi and L-30. However one exotic tolerant came in third position at Konni.

A combined data analysis showed significant differences among the 20 entries for all traits. This high variability is a good point for a breeding program on soil acidity. The use of local material will be of big importance in such a program.

Sorghum breeding - Issoufou Kapran/Maradi

This year's trials were conducted by Mr. Magagi Abdou (research technician at Maradi) following instructions from Issoufou Kapran on study leave at Purdue. There were three trials at Maradi and one at Konni, this being the second year for all four.

One hundred twenty-six new hybrids and parental lines were tested on sandy soil at Maradi, Four check entries were

Mota Galmi, Mota Maradi, Sepon-82, and NAD-1. A good number of hybrids were rated as adapted and having a yield potential comparable to that of NAD-1. The female parent ABON34 had the most impressive hybrids.

Evaluation of midge tolerant lines: following the encouraging results from 1992, a set of material originally from Texas A&M and ICRISAT were planted to evaluate further their adaptation and reaction to midge. The insect damage was however minimal this season and the data collected included only yield and flowering notes.

Evaluation of lines for head bug resistance. This material also came from Texas A&M. Here too the head bug damage was minimal.

Evaluation of *Striga* resistance under natural infestation (Konni). A number of recombinant inbred lines derived from SRN-39 were observed for their *Striga* reaction under natural infestation. Unfortunately very few *Striga* plants emerged in the entire trial even though this was a field with a history of heavy *Striga* infestation.

1993 was a relatively dry year, and in the past the above parasites have not prevailed under dry conditions, especially *Striga* and head bugs. About sorghum midge, the planting date (July 7) may have helped the material to escape. In 1992 we noticed that one week difference in planting dates (July 7-14) was a key factor in seed set reduction caused by the insect at Maradi. The low rainfall of 1993 was however a good setting for the evaluation of the new sorghum hybrids at Maradi. All the above trials were visited by INTSORMIL and other scientists during the EEP review (October 1993). The opportunity was also taken to view the results of another activity supported by INTSORMIL: hybrid seed production and farmer demonstration plots. The seed production in isolated plots of NAD-1 was expanded this year, to include the INRAN stations of Maradi, Konni, Kollo, Bengou, and Lossa. In addition one field was planted in late September at Maradi for off season seed production, the seed quality being superior. This field is irrigated. Farmer demonstration plots (NAD-1) were also spread all over the country especially around research stations. The 1992 hybrid seed was not always of a good quality so that not all plots were realized. Some of the farmers at Konni planted their entire field with the hybrid because they have observed it the previous season, so that a comparison with the local variety was not always possible. Yield estimates were not always possible because most farmers save their production in tied bundles of the heads that are not weighed. Still we obtained yield estimates from 10 farmers around Konni and Djirataoua (Maradi). They range from 923 to 4667 kg/ha, with an average of 2350 kg/ha. Bundle weight ranged from 10.1 to 17.20 kg. Local varieties Mota Maradi (2 fields), Mota Galmi (1 field) and El Bazanga (1 field) averaged 1575, 870 and 820 kg/ha, respectively. That is, NAD-1 produced one and one-half times more than the highest yielding local (MM). Although the data sample is small, this data is very indicative of the kind of results expected on the basis of all previous trials involving NAD-1.

Sorghum entomology - Hame Kadi-Kadi

Two trials were conducted for the second year at Maradi, Konni, and Bengou to evaluate the midge resistance and head bug resistance of lines provided originally by Texas A&M.

Sorghum midge. The trial was planted on three different dates for each location. The ICRISAT scale was used to evaluate severity of damage, by weighing selfed and open panicles for each of the twenty-seven entries; percent loss per panicle was also obtained. The data show different entries escape or resist to midge damage depending on planting data and location. The local check MM and entry TAM2566, TX2890 are the most commonly observed as tolerant or escaping, especially at the first planting date.

Sorghum head bugs. Twenty entries including two checks and 18 TAMU lines were screened under the same experimental conditions as above. Here also an ICRISAT scale was used to assess damage. Results varied with variety, location and planting date but Dorado was the most constantly safe from head bug damage.

Sorghum/millet pathology - Issoufou Kollo

Screening sorghum for mold resistance. One hundred entries were planted at Bengou and scored using the scale of 1-5 described by Corrales and Frederiksen (1978). Entries were provided by ICRISAT-Hyderabad. More than 50% were free of any sign of mold damage, compared to the local susceptible check BDF; however these lines suffer from zonate leaf spot, while being mostly resistant to anthracnose.

Study of resistance to long smut in sorghum. Plastic bag crosses between resistant and susceptible lines were evaluated this season. Parents, F1 and F2 populations will be evaluated in 1994. A preliminary screening nursery was planted to classify the long smut reaction of 98 entries, using TX623A as a susceptible check. Although the natural long smut pressure was low, 21 entries were selected and will be artificially inoculated in the off season.

Effects of N, P and K interactions on the incidence of *Striga hermonthica* on pearl millet. The trial was conducted at Kollo and Bengou with the millet variety Souna III and three levels of each N, P, K fertilizer. Additional *Striga* seeds were mixed with millet at planting although fields were selected for their heavy *Striga* infestation. Contrary to other workers (Farina et al, 1985; Bebawi, 1987) we did not find any significant interaction between N, P, K. Nitrogen application did not reduce the amount of *Striga* infestation, but this may be explained by previous fertilizer trials in the plots. Phosphorous application reduced the number of *Striga* at Kollo and increased it at Bengou. Potassium had no effect on *Striga* at Kollo but increased it at Bengou. The

soil at Kollo is 99% sand and 0.5% organic matter whereas Bengou has 63% sand, 23% silt, and 15% clay. The difference in soil type and maybe in rainfall could explain the effects of P and K at the 2 locations. Potassium has been reported to increase the number of *Striga* (Farina et al, 1985). This experiment will be reconducted in 1994.

Screening pearl millet for *Striga* resistance. The objective was to evaluate the incidence of *Striga* on several populations and advanced breeding lines of the INRAN millet program. Thirty-two entries were planted at Kollo, the millet seed being mixed with *Striga* seeds at planting. *Striga* counts showed a significant difference among entries, Tchouma local being least susceptible. This cultivar was described as resistant by several farmers. Most of the lines derived from the cross P3Kolo x Ex Bornu were susceptible. *Striga* number is not a sufficient criterion, however, considering that some varieties remain green despite heavy infestation; also there is a high within population variability.

Chemical control of *Striga* on pearl millet. This study was done using the herbicides Dicamba and Chlorosulfon provided by Dr. Frederiksen. These herbicides were highly phytotoxic to pearl millet at all rates used. In the pots where millet survived, *Striga* emerged only after maturity. Future work should look at ways of reducing the herbicide toxicity on millets.

Food quality of sorghum and millet - Moussa Oumarou

This study aimed at finding optimum ratios of sorghum or millet to use in composite flour with imported wheat for bread making. Preliminary trials were done to master the technique of flour mixing and baking, using the sorghum variety El Mota and millet variety Souna III. Flour from wheat and the mixture had no difference in protein content. There was no difference in preference for wheat bread or bread from composite flour having 10 to 30% millet or sorghum. No clear indications were obtained on digestibility. In 1994, grain from the sorghum varieties Mota Maradi, Sepon-82 and NAD-1 will be used in the experiment.

Socioeconomics - Tahirou Abdoulaye

For the second year, a survey on the role of by-products in sorghum production was conducted around Konni. Data was obtained concerning cultural practices, yields, and use of by-products. Not all data have been analyzed but information is available on cultural practices. Of the 68 fields surveyed, 47 or 69 % were intercropped with millet, sorghum and cowpeas. This favored cropping system is more common in the village of Kakou than in Dagarka.

Plant populations were found to be higher on valley soils and on fertilized fields. Organic fertilizer is the most used and may be transported from the village or obtained from cattle present in the fields. The village of Dagarka uses more fertilizer (organic and mineral) probably in relation to the irrigation project there. Farmers in the sample have planted 8 different sorghum varieties with Mace Da Kunya (MDK) being the most popular; it is a late maturing variety adapted to both valley and sandy soils. NAD-1 was found in two fields where it was mixed with a local variety; the hybrid seed is a leftover from demonstration plots.

South America (Colombia/CIAT)

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Institutions Involved

Mississippi State University (MSU)
Instituto Colombiano Agropecuario (ICA)
El Alcaraván Foundation
Federación Nacional de Cultivadores de Cereales (FENALCE)
Centro Internacional de Agricultura Tropical (CIAT)
Universidad Tecnológica de los Llanos
Universidad Nacional de Colombia at Palmira
Universidad del Tolima
Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA)
Instituto de Investigación Agropecuaria de Panamá
Fondo Nacional de Investigaciones Agropecuarias, Venezuela
Private sector, including national and multinational seed enterprises

Collaborative Program

Memorandum of Understanding

This collaborative research project operates in Colombia under four formal and several informal agreements which facilitate the project's involvement in a broad range of research activities. In 1981, a Memorandum of Intention was signed by the Directors of INTSORMIL, ICRISAT, and CIAT. Research started in 1982 through informal cooperation among ICA, the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), and INTSORMIL. Sorghum and millet research was formalized with the Colombian government in 1988 through a Memorandum of Agreement among ICA, INTSORMIL, and CIAT. Since then, CIAT has significantly helped the project to achieve its established goals.

In 1988, research was initiated in the acid savannas of Arauca through a Memorandum of Agreement between INTSORMIL and the El Alcaraván Foundation, a consortium of petroleum companies (Shell, Ecopetrol, and Occidental de Colombia) managed by Occidental. Informal agreements and close links have been established with non-profit organizations such as the Federación Nacional de Cultivadores de Cereales, (FENALCE), a Colombian production and extension-oriented organization, and three Colombian universities. Since 1990, formal and informal agreements in different research areas were made with seed companies that have research programs in Colombia, such as CIBA-Geigy and the Federación Nacional de Arroceros de Colombia (FEDEARROZ).

The INTSORMIL collaborative research project, MSU-111, is managed by the Office of International Programs, Mississippi State University.

Interdisciplinary Research

The MSU-111 project operates from CIAT, near Palmira in the Cauca Valley, where multinational seed companies have most of their experiment stations. Through CIAT infrastructure, the project can readily establish links with most public and private research programs, and national agricultural research systems (NARS) of other Latin American countries.

The major center for seed increase and distribution is at CIAT, Palmira. In contrast, germplasm selections take place at different sites in the Colombian Eastern Plains (Llanos Orientales), where soils with different levels of aluminum saturation are found in both well-drained and poorly drained savannas. The project uses ICA's experiment farms, or land rented from either CIAT or private farmers to obtain a range of ecosystems for each level of Al saturation. At ICA-La Libertad (near Villavicencio, Department of Meta), scientists from ICA, FENALCE, and INTSORMIL collaborate

in research and selection, according to established objectives.

Over the years, the project's research priorities adapted to changing needs. During 1981-1988, the goal was to identify and develop sources of acid soil tolerant germplasm. By 1991, the first two Al-tolerant varieties were released through the ICA/CIAT/INTSORMIL cooperative agreement. In 1988, the project began developing and evaluating germplasm adapted to soils with poor water infiltration. One research priority retained throughout the years was developing germplasm adapted to acid soils with Al-saturation levels of more than 40%.

Because of the diversity of collaborating institutions, the project carries out other activities. For example, FENALCE develops lines for semiarid areas (TAM-122) and lines resistant to grain molds. ICA develops drought-tolerant lines, adapted to acid soils and resistant to grain molds (TAM-124). The universities do research in agronomy and physiology (UNL-114), and entomology (TAM-124 and MSU-105). The El Alcaraván Foundation develops germplasm adapted to acid savannas and slightly acid soils ("vegas"). Two varieties were released in 1993. The Foundation is also increasingly interested in grain quality and utilization (TAM-126 and PRF-103B). Most of these research activities are conducted by scientists from ICA or the private sector, supported by undergraduate students working toward their B.Sc. theses.

Financial Inputs and Management

When the project was first established in Colombia, funds from INTSORMIL permitted work at multiple sites fulfilling the project's objectives. In 1987, funds were drastically cut, forcing the project to choose only the highest priorities and to encourage other institutions of sorghum research, both public and private, to assist with the research effort. Funds for the project are also obtained from contributions in kind from collaborating research institutions, and directly from the private sector. Funds from these sources often amount to more than those received directly from INTSORMIL. Colombia has a USAID representative only, so no Mission funds are available

Operational funds for the MSU-111 project are transferred from MSU to CIAT and are accounted for as an externally funded project. CIAT also manages the El Alcaraván account for INTSORMIL. Although the amount of real money provided by collaborating institutions is small, the strong cooperation among them has resulted in their absorbing most of the fixed costs, thus reducing costs considerably.

The El Alcaraván Foundation supplied almost US$500,000, during 1988-1992 for the sole purpose of supporting INTSORMIL's collaborative research in the Colombian Territory of Arauca. FENALCE contributed an agronomist (B.Sc.) for the La Libertad project and another for the drought project at Motilonia, Colombian North Coast. ICA provides all the infrastructure for experimental activities in the acid-soil areas of Meta. The sum of all additional support (land, equipment, human resources, miscellaneous facilities) provided by the Colombian organizations represents four times INTSORMIL's support.

Collaboration with Other Organizations

Because of scarce resources, most interinstitutional cooperation for Latin America has had to be, and will have to be, developed in Colombia.

International Centers

As a result of the 1991 International Seminar on Sorghum ("Sorghum for the Future"), ICRISAT and INTSORMIL have collaborated to activate research programs, promote germplasm exchange, and improve exploitation of available resources in major sorghum-producing countries of Latin America. INTSORMIL has organized several meetings in Colombia, with participation from scientists from all over Latin America. As a result of these activities, the Comité Latino Américano de Investigadores en Sorgo (CLAIS) and the Comité Interinstitucional del Sorgo (CIS) have suggested that INTSORMIL coordinates networking activities for Latin America, using CIAT as headquarters.

Since 1982, CIAT has supported the project in several ways: administratively, establishing relationships with other scientists, and opening alternatives for new research areas. Land, laboratories, equipment, and transport are only some of the facilities that CIAT has made available to the project. CIAT also increases basic seed of INTSORMIL lines for release in Colombia.

Private Sector

INTSORMIL has always collaborated closely with the private sector, which includes national as well as multinational entities headquartered in Colombia. Since 1982, many private companies have sent lines from the world collection for evaluation of acid-soil tolerance under different Latin American conditions. Although lines were identified as Al-tolerant and used as progenitors for developing genotypes adapted to tropical conditions, a major problem was excessive plant height of more than 200 cm of their F1 progeny. Most Latin American countries prefer short hybrids. Collaboration with the private sector has increased the possibility of finding hybrids adapted to the stresses predominant in Latin America's acid soils.

Most Latin American countries are privatizing and opening up their economies. The NARS involved in the sorghum and millet research have also been part of this process. In Colombia and Peru, future public research will become the responsibility of private or joint venture companies.

In Colombia, FENALCE stations an agronomist (B.S.) in each sorghum-growing region to provide farmers with technical support. ICA provides farms and scientists for all projects involving both institutions. The El Alcaraván Foundation fully supports research in Arauca under INTSORMIL's leadership.

Planning Collaborative Research

From the beginning, a close relationship was established with CIAT, facilitating work and promoting linkages with both foreign and national entities. ICA was INTSORMIL's principal scientific collaborator. The PI assigned to Colombia and the ICA scientist assigned to ICA's sorghum program at La Libertad meet annually to establish work plans.

Since 1987, relationships among the institutions involved in Colombian sorghum research have become complex, requiring careful coordination of research activities. Specific short- and long-term goals have been developed jointly with ICA, El Alcaraván, FENALCE, and the universities. Formal planning meetings are held annually to discuss specific experiments, organizational funding, and individual responsibilities. Results are published annually, and distributed among those involved.

Research on Sorghum and Millet Constraints

Constraints

Sorghum production in Latin America suffers from two major sets of constraints: first, and perhaps the more important, is production costs. When opening up the market, a country must produce sorghum at production and transport costs below international prices. The second set of constraints can be subdivided into abiotic and biotic. Sorghum in Latin America is produced under tropical conditions, with climates that vary from humid to dry, including drought during critical stages of the plant's development. Soils may be acid, with high Al saturation and low fertility. Major diseases attacking sorghum are leaf anthracnose and a complex of panicle fungal diseases.

In 1982, the first introductions of sorghum germplasm tolerant to acid soils were made from the world collection stored at Purdue University. This germplasm was selected according to their African country of origin with acid soils.

Through collaborative research, the first sorghum evaluations were conducted at CIAT's experiment station at Quilichao, using field plots with three lime rates to vary the percentage of Al saturation. Germplasm selected as tolerant was later evaluated at ICA-La Libertad, in the Colombian Eastern Plains.

Research Methods

Most of the MSU-111 project's initial research in Colombia was oriented toward identifying hybrids or varieties that could be incorporated within a sustainable production system for Latin America's tropical conditions. Once appropriate sources of germplasm were identified, crosses were made to improve the agronomic characteristics of the lines originally selected. Segregating populations were evaluated under different levels of Al saturation, according to production objectives and adaptation to ecosystems at each level. In all cases, selections were made under low-input technology, with minimal fungicide and insecticide use, and low levels of fertilizer. The project attempted to maximize the adaptability of the selected germplasm, given that hardiness is sorghum's comparative advantage over other crops.

Although the pedigree system was the main breeding method used, since 1992 recurrent selection was adopted to augment the original Al tolerance. Selected germplasm is sent to different sites for final selection for specific ecosystems. Besides breeding, the project also attempts to establish and characterize specific ecosystems in which sorghum could be grown and to search for agronomic and physiological solutions to the naturally low fertility of Latin American soils.

Research Progress

As a result of the El Alcaraván/INTSORMIL agreement, two sorghum genotypes (IS 3071 and IS 8577) were released in Colombia in 1993. These genotypes were developed from the first materials adapted to poorly drained savannas and were officially released for this ecosystem. Icaraván 1 (IS 3071) tolerates flooding after flowering; Icaraván 2 (IS 8577) yields profitably in soils with Al saturation levels as high as 70%. In 1990, ICA released two other genotypes resulting from collaborative research with INTSORMIL. Sorghica Real 40 yields profitably in soils with as much as 40% and Sorghica Real 60 in soils with 60% Al saturation. Through collaboration with FEDEARROZ, a hybrid using an A-line from INTSORMIL MSU-111 as female and an R-line from Texas, was released.

In a recently completed study, Ricaurte found that Al-tolerant sorghum produced larger benefit-to-cost ratios than rice at two levels of Al saturation (Table 1). At the higher level of Al saturation and low-input technology, sorghum had larger benefit-to-cost ratios than rice and soybeans, but slightly smaller than maize using partial budgeting. Compared with the gross margin of other crops, soybeans are the most profitable to produce in soils with 63% Al saturation, followed by sorghum, maize and rice (Table 2).

Mutual Research Benefits

National and multinational seed companies in Latin America will use the technology from this collaborative project to produce acid-soil tolerant varieties and hybrids that are also resistant to grain mold diseases. The release of Al-tolerant A- and B- lines will also expand the agricultural industrial market in the United States.

Table 1. Comparison of yield and benefit-to-cost ratio of maize and soybean at one level and sorghum and rice at two levels of aluminum saturation using two systems of technology.

	Aluminum saturation level: 35% - 60%		
	Sorghum		
	S. Real 40	S. Real 60	Icaima
Low-input technology	2137 (3.37)	1966 (3.02)	1487 (2.04)**
High-input technology	2031 (0.91)	2264 (1.13)	1772 (0.66)
	Rice		
	O. Sabana 6	O. Llanos 5	CICA 8
Low-input technology	2873 (1.30)	2647 (1.60)	1654 (0.01)
High-input technology	2533 (0.51)	2530 (0.85)	1372 (-0.3)
	Aluminum saturation level: 61% - 90%		
	Sorghum		
	S. Real 40	S. Real 60	Icaima
Low-input technology	1564 (2.20)	1498 (2.07)	593 (0.21)
High-input technology	2074 (0.95)	1926 (0.81)	663 (-0.4)
	Rice		
	O. Sabana 6	O. Llanos 5	CICA 8
Low-input technology	2768 (1.22)	1514 (0.50)	1033 (-0.4)
High-input technology	2771 (0.66)	1502 (0.10)	776 (-0.6)
	Maize		
	Cimcali-91-sa3	CIAT-88-sa3t	ICA-V-156
Low-input technology	1312 (2.64)	1326 (2.68)	554 (0.60)
High-input technology	2485 (1.18)	2321 (1.04)	1292 (0.18)
	Soybeans		
	SV-89	Soyica P33	Lita 6
Low-input technology	1827 (2.03)	1433 (1.65)	1430 (1.46)
High-input technology	1981 (1.48)	1519 (0.88)	1547 (1.00)

**Yields are in kg ha^{-1} and benefit-to-cost ratios in parenthesis are by partial budgeting.

Source: Jaumer Ricaurte. Análisis agroeconómico de cuatro cultivos en suelos acidos de baja fertilidad de los Llanos Orientales Colombianos. Degree thesis. Universidad del Tolima..

Table 2. Gross margin and marginal return rate, comparing the best treatments of different genotypes of rice, maize, sorghum, and soybean, evaluated under low inputs, in acid soils (46% and 63% Al saturation), Colombian Eastern Plains - 1992 B.

	Aluminum level 2 B (46% saturation)			
Crop	Genotype	Gross margin[1]	Marginal return rate on sorghum - Ll. 5 B	
Sorghum	Icaima	103.907	1.32	
Sorghum	S. Real 60	153.758	0.70	
Sorghum	S. Real 40	171.555	0.48	
Rice	O. Llanos 5	209.476		
	Aluminum level 3 A (63% saturation)			
			Marginal return rate	
	Genotype	Gross margin	Maize[2]	Sorghum[3]
Maize	CIAT-88-sa3t	105.425		
Sorghum	S. Real 40	111.920	0.56	
Soybean	Lita 6	166.261		0.86
Soybean	Soyica P33	188.067		1.20
Soybean	SV-89	247.580	1.72	1.91

[1]Gross margin by partial budgeting.
[2]Marginal rate of return from the best maize treatment (genotype CIAT-88-sa3t with low inputs) to the best of sorghum and soybean.
[3]Marginal rate of return of changing from the best treatment of sorghum (variety Sorghica Real 40 with low inputs) to the best of soybean.

Source: Jaumer Ricaurte. Análisis agroeconómico de cuatro cultivos en suelos acidos de baja fertilidad de los Llanos Orientales Colombianos. Degree thesis. Universidad del Tolima.

Institutional Building

Research Support

Over the years, INTSORMIL has donated many items of equipment and supplies to ICA, including threshers, air conditioners, humidity chambers, pollination bags, harvest bags, and harvesting materials. INTSORMIL has also provided assistance in statistical analysis. Periodically, it provides scientific information on innovations in sorghum research, and finances scientists who work directly with INTSORMIL to visit CIAT to use its excellent library and to learn the most up-to-date research techniques. INTSORMIL also finances ICA's sorghum scientists to attend occasional meetings on scientific advances and problems in sorghum production within Colombia and on the continent overall. Annual meetings are held on specific themes of importance to the country and/or Latin America. These meetings bring together outstanding scientists, keeping them up to date on the latest research advances in sorghum.

Some recent INTSORMIL contributions are:

Visits by highly experienced sorghum scientists and technicians. Larry Claflin from Kansas State University and Steve Mason from the University of Nebraska, visited Colombia for meetings and to provide technical support. The length of visits ranged from a few days to several weeks.

Research assistantships were given to Colombian personnel. Colombian scientists, Darío Narváez and Jairo Osorio, are studying at U.S. universities.

Donations of germplasm and equipment for use by both ICA and MSU-111 Project. A full set of the germplasm developed at Arauca was donated to ICA-La Libertad.

Literature was donated to support collaborative research projects in Colombia. A complete set of all theses conducted on sorghum in Colombia was donated to CIAT.

INTSORMIL paid the in-country expenses of all international scientists who visited Colombia to plan or conduct research on acid soils.

Trips for ICA personnel to the U.S. or other countries.

Organization of periodic work-meetings that benefit INTSORMIL's collaborators in Colombia and enhance the exchange of information among researchers. In August 1993, the second international meeting on acid soils research was held at ICA-La Libertad, to which more than 80 Latin American scientists attended.

National meetings have been organized every year since the MOA was signed with ICA. In February 1993, a national meeting was held at ICA-La Libertad for scientists working on acid soils in Colombia.

International Committee for Sorghum (CIS)

The CIS is a result of joint economic and research efforts among ICA, FENALCE, INTSORMIL, and the private sector. The CIS's objectives for Latin America are to:

Promote integration among institutions and persons related to sorghum research and production.

Provide orientation and enhance development of research and technology transfer programs on sorghum production.

Serve as a mechanism whereby personnel involved in sorghum research, technology transfer, and development can seek advice and orientation.

Promote and sponsor the organization and conduct of research and technology transfer activities related to sorghum production, and to diffuse information through publications and other documents.

Establish liaison with international institutions having similar objectives.

Although research support funds for ICA have been cut, its capacities have been strengthened by INTSORMIL's contribution towards equipment, literature, trained staff, field labor, seed storage facilities, and germplasm distribution.

Activities of Project Staff and Collaborators

Dr. Guillermo Muñoz, Associate Senior Staff at CIAT's headquarters, was appointed INTSORMIL PI for the MSU-111 project in July 1988, but has been acting PI since 1987. He initiated the activities in which the project is now involved. He coordinates research (especially in plant breeding, soil science, and seed technology) and training activities with collaborating organizations in Colombia and with INTSORMIL projects in the U.S.

Mr. Jaime Bernal (M.S., University of Nebraska) is the Principal Sorghum Breeder at ICA's main acid-soil research station at La Libertad.

Agronomist Alfonso González, a B.S. student trained by INTSORMIL, is working in sorghum research for the ICA/FENALCE agreement and has strengthened ICA's sorghum program at La Libertad. He has been in charge of specific experiments and the semicommercial fields. He is currently coordinating all student research activities in that region.

Agronomist Walter Rendón, a B.S. student trained by INTSORMIL, is working as Director of ICA/CRECED in Arauca and has strengthened both ICA's sorghum research program at Arauca and the El Alcaraván Foundation activities. He has been in charge of specific experiments and the semicommercial fields. He has made field selections with

the INTSORMIL PI, strengthening the genetic variability for the future development of varieties in Arauca and the Eastern Plains. He has been involved in the screening of sorghum lines for poorly drained savannas.

Considerable research was done through B.S. degree students to increase the project's research capacity. Ten B.S. students from the Universidad Nacional de Colombia at Palmira, the Universidad del Tolima, and the Universidad Tecnológica de los Llanos are developing their theses in collaboration with INTSORMIL.

Research Accomplishments

Two new varieties, Icaraván 1 and Icaraván 2, were evaluated and released in Arauca in 1993 through the ICA/El Alcaraván breeding program, with collaboration from INTSORMIL. Research conducted by INTSORMIL has developed specific varieties for the poorly drained savannas of Arauca.

Selections were made for different ecosystems from several segregating populations developed by the MSU-111 project at Arauca and La Libertad. Short lines with good yield potential are being evaluated in regional trials at La Libertad. The selected lines are agronomically better than lines from the world collection.

In summary, INTSORMIL's major accomplishment in Colombia has been the evaluation and release of four Al-tolerant sorghum varieties. These varieties were released as Sorghica Real 40 (156-P5-Serere 1), Sorghica Real 60 (MN-4508), Icaraván 1 (IS-3071), and Icaraván 2 (IS-8577) by ICA. The MSU-111 project also contributed toward a hybrid released by the FEDEARROZ/INTSORMIL agreement.

Sudan

Gebisa Ejeta
Purdue University

Country Coordinators

Gebisa Ejeta, Country Coordinator, Purdue University, West Lafayette, IN 47907
El Hilu Omer, Host Country Coordinator, Agricultural Research Corporation (ARC), Gezira Research Station, Wad Medani, Sudan

Collaborative Program

Organization

The INTSORMIL/U.S. principal investigators develop their scope of work jointly with ARC scientists. These workplans are reviewed and approved by the ARC Director General, Dr. El Hilu Omer, ARC/INTSORMIL coordinator and Dr. Gebisa Ejeta, Sudan Country Coordinator, and become part of the INTSORMIL Memorandum of Agreement.

Each workplan has its own funding. Funds are forwarded directly from Purdue University or the INTSORMIL Management Entity at the University of Nebraska and then are disbursed in Sudan to each ARC scientist to carry out their research program.

Dr. Ejeta and Katy Ibrahim coordinate the management of this program with U.S. principal investigators at Texas A&M, Nebraska, Mississippi State, and Purdue Universities.

Since direct communication with Sudan is rather difficult, the USAID Mission has provided excellent logistical support to relay communication to the ARC at the Wad Medani and El Obeid research stations.

Research Disciplines

Cooperative Sorghum Breeding and Genetic Evaluation- Osman I. Obeid Ibrahim, ARC; Gebisa Ejeta, and Darrell Rosenow, INTSORMIL.

Cooperative Millet Breeding - El Haj Abu El Gasim, ARC; David Andrews, INTSORMIL.

Agronomy and Water Management Program - S.M. Farah, ARC; Jerry Eastin, INTSORMIL.

Plant Pathology Program - El Hilu Omer, ARC; Richard Frederiksen and Darrell Rosenow, INTSORMIL.

Striga and Weed Control - H.M. Hamdoun and A.G.T. Babiker, ARC; Larry Butler and Gebisa Ejeta, INTSORMIL.

Entomology Program - N. Sharaf Eldin, ARC; Henry Pitre, INTSORMIL.

Food Quality Program - S.M. Badi, ARC; Allen Kirleis, and Bruce Hamaker, INTSORMIL.

Economic Program - Hamid Faki, Abdel Moneim Taha ARC; and John Sanders, INTSORMIL.

Collaboration with Other Organizations

The INTSORMIL/Sudan country program continues to collaborate with the following host country and U.S. organizations:

Agricultural Research Corporation (ARC)
Gezira Research Station (GRS)
Kadugli Research Station
Food Research Centre, Shambat
Sudan National Seed Administration
El Obeid Research Station
USAID/Khartoum
University of Nebraska-Lincoln
Texas A&M University
Mississippi State University
Purdue University

The Scope and Thrust of the Program

Production and Utilization Constraints

The potential for expansion of sorghum in the rainfed areas of Sudan is enormous; however, the major constraints limiting expansion are inadequate soil moisture, inadequate soil nutrients, and shortage of labor. Other factors that reduce sorghum yields in Sudan include insect pests, plant diseases, and *Striga*. High yielding cultivars with good grain quality suitable for mechanical harvesting are also requirements for future expansion of sorghum in the rainfed central clay plain regions of Sudan.

Breeding efforts currently under way in Sudan to incorporate drought tolerance with higher-than-average yield potential in sorghum are limited by the lack of a rapid field screening procedure and lack of knowledge on sources of

sorghum germplasm with useful traits. The insect pests known to attack sorghum, especially in the rainfed areas of Sudan, include stem borers, American bollworm, and central shoot fly. The major fungal diseases that affect sorghum production in Sudan include charcoal rot, anthracnose, long smut and a variety of grain molds. *Striga*, a parasitic weed of sorghum, constitutes a major constraint to sorghum production in Sudan. There is very little sorghum germplasm with resistance to *Striga* and the mechanism that renders resistance to *Striga* is not well understood. Knowledge about the inheritance of this trait is also lacking. The lack of absolute definitions and good screening methods for food quality to some extent also limit the utilization of high yielding sorghum varieties and hybrids in Sudan. Work on all these aspects is needed to improve sorghum production and utilization in Sudan.

Almost all of the pearl millet grown in Sudan is used for home consumption by farmers in western Sudan. The exception is a small but growing activity of millet cultivation in the mechanized rainfed regions where millet is produced on fields where sorghum yields have fallen too low. In western Sudan the crop/bush fallow system of production has traditionally been used to provide enough nutrients and possibly some moisture for a period of crop years (5-10 years fallow/2-4 years cropping). Crops are often grown in an intercropping system with millet to maximize production. Over the last 20 years rainfall has declined, thus reducing the soil recovery rate during fallow. Fallow periods have also decreased due to higher human and animal pressure on plant cover, further aggravating the loss of moisture, nutrients and soil structure. As a result, there has been further reduction in millet yields. Accordingly, the primary constraints to millet production in western Sudan are lack of moisture and soil nutrients, and poor husbandry. Crop losses to insect pests (Raghuva), and diseases and *Striga* are also important factors limiting millet production.

Research Methods

Research conducted by participating PIs at the Agricultural Research Corporation, Sudan is primarily applied in nature. Research Scientists are closely tuned-in with crop production, protection, and utilization constraints encountered by farmers in the various agricultural schemes in the country. Research constraints are assessed and prioritized on a regular basis, often annually and in collaboration with production scheme managers. Field facilities at ARC stations and particularly at the Gezira Research Station are excellent. Machinery and equipment often have been adequate and appropriate. Technical support has always been good. Laboratory facilities are modest and supplies have always been short. Interdisciplinary interaction have traditionally been good. Statistical and analytical consultation have been readily available. Good attempts have always been made to summarize research results to share information, informally and formally, with production agencies and their extension services. In general a good research infrastructure manned by an excellent cadre of manpower focused on sorghum and millet research exists in the Sudan.

Research Progress

Several years of collaborative research between and among ARC and INTSORMIL scientists has produced many results ranging from generation of basic scientific information to developing technologies readily applicable to alleviating major constraints to sorghum and millet production and utilization in Sudan. Contributions made in the following areas are briefly summarized to highlight some of the major achievements.

Sorghum Breeding

A strong sorghum breeding program has been put in place at the Gezira Research Station. The current leader of the program, Dr. Osman I. Obeid Ibrahim, received his graduate training at Purdue University under Dr. John Axtell. A wide range of elite sorghum germplasm has been assembled and effectively utilized. Germplasm developed in the program have been effectively and extensively evaluated in a network of test locations. Breeding efforts at GRS has included both varietal and hybrid development. However, following the successful diffusion of Hageen Dura -1, recent program efforts have slanted greatly towards development of hybrids for the irrigated Gezira Scheme. Yet both varieties and hybrids have been officially recommended and released for wide cultivation. Additionally a number of new experimental hybrids have been identified as being superior based on multi-location testing over several seasons. A number of elite seed parents have been identified and some will likely be used as seed parents to replace TX623, the seed parent currently used to produce HD-1 seed. Breeding for drought tolerance has progressed well using irrigated plots where water was withheld at key developmental stages. Parental lines recognized for increased drought tolerance have been put in hybrid combinations and tested. Evaluation of these hybrids showed that many of these lines possess superior combining ability and increased drought tolerance in hybrid combination. INTSORMIL has contributed significantly in the accumulation of the wealth of elite germplasm and in shaping the focus of the breeding program through continued dialogue and interaction among collaborating PIs.

Seed Industry Development

The development and release of Hageen Dura-1 as the first commercial Sorghum hybrid in the Sudan necessitated a change in the operations of sorghum seed production and distribution.

A Pilot Project was envisioned and implemented, with support from USAID/Khartoum to lay the ground for the development of an infant seed industry in Sudan. It was soon recognized by participating agencies, including the National Seed Administration (NSA) and the Agricultural Research Corporation (ARC) that the ramifications for hybrid seed

production were much different from those of varietal seeds. It was determined that good quality hybrid seed will have to be produced annually to win the confidence of farmers. The experience also showed that a seed industry integrating both the public and private sectors serves the interests of the farm community and enriches the agricultural sector of the economy. There is still an on-going education on the role of the private sector and the policies that will encourage its development. The eventual growth and development of a successful seed industry in Sudan will rely much on how well this education proceeds. However it is indeed positive that in a country where no private seed business existed before the advent of HD-1, there is a significant private sector seed sales and operations today. INTSORMIL scientists and their Sudanese counterparts facilitated and nurtured this positive development.

Striga Control

There is a long history of *Striga* research in Sudan. Significant observations that have served as landmarks in the scientific literature on *Striga* have been made in the Sudan beginning with the 1940s. Financial support for *Striga* research in Sudan has never been strong. However, in the late 1970 and mid 1980s, IDRC, Canada provided assistance to the Sudan National *Striga* Research efforts. Support from INTSORMIL, although meager, has been indispensable in maintaining the momentum of strong *Striga* research at the Agricultural Research Corporation. Collaborative *Striga* research between INTSORMIL and ARC scientists has focused on the elucidation of mechanisms of host plant resistance to *Striga*, identification and development of *Striga* resistant host genotypes, evaluation of cultural practices and chemical compounds that minimize *Striga* infestation or reduce damage of *Striga* on host plants. Progress has been made on all fronts. The superiority of a *Striga* resistant sorghum cultivar, SRN 39, was demonstrated in a series of field tests as well as using a rapid assay developed at Purdue University to predict genetic resistance to *Striga*. The roots of SRN 39 produce unusually low amounts of *Striga* germination stimulant. *Striga* parasitism also has relatively little effect on its productivity. This unique cultivar, SRN 39, has been officially released for farm cultivation in Sudan and in its first year of release some 24,000 hectares were grown. The beneficial effects of herbicide and/or supplemental nitrogen on resistant and tolerant sorghum genotype in *Striga* infected fields was shown. Under these conditions, susceptible sorghums get heavily infested and produce no crop while resistant varieties such as SRN39 reach near full yield potential and show no sign of damage. Work in Sudan has also shown that sorghum crops planted in rotation with a legume crop supports significantly less *Striga* than that grown with no legume rotation. As reported in PRF-104B and PRF-111 an array of new scientific findings have been generated from *Striga* work in INTSORMIL, and much of which has been as a result of collaborative work with scientists at ARC, Sudan.

Plant Pathology

An effective partnership has also been developed between INTSORMIL and ARC, Sudan scientists in the area of plant disease control. Though several sorghum diseases have been addressed, the work on long smut has been notable. Long smut is a disease that is emerging as an economically significant sorghum disease in many African countries. Results of our collaborative program has focused on development of a screening technique for differentiating resistant and susceptible sorghum genotypes. Investigations focused on finding optimum type of spore and stage of plant development when infection is maximized. Results of several years of testing have shown that sporidial inoculation gives highest percent infection compared to teliospore inocula. The early boot stage is the most receptive stage for infection. Delayed bloom of sorghum panicles favors production of high infection level. Also shown is the tendency for wild sorghum (adars) to support more infection, and thus may play a role in increasing inoculum potential. Studies on effects of temperature and humidity showed that teliospores tolerate elevated temperature where as sporidia are sensitive to both high temperature and desiccation. Anatomical and histological studies have established that penetration of the fungus is only achieved through the stylar region of developing florets. The development of the pathogen in the infected kernels takes place from the upper part of the ovary and then progresses downward to the center of the infected ovaries. This was confirmed by the production of mature spore balls situated at the upper portion of the ovary and at the upper ovary sides, and spore balls in the phase of formation and reorganization located at the bottom part of the ovaries. Sections of early smutted kernels also show a non commuted region present under the immature spore balls.

The collaborating PIs on the project have effectively transferred the technology for screening against long smut in sorghum to collaborators in West Africa. The PI from Sudan, Dr. Hilu Omer, was invited to train Mr. Issoufou Kollo on developing an appropriate protocol for establishing long smut infection under Niger (Niamey) conditions. Mr. Kollo has since utilized this technique in germplasm evaluation for resistance to long smut in the INRAN program in Niger.

Sorghum Food Quality

The Food Research Center (FRC) at Shambat, Sudan is one of the leading centers in Cereal Quality Research in Africa. Research and development efforts at FRC include direct and value-added use of sorghum and millet in both traditional and new products made from these important staple crops. Most food products made from sorghum and millet in Sudan are processed through some level of fermentation. Collaborative research between ARC and INTSORMIL has shown that fermentation as practiced in Sudanese households improves protein digestibility of cooked sorghum products. This work conducted on both Kisra (the

staple bread) and nasha (a weaning food) has made significant contributions to a better understanding of the factors that influence protein digestibility in grain sorghum.

Dr. Laila Manawar spent time at Purdue University and conducted studies that led to developing a weaning food called "instant nasha" by the FRC. The instant nasha is a drum dried product which can be reconstituted to make a ready-to-eat gruel by adding water. One of the studies conducted was to evaluate the feasibility of utilizing the process of heat extrusion, which is less expensive, as a replacement for the more energy intensive and thus expensive process of drum drying to make the product affordable to poor people. They also evaluated the in vitro protein digestibility of the extruded products and found it to be highly digestible.

Dr. Sitt Badi, Director of FRC and Dr. Paul Bureng have tested various proportions of mixtures of wheat and sorghum that would result in acceptable bread. Their work has shown that of all the commercially available sorghum varieties that they tested, the new commercial hybrid, HD-1 had the hardest grain, more easily decorticated than most local sorghum, and thus produces a high yield of very white sorghum flour. As a result an acceptable good quality bread can be made with a composite flour containing up to 40% HD-1 decorticated flour. Local Sudanese sorghum can only be added at 10-20% level without adversely affecting the quality and acceptability of the bread product. This technology, composite flour mixture for bread making, was recommended for commercialization using HD-1 as the sorghum flour of choice. However, implementation and wide use was limited because of non-technical policy concerns between millers and the Government of Sudan (GOS).

Kisra is a fermented, thin pancake-like bread eaten as a staple in Sudan. There is a trend towards commercialization of kisra in urban areas. Studies were conducted at Purdue University in cooperation with Sudanese investigators to 1) find a standardized predictive test for consistency of kisra batter to be used in commercial operation and to predict kisra making quality of different sorghums, and 2) characterize the changes occurring during the fermentation process and develop a starter culture that could be used commercially. A critical step in the kisra making process is the thinning of the thick fermented batter so that it can easily be spread on the hot griddle to make the pancake. The thinness of the batter determines the ease of spreading, thickness of the kisra sheet, and the ease of removing the baked kisra from the griddle. This step is a subjective one necessarily made by an experienced kisra maker. An objective test was developed using a Bostwick consistometer, an inexpensive and simple fluid viscosity tester. Bostwick readings were found to increase linearly for batters with water/flour ratios from 1.40-1.67. A water/flour ratio of 1.45 was used to compare the behavior of fermented and unfermented suspensions of five Sudanese sorghum flours. All flours exhibited an increase in Bostwick consistency (became more fluid) after fermentation, however, those with the lowest unfermented values increased more after fermentation than samples with higher Bostwick values.

The fermentation process was studied and it was found that in a naturally fermented flour (microbes found in the flour, cultivar - Dabar) bacterial population increased with fermentation time and reached a plateau at 18 hours. The micro flora of the sorghum flour obtained from Sudan consisted of lactic acid, coliforms, and other acid producing bacterial and yeasts/molds. Lactic acid content increased to 0.8% causing a pH drop from 5.95 to 3.73. In flour that was fermented by adding a backstop from a previously fermented sorghum, the bacterial population increased with time and fermentation plateaued at nine hours. The bacterial population consisted mainly of lactic acid bacteria. Yeast and mold counts were low, and coliform growth was suppressed by other organisms. At the end of nine hours the lactic acid content was 1.5% and pH was 3.73. The end products produced from the sorghum flour fermentation were lactic acid, acetic acid, proprionic acid, isobutyric acid, ethanol, propyl acetate, and 2-furan-methanol. By the end of the fermentation using an inoculum from previous fermentation, simple sugars were not detectable. Starter cultures developed in the laboratory from combinations of lactic acid bacteria with different proportions of hetero- to homolactics or combinations of lactic acid bacteria and yeasts did not produce the same amount or types of end products that were produced during natural fermentation of sorghum flour. Sensory trials remain key to selecting proper combinations of microorganisms for an optimal kisra. A suitable culture and objective testing method would permit larger scale kisra bakeries to operate to produce good, consistent quality product that could compete with large wheat bread operations.

Economics

The principal focus of economic research in Sudan has been in studying the diffusion of Hageen Dura-1, a sorghum hybrid, in the Gezira Irrigated Scheme; estimation of the returns to research from investment in HD-1; studying the impact of deteriorating soil fertility resulting from extensive production practices as land becomes scarce and fallowing is discontinued, and studying the operation of the input markets, particularly fertilizer and seeds.

In the summer of 1990, Mohammed M. Ahmed and John H. Sanders did field work in the Gezira irrigation project to estimate the returns to research from investment in HD-1. HD-1 is in the early stage of diffusion there on approximately 17,000 hectares, or 8-9% of the sorghum crop area. Even at this early stage of diffusion, there is a reasonable financial rate of return of 23 to 31%. Eliminating the price and exchange-rate distortions gives an economic return of 16 to 21%. Measures to eliminate these distortions, especially the overvalued exchange rate, would encourage sorghum exports by increasing their competitiveness and would enable the market rather than the governmental sector

and foreign-aid donors to allocate the critical input of chemical fertilizer.

The diffusion of Hageen Dura 1 in 1991-92 has reached 35,229 ha., that is 12% of the total sorghum area in Gezira. This represents a 103% area increase over what it was in 1990-91. The extent of diffusion would have been greater if hybrid seeds was available. The public seed producers were unable to respond to the rapidly increasing demand in both 1990-91 and 1991-92. This shortage in seeds has been shown to have implications in farm level adoption studies, where an objective is to identify the farmer and farm characteristics that are influencing the decision to adopt. When the impact of the supply shortage is not taken into account some of the variables identified econometrically, may be measuring the differential ability of farmers to have access to the rationed seeds. The diffusion of Hageen Dura 1 in the rainfed sector so far is minimal. The only documented large scale seed distribution of Hageen Dura-1 was made by Pioneer Seed Company/Sudan in 1991-92. They distributed 66 Mt.

The research emphasis in the mechanized rainfed sector is on evaluating the long-run sustainability effects of present and potential technologies on the vertisols. The crop/water/soil sustainability effects of present potential technologies on the vertisols were evaluated. The crop/water/soil model (Erosion Productivity Impact Calculator - EPIC) was used to look at changes in crop yields and soil characteristics over time. The simulation results of the model show that extensive sorghum production has led to approximately 50% declined in yield after eight years. The model results also show that through the use of moderate levels of chemical fertilizer, an improved cultivar, and improved agronomic practices, yields can be raised and be maintained at 1.2 to 1.4 mt/ha. from the observed average yields of 06. Mt/ha.

Institution Building

Research Support

The INTSORMIL/Sudan program has continued to provide direct allocation of funds to the Agricultural Research Corporation.

During 1990. INTSORMIL purchased two vehicles for use by ARC/INTSORMIL staff in Sudan. These vehicle have greatly facilitated collaborative activities in-country. Acquisitions for the ARC libraries continue to be based upon requests from Sudanese scientists.

Buy-in

At the suggestion of the USAID Mission in Khartoum, a grant proposal was prepared in November 1989 requesting PL 480 counterpart funds to supplement the INTSORMIL/ARC budgetary commitments. This grant was awarded after persistent follow-up by ARC staff, INTSORMIL, and the USAID Mission Staff in Khartoum. The grant was approved as requested for a total of L.S. 1,549,000 (Sudanese pounds) during the first year, all in local currency.

Since 1989, regular reimbursement of these funds have been provided by the Ministry of Finance and planning thus effectively enhancing the supplies and equipment budget of sorghum and millet research at the Agricultural Research Corporation.

The grant proposal was prepared by INTSORMIL/ARC staff in consultation with the USAID Mission. This grant has been governed by GOS regulations, involving certain rigid restrictions such as the requirement of prior Ministry of Planning approval for purchase greater than L.S. 5000. An understanding has been developed with ARC staff that as long as the PL480 local currency fund is available, INTSORMIL dollar funds will be used for purchase of equipment and travel support. As a result, much of the INTSORMIL financial support to ARC during the last few years has been in sponsoring travel and purchasing equipment and supplies for ARC scientists. Table 1 shows the ARC scientists sponsored to attend international conferences both in the U.S. and overseas.

In addition to expendable supplies and equipment shipped to the Agricultural Research Corporation and the Food Research Centre the following major laboratory and office equipment were shipped to Sudan: Autoclave Dryer, Alpine Air Jet Sieve with accessories, Percival controlled temperature and lighting biological incubator, Swanson mixer, analytical balance, precision top pan balance, Bench top centrifuge, convection oven, count-a-pack seed counter, germinator, Model 140 Ph Meter, Bench Top Centrifuge, and Luxmeter PV150 with accessories.

In addition, an IBM PS/2 Model 50 with printer as well as overhead and slide projectors and Minolta copier were also purchased for the Agricultural Research Corporation.

In 1990, two vehicles were also purchased in support of our collaborative program. A Toyota Land Cruiser station wagon and 4-wheel drive diesel pick up truck were ordered and shipped from Saudi Arabia.

Summary

The collaborative research relationship between the Agricultural Research Corporation (ARC), Sudan and INTSORMIL that started in 1980 has developed into a strong, mutually beneficial partnership that produced several excellent results. Tangible results ranging from training to development of useful technologies and elite germplasm have been generated.

Even before the advent of INTSORMIL, ARC/Sudan had a "critical mass" of well trained manpower in place. Sudan is unique in Africa in this regard. Over decades it had

Table 1. ARC scientists sponsored to attend international conferences both in the U.S. and overseas.

Name	Purpose	Dates
Sit Nafr el Badi	Participate in International Crop Science Congress, Ames, IA. Purdue - INTSORMIL/Sudan planning meeting	7/14/92 - 7/27/92
Mahmoud M. Ahmed	International Crop Science Congress, Ames, IA Purdue - INTSORMIL/Sudan planning meeting	7/14/92 - 8/3/92
Laila Monawar	Cairo, Purdue, Texas - sorghum food quality research	9/20/89 - 10/18/89
Ahmed Taha	International Crop Science Congress, Ames, IA	7/14/92 - 7/27/92
El Hilu Omer	Niger - Collaborate with R. Frederiksen & I. Kollo (INRAN) on long smut research INTSORMIL PI meeting in Arizona and to Kansas State to work with Larry Claflin on bacterial disease techniques International Crop Science Congress, Ames, Iowa and Purdue University Niger - participate in 10 year INTSORMIL Strategy planning meeting	10/21/88 - 11/1/88 1/2/89 - 1/14/89 7/14/92 - 7/27/92 10/10/93 - 10/24/93
Osman Ibrahim	Texas - International Conference on Dryland Agriculture; Texas A& M (Rooney, Miller, Frederiksen) Agricultural Research Center, Lubbock (Rosenow) University of Nebraska (Andrews, Eastin) Purdue University (Ejeta) Collect materials and exchange information on sorghum breeding with collaborators International Crop Science Congress, Ames, Iowa Purdue, Sudan planning meetings Attend conference on Adaptation of Plants to Soil Stresses, Nebraska and to Purdue University to work with Ejeta on data analysis	8/15/88 - 8/19/88 7/14/92 - 7/27/92 7/30/93 - 8/9/93
Abdel Gabbar Babiker	Charlotteville, VA; Whiteville, NC and Lafayette, IN Frankfurt, Germany - International Weed Symposium Purdue - sabbatic to work on *Striga* with Butler and Ejeta Sudan - Participate in field trials on *Striga* Purdue/Denver - participate in Weed Science Society of America Amsterdam - International Weed Symposium	8/9/87 - 8/22/87 7/31/87 - 8-8/87 1/4/92 - 2/18/93 6/29/92 - 7/21/92 2/8/93 - 2/11/93 11/6/93 - 11/14/93

invested its own scant resources into developing a sufficient cadre of agricultural manpower. However INTSORMIL has also trained several Sudanese scientists who have returned and filled in key positions particularly in sorghum/millet research related areas. Sudanese graduates of INTSORMIL institutions currently provide service in sorghum breeding (2), plant pathology (1), entomology (1), agronomy (1), food science (1) and agricultural economics (1). A few Sudanese trained and sponsored by INTSORMIL currently also serve in IARCs and national programs elsewhere. Of significance has been the contribution made by INTSORMIL in mentoring of young graduates as they returned to ARC. Furthermore several ARC scientists have spent valuable time in the laboratories of their counterparts in the U.S. Some have done this more than once. In some of these cases, significant research findings have come out of these experiences and the results have been published as joint contributions of ARC and INTSORMIL.

On numerous occasions, and at times on a regular basis annually, INTSORMIL and ARC scientist have held round table discussions on assessing and reevaluating production and utilization constraints in sorghum and millets in Sudan, assessing of research findings and utility of technologies jointly developed, and more significantly in setting priorities. The ARC has used these deliberations to assess priorities and progress and to sharpen the focus in the sorghum/millet research in Sudan. ARC has often involved INTSORMIL PIs in setting the national agenda around sorghum/millet research as well as in finding better ways of extending technologies derived from research.

Tangible technologies that resulted from ARC/INTSORMIL partnership include:

- development, release, and distribution of Hageen Dura-1, as the first commercial sorghum hybrid
- identification, wide-testing and release of SRN39 and IS-9830 as the first *Striga* resistant sorghum releases
- the development of an infant seed industry that began with the pilot project around HD-1 seed production
- the testing and recommendation of use of composite - flour for bread making and the better quality mix obtained with use of HD-1 grain
- the economic evaluation on the impact of HD-1 (the social returns to research investments)
- the development of a technology to produce "instant nasha" as a weaning food

- establishing fermentation (a traditional process) as an effective method to alleviate problems of protein digestibility associated with sorghum grain.

Benefits accrued to INTSORMIL scientists and U.S. agriculture from ARC/INTSORMIL collaboration include the following:

- Contribution of germplasm tested in Sudan in enhancing drought tolerance of material developed for the U.S. seed industry. Recently 10 drought tolerant lines derived from crosses between U.S. and Sudan sections were released to the seed industry in the U.S.

- Raw germplasm from Sudan for potential use in the U.S. Recently over 3000 Sudanese land races were contributed by ARC to the USDA.

- The development and refinement of new technologies with potential use in the U.S. For instance Long Smut is not a disease of economic importance in the U.S. However, should it become one, screening technology INTSORMIL scientists helped develop in Sudan, will come in handy.

- The finding that the traditional process of fermentation as a means to alleviate the protein digestibility problem in sorghum laid the foundation for the scientific understanding of factors that influence protein digestibility in grain sorghum.

The excellent field demonstration program by Global 2000 and the persistent efforts of ARC/INTSORMIL in assisting the seed production programs have established Hageen Dura-1 as an ARC generated technology with significant impact to sorghum agriculture in Sudan. Added to other research technologies which have been generated by ARC, including those listed above, ARC has been recognized by the GOS and other agencies operating in the Sudan. For instance, the USAID mission with prodding from INTSORMIL PIs, granted a substantial amount of PL480 funds to ARC in support of sorghum/millet research. In return, that encouraged the Ministry of Planning to continue to provide unprecedented level of support specifically for sorghum/millet research in Sudan. Individually, particularly ARC scientists in the area of *Striga*, pathology, and cereal quality, have produced significant results that have given them due recognition in the sorghum/millet research community. The collaborative partnership between INTSORMIL and ARC has clearly demonstrated that sustained support and focused research efforts would produce tangible and useful results. It also showed that an effective utilization of research generated technologies would in return eventually bring due recognition to scientists and research programs, and generate increased and sustained support for agricultural research, even in a national program of a developing country with numerous, seemingly insurmountable problems.

Training

TRAINING

INTSORMIL gives high priority to training host country scientists who will have major responsibilities for sorghum and millet research in their home countries. Training is also provided for young U.S. scientists who plan for careers in overseas development work.

The most frequently used mode of training is graduate study for advanced degrees, with the students' research forming an integral part of an INTSORMIL project. During the year covered by this report, 90 students from 33 different countries were enrolled in an INTSORMIL advanced degree program. Approximately 77% of these students come from countries other than the U.S. which shows the emphasis placed on host country institutional development (Figure 1).

Figure 1. Training analysis - country breakdown.

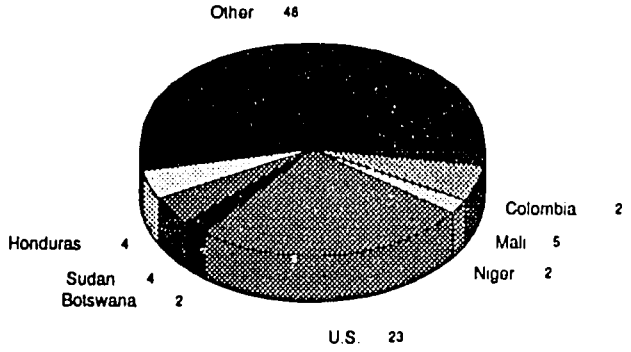
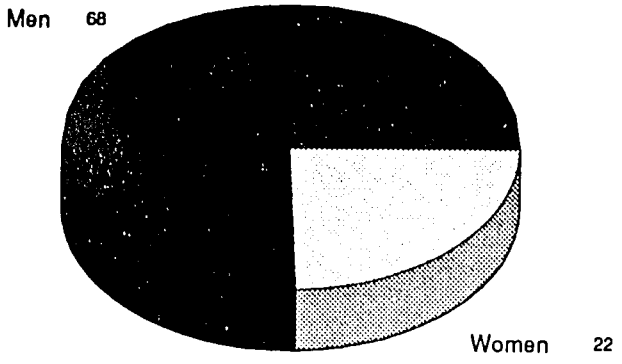
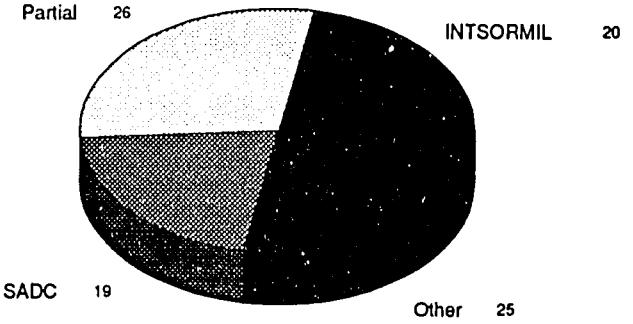


Figure 2. Training analysis - gender breakdown.



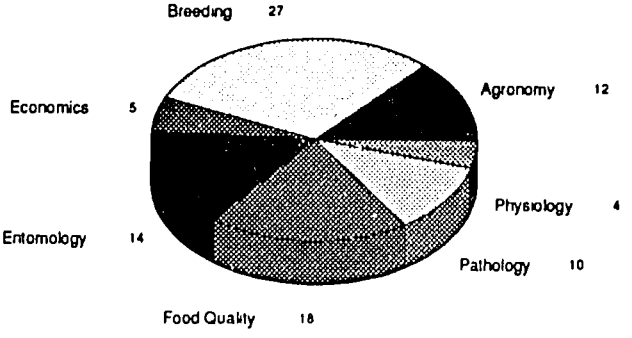
INTSORMIL also places a high priority on training women which is reflected in Figure 2. In 1993, 22% of all INTSORMIL graduate participants were women. Twenty of the total 90 students received full INTSORMIL scholarships. An additional 26 students received partial INTSORMIL funding and the remaining 44 students were funded from other sources as shown in Figure 3.

Figure 3. Training analysis - Source of Funding.



All 90 students worked directly with INTSORMIL principal investigators on INTSORMIL projects. These students are enrolled in graduate programs in all seven INTSORMIL disciplines. Figure 4 also shows that there has been a significant increase in the number of students enrolling in food techology, reflecting the importance of product development and food processing.

Figure 4. Training analysis - Discipline breakdown.



Total student numbers decreased slightly in 1992-93 as compared to 1991 and 1992. However, the number of INTSORMIL funded students has decreased gradually over the years.

In addition to graduate degree programs, short term training programs have been designed and implemented on a case by case basis to suit the needs of host country scientists. Several Host Country scientists were provided the opportunity to upgrade their skills in this fashion during 1993.

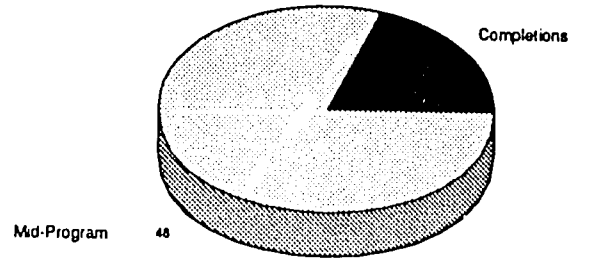
INTSORMIL cooperated with ICRISAT on a ten year special training program for countries of the Southern African Development Community SADC which terminated in 1993. The SADC/ICRISAT regional Sorghum and Millet Research Program was designed to respond to the need of the 10 member states of SADC, to initiate research on sorghum and millets in the marginal rainfall areas of the region. The program is implemented by ICRISAT and funded by USAID, CIDA and GTZ.

A major component of the program has been Training and Staff Development. The objective of this component has been to strengthen the scientific and technical research capability of National Research Programs through advanced degree and technical training. In order to accomplish the objective, ICRISAT has sub-contracted the advanced degree training element to INTSORMIL, the International Sorghum and Millet Collaborative Research Support Program, where the necessary linkages and institutions exist.

The total number of active SADC students is 60 for 1992-93. (Figure 5)

The SADC/ICRISAT Southern African training program held a high profile in INTSORMIL training activities. Of 48 students matriculating in the U.S., Canada and Brazil, 19 are studying under INTSORMIL scientists while the remainder are with subject matter specialists not covered by INTSORMIL scientists. There were 12 degree completions in 1992.

Figure 5. SADC training analysis - annual status.



The following table is a compilation of all INTSORMIL training activities for the period July 1, 1992 through June 30, 1993.

Year 14 INTSORMIL Training Participants

Name	Country	Univ.	Discipline	Advisor	Degree	Gender	Funding*
Gono, Lawrence	Zimbabwe	KSU	Agronomy	Vanderlip	PHD	M	S
Heiniger, Ronnie	U.S.	KSU	Agronomy	Vanderlip	PHD	M	I
Lele, Etani	Botswana	KSU	Agronomy	Vanderlip	MSC	M	S
Madulu, Ruth	Tanzania	KSU	Agronomy	Vanderlip	MSC	F	S
Gutierrez, Patricio F.	Ecuador	UNL	Agronomy	Clegg	MSC	M	I
Maliro, Charles	Malawi	UNL	Agronomy	Clegg	PHD	M	S
Mohamed, Mirghani S.	Sudan	UNL	Agronomy	Clegg	PHD	M	I
Buah, Samuel	Ghana	UNL	Agronomy	Maranville/Andrews	MSC	M	O
Masi, Cassim	Zambia	UNL	Agronomy	Maranville	PHD	M	S
Rivera, Roberto	Honduras	UNL	Agronomy	Maranville	PHD	M	O
Traore, Abdoulaye	Mali	UNL	Agronomy	Maranville	PHD	M	I
Wu, Yi	China	UNL	Agronomy	Maranville	PHD	F	O
Rao, Aluri Sambosiva	India	KSU	Breeding	Stegmeier	VS[1]	M	I
Goggi, Susani	Argentina	MSU	Breeding	Gourley	PD[2]	F	I
Zake, Vincent	Uganda	MSU	Breeding	Gourley	PHD	M	O
Kapran, Issoufou	Niger	PRF	Breeding	Axtell	PHD	M	P
Peters, Paul	U.S.	PRF	Breeding	Axtell	PHD	M	P
Cisse, N'Diaga	Senegal	PRF	Breeding	Ejeta	PHD	M	O
Grote, Ed	U.S.	PRF	Breeding	Ejeta	PHD	M	O
Ibrahim, Yahia	Sudan	PRF	Breeding	Ejeta	MSC	M	O
Johnson, Richard	U.S.	PRF	Breeding	Ejeta	MSC	M	O
Menkir, Abebe	Ethiopia	PRF	Breeding	Ejeta	PD[2]	M	O
Tuinstra, Mitchell	U.S.	PRF	Breeding	Ejeta	PHD	M	O
Vogler, Renee	U.S.	PRF	Breeding	Ejeta	MSC	F	I
Weerasuriya, Yohan	Sri Lanka	PRF	Breeding	Ejeta	PHD	M	O
Gouveia, Sergio Jeremias	Mozambique	TAM	Breeding	Miller/Rosenow	MSC	M	P
Nesbitt, T. Clint	U.S.	TAM	Breeding	Miller	MSC	M	P
Ombakho, George	Kenya	TAM	Breeding	Miller/Rosenow	PHD	M	P
Palma Carias, Alejandro	Honduras	TAM	Breeding	Miller	MSC	M	P
Stewart, Klint G.	U.S.	TAM	Breeding	Miller	MSC	M	P
Tenkouano, Abdou	Burkina Faso	TAM	Breeding	Miller	PHD	M	P
Crasta, Oswald	India	TAM	Breeding	Rosenow	PHD	M	P
Mkhabela, Milton	Swaziland	TTU	Breeding	Rosenow	PHD	M	S
Munera, Alvaro	Colombia	TTU	Breeding	Rosenow	MSC	M	P
Doumbia, Mamadou	Mali	TAM	Breeding	Peterson/Onken	PHD	M	O
Jeutong, Fabien	Cameroon	UNL	Breeding	Andrews	PHD	M	O
Kiula, Barnabas	Tanzania	UNL	Breeding	Andrews	MSC	M	S
Mahama, A. Assibi	Ghana	UNL	Breeding	Andrews	MSC	M	O
Muza, F.R.	Zimbabwe	UNL	Breeding	Andrews	PHD	M	S
Ahmed, Mohamed	Sudan	PRF	Economics	Sanders	PHD	M	I
Coulibaly, Ousmane	Mali	PRF	Economics	Sanders	PHD	M	I
Garcia, Joao Carlos	Brazil	PRF	Economics	Sanders	VS[1]	M	O
Lawrence, Pareena Gupta	U.S.	PRF	Economics	Sanders	PHD	F	P
Nichola, Tennassie	Ethiopia	PRF	Economics	Sanders	PHD	M	I
Ching'oma, Godfrey	Malawi	MSU	Entomology	Pitre	MSC	M	S
Lopez, Julio	Honduras	MSU	Entomology	Pitre	MSC	M	I
Portillo, Hector	Honduras	MSU	Entomology	Pitre	PHD	M	I
Bayoum, Imad	Lebanon	TAM	Entomology	Gilstrap	PHD	M	P
Behle, Robert	U.S.	TAM	Entomology	Gilstrap	PHD	M	I
Ciomperlik, Matthew	U.S.	TAM	Entomology	Gilstrap	PHD	M	P
Rao, Asha	India	TAM	Entomology	Gilstrap	MSC	F	I
Roque, Javier	Mexico	TAM	Entomology	Gilstrap	PHD	M	P

Name	Country	Univ.	Discipline	Advisor	Degree	Gender	Funding*
Diarisso Yaro, Niamoye	Mali	TAM	Entomology	Teetes	PHD	F	O
Jimenez, Nora	Colombia	TAM	Entomology	Teetes	MSC	F	P
Jost, Douglas	U.S.	TAM	Entomology	Teetes	MSC	M	I
Magallenes, Ricardo	Mexico	TAM	Entomology	Teetes	PHD	M	P
Paliani, Anderson	Malawi	TAM	Entomology	Teetes	MSC	M	S
Pendleton, Bonnie	U.S.	TAM	Entomology	Teetes	PHD	F	P
Lelong, Dolly Bell	Tanzania	PRF	Food Quality/Util	Butler	PHD	F	O
Siame, Anthony Bupe	Zambia	PRF	Food Quality/Util	Butler	PHD	M	S
Tarimo, Thadeo	Tanzania	PRF	Food Quality/Util	Butler	PHD	M	S
Aboubacar, Adam	U.S.	PRF	Food Quality/Util	Hamaker	MSC	M	O
Mamadou, Lewamy	Niger	PRF	Food Quality/Util	Hamaker	MSC	M	O
Oria, Maria P.	Spain	PRF	Food Quality/Util	Hamaker	PHD	F	I
Weaver, Charlotte	U.S.	PRF	Food Quality/Util	Hamaker	MSC	F	I
Anderson, Brian	U.S.	TAM	Food Quality/Util	Rooney	MSC	M	P
Beta, Trust	Zimbabwe	TAM	Food Quality/Util	Rooney	MSC	F	S
Cruz y Celis, Laura	Mexico	TAM	Food Quality/Util	Rooney	MSC	F	P
Floyd, Cherie	U.S.	TAM	Food Quality/Util	Rooney	MSC	M	P
Hugo, Leda	Mozambique	TAM	Food Quality/Util	Rooney	MSC	F	S
Islas-Rubio, Alma	Mexico	TAM	Food Quality/Util	Rooney	PHD	F	P
Lekalake, Rosemary	Botswana	TAM	Food Quality/Util	Rooney	MSC	F	S
Mireles, Raquel	U.S.	TAM	Food Quality/Util	Rooney	MSC	F	P
Mrema, Greyson	Tanzania	TAM	Food Quality/Util	Rooney	MSC	M	S
Suhendro, Elly	Indonesia	TAM	Food Quality/Util	Rooney	MSC	F	O
Wright, Lee	U.S.	TAM	Food Quality/Util	Rooney	MSC	M	P
Diourte, Mamourou	Mali	KSU	Pathology	Claflin	PHD	M	O
Muriithi, Linus M.	Kenya	KSU	Pathology	Claflin	PHD	M	O
Anderson, Cindy	U.S.	KSU	Pathology	Leslie	M.S.	F	O
Huss, Martin	U.S.	KSU	Pathology	Leslie	PD[2]	M	P
Xu, Jin-Rong	China	KSU	Pathology	Leslie	PHD	M	P
Oh, B.J.	Korea	TAM	Pathology	Frederiksen	PHD	M	O
Rosewich, Ute L.	Germany	TAM	Pathology	Frederiksen	PHD	F	I
Guthrie, Phillip	Great Britain	TAM	Pathology	Odvody/Frederiksen	PHD	M	I
Mansuetus, Anaclet	Tanzania	TAM	Pathology	Odvody/Frederiksen	PHD	M	S
Alexander, John	U.S.	TAM	Pathology	Toler	PHD	M	O
Gandoul, Gandoul I.	Sudan	UNL	Physiology	Eastin	PHD	M	I
Kubic, Keith	U.S.	UNL	Physiology	Eastin	PHD	M	P
Ngulube-Msikita, Rachel	Zambia	UNL	Physiology	Eastin	MSC	F	S
Nyakatawa, Ernson	Zimbabwe	UNL	Physiology	Eastin	MSC	M	S

* I = Completely funded by INTSORMIL
P = Partially funded by INTSORMIL
S = SADC/ICRISAT funded
O = Other source

[1]VS = Visiting Scientist
[2]PD = Post Doctoral

KSU = Kansas State University
MSU = Mississippi State University
PRF = Purdue University
TAM = Texas A&M University
TTU = Texas Tech University
UNL = University of Nebraska - Lincoln

Year 14 SADC/ICRISAT Training Participants

Name	Country	University	Discipline	Advisor	Degree	Gender
Alfredo, Manuel	Angola	Vicosa	Pathology	Ferreira da Silva	MSC	M
Chitengue, Jone	Angola	Vicosa	Breeding	Vieira	MSC	M
Domingos, M'panzo	Angola	Vicosa	Agronomy	Nogueira Fontes	MSC	M
Jose, Joao	Angola	Vicosa	Breeding	Cardosa	MSC	M
Lekalake, Rosemary	Botswana	TAM	Food Science	Rooney	MSC	F
Lele, Etani	Botswana	KSU	Agronomy	Vanderlip	MSC	M
Makhwaje, Ernest	Botswana	KSU	FSR/Econ	Norman	MSC	M
Malepa, Dollina	Botswana	UNL	Plant/Soil	Walters	PHD	F
Molapong, Keoagile	Botswana	N. Carolina St.	Plant/Soil	Cox	PHD	M
Khalema, Tieiso	Lesotho	Texas Tech	FSR/Econ	Ervin	MSC	M
Mokhoro, Cyprian	Lesotho	UNL	Food Science	Jackson	MSC	M
Ranthamane, Matla	Lesotho	KSU	Breeding	Bramel-Cox	MSC	M
Sefika, Phakiso	Lesotho	UNL	Forages	Anderson, B.	MSC	M
Ching'oma, Godfrey	Malawi	MSU	Entomology	Pitre	MSC	M
Maliro, Charles	Malawi	UNL	Agronomy	Clegg	PHD	M
Paliani, Anderson	Malawi	TAM	Entomology	Teetes	MSC	M
Brito, Rui	Mozambique	CSU	Agronomy	Dumford	PHD	M
Gouveia, Sergio	Mozambique	TAM	Breeding	Miller	MSC	M
Hugo, Leda	Mozambique	TAM	Food Science	Rooney	MSC	F
Maposse, Inacio	Mozambique	UNL	Forages	Anderson, B.	MSC	M
Mucavele, Firmino	Mozambique	Florida	FSR/Econ	Spreen	PHD	M
Mabuza, Khanyisile	Swaziland	Guelph	Food Science	Gullet	MSC	F
Malaza, Millicent	Swaziland	Penn St.	FSR/Econ	Warland	PHD	F
Matsebula, Sebenzile	Swaziland	Saskatchewan	Biometrics	Baker	PHD	F
Mkhabela, Milton	Swaziland	Texas Tech	Breeding	Rosenow/Nguyen	PHD	M
Felix, Joel	Tanzania	PRF	Agronomy	Vorst	MSC	M
Kaganda, Suleiman	Tanzania	UNL	Forages	Anderson/Moser	MSC	M
Kiula, Barnabas	Tanzania	UNL	Breeding	Andrews	MSC	M
Madulu, Ruth	Tanzania	KSU	Agronomy	Vanderlip	MSC	F
Mansuetus, Anaclet	Tanzanaia	TAM	Pathology	Fredriksen	PHD	M
Matowo, Peter	Tanzania	KSU	Agronomy	Pierzwnski	PHD	M
Mbuya, Odemari	Tanzania	Florida	Agronomy	Boote	PHD	M
Mrema, William	Tanzania	TAM	Food Science	Rooney	MSC	M
Mtwaenzi, Hamis	Tanzania	MSU	Weed Science	Coats	MSC	M
Tarimo, Thadeo	Tanzania	PRF	Bird Control	Butler/Weeks	PHD	M
Chisi, Medson	Zambia	KSU	Breeding	Bramel-Cox	PHD	M
Hikeezi, Doreen	Zambia	KSU	Food Science	Walker	MSC	F
Masi, Cassim	Zambia	UNL	Agronomy	Maranville	PHD	M
Mwale, Moses	Zambia	UNL	Plant/Soil	Walters	MSC	M
Ngulube-Msikita, Rachel	Zambia	UNL	Breeding	Moser	BSC	F
Siame, Anthony	Zambia	PRF	Food Science	Butler	PHD	M
Beta, Trust	Zimbabwe	TAM	Food Science	Rooney	MSC	F
Gono, Tigere Lawrence	Zimbabwe	KSU	Agronomy	Vanderlip	PHD	M
Mahuku, George	Zimbabwe	Guelph	Pathology	Hall	PHD	M
Makaudze, Ephias	Zimbabwe	TAM	FSR/Econ	Fuller	MSC	M
Mazhangara, Edward	Zimbabwe	PRF	FSR/Econ	Masters	MSC	M

Name	Country	University	Discipline	Advisor	Degree	Gender
Muza, Figuhr	Zimbabwe	UNL	Breeding	Lee	PHD	M
Nyakatawa, Ermson	Zimbabwe	UNL	Agronomy	Eastin/Schilling	MSC	M

CSU = Colorado State University, Fort Collins, Colorado
KSU = Kansas State University, Manhattan, Kansas
MSU= Mississippi State University, Mississisippi State, Mississippi
PRF = Purdue University, West Lafayette, Indiana
TAM= Texas A&M University, College Station, Texas
UNL = University of Nebraska, Lincoln, Nebraska

Florida = University of Florida, Gainesville, Florida
Guelph = University of Guelph, Ontario, Canada
N. Carolina St. = North Carolina State University, Raleigh, North Carolina
Penn St. = Penn State University, University Park, Pennsylvania
Saskatchewan = University of Saskatchewan, Saskatoon, Canada
So. Illinois = Southern Illinois University, Carbondale, Illinois
Texas Tech = Texas Tech University, Lubbock, Texas
Vicosa = Universidad Federal de Vicosa, Brazil

Appendices

INTSORMIL Buy-Ins

University/ Project No.	Buy-In	Year	Life of Buy-In	Annual Amount	Total
KSU-106	Kansas Sorghum Board	1985	6 years	17,500	105,000
	Kansas Agric. Exp. Station	1989	3 years	19,000	57,000
	Kansas Agric. Exp. Station	1989	3 years	13,333	40,000
	Kansas Sorghum Board	1991	4 years	15,334	61,338
	Kansas Agric. Exp. Station	1990	3 years	19,000	57,000
	EPA/Univ. of Nebraska	1990	2 years	32,518	65,036
					$ 385,374
KSU-108	Kansas Sorghum Board	1985	9 years	18,482	166,338
	Kansas Corn Commission	1988	3 years	16,845	50,535
	Kansas Sorghum Commission	1989	1 year	7,166	7,166
	Kansas Sorghum Commission	1989	1 year	6,500	6,500
	EPA	1990	3 years	39,523	118,569
	Kansas Agric. Exp. Station	1991	3 years	19,000	57,000
	USDA/ARS	1992	1 year	14,400	14,400
					$ 420,508
MSU-104	MIAC/Kenya	1990	2 years	115,725	231,450
	MIAC/Kenya	1992	3.5 years	142,000	497,000
					$ 728,450
MSU-105	FAO	1992	3 years	2,245	**$ 6,735**
MSU-111	Fedearroz	1990	5 years	10,000	50,000
	El Alcaravan Foundation	1990	2 years	200,000	400,000
	Fenalce	1991	1 year	5,000	5,000
					$ 455,000
PRF-103A	AID/Program Support Grant	1988	2 years	7,500	15,000
	Agric. Exp. Station	1988	2 years	6,000	12,000
	Purdue Agronomy Dept.	1989	2 years	1,000	2,000
	McKnight Foundation	1989	3 years	250,000	750,000
	Corporation for Science & Tech.	1991	1 year	10,000	10,000
	Pioneer Hi-Bred Intern.	1992	3 years	33,900	101,693
	Purdue Agronomy Dept.	1992	1 year	1,000	1,000
	McKnight Foundation	1992	3 years	250,000	750,000
					$ 1,641,693
PRF-103B	USDA Training	1989	3 years	15,000	45,000
	AFGRAD Training	1989	4 years	9,000	36,000
	NAAR Project	1991	1 year	3,000	3,000
					$ 84,000
PRF-104B & 104C	USAID PSG	1989	2 years	7,500	15,000
	Rockefeller Foundation	1989	3 years	23,067	69,200
	USAID/PSTC	1990	4 years	37,450	150,000
	USAID PSG	1991	2 years	10,000	20,000
	Purdue Research Foundation	1991	1 year	2,800	2,800
	Pioneer Seed Co.	1991	3 years	40,000	120,000
	PSTC/USAID	1991	3 years	50,000	150,000
	Pioneer Seed Co.	1991	2 years	30,000	60,000
	NSF	1992	1.5 years	173,333	260,000
	Pioneer Seed Co.	1993	2 years	13,600	27,192
					$ 874,192
PRF-105	USAID PSG	1989	4 years	5,000	20,000
	USAID PSG	1989	3 years	5,000	15,000
	World Bank	1989	2.5 years	10,000	25,000
	World Bank/IDA	1989	1 year	4,500	4,500
	USAID/Bean-Cowpea CRSP	1990	1 year	27,000	27,000
	EMBRAPA	1992	1 year	10,000	10,000
	USAID/AFT/ARTS	1992	1 year	20,000	20,000
					$ 121,500

University/ Project No.	Buy-In	Year	Life of Buy-In	Annual Amount	Total
PRF-107	Purdue Agronomy Dept.	1988	1 year	1,500	1,500
	State of Indiana	1990	1 year	7,000	7,000
	McKnight Foundation	1990	3 years	20,632	61,896
	USAID PSG	1990	2 years	14,000	28,000
	McKnight Foundation	1990	3 years	22,000	66,000
	Pioneer Seed Co.	1991	2 years	30,000	60,000
	State of Indiana	1991	1 year	1,200	1,200
					$ 225,596
PRF-109	USDA Grant	1990	2 years	60,000	**$ 120,000**
TAM Joint	USAID/TAMU	1989	3 years	15,000	45,000
	USAID/TAMU	1991	3 years	15,000	45,000
					$ 90,000
TAM-122	State of Texas Grant	1989	2 years	20,000	40,000
	USAID/TAMU	1990	2 years	10,000	20,000
	USAID/TAMU	1990	3 years	13,000	39,000
	Texas Higher Coordinating Board	1991	2 years	27,000	54,000
	USDA	1991	2 years	7,500	15,000
	USAID/TAMU	1992	2 years	28,000	56,000
					$ 224,000
TAM-123	Texas Grain Sorghum Producers	1990	5 years	50,000	250,000
	USAID/TAMU	1990	1 year	17,000	17,000
	USAID/TAMU	1991	1 year	28,000	28,000
					$ 295,000
TAM-124	USDA	1989	3 years	10,000	30,000
	Texas Advanced Research	1989	1 year	75,000	75,000
	TAES/ERA	1989	2 years	32,000	64,000
	Texas Advanced Research	1990	3 years	15,000	45,000
	Rockefeller Foundation	1990	2 years	30,000	60,000
	Texas Advanced Research	1992	2 years	10,000	20,000
	Rockefeller Foundation	1992	2 years	7,000	14,000
					$ 308,000
TAM-125	TAMU/PSG	1989	2 years	45,000	90,000
	Industry Grant	1989	2 years	10,000	20,000
	USDA/CRSP	1989	1 year	15,000	15,000
	USDA/APHIS	1989	2 years	15,000	30,000
	USDA/APHIS	1989	1 year	14,000	14,000
	Texas Agric. Exp. Station	1990	2 years	7,000	14,000
	USDA/APHIS	1990	3 years	23,734	71,202
	USDA/CSRS	1990	2 years	59,819	119,638
	TAMU/Program Support Grant	1990	2 years	18,638	37,276
	TAMU/Program Support Grant	1990	2 years	30,000	60,000
	Texas Grain Sorghum Producers	1990	2 years	50,000	100,000
	USDA/APHIS	1991	1 year	13,200	13,200
	TAMU/Program Support Grant	1990	3 years	27,000	81,000
	Texas Grain Sorghum Producers	1993	5 years	25,000	125,000
					$ 790,316
TAM125-B	TAES	1993	2 years	29,000	58,000
	USDA/APHIS	1993	4 years	32,500	130,000
	USDA/CSRS-SR	1993	2 years	45,000	90,000
	USDA/APHIS	1993	4 years	15,000	60,000
					$ 338,000
TAM-126	Texas Center for Energy	1989	1 year	14,500	14,500
	TAMU/Program Support Grant	1989	3 years	10,000	30,000
	Texas Agr. Exp. Station	1989	5 years	50,000	250,000
	TAES/ERA	1990	2 years	25,000	50,000
	HATCH	1990	4 years	35,000	140,000
	Texas Sorghum Producers	1990	1 year	15,000	15,000

University/ Project No.	Buy-In	Year	Life of Buy-In	Annual Amount	Total
TAM-126 (Cont.)	Grain Sorghum Producers	1991	3 years	10,300	30,900
	TAMU/Hatch	1992	5 years	31,184	155,920
	TAES/ERA	1990	2 years	19,000	38,000
	Grain Sorghum Producers	1992	2 years	20,000	40,000
					$ 764,320
TAM-131	USAID/Honduras PL480	1990	1 year	111,395	111,395
	USAID/Honduras PL480	1991	1 year	120,000	120,000
	USAID/Honduras PL480	1992	1 year	88,704	88,704
	USAID/Honduras PL480	1993	1 year	88,704	88,704
	Commercial Seed Co.	1992	1 year	7,000	7,000
	EEC/IICA/PRAIG	1992	3 years	9,260	27,780
	EEC/IICA/PRAIG	1993	3 years	10,975	32,920
					$ 476,508
UNL-113	Rockefeller Foundation	1988	3 years	8,333	25,000
	Ministry of Science (Leave)	1991	1 year	25,000	25,000
					$ 50,000
UNL-114	German Acad.Exchange Serv.	1993	2.5 years	11,000	$ 27,500
UNL-115 & 118	Michigan State/Senegal Agric.	1989	3 years	46,700	140,000
	USAID/Dakar	1992	5 years	70,000	350,000
					$ 490,000
UNL-116	Elliott Grant	1986	4 years	17,250	69,000
	USDA/OICD	1989	3 years	14,667	44,000
	Nebraska Sorghum Board	1990	3 years	24,00	72,000
	USAID/OICD	1990	3 years	43,000	129,000
	USAID/OICD	1990	1 year	4,000	4,000
					$ 318,000
UNL-123	USAID/PSTC Grant	1989	3 years	50,000	150,000
	USDA/ARS	1986	5 years	22,669	113,345
	USDA/ARS	1991	5 years	24,356	121,780
					$ 271,750
M.E.	INTSORMIL/Egypt/NARP Nebraska/Kansas St.	1991	3 years	156,727	$ 470,183
	SADC/ICRISAT/INTSORMIL Training	1990	5 years	1,280,400	6,402,039
	AID/CROSS CRSP Activities	1990	1 year	100,000	100,000
	USAID/Botswana/DAR	1990	1 year	35,860	35,860
	USAID/Khartoum/ARC	1990	1 year	80,000	80,000
	Social Science Research Workshop	1991	1 year	31,600	31,600
	Adaptation of Plants to Soil Stress Workshop	1992	1 year	25,000	25,000
	Rockefeller Foundation-Conference	1993	1 year	6,500	6,500
					$ 7,151,182
Total Buy-Ins					$ 16,770,969

INTSORMIL Sponsored and Co-Sponsored Workshops 1979 - 1993

	Name	Where	When
1.	International Short Course in Host Plant Resistance	College Station, Texas	1979
2.	INTSORMIL PI Conference	Lincoln, Nebraska	1/80
3.	West Africa Farming Systems	West Lafayette, Indiana	5/80
4.	Sorghum Disease Short Course for Latin America	Mexico	3/81
5.	International Symposium on Sorghum Grain Quality	ICRISAT	10/81
6.	International Symposium on Food Quality	Hyderabad, India	10/81
7.	Agrimeteorology of Sorghum and Millet in the Semi-Arid Tropics	ICRISAT	1982
8.	Latin America Sorghum Quality Short Course	El Batan, Mexico	4/82
9.	Sorghum Food Quality Workshop	El Batan, Mexico	4/82
10.	Sorghum Downy Mildew Workshop	Corpus Christi, Texas	6/82
11.	Plant Pathology	CIMMYT	6/82
12.	Striga Workshop	Raleigh, North Carolina	8/82
13.	INTSORMIL PI Conference	Scottsdale, Arizona	1/83
14.	INTSORMIL-ICRISAT Plant Breeding Workshop	CIMMYT	4/83
15.	Hybrid Sorghum Seed Workshop	Wad Medani, Sudan	11/83
16.	Stalk and Root Rots	Bellagio, Italy	11/83
17.	Sorghum in the '80s	ICRISAT	1984
18.	Dominican Republic/Sorghum	Santo Domingo	1984
19.	Sorghum Production Systems in Latin America	CIMMYT	1984
20.	INTSORMIL PI Conference	Scottsdale, Arizona	1/84
21.	Primer Seminario National Sobre Produccion y Utilizacion del Sorgo	Santo Domingo, Dominican Republic	2/84
22.	Evaluating Sorghum for Al Toxicity in Tropical Soils of Latin America	Cali, Colombia	4/84
23.	First Consultative and Review on Sorghum Research in the Philippines	Los Banos, Philippines	6/84
24.	INTSORMIL Graduate Student Workshop and Tour	College Station, Texas	6/84
25.	International Sorghum Entomology Workshop	College Station, Texas	7/84
26.	INTSORMIL PI Conference	Lubbock, Texas	2/85
27.	Niger Prime Site Workshop	Niamey, Niger	10/85
28.	Sorghum Seed Production Workshop	CIMMYT	10/85
29.	International Millet Conference	ICRISAT	4/86
30.	Maicillos Criollos and Other Sorghum in Middle America Workshop	Tegucigalpa, Honduras	12/87
31.	INTSORMIL PI Conference	Kansas City, Missouri	1/87
32.	2nd Global Conference on Sorghum/Millet Diseases	Harare, Zimbabwe	3/88
33.	6th Annual CLAIS Meeting	San Salvador, El Salvador	12/88
34.	International INTSORMIL Research Conference	Scottsdale, Arizona	1/89
35.	INTSORMIL Graduate Student Workshop and Tour	College Station, Texas	7/89
36.	ARC/INTSORMIL Sorghum/Millet Workshop	Wad Medani, Sudan	11/89
37.	Workshop on Sorghum Nutritional Grain Quality	West Lafayette, Indiana	2/90
38.	Sorghum for the Future Workshop	Cali, Colombia	1/91
39.	INTSORMIL PI Conference	Corpus Christi, Texas	7/91
40.	Social Science Research and the CRSPs	Lexington, KY	6/92

Acronyms

AAA/SFAA	American Anthropological Association/Society for Applied Anthropology
ABA	Abscisic Acid
ADC's	Advanced Developing Countries
ADIN	All Disease and Insect Nursery
ADRA	Adventist Development and Relief Agency
A.I.D	Agency for International Development
AID/H	Agency for International Development in Honduras
ALDEP	Arable Lands Development Program
APHIS	Animal and Plant Health Inspection Service, U.S.
ARC	Agricultural Research Corporation, Sudan
ARGN	Anthracnose Resistant Germplasm Nursery
ARS	Agricultural Research Service
ASA	American Society of Agronomy
ATIP	Agricultural Technology Improvement Project
BAMB	Botswana Agricultural Marketing Board
BIFADEC	Board for International Food and Agricultural Development and Economic Cooperation
BFTC	Botswana Food Technology Centre
CARE	Cooperative for American Remittances to Europe, Inc.
CARO	Chief Agricultural Research Officer
CARS	Central Agricultural Research Station, Kenya
CATIE	Centro Agronómico Tropical de Investigación y Enseñanza, Costa Rica
CEDA	Centro de Enseñanza y Adiestramiento, SRN, Honduras
CEDIA	Agricultural Document and Information Center, Honduras
CENTA	Centro de Technologia de Agricola, El Salvador
CGIAR	Consultative Group on International Agricultural Research
CIAB	Agricultural Research Center of the Lowlands, Mexico
CIDA	Canadian International Development Agency
CIAT	International Center for Tropical Agriculture, Colombia
CILSS	Interstate Committee to Combat Drought in the Sahel
CIMAR	Centro de Investigación en Ciencias del Mar y Limnologia, Costa Rica
CIMMYT	International Maize and Wheat Improvement Center
CIRAD	Centre International en Recherche Agronomique pour le Dèveloppement
CLAIS	Consejo Latin Americana de Investigadores en Sorgho
CNPQ	Conselo Nacional de Desenvolvimento Cientifico e Tecnologico
CNRA	National Center for Agricultural Research, Senegal
CRSP	Collaborative Research Support Program
CSIR	Council for Scientific and Industrial Research

CSIRO	Commonwealth Scientific and Industrial Research Organization, Australia
DAR	Department of Agricultural Research, Botswana
DR	Dominican Republic
DRI-Yoro	Integrated Rural Development Project, Honduras-Switzerland
EAP	Escuela Agricola Panamericana, Honduras
EARSAM	East Africa Regional Sorghum and Millets
EAVN	Extended Anthracnose Virulence Nursery
ECHO	Educational Concerns for Hunger Organization
EEC	European Economic Community
EEP	External Evaluation Panel
EIME	Ensayo Internacional de los Maicillos Enanos
ELISA	Enzyme-linked Immunosorbent Assay
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuaria, Brazil
EMBRAPA-CNPMS	EMBRAPA-Centro Nacional para Maize e Sorgo
ENA	National School of Agriculture, Honduras
EPIC	Erosion Productivity Impact Calculator
ERS/IEC	Economic Research Service/International Economic Development
EZC	Ecogeographic Zone Council
DRA	Division de la Recherche Agronomique, IER Mali
FAO	Food and Agriculture Organization of the United States
FEDEARROZ	Federación Nacional de Arroceros de Colombia
FENALCE	Federacion Nacional de Cultivadores de Cereales
FHIA	Fundacion Hondurena de Investigacion Agricola, Honduras
FPX	Federation of Agricultural and Agro-Industrial Producers and Exporters
FSR	Farming Systems Research
FSR/E	Farming Systems Research/Extension
GASGA	Group for Assistance on Systems Relating to Grain after Harvest
GMB	Grain Marketing Board
GOB	Government of Botswana
GOH	Government of Honduras
GTZ	German Agency for Technical Cooperation
HIAH	Honduran Institute of Anthropology and History
IAN	Institute Agronomia Nacional, Paraguay
IANR	Institute of Agriculture and Natural Resources, University of Nebraska - Lincoln
IARC	International Agriculture Research Center
IBSNAT	International Benchmark Soils Network for Agrotechnology Transfer
ICA	Instituto Colombiano Agropecuario/Colombian Agricultural Institute
ICAR	Indian Council of Agricultural Research
ICARDA	International Centre for Agricultural Research in the Dry Areas
ICC	International Association for Cereal Chemistry

ICRISAT	International Crops Research Institute for the Semiarid Tropics
ICTA	Instituto de Ciencias y Technologia Agricolas, Guatemala
IDIAP	Agricultural Research Institute of Panama
IDIN	International Disease and Insect Nursery
IDRC	International Development Research Center
IER	Institute of Rural Economy, Mali
IFPRI	International Food Policy Research Institute
IFSAT	International Food Sorghum Adaptation Trial
IHAH	Instituto Hondureno de Antropologia e Historia
IICA	Instituto Interamericano de Cooperación para la Agricultura
IIMYT	International Improved Maicillo Yield Trial
IITA	International Institute of Tropical Agriculture
ILCA	Instituto Interamericano de Cooperación para la Agricultura
INCAP	Instituto de Nutricion de Centro America y Panama
IN.ERA	Institut d'Etudes et de Recherche Agricoles Agricultural Research Institute
INFOP	National Institute for Professional Development
INIA	Instituto Nacional de Investigacions Agricola, Mexico
INIAP	National Agricultural Research Institute, Ecuador
INIPA	National Agricultural Research Institute, Peru
INRAN	Institute Nigerien du Recherche Agronomic, Niger
INTSORMIL	International Sorghum/Millet, Collaborative Research Support Program (CRSP)
IPA	Instituto de Pesquisas Agronomicas, Brazil
IPIA	International Programs in Agriculture, Purdue University
IPM	Integrated Pest Management
IRAT	Institute of Tropical Agriculture and Food Crop Research
IRRI	International Rice Research Institute, Philippines
ISAVN	International Sorghum Antnracnose Virulence Nursery
ISC	ICRISAT Sahelian Center
ISRA	Institute of Agricultural Research, Senegal
ISVN	International Sorghum Virus Nursery
ITA	Institut de Technologie Alimentaire, Senegal
ITAT	International Tropical Adaptation Trials
ITESM	Monterrey Institute of Technology, Mexico
ITVAN	International Tall Variety Adaptation Nursery
JCARD	Joint Committee on Agricultural Research and Development
KARI	Kenya Agriculture Research Institute
KIRDI	Kenya Industrial Research and Development Institute
KSU	Kansas State University
LASIP	Latin American Sorghum Improvement Project, Mexico
LDC	Less Developed Country

LIDA	Low Input Dryland Agriculture
LIFE	League for International Food Education
LUPE	Land Use and Productivity Enhancement
LWMP	Land and Water Management Project
MAFES	Mississippi Agricultural and Forestry Experiment Station
MC	Maicillc Criollo
ME	Management Entity
MFC	Mechanized Farming Corporation, Sudan
MIAC	MidAmerica International Agricultural Consortium
MIPH	Honduran Integrated Pest Management Project
MNR	Ministry of Natural Resources, Honduras
MOA	Memorandum of Agreement
MOA	Ministry of Agriculture, Botswana
MOALD	Ministry of Agriculture and Livestock Development, Kenya
MOU	Memorandum of Understanding
MRN	Ministerio de Recursos Naturales, Honduras
MSU	Mississippi State University
NAARP	Niger Applied Agricultural Research Project
NARP	National Agricultural Research Project
NARS	National Agricultural Research System
NCRP	Niger Cereals Research Project
NGO	Non-Government Organization
NSF	National Science Foundation
NSP	National Sorghum Program
NSSL	National Seed Storage Laboratory, Fort Collins, CO
NU	University of Nebraska
OAS	Organization of American States
OAU	Organization of African Unity
OICD	Office of International Cooperation and Development
PCCMCA	Programa Cooperativo Centroamericano para el Mejoramiento de Cultivos Alimenticios
PI	Principal Investigator
PL480	Public Law No. 480
PRF	Purdue Research Foundation
PRIAG	Regional Program to Strengthen Agronomical Research on Basic Grains in Central America
PROMEC	Program for Research on Mycotoxicology and Experimental Carcinogensis, South African Medical Research Council
PSTC	Program in Science & Technology Cooperation
PVO	Private Volunteer Organization
RADRSN	Regional Advanced Disease Resistance Screening Nursery
RARSN	Regional Anthracnose Resistance Screening Nursery

RFP	Request for Proposals
RIIC	Rural Industry Innovation Centre, Botswana
ROCAFREMI	Réseau Ouest et Centre Africain de Recherche sur le Mil, Niger
RPDRSN	Regional Preliminary Disease Resistance Screening Nursery
SACCAR	Southern African Centre for Cooperation in Agricultural Research
SADC	Southern Africa Development Conference
SAFGRAD	Semi-Arid Food Grains Research and Development Project
SANREM	Sustainable Agriculture and Natural Resource Management CRSP
SAT	Semi-Arid Tropics
SDM	Sorghum Downy Mildew
SDMVN	Sorghum Downy Mildew Virulent Nursery
SICNA	Sorghum Improvement Conference of North America
SIDA	Swedish International Development Agency
SMIP	Sorghum and Millet Improvement Program
SPARC	Strengthening Research Planning and Research on Commodities Project, Mali
SRCVO	Section of Food Crops Research, Mali
SRN	Secretaria de Recursos Naturales, Honduras
TAES	Texas Agricultural Experiment Station
TAMU	Texas A&M University
TARS	Tropical Agriculture Research Station
TC	Technical Committee
TropSoils	Tropical Soils Collaborative Research Program, CRSP
UANL	Universidad Autonoma de Nuevo Leon, Mexico
UHSN	Uniform Head Smut Nursery
UNILLANOS	Universidad Technologica de los Llanos
UNL	University of Nebraska - Lincoln
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
USDA/TARS	United States Department of Agriculture/Tropical Agriculture Research Station
VCG	Vegetative Compatibility Group
WASAT	West African Semi-Arid Tropics
WASIP	West Africa Sorghum Improvement Program
WSARP	Western Sudan Agricultural Research Project