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INTSORMIL

Annual Report 1994

SORGHUM/MILLET COLLABORATIVE RESEARCH SUPPORT PROGRAM (CRSP)

Fighting Hunger with Research ... a team effort

Funding support through the Agency for International Development

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Cover Photographs
(top to bottom)

1. Aboubacar Touré with panicle of new advanced generation white seeded, tan plant, Guinea type breeding line. Sotuba, Mali - October, 1994. Photo courtesy of Dr. Darrell Rosenow.

2. A Nicaraguan worker selecting broomcorn fiber by different sizes. Photo courtesy of Dr. Franciso Gomez.

3. John Yohe, INTSORMIL Program Director, on the left and Phillip Warren, USAID INTSORMIL Project Officer, on the right, reviewing the sorghum nursery at Purdue University. Photo courtesy of Phillip Warren.

4. Quarantine growout and increase of Sudan sorghum collection (approximately 3,100 sorghum cultivars) in St. Croix, U.S Virgin Islands - January 1994. Photo courtesy of Dr. Darrell Rosenow.

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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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A Research Development Program of the Agency for International Development, the Board for International Food and Agricultural Development and Economic Cooperation (BIFADEC), Participating Land-Grant Universities, Host Country Research Agencies and Private Donors

INTSORMIL INSTITUTIONS

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

INTSORMIL Institutions are affirmative action/equal opportunity institutions.

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

In working with selected host countries where sorghum and millet are important crops, INTSORMIL is now capitalizing upon the institutional and technical expertise of five 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 can be attributed to five unique features.

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

- INTSORMIL is an integrated, interdisciplinary organization encompassing breeding, agronomy, physiology, insect and disease management, food quality, and economics.

- INTSORMIL enhances the capacity of NARS to solve country and region-specific problems through collaborative research, thus increasing NARS technical and institutional productivity.

- INTSORMIL activities are constraint and NARS driven: identification and alleviation of priority production constraints are achieved in concert with NARS.

- The INTSORMIL strategy focuses on five technical thrusts, each aimed at increasing productivity and 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 development 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 CRSF 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.

- Draft No. 3 of the INTSORMIL Ten Year Strategic Plan has been prepared. Two other documents for the Strategic Plan were prepared. Those are:
  - * Reports on Domestic Sites covering all current INTSORMIL domestic institutions.
  - * Country Status Reports covering all the countries where INTSORMIL is operating.
- The INTSORMIL External Evaluation Panel (EEP) completed its five year review of the host country sites in October, 1993. During the period of July 1, 1993 to June 30, 1994 the EEP completed the review of all domestic research sites (Texas A&M, Mississippi State, Nebraska, Kansas State and Purdue Universities). The panel's Five Year Report was released in March, 1994.
- INTSORMIL served as joint sponsor and organizer of the workshop, "Adaptation of Plants to Soil Stress" which was held August 1-4, 1993 at the University of Nebraska. Sixty-seven invited participants representing eleven countries were present for the meeting.
- The major publications organized and published by the ME office during the year included:
  - * INTSORMIL Newsletter, INTSORMIL Publication No. 94-1.
  - * Proceedings of the Workshop on Adaptation of Plants to Soil Stresses, August 1-4, 1993, INTSORMIL Publication No. 94-2.
  - * INTSORMIL Newsletter, INTSORMIL Publication No. 94-3.
  - * INTSORMIL Annual Report 1993, INTSORMIL Publication No. 94-4.
  - * INTSORMIL Annual Report 1993, Executive Summary, INTSORMIL
  - * INTSORMIL Bibliography, 1984-1994, INTSORMIL Publication No. 94-5.
  - * The research bulletin entitled "New Approaches to the Control of *Striga*" written by scientists at Purdue University and collaborating Sudanese scientists was published by the Purdue University Experiment Station.
- The INTSORMIL Host Country Coordinators from Mali, Niger, Sudan and Botswana elected Dr. Ouendeba Botorou of Niger as the first Host Country representative to the Ecogeographic Zone Council.
- Dr. Francisco Gomez, Esquela Panamericana, San Zamorano, Honduras was elected as the first Host Country representative to the Technical Committee.
- The INTSORMIL BOD approved the 1994-95 annual budget which included a 11.1% reduction in funds.
- INTSORMIL opened a worldwide search for the position of Associate Director. This search was later canceled due to the budget reduction.
- INTSORMIL plant pathologists, Dr. John F. Leslie, Kansas State University and Dr. R.A. Frederiksen, Texas A&M University, were responsible for organizing a conference on "Application of Genetics and Biotechnology to the Characterization and Control of Fungal Pathogens: An International Sorghum and Millet Perspective". The conference was held at the Rockefeller Foundation Center, Bellagio, Italy, November 15-19, 1994. A broad range of topics in the general area of molecular biology, genetic maps and diversity, plant disease control, mating populations, and pathotype diversity of fungal pathogens of sorghum and millet were covered. The proceedings of this conference are to be published in early 1995.
- The International Consultative Workshop on Panicle Insect Pests of Sorghum and Pearl Millet was jointly organized and sponsored by ICRISAT and INTSORMIL. It was held October 4-7, 1993, at the ICRISAT Sahelian Center, Niamey, Niger.
- Based upon a request from the Institute of Agricultural Research (IAR) of Ethiopia, INTSORMIL provided short-term (3-6 months) training for six Ethiopian scientists at three INTSORMIL Universities. Each of these Ethiopians holds an M.S. degree and had over five years of work experience in research. This special training focused on different disciplines of sorghum

research and was sponsored by the IAR through World Bank funding.

- INTSORMIL's three year grant under the Egyptian National Agricultural Research Program (NARP) entitled "Sorghum/Millet Collaborative Research" ended on June 30, 1994. Components of the grant were "Water Use Efficiency in Sorghum Based Cropping Systems" in collaboration with Dr. Jerry Eastin at the University of Nebraska, and "Stalk and Root Rot Complexes and Associated Diseases of Sorghum in Egypt" in collaboration with Drs. Larry Claflin and John Leslie at Kansas State University. "Pokkah boeng" was identified as a serious disease problem on one of the most popular Egyptian cultivars, Giza 15, and has become a new area of research that is continuing even though this project has formally lapsed.

CRSP Review Team

USAID conducted an overall evaluation of the Collaborative Research Support Programs (CRSPs), including INTSORMIL, between May and July 1994. According to the "CRSP Evaluation Scope of Work" developed by USAID, the goal of this evaluation was to provide an objective assessment of the degree to which each of the CRSPs has had an impact on increasing agricultural production and development, and improving natural resource management through the development and dissemination of new and/or more appropriate sustainable agriculture technologies. The evaluation also assessed the extent to which the CRSP framework has responded to past Agency expectations and objectives and if the CRSP model can be used to respond to future Agency needs and requirements.

The members of the evaluation team were: Dr. Les Swindale, Team Leader and Institutional Management Specialist; Dr. John Ericksen, Agricultural Economist; Dr. Charlotte Miller, Rural Sociologist; Dr. George Marlowe, Plant Scientist; Dr. Rattan Lal, Soil Scientist; Dr. Richard Gray, Animal Scientist; Dr. Gary Jensen, Aquaculture Specialist; and Dr. Izadore Barrett, Fisheries Specialist.

The team visited both domestic and host country sites where the CRSPs are operating. The domestic INTSORMIL institutions visited were the University of Nebraska, Purdue University and Texas A&M University. The host country sites which were visited, with the objective of evaluating past and/or present INTSORMIL related collaborative programs, were Mali, Niger, Kenya, Honduras and Brazil. In addition to INTSORMIL, six other CRSPs were being evaluated by the team.

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.

During 1993-94, 96 students from 33 different countries were enrolled in an INTSORMIL advanced degree program and advised by an INTSORMIL principal investigator. Seventy-eight percent of these students came from countries other than the U.S. which illustrates the emphasis placed on host country institutional development. INTSORMIL also places importance on training women which is reflected in the fact that 20% of all INTSORMIL graduate students were women.

The number of students receiving 100% funding by INTSORMIL in 1993-94 totaled 17. An additional 29 students received partial funding from INTSORMIL. The remaining 50 students were funded from other sources but are working on INTSORMIL projects. Total student numbers increased by six as compared to 1992-93. The number of students receiving 100% funding from INTSORMIL has dropped from a high of 71 in 1986 down to a low of 17 in 1993-94. This is, in part, due to training taking place under other funding sources, but an even more significant factor is that budget flexibility for supporting training under INTSORMIL projects has been greatly diminished because of reductions in our overall program budget and because of inflationary pressures.

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 1993-94.

INTSORMIL cooperated with ICRISAT on a ten year special training program for countries of the Southern Africa Development Community 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 was implemented by ICRISAT and funded by USAID, CIDA and GTZ. The total number of active SADC students was 40 for 1993-94.

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, and for coordination of research and long term training. INTSORMIL is working with newly emerging networks, such as ROCAFREMI (Réseau Ouest et Centre Africain de Recherche sur le Mil, Niger) 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.

INTSORMIL/Mali

The research accomplishments in Mali are immediately and directly transferable to most countries in West Africa. Work on sorghum and millet food technology applies to Africa and many areas of the world. Head bugs and drought are common to West Africa. Grain mold is a world-wide problem. Exchange of elite germplasm with useful traits is an excellent means of networking among breeders. Effort is being made to utilize existing networks to extend technology to the region in both sorghum and millet. There has been a long history of collaboration with ICRISAT in Mali, and collaboration with ICRISAT continues to be useful in networking in the areas of entomology, pathology, and breeding.

Within Mali, there is a pre-extension organization to do on-farm trials, followed by extension personnel doing detailed evaluation and demonstration of new technologies. Minamba Bagayoko coordinates extension on-farm trials in the Mopti region. Future plans call for linkages and networking with the NGOs and PVOs working in Mali.

INTSORMIL/Niger

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 West African countries.

INTSORMIL/Sudan

The Agricultural Research Corporation of Sudan, INTSORMIL's sole collaborator in Sudan, has an effective network for dissemination of research results to clientele groups. The many agricultural production schemes in Sudan are managed by well-trained agriculturists who interact with ARC scientists in both organized and informal forums. Annual agricultural meetings are held where current research results are presented and emerging constraints are discussed. Both agricultural research and extension scientists from the Ministry of Agriculture attend these annual meetings. Sudanese scientists are active participants in regional and international workshops where contemporary agricultural issues are discussed. Many Sudanese scientists hold leadership positions in regional networking activities. For instance, Dr. A.G.T. Babiker has been the leader of the Pan African *Striga* Control Network and attended meetings in Zimbabwe and Kenya in 1993.

INTSORMIL/Botswana and Southern Africa

Participation of the host country and INTSORMIL scientists in the SADC/ICRISAT Sorghum and Pearl Millet Research Network is increasing.

Electronic mail linkage between national research institutions and universities (both host country and U.S.) is almost a reality. A sorghum/pearl millet bulletin board on Internet would be an excellent vehicle for networking among Southern Africa scientists.

INTSORMIL/Honduras

INTSORMIL's long-term relationship with the MNR has enabled Honduras to develop a long term comprehensive sorghum research program that is beginning to gain support from the sorghum industry in Honduras and other international donors. Special projects are being developed to create new funding sources. To date, these projects have focused on commercial hybrid testing and the international sorghum downy mildew nursery in Comayagua. The national sorghum program won two strengthening grants ($15,000 each) from the EEC this year for the control of sorghum downy mildew in Honduras and support to maicillo breeding activities.

In 1994, Dr. Francisco Gomez was appointed Vice-president of the National Council of PRIAG (Regional Program to Strengthen Agronomic Research on Basic Grains in Central America) which is sponsored by the European Economic Community and administered by IICA. As a senior scientist in the region, he is providing valuable advice to PRIAG in establishing their research grant program. This position adds an important new facet to networking.

Dr. Gómez acts as the liaison officer between the American Society of Agronomy (ASA) and PCCMCA. Dr. Gomez attended the 1994 ASA meetings where he investigated possibilities for opening an ASA Chapter at EAP.

Dr. Fred Miller, INTSORMIL/Texas A&M University sent 4 female and 53 male lines for hybrid seed production in Comayagua. Seed from two improved maiciollos was distributed among 62 farmers in southern Honduras. Seed of six enhanced maiciollos and maicillo criollo was sent to Dr. Page Morgan, Texas A&M University to initiate a study in photosensitivity control. Seed of five broomcorn varieties was sent to Eng. Adolfo Montiel for adaptation studies in Nicaragua.

INTSORMIL/Colombia

This Prime Site was informally linked with many countries in South and Central America and in Africa where CIAT conducts research. Over the years, cooperative research linkages were established with the national research programs of ICA-Colombia. EMBRAPA-Brazil, CENIAP-FONAIAP-Venezuela, INIPA-Peru, and IDIAP-Panama. These countries are in the major acid soil areas and are conducting research to solve soil acidity problems. This collaborative linkage network unified INTSORMIL researchers and host country scientists to solve a common problem in the region through exchange of germplasm, research result dissemination, technical consultation, training, and workshops.

The INTSORMIL Colombian Program, headquartered at CIAT, promoted and established a Latin American network. International workshops held in Colombia were developed and coordinated by INTSORMIL PIs in 1984, 1991, 1992, and 1993. Involving both public and private sectors at national and international levels, the network emphasized the introduction, exchange, storage, increase, and distribution of germplasm. The network planned to 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.

Current Country Specific Activites

Mali

The program in Mali is a coordinated effort between INTSORMIL and IER. It is multidisciplinary and multi-institutional in scope and includes all aspects of sorghum and millet improvement, production, and utilization. Each Malian scientist develops research plans cooperatively with an INTSORMIL counterpart in concert with the overall IER Mali research plan. Major INTSORMIL collaborators travel to Mali annually during the critical period of the crop year to consult, review progress, and plan future collaborative activities with their Malian counterparts. Occasionally, IER scientists travel to the U.S. for annual review and planning. These plans are reviewed by the country coordinators, consolidated, and then presented to the IER for their annual research planning process for approval or modification. This insures that the research fits into the annual overall IER plan.

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 needs of 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.

Head bugs and associated grain 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.

Grain prices which cycle between high and low yield-level years are a deterrent to adoption of improved technology, thus milling properties become critical for 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.

Efforts are concentrated to strengthen research on breeding, crop physiology, soil and water relationships, entomology, pathology, *Striga*, food processing, and food 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.

Research Progress

Pearl Millet Breeding

The pearl millet breeding program in Mali is making good progress in addressing needed improvements regarding disease and insect resistance, adaptation, and agronomic characteristics that affect productivity. Landraces from different ecological zones have been evaluated at different locations. These materials were collected at Nioro, Bema, Mopti (northeast), and Sikasso (south). Ten high performing ecotypes were selected. They are being improved via the mass selection method. The same entries are being used in a crossing block for their grain quality (kernel size and color).

Many experimental varieties have been evaluated in the CIVAREX, "Cinzana Varieties Experimentales". Several performed well and will be suitable for intercropping with legumes such as cowpea and peanut, and root crops like cassava and sweet potatoes. Several composites were evaluated in isolated plots for dwarfness, head compactness, and downy mildew resistance. Roguing and recombination gave good results.

Several lines derived from nine Malian varieties were screened at Hays, Kansas. Three good lines were retained in Mali. Also, crosses were made between Kansas elite lines and materials from Mali. Fifty-two F_1 and forty-eight F_2

selections were evaluated. They had an acceptable level of downy mildew resistance. Backcrosses will be made with most of these lines. They had suitable height for intercropping. More than sixty entries were evaluated through ICRISAT and ROCAFREMI (Millet Improvement Network in Central and West Africa) collaborative programs. Two or three years evaluation will allow selection of some entries for on-farm evaluation.

Sorghum Breeding
Crossing and Breeding Nurseries

In the 1993 rainy season, 48 parents were planted at Sotuba with 115 new crosses made. These F_1s were planted at Sotuba during the 93-94 off-season to produce F_2s. The best tan-plant Guinea F_6 derivatives were selected to be backcrossed to CSM 388, Bimbiri Soumale and Tiemarifing, in order to enhance the guinea traits to develop very true tan-plant guinea lines.

F_2, F_3, and F_4 progeny were grown at Sotuba, Samanko, Bema, Cinzana, and Longorola with 350 F_2 selections, and 255 F_3 selections made. Eighty-one F_4 families were selected for advance in the off-season to the Preliminary Trial in 1991.

Excellent progress was made in the objective to develop white-seeded, tan-plant guinea cultivars. F_6 progenies from crosses involving Bimbiri Soumale and CSM388 looked very promising. Especially outstanding were the derivatives of the cross, Bimbiri Soumale *87CZ-Zera Zera. They appear to have excellent yield potential. They have good guinea plant, grain, glume, and panicle characteristics, and some have juicy stems. Most Bimbiri Soumale derivatives were F_6s in the preliminary trials, while the best CSM388 derivatives were in the F_4 stage. They will move to the Advanced Trials and Preliminary Trials in 1994.

The progenies from late maturing improved maicillo varieties from the INTSORMIL program in Honduras were not acceptable for grain quality, but had proper maturity for southern Mali. They were recrossed to local and improved types in an attempt to improve the head bug and grain mold resistance.

Advanced Varieties

Three different Preliminary Yield Trials and three Advanced Yield Trials (to fit rainfall belts) were planted and evaluated at Bema, Cinzana, Massantola, Katibougou, Sotuba, Samanko, and Soukoula. From the Advanced Trials, eight were selected for on-farm testing. From the Preliminary Trials, entries were selected to be promoted to the Advanced Trial next year.

In southern Mali, seven cultivars selected from the CMDT southern Mali collection of late, photosensitive sorghums were evaluated at Longorola, Soukoula, and Tieroual a. After two years of evaluation, three were selected for on-farm testing and for crosses, Kalagua Seguetana, Foulatieba, and Kalofolo.

Plant Protection

Entomology

Research activities for 1993 were focused essentially on the bio-ecology of head bug (*Eurystylus marginatus*) and the identification of new resistance sources. The fluctuation of larva and adult populations was studied. The population of head bugs was higher in 1993 than in 1992.

In preliminary screening in the field nursery at Sotuba, 49 new advanced generation lines were evaluated under natural infestation conditions. In another three year experiment screening for resistance, we evaluated 50 advanced breeding lines. In the first experiment the entries showing good head bug resistance were 89-CZ-CS-F_5-73 AF, ACSV 401, 88-BE-F_4-257-3, 87-SB-F_4-275-2 and 87-SB-LO-F_4-155 with a visual rating between 1.0 and 1.7. Results in the second experiment showed that the INTSORMIL lines from Texas 90-CZ-CS-TX-2, 90-CZ-CS-TX-12, 90-CZ-CS-TX-6, 90-CZ-CS-TX-1, PR2566 and PR2562 were resistant to head bug under severe natural infestation. All are derivatives of Malisor 84-7. In another advanced screening trial, IS21468 was confirmed as having resistance equal to that of Malisor 84-7.

Diazinon again looked promising in controlling head bugs in 1993. In lines treated with diazinon, the head bug incidence under natural infestation was very low compared to the check. Also, 200 grain-weight was higher for treated heads (4.21g) than for the control under natural infestation (3.20g).

Pathology

Forty lines from INTSORMIL in the GWT (Grain Weathering Test) were screened for grain mold resistance at Sotuba under natural conditions. Six lines, SC170-6-17, SC279-14E, R6078, 87BH8606-6, Town, and BE7149, showed resistance and will be used for further testing.

The 70 entry ADIN (All Disease and Insect Nursery) was evaluated under natural infestation for anthracnose and sooty stripe at Sotuba with several lines showing useful levels of resistance.

Striga

Cultivars from the Malian Collection (Seguetana), selected lines from Dr. G. Ejeta, Purdue University and from the national breeding program were used in the *Striga* evaluation field trials in 1993. Among the cultivars collected in southern Mali, the best six, CMDT 30, CMDT 39, CMDT45, CMDT48, CMDT76, and CMDT115, showed less *Striga* incidence than the check Tiemarifing.

At Samanko and Katibougou, selected F_5 breeding lines (Malisor 84-7*SRN39) from Purdue were as resistant as the resistant check, Tiemarifing, in preliminary screening trials. Six advanced generation lines (SRN39*Zerazera) developed and selected at Purdue for resistance to *Striga asiatic* were tested on-farm in the Katiabougou area. All showed high levels of resistance to *S. hermonthica* and 92PR-203 also showed excellent agronomic traits.

At Cinzana, a reportedly resistant local guinea landrace variety, Seguctana Cinzana, showed excellent resistance in a field screening nursery. This line will be studied in the Purdue Lab.

Crop Production/Agronomy Physiology Soils

Seedling Screening for Drought and Heat Tolerance

Selected early and intermediate maturity advanced including breeding lines were tested for high heat and drought tolerance in the 92-93 off-season in charcoal pits at Cinzana. In the early trial 87-LO-F_4-92 (Malisor 84-1), 88-CZ-F_4-173-3, 89-CZ-CS-F_5-126AF and Bagoba were tolerant. Malisor 92-1 had the highest plant survival at the 3rd, 7th, and 15th day after planting. In the intermediate maturity trial, 90-CZ-CS-104 and 90-CZ-CS-F5-65 showed good seedling survival.

Peanut-Sorghum Rotation

In 1993, previous peanut crop effect was very important to sorghum grain yield. There was a 74% increase due to previous peanut cropping alone at zero N level, and 114% and 102% yield increase when 40kg and 80kg of N were applied to previous peanut plots. Other results have indicated that the rotation effect is not due only to legume N effect.

Sorghum-Peanut Intercropping

The land equivalent ratio (LER) is used as a land use efficiency indicator. The efficiency of sorghum peanut intercropping in 1993 was estimated at 1.48. The yield of sorghum grain in intercrop was 48% of sole sorghum and that of intercropped peanut was 100% of the yield of sole peanut crop. Rotations with sorghum-peanut intercrop, compared to sole sorghum, showed a 36% yield increase of sorghum grain in the rotation compared to sole sorghum.

Cowpea - Pearl Millet Rotation

Previous cowpea had a significant effect on pearl millet grain yield. At the zero N level there was a 56% yield increase. This increase was more than the effect of 20kg N/ha (15% increase) and equivalent to that of 40kg N/ha (56% yield increase). Combined nitrogen and previous cowpea was even greater with yield increases of 67%.

Pearl Millet - Cowpea Intercropping

The land equivalent ratio (LER) of millet-cowpea intercrop indicated a 55% yield increase in total production. Partial LER of pearl millet grain yield over nitrogen levels was 100% for zero and 85% and 73% for 20 and 40 kg N/ha. The rotation effect of millet-cowpea intercrop on succeeding sole millet was a positive 14% without N application.

Long Term Residue Management Study

A residue management study on sorghum and millet monoculture and rotation of cereal-legume was initiated in 1990 with three residue treatments: removed; leaving residue on soil surface; and incorporated. There was no effect on grain or stover the first three years, but in 1993 grain yield differences occurred for the first time. For both crops, incorporated and removed were superior to leaving residue on the surface. The consistent lower yields where residue was maintained on the surface could be due partially to an observed reduction in stand. The crop residue treatments showed no effect on peanut and cowpea yields.

Biomass-Harvest Index Study

Different planting dates and different fertilizer levels had no significant effect upon total biomass or harvest index of 15 local Malian varieties. Similar results were obtained on a similar study of five advanced Malian breeding lines.

Sorghum Photosensitivity Adaptation Study

Three Guinea types and three non-sensitive improved cultivars were planted every 15 days from May to the end of July. The days to flower changed for the Guineas until the last two dates, while the nonsensitive lines showed little effect upon days to flower. The Guineas flowered earlier with the later planting dates.

Sandy Soil Toxicity on Sorghum Study

This InterCRSP activity among IER, INTSORMIL, and the Soil Management CRSP involved evaluation of sorghum genotypes for tolerance in field plots at Cinzana. In 1992, F_2 population involving Bagoba, Babadia Fara, and Gadiaba consistently showed tolerance. In 1993, 46 cultivars were evaluated in the same plot, and under very severe conditions, the northern Mali durra cultivar, Cadiaba (Cinzana) consistently showed genetic resistance to this soil problem. Analyses of soil next to individual plants by the Soil Management CRSP was done to attempt to determine the cause of the extreme spatial variability.

Grain Quality Studies

Breeding Line Evaluation

The advanced medium maturity trial and early trial grain samples were evaluated in the Cereal Technology Lab for kernel characteristics, physical properties, decortication yield, and tô properties. The early materials generally had a slightly lower decortication yield. In general, all gave good tô color and quality. The preliminary trials from Cinzana and Bema were also analyzed. Data are used by breeders in making decisions to discard or keep test entries.

Couscous Preparation Survey

A study was conducted in Bamako to determine parameters important in couscous preparation, using 117 women from 14 different ethnic groups. The sorghum variety was consistently an important consideration in couscous quality. Large white seed which decorticates easily, with high flour yield, produces good couscous. Other factors important to couscous quality are flour textile, grain mold, making fashion, water quality, type of steamer, steaming time, and mucilage type.

Seed Germination

The seed laboratory germinated 537 samples of sorghum from the entomology program to study the effects of head bug and grain mold/weathering. Only 43% of the samples gave excellent germination. There were large differences among genotypes.

Economics

Ousmane Coulibaly, a Malian Ph.D. student at Purdue, initiated his thesis fieldwork in Mali on a study of technologies to increase water availability and soil fertility in the Sudanian and Sudano-Guinean zones of Mali. He also assisted IER scientists in their evaluation of the economic effect of a fungicide application for downy mildew control on pearl millet.

Niger

Collaborative Program

This is an interdisciplinary, multi-institutional collaborative research program which involves INRAN and U.S./INTSORMIL institutions.

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 Soil Management CRSP, ICRISAT Sahelian Center, the USAID/Purdue/INRAN National Cereals Research project, the International Fertilizer Development Center (IFDC), and 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.

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 been other organizations and International Centers who collaborated with our program in Niger. These include the Soil Management CRSP, the Agricultural Research Corporation in Wad Medani, Sudan, IN.E.R.A. in Burkina Faso, and the Purdue/Niger Applied Agricultural Research (NAAR) project.

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 budgets 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.

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 establishment. 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 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 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 the 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 xP3Kolo 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.

Research Accomplishments

Socioeconomics - Abdoulaye Tahirou, Mohamadou Abdoulaye and J. Lowenberg-Deboer

During the 1993 agricultural season, the socioeconomics component of the INRAN/INTSORMIL collaborative research program has continued the investigation of sorghum by-products. The general objective of the study is to determine how by-products affect farmer decisions. This second year of data collection is intended to give a dynamic view of the system.

Data were collected in Dagarka and Kaku, the same two villages in the area of Birni N'Konni that were surveyed in 1992. The same 23 farmers were interviewed. Sorghum by-products were found to be an important part of the agricultural system in the area of Birni N'Konni. They are important in animal nutrition, and farmers get a certain cash revenue from them.

The average value of the sorghum stover at harvest (October) was 7752 fcfa per hectare. If the farmers can store their sorghum stover production until March, the average value is almost doubled to 14535 fcfa per hectare. Sorghum stover and stalks are commonly used for forage and energy. They are also used for fences and making beds. All the farmers in the sample report the use of sorghum stover as forage, about 80% for energy, 10% for fences and 25% (all at Kaku) for bed construction. Sorghum bran is used mainly for animal nutrition or sold.

Less than 30% of farmers interviewed in both villages responded that they could leave part or all the sorghum stover they produced on the field to help control wind erosion and/or maintain soil fertility. Farmers know that this can help control erosion, but the use of the stover short term benefits are important in this subsistence farming system.

Although many aspects are taken into account for the choice of a sorghum variety, the first criteria tends to be the overall grain yield. Other aspects farmers look at when choosing a variety include: the color (especially the flour), the hardness of the grain (bran is more easily removed without damaging the grain from hard grains), the color of the stover and its quantity after the harvest.

It is essential that future economic evaluation of technologies in this area take into account the value of sorghum stover. Sorghum production in this area is mainly carried out through an intercropping system with millet and cowpea. Agronomic evaluation on-station or on-farm can help identify varieties suitable for intercropping.

Data collected in this survey are being used to develop a representative farm model for this area which includes both crop and livestock activities. The interaction between these two activities among Nigerien farmers is becoming more important especially now with the devaluation of its currency making imported inputs more expensive.

Entomology - Hame Kadi-Kadi, Ousmane Youm and Frank Gilstrap

In 1993, discussions were held with Mamadou Ouattara, Ouendeba Botorou and Hame Kadi-Kadi (INRAN), Ousmane Youm (ICRISAT), I. Bayoun and F. Gilstrap to develop collaborative plans to assess the sources of mortality for the millet head miner (MHM) in Sadore and Maradi. These plans called for Mr. Kadi-Kadi to come to ICRISAT-ISC in September-October, 1993, and receive short-term training from Mr. Bayoun and Dr. Youm on methods and techniques needed for 1994 research. However, Mr. Kadi-Kadi was unable to participate in the training. The work reported below was conducted entirely on and near the facilities of the ISC.

The millet head miner (MHM), *Heliocheilus albipunctella* (de Joannis), commonly causes significant crop losses of pearl millet, *Pennisetum glaucum* L., a primary food crop in Sahelian West Africa. MHM is an excellent candidate for demonstrating a control strategy that emphasizes effective natural enemies. It occupies a predictable habitat in an ecosystem with relatively consistent annual habitats, has one generation per year, attacks several host plants including wild millet, and across West Africa supports a relatively large guild of natural enemies. The objective of this research is to evaluate natural enemies of *H. albipunctella*, and the results will serve to appraise tactics and develop a biological control strategy for *H. albipunctella*.

The following research is needed before biological control can be used as part of an integrated management strategy that deals effectively with MHM. During 1993-1996, collaborative exclusion studies on MHM developmental stages in Sadore and Maradi will be conducted and the data will be used to construct life tables for MHM. The 1993 research will provide baseline methods and initial results for planning 1994 experimentation. The 1993 experimentation consisted of cage exclusion studies and population monitoring at Sadore.

Exclusion experiments are essentially a series of paired plots in which natural enemies are excluded from one-half, and are allowed access to the other one-half (Control or Check). Survival is measured in all plots, and the differences between treatments are a direct measure of the natural enemies' controlling impact. Treatments can be modified in many ways to collect different kinds of pest mortality information. In 1993, caged exclusions that consisted of placing a physical barrier (i.e., panicle cage) over panicles in the plots were used. Openings were made in one-half of these cages to permit natural enemy ingress and egress. Different types of cage treatments were set up to evaluate enemies occurring on different MHM stages (i.e., eggs, early and late instars) separately. Treatments included (1) cages closed throughout panicle development, which excluded all natural enemies; (2) cages opened only during the egg stage, and then closed until the end of the season; (3) cages opened only during early MHM instars, and then closed until the end of the season; (4) cages opened only during development of late MHM instars; and (5) cages opened throughout panicle development. At the end of the season, millet heads were cut and MHM were counted.

Results showed attacks by natural enemies have a very significant impact on mortality of MHM, and most of this mortality occurs during the late larval stages. Cages opened throughout panicle development had the same total number of surviving MHM individuals as closed cages. A significant finding from this first year of data is that we encountered relatively few species of enemies attacking MHM. Two predators and two parasites were the most commonly recovered natural enemies.

The two most common predator was Orius sp., a small anthocorid predator that attacks MHM eggs and early instars. The second most common was an ant that attacked full-grown larvae after they dropped to the soil to pupate.

The two commonly encountered parasites were both parasitic Hymenoptera. The most common parasite was an encyrtid, *Copidosoma* sp., an egg-prepupal parasite that attacks the MHM eggs and emerges as an adult from the MHM prepupa. This parasite is polyembryonic, i.e., one parasite egg produces offspring. An average of 394 (maximum = 802) adult parasites emerged from each parasitized MHM. The second most common parasite was a braconid, *Bracon hebetor*. *Bracon* is a gregarious ectoparasite that attacks late larval stages of MHM. Parasitism by *B. hebetor* occurs mostly late in the season, and can reach 80-90% of the total MHM population. Female *B. hebetor* attack late MHM instars, permanently paralyzing them. Some attacks result in the parasite ovipositing eggs externally on the MHM host. Studies in 1993 encountered many larvae killed by *B. hebetor* but without parasite eggs. Thus, *Bracon hebetor* functions ecologically both as a predator and as a parasite. *Bracon hebetor* has a short generation time and is polyphagous.

In 1994, the team will continue these experiments, and conduct additional experiments as needed for an age-specific life table for MHM. These experiments will take a natural cohort of MHM and follow it through to the end of the season and then to the next season. They will then construct survival budgets for MHM, and characterize the portion of MHM population removed by natural enemies. Their research approach will consist of host exposure techniques, caged exclosures and natural population monitoring.

Cereal Quality - Moussa Oumarou,
Adam Aboubacar and Bruce Hamaker

The Cereal Quality Laboratory (LQC) at INRAN has conducted several surveys to determine the different methods of couscous preparation used in Niger. Two different locations were selected for the surveys. In one location (Maine-Soroa), three types of locally grown cereals (sorghum, millet and durum wheat) were used to produce couscous using the preparation method of that location. All three cereals were processed the same way and produced acceptable couscous. In the other location (Tera), couscous was produced using three millet varieties (C.I.V.T., SOUNA 3, and H.K.B. Tif) grown in 1992 at the Kollo station.

Four different processing methods were used to produce couscous and a macaroni type product. Two of the procedures, one for couscous and the other for macaroni were different from the other two only in the fermentation step. A sensory panel was used to evaluate the different products and their quality was found to be improved by fermentation. All processing steps were recorded in order to determine the best method(s) that could be used for a commercial production of couscous.

The LQC has also conducted a study on composite flour breads. Breads were made in collaboration with a local bakery at Niamey, using a blend of 10, 20, 30, and 40% sorghum and millet flour with wheat flour. The results showed that incorporation of millet or sorghum flour up to 20% gave acceptable bread. At higher concentrations, the bread was heavier and tended to break easily. It was also found that increasing the proof time increased loaf volume. A sensory evaluation study indicated that consumers preferred the incorporation of millet flour over sorghum. Demonstrations of bread from composite flour were made to processors and government officials at a workshop organized by INRAN in Niamey.

Sorghum Breeding - Moussa Adamou,
Issoufou Kapran, Gebisa Ejeta and John Axtell

During the summer of 1993, several trials were conducted at the main INRAN stations at Maradi and Kollo, while *Striga* resistance testing was conducted at the Konni station. In addition, demonstration plots were conducted by a large number of farmers, especially around Maradi and Konni. In all cases, the results were very satisfactory, with new elite material being observed on-station and farmer interest in the demonstration plots on the rise. It was therefore decided to keep the breeding project at least at the same level of activity for 1994. For this crop season, most of the genetic material was provided by the Purdue University/INTSORMIL program, and some was also provided by Nebraska.

The germplasm from Purdue covers many aspects of sorghum improvement, including early generation material for pedigree selection, elite lines for adaptation/observation in Niger, hybrid yield trials to evaluate the performance of new R and B lines, on-station testing of new *Striga* resistant lines and a *Striga* resistance population, and aspects of hybrid seed production and on-farm testing. Following a conversation with I. Kapran, Prof. David Andrews provided some new lines and hybrids for comparison with other INRAN/INTSORMIL germplasm. Conduct of these trials and nurseries was discussed in early June 1994 at Niamey, Kollo and Maradi between I. Kapran and Dr. Moussa Adamou, Issoufou Kollo for the *Striga* tests, and the two sorghum technicians M. Abdou and N. Kondo. Except for Kapran, on study leave at Purdue, these individuals are primarily responsible for the field work in Niger. Actual planting was started toward the end of June, and to date the rainfall figure has been exceptionally high in almost all of Niger. In fact, flooding has occurred on the heavier soils of the two main INRAN stations at Kollo and Maradi, as well as on some of the on-farm plots. Still, preliminary observations suggest that at least on the drier soils, nurseries will provide interesting data. Experimental hybrid seed production continues at several locations to provide more seed for future demonstration plots, as well as mastering the best nicking scheme between the parents of NAD-1 hybrid. Field days are once again scheduled for early October to provide more farmers the opportunity to visit other demonstration plots and research plots in nearby INRAN stations.

Plant Pathology - Issoufou Kollo and Richard Frederiksen

Cooperation with ICRISAT was continued through the joint International Anthracnose Virulence Nursery. The enhanced collaboration stems from the recognition of the importance of this disease in the more humid sorghum growing regions of the developing world. Anthracnose collaboration permits the better evaluation of the durability of host resistance and a better estimate of the variation in pathogenicity among isolates of the pathogen worldwide. Participating regions include West Africa, Mali and Niger; East Africa, Sudan; Southern Africa, Zambia and Zimbabwe; and Brazil. INTSORMIL research has demonstrated that there is tremendous variation among isolates from locations and between locations. Sorghum downy mildew has become less and less of a problem because of global cooperation in the development of host resistance, characterization of isolates and through the use of highly effective fungicide seed dressings. RFLP and RAPD markers linked to head smut, downy mildew, and acremonium wilt resistance have been placed within specific linkage groups on the sorghum genome.

INRAN's sorghum program has released to the Niger Extension Service two grain sorghum open-pollinated varieties and one hybrid for the heavier and better structured soils with more than 500 mm rainfall. These improved varieties, Sepon-82 (=M90382) and SRN-39 (=ICSV1007BF), were developed in collaboration with INTSORMIL and ICRISAT. The hybrid is designated NAD1 and has ATX623 as female parent and MR-732 as male restorer. Mean grain yields of the three improved cultivars from yield trials at different sites in Niger from 1986 to 1991 were submitted to yield stability analyses by regression against the yield of the local variety. For Sepon-82 there were 67 data points available with yields ranging from 370 to 3780 kg/ha. The hybrid NAD1 had 27 data points with yields ranging from 580 to 5340 kg/ha. SRN-39 had 14 data points in *Striga*-infested fields [*Striga hermonthica* (Del.) Benth.] and 22 in non-infested fields with yields from 310 to 3130 kg/ha. Simple linear regression was computed for each cultivar. The intercept and the slope for Sepon-82 regression line did not differ significantly from the equal yield situation, but was completely above the equal yield line, indicating that it is at least as stable for grain yields as the local variety. The intercept of NAD1 was significantly higher (p) than the equal yield situation but the slope was not significantly different, meaning that the hybrid outyielded the local variety by 482 kg/ha even in the low yield environments. The low correlation of grain yields of SRN-39 and the local variety in non-*Striga*-infested fields gave an intercept and slope not significantly different from the equal yield situation. In *Striga*-infested fields the intercept was significantly higher, with a mean grain yield advantage of 974 kg/ha by SRN-39 over the local variety. Therefore SRN-39 yielded more in *Striga*-infested fields and was at least equal in the absence of *Striga*. SRN-39 appears to be less adapted to the higher rainfall zone of Niger (800 MM+), where it yielded consistently less than the long-cycle local variety. The cultivars NAD1, SRN-39 and Sepon-82 have proven to be well adapted to Niger's severe climatic conditions and produced better grain yields than local varieties, even under unfavorable conditions.

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 Dr. Badir Salim, 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 disbursed in Sudan to each ARC scientist to carry out his 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 basically nonexistent, the USAID Mission has provided excellent logistical support to relay communication to the ARC at the Wad Medani and El Obeid research stations.

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 Progress

Sorghum Breeding
Osman El Obeid Ibrahim

During the 1993 crop-season, the sorghum breeding program at Gezira Research Station (GRS) ARC, continued to concentrate on hybrids and varietal development and evaluation. Major emphases were placed on hybrids and varieties with multilocation testing. The varietal breeding nurseries included new crosses, establishment of F_1 plants, advancement of segregating generations and evaluation of converted lines, drought tolerant parental lines and backcross progenies as part of ARC/ INTSORMIL collaborative breeding research. Varietal trials at GRS included evaluation of advanced (36 entries) and preliminary (176 entries) trials for yield potential and/or drought tolerance.

The hybrid breeding nurseries included evaluation of new parental lines and synthesis and evaluation of new experimental hybrids. The hybrid trials included advanced (72 entries) and preliminary (144 entries) tests. The ARC/ INTSORMIL collaborative joint trial for the 1993 crop-season, contained 126 sorghum hybrids and their parental lines, and was conducted under irrigation and rainfed situations at GRS.

As a result of several years of on-station varietal and hybrids development and evaluation, several promising experimental varieties and hybrids were identified and advanced to on-farm and standard levels of multilocation trials during the 1993 crop-season. The on-farm test contained one hybrid and two open pollinated varieties. The standard test included 11 varieties and 15 hybrids. Multilocation testing was extended to cover eight irrigated and four rainfed locations. Two open pollinated varieties and one hybrid, showed good and stable yields, namely 89/OSFS 2431 under irrigation and high rainfall zones, P-967083 under Jebel Marra conditions, and 89/OSH 5283 under irrigation. These cultivars will be considered for submission to the National Variety Release Committee, hopefully, during 1994-95.

As a result of intensive breeding work in the last ten years, several promising elite varieties and hybrids have been accumulated in the program. However, testing of these materials has been restricted to limited numbers of locations and agroecological zones in the country. There is a pressing need for intensifying the testing program to cover more locations and agro-ecological zones, especially in traditionally sorghum-growing rainfed areas, where the bulk of the crop is produced. Another factor slowing or discouraging the release of new products, especially hybrids, is the lack of a viable seed industry. Farmers, especially in irrigated production areas, have come to highly appreciate the concept and value of pure and or improved seeds, which should encourage the development of seed industry in the country.

Striga Research

A.G.T. Babiker, S.M. Eltyeab
and M.T. El Mana

On-farm and on-station trials were undertaken on irrigated and rain grown sorghums. The objective of the on-station trials was to develop control measures which are effective during the early subterranean stages of the parasite growth. The objective of the on-farm trials was to demonstrate to farmers and extension workers the technical feasibility of some of our previous findings.

Sorghum trials were planted in an artificially *Striga*-infected plot. Improved lines obtained from Purdue University, as well as local popular high yielding varieties were used. Urea (190 kg/ha) was applied at planting. Chlorsulfuron (2.4g/ha) was applied 4 weeks after planting as a soil directed spray. *Striga* count was made 75 days after planting. Lines tested were PR 227, PR 239, PR 269 and PR 293. Dabar (*Striga* susceptible) and SRN 39 (*Striga* resistant) were included as controls. *Striga* population density varied between 7 and 39 plants/m^2. PR 269, PR 239 and SRN 39 sustained the lowest emergence (7-14 plants/m^2) while Dabar had the highest emergence (39 plants/m^2). Urea reduced infestation by 52 to 86%. Infestation on PR 269, PR 239 and SRN 39 was the most reduced, while that on Dabar was the least affected. Chlorsulfuron reduced *Striga* infestation by 68 to 94%. The herbicide suppressed *Striga* infestation about equally on all varieties, except on PR 293. *Striga* reduced crop stand. Dabar was the most affected, while SRN 39 was the least. Urea mitigated the adverse effects of *Striga* on sorghum in all varieties, except on Dabar and on PR 293. Chlorsulfuron, on the other hand, resulted in a substantial increase in crop stand, irrespective of the variety used. The parasite delayed heading in all varieties. Urea and chlorsulfuron, invariably, increased the number of heads. Among all varieties, Dabar and PR 293 were the least responsive to the herbicide and fertilizer. SRN 39, PR 227 and PR 269 showed about equal response to both herbicide and fertilizer. *Striga* reduced straw yield of all varieties. Untreated SRN 39 and PR 269 had the highest straw yield, while Dabar and PR 293 displayed the lowest yield. Urea and chlorsulfuron mitigated the adverse effects of *Striga* on straw yield. Dabar and PR 293 displayed a low response to urea, while PR 269 was highly responsive. Across varieties, chlorsulfuron was more effective than urea.

The local varieties Gadam EL Hamam, AjabSedo, Iriana, Korakolo; Safra, SRN 39 and Tetron were tested in a separate experiment. Compared to the *Striga* resistant variety (SRN 39), the local varieties supported two to three fold greater *Striga* emergence. *Striga* emergence was reduced by both urea and chlorsulfron. The suppressive effects of urea on *Striga* emergence was negligible on Ajabsedo, moderate on Iriana, Korakolo and Gadam EL Hamam and was good to excellent on Safra, Tetron and SRN 39. Chlorsulfuron was more effective against the parasite than urea. *Striga* emergence was moderate on AjabSedo and Iriana, low on Gadam EL Hamam, Korakolo and Safra and was negligible on Tetron and SRN 39. The stand of all varieties, except SRN 39, was reduced by the parasite. The highest reduction was displayed by AjabSedo, while moderate losses were exhibited by Iriana, Korakolo, and Safra. Urea, substantially, improved the stands of Korakolo, Iriana and AjabSedo. However, its effect on Safra was negligible. The herbicide improved stands of most varieties with more pronounced effects on Gadam EL Hamam, AjabSedo and Safra. Sorghum heading was considerably curtailed by the parasite as only 25 - 69% of plants produced heads. SRN 39 was the least affected. Urea and Chlorsulfuron improved heading in all varieties. Safra and Korakolo displayed the lowest and highest response to urea, respectively. Chlorsulfuron was more effective than urea. Among varieties, Gadam EL Hamam, AjabSedo, Iriana, Korakolo and Safra displayed the highest response. The parasite reduced straw yield of all varieties. Urea increased straw yield by 70 to 140%. Gadam EL Hamam, SRN 39 and Tetron were the most responsive. Chlorsulfuron increased straw yield by 80 to 560%. Chlorsulfuron-treated Tetron and SRN 39 gave the highest yield.

In yet another test, the hybrid Hageen Dura-1 (HD-1), Gadam EL Hamam, Dabar, AbuSabeen, Tozi Umbenein, SRN 39 and Mogud were evaluated. Emergence of *Striga* varied between 10 and 21 plants/m^2. The highest emergence was supported by AbuSabeen, Tozi Umbenein and Gadam EL Hamam. SRN 39, on the other hand, supported the lowest emergence. Urea reduced *Striga* infestation on all varieties except HD-1. *Striga* suppression varied from moderate (52%) on AbuSabeen to excellent (95%) on SRN 39. Chlorsulfuron effectively reduced *Striga* emergence on all varieties. Complete suppression of the parasite was achieved on SRN 39. *Striga* reduced crop stand. The observed losses were negligible on SRN 39 and Tozi Umbenein, but were severe on HD-1 and Abu Sabeen. Urea and Chlorsulfuron improved stand on all varieties except HD-1. *Striga* reduced heading in all varieties. Losses due to the parasite were heavy (78-79%) for HD-1 and Abu Sabeen and were negligible for Tozi Umbenein and SRN 39. Urea and chlorsulfuron increased heading in all varieties. Heading in HD-1 and Abu Sabeen was increased by two to four fold. The parasite reduced straw yield of all varieties except SRN 39 and Tozi Umbenein. HD-1, Abu Sabeen and Dabar displayed the highest losses. Urea and chlorsulfuron mitigated the adverse effects of *Striga* on straw yield, particularly that of the susceptible varieties. Straw yield of Abu Sabeen was increased by two to four fold.

An on-farm trial, in collaboration with the extension service, was undertaken at El Rawashda, a village north of Gadaref town. Sorghum (CV. Korakolo) was planted in early August, with rows 80 cm apart and spacing within the row 10 cm apart. The crop was later thinned to single plants per hill. Sorghum treated or untreated with urea at planting, was sprayed with a tank mix of chlorsulfuron (2.4g/ha) and dicamba (300 g/ha) or left untreated. The herbicides were applied as soil directed sprays, four weeks after planting. Sorghum planted late August was included as a control to reflect the farmers practice of late planting in *Striga* infested areas.

Sorghum sown early August was heavily infested by *Striga* (73 plants/m^2). Late August sown crop sustained a lesser infestation (25 plants/m^2). The tank mix of chlorsulfuron and dicamba, when not preceded by urea, effected 83% control. Urea treatments made prior to herbicide application increased herbicidal efficacy (95% control).

Untreated early sown sorghum gave low yield (0.39t/ha). Late planting of sorghum effected a higher yield (0.6t/ha). The tank mix of chlorsulfuron and dicamba, irrespective of the preceding urea treatment, increased sorghum yield to about 0.8 t/ha.

Sorghum-Millet Pathology
El Hilu Omer

Screening of Sudan germplasm for resistance to long smut was continued this season. Five hundred entries were planted as single lines and at boot stage were inoculated in the standard method reported before. Twenty cultivars were fairly resistant. These will be subjected to further confirmation tests during the 1994 season. None of the 21 cultivars introduced from Egypt and Syria proved tolerant to long smut.

Disease survey in six districts of Kordofan State indicated that downy mildew (*Sclerospora graminicola*) on pearl millet is the most serious disease. Infection ranged from 16-80%. It was more prevalent in high rainfall areas, getting less in drier areas. Ergot (*Claviceps fusilformis*) and smut (*Tolyposporium penicillariae*) are second to downy mildew in importance. Grow-out of farmers varieties, in Gezira Research Station, indicated that the seed plays a primary role in disease spread.

Sorghum Entomology

Four seed treatments were compared for assessing damage incurred to sorghum by insect pests before emergence and throughout the seedling stage. The most serious pests considered were mole crickets, termites, cutworms, soil weevils and to a lesser extent, white grubs. The seed dressings tested were Promet at 0.3, 0.4 and 0.5 ml/10 kg; Gaucho at 150, 100 and 80 g/100 kg and Lindane (standard) at 150 g/100 kg. An untreated control was added for comparison. The trial was carried out at Sim-Sim and Rahad Research Station. Row spacing was 60 cm. and 10 cm. between plant holes and 3 seeds/hole were used in replicated trial.

Higher rates of Promet, Lindane and all rates of Gaucho gave good crop establishment and were significantly better than the untreated control but were not dissimilar to the standard. However, insect infestation was remarkably higher in rainfed areas compared to irrigated Rahad. In Rahad, delayed sowing gave higher infestation compared to optimum sowing date. Early sowing under irrigation, irrespect of the treatment, gave higher grain yield; 4517 kg/ha for July sowing as compared to 3048 kg/ha for August sowing.

Among chemicals tested for control of American bollworm, Damazine Thiodan 35 ULV at 2.38 l/ha was the best chemical for control of the pest and gave a significant higher yield than the unsprayed control. None of the 14 tested varieties and promising cultivars showed tolerance to stem borers but, HD-1 gave the lowest infestation.

Botswana/Southern Africa

Collaborative Program

The INTSORMIL collaborative research program in southern Africa is in transition from using an expatriate scientist to coordinate activities in Botswana to direct INTSORMIL U.S. Principal Investigators collaboration with host country scientists in several southern Africa countries. This transition has been slow because of budgetary constraints and logistical/communication difficulties.

Organization

After termination of the ATIP project which included financial support for the expatriate scientist, the new mode of operation for Botswana and southern Africa was for U.S. and host country scientists to form joint partnerships and prepare research proposals to access INTSORMIL funds allocated for this region. Unfortunately, these funds were eliminated because of INTSORMIL funding constraints, thus, collaborative research during 1993-94 was direct scientist to scientist collaboration with funding coming from U.S. INTSORMIL Principal Investigators budgets. These results are presented in the individual project reports.

Sorghum/Millet Constraints Researched

Sorghum and pearl millet are important crops in the SADC countries, with both grain and stover being widely used. The grain is used mainly for human food, but some grain and the stover are used as livestock feed. During the 1980s, farmers yields have averaged less than 500 kg ha^{-1}. These low yields partially reflect crop failures when no grain was harvested. It also reflects the low natural level of soil fertility, and the limited use of fertilizers and/or crop rotation. To reach the critical yield level of 1.5 to 2.0 Mg ha^{-1}, a crop uptake of 45 to 60 kg ha^{-1} N, and 16 to 20 kg ha^{-1} P is required regardless of the cultivar or production practices used.

The low, irregular, and low-efficiency rainfall patterns of the region combined with sandveld and hardveld soils with low water retention and poor weed control also contribute to the low yields of sorghum and millet. In some instances, broadly soil texture fractions, (i.e., coarse sand, fine sand, silt, clay) and unstable surface soil properties result in a high bulk density (compaction) when dry, and surface sealing with crust formation. This slows the infiltration rate of rain and limits crop root penetration.

Water conservation and redistribution technologies, soil fertility improvement, residue incorporation, and weed control are urgently needed to improve soil structure and water conservation for crop establishment, and production of higher grain and stover yields.

Research Progress

There are two large, distinctly different clientele for sorghum production in Botswana. One is the small family farmer who uses sorghum primarily for food and brewing, and the other is the large farmer who has the resources to utilize hybrid sorghum seed, fertilizer, and large equipment for sorghum production. The latter is generally located in the Pandamatenga region.

Several sorghum hybrids, and sorghum and pearl millet varieties are scheduled to be released soon. They all will be cultivars with good food quality characteristics, and are presently being rated for insect and disease resistance/tolerance by INTSORMIL and host country plant pathologists.

The 1993-94 cropping season was characterized by farmers having problems with poor stand establishment and severe drought. Farmers who had prepared their land early and planted at the proper time had average crops. Many farmers plowed and planted too late resulting in very poor stands. Research with seed dressings (fungicides plus insecticides) resulted in improved sorghum stands. Early plowing (first rain) combined with continued weed control until a December planting rain, resulted in increased sorghum yields.

Disease evaluations done at Pandamatenga, Botswana in early April 1994 indicated the presence of a virus disease similar to that observed in 1993. Red- and tan-leaf necrosis were the most common symptoms with only a minimal amount of viral mosaic observed. Reaction of sorghum entries from the International Sorghum Virus Nursery planted at this site were typical of MDMV-A or MDMV-B. Further evaluations are being conducted by DAR pathologists on virus specimens collected and transferred to the Sebele Station in Gaborone. MDMV-B is suspected because of its previous identification at the Mt. Makulu station in Zambia. In late March 1994, the incidence of MDMV-B and associated red- and tan-leaf necrosis (depending on host pigmentation) were quite heavy at Mt. Makulu in some released sorghum inbreds. In early April 1994, the drought response of sorghum in the Drought Line Test (DLT) and Preliminary Drought Line Test (PDLT) at two locations in Southern Zimbabwe (moderate to heavy drought stress at Matopos and early, heavy drought stress at Lucydale) indicated the necessity for pre-flowering drought tolerance in sorghum cultivars for this region. Sorghums primarily possessing post-flowering drought tolerance developed moderate to complete head blasting as stress increased in severity, especially if stress also occurred earlier in the season. Despite environmental stress and susceptible cultivars charcoal stalk rot was observed in only a few definitive instances.

Zimbabwe

The sorghum program has developed three early maturing seed parents from UNL-115 which initially was grown in Sebele. Selections from Botswana Serere 6A had also performed well in Namibia.

Male sterility in finger millet has been developed and is easily recognized. Seed set on unbagged male sterile heads shows 5-10% crossing which will occur with fertile plants in adjacent rows. This is sufficient for random mating and convenient for 'marking' sterile plants. Higher levels of seed can be obtained by deliberate pollination.

Screening of sorghum breeding materials found that lines having SC326-6 and SC120 in their background generally had better resistance to leaf blight than local and other improved cultivars.

Namibia

The national research focus is on breeding and agronomy of pearl millet. The national breeding program is comprehensive in its objectives, and David Andrews provides technical support to host country scientists. Agronomy and fertility experiments are in progress using cattle manure (kraaling overnight) and/or different levels of N and P fertilizers.

Zambia

Various plant disease problems were observed at Mansa, Mt. Makulu, and Golden Valley. At Mansa, anthracnose studies are being emphasized. At Mt. Makulu, viral necrosis ranged from 30-60% among the cultivars present. Severity of incidence ranged from minimal to 50% necrosis of leaves. At Golden Valley, sooty stripe destroyed 60% of the leaf tissue on susceptible cultivars. Research is being conducted on the use of seed treatment for control of sorghum downy mildew (SDM).

Senegal

Negotiations were continued with Oregon State University, the lead contractor in the new Senegal Natural Resources Based Agricultural Research Project (SNRBARP), on how INTSORMIL will be involved.

Kenya

Development of sorghum cultivars with tolerance to soil acidity is an environmentally friendly, relatively inexpensive, and permanent means of increasing sorghum yields on such soils. Cultural practices of resource-poor farmers without improved tolerant cultivars are labor intensive and because local types are used, low yielding. Acid soil tolerant varieties and hybrids, developed by INTSORMIL in Colombia, South America, perform well on acid soils in Kenya. Recent trials show that these tolerant sorghums are adapted to Western Kenya where soils are infertile and becoming increasingly acidified due to farming practices.

Five sources of *Striga* resistance, 11 lines with resistance to aphids, and 11 lines with drought resistance from Kenya were increased in Texas and crosses to elite photoperiod insensitive lines were made.

Honduras

Activities in the SRN/EAP/INTSORMIL program continued on schedule. Breeding plots have been planted in several locations.

Documentation was submitted to the Honduran National Seed Commission to release the downy mildew resistant sorghum-sudan forage hybrid (AT623*Tx2784). This hybrid has undergone extensive testing in Honduras since 1986 and is a significant step towards intensifying land use—a USAID mission objective. It has increased forage production by as much as 30% in some commercial operations. Some 70 on-farm demonstration plots had been distributed in 1993. It is important to note that INTSORMIL developed enhanced maicillo hybrids were the only sorghum cultivars that produced grain in the low rainfall area around Tapaire, Choluteca. Improvement of local landrace populations, such as development of maicillo hybrids, has been a long term objective of the INTSORMIL program in Honduras and this effort is now beginning to pay off.

Also, it was evident that small farmers had begun commercializing seed of enhanced maicillo varieties. For example, DMV179 was distributed to Miguel Gomez in 1990 at Las Espaveles. The following year, Miguel sold a portion of his harvest to Lorenzo Sell who took it to a World Neighbors community near San Ramón. A visit to the San Ramón area during a TAMU team visit revealed that a farmer had converted his field to DMV179—with about 10% mixture/outcrossing with local maicillo. In another part of Choluteca, a farmer had planted 5 ha of the enhanced maicillo variety DMV197. He was expecting yields of 50-57 t/ha from DMV197 whereas local landrace varieties were expected to yield 1.7-2.1 t/ha.

INTSORMIL collaborators at the EAP established a broomcorn variety test in Nicaragua near the Honduran border. Of the five varieties tested, Acme broomcorn performed the best. That particular farmer produces about 70 ha of broomcorn (on land rented from the Contras) and is eager to begin producing seed of Acme. He harvests about 180 kg/ha fiber on dryland and 450 kg/ha on irrigated production sites. Producing broomcorn and making brooms has become a cottage industry in Nicaragua. Fields of broomcorn and selling round brooms on the roadside is a frequent sight as one travels from the border to Managua in Nicaragua.

Plans for the 1994 cropping season are in progress. This will be the first cropping season without an INTSORMIL long-term expatriate stationed in Honduras. Plans are for the research program to continue in the same manner as before with the same locations and nurseries. Increased involvement in regional activities is anticipated during 1994. The program is orienting toward a more collaborative mode involving host country and U.S. scientists.

Henry Pitre, MSU-105 PI, continued his collaborative research on entomology in Honduras.

Metaponpneumata rogenhoferi (Moschler) (Lepidoptera: Noctuidae) is one of four insect species in a complex of lepidopterous defoliators, locally referred to as "langosta", limiting production of intercropped sorghum and maize in Honduras. The limited time of occurrence of this very destructive species in this region was investigated in relation to diapause behavior. The influence of age of pupae and soil moisture on diapause was measured in the laboratory (90°). Pupae collected in the field were exposed to different levels of soil moisture at intervals after pupation. Adults emerged (ca. 20%) from pupae exposed at intervals from August through October; emergence decreased to 5-7% for pupae exposed for the first time after October. Soil moisture level, however, did not appear to be closely associated with termination of diapause, but time in diapause appeared to have some effect. Information on diapause behavior of this species and other species in the "langosta" pest complex will further our ability to use insect behavior in developing insect pest management practices for specific crop production regions.

Colombia

Collaborative Program

This is a terminal report for the INTSORMIL Colombian Prime Site. This Prime Site was terminated and INTSORMIL activities merged with the Honduran Prime Site on June 30, 1994 by INTSORMIL, primarily because of USAID travel restrictions to Colombia. This report will summarize the Colombian Prime Site's activities and productivity since its inception.

Program Implementation

This collaborative research project operated in Colombia under four formal and several informal agreements which facilitated 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, 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.

Through a 1988 INTSORMIL buy-in, research was initiated in the acid savannas of Arauca by means of 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 nonprofit organizations such as 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 FEDEARROZ.

The INTSORMIL collaborative research project, MSU-111, was managed by the Office of International Programs, Mississippi State University.

Interdisciplinary Research

This Prime Site was originally established to conduct breeding research on problems relating to acid soil production constraints of sorghum and pearl millet. The research was initiated in 1982 by Dr. Lynn M. Gourley, MSU-104 PI. Plant breeders at all INTSORMIL institutions have had germplasm evaluated at this site through germplasm exchange. Specific long-range research goals in Colombia had included breeding for acid soil tolerance (MSU-104), pearl millet (UNL-118 and KSU-101), drought tolerance (TAM-122), pathology (TAM-124), and grain quality (TAM-126 and PRF-103B) investigations. Some entomology input was provided by MSU-105.

The MSU-111 project (also terminated on June 30, 1994) operated from CIAT, near Palmira in the Cauca Valley, where multinational seed companies have most of their experiment stations. Through CIAT infrastructure, the project had established linkages with most public and private research programs, and NARS of other Latin American countries.

The major center for seed increase and distribution was at CIAT, Palmira. In contrast, breeding activities took place at different sites in the Colombian Eastern Plains (Llanos Orientales), where soils with different levels of Al saturation are found in both well-drained and poorly drained savannas. The project used 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 collaborated in agronomic and breeding research, according to established objectives.

Because of the diversity of collaborating institutions, the project conducted more than just acid soil tolerance breeding research. For example, FENALCE developed lines for semiarid areas (TAM-122) and lines resistant to grain molds. ICA developed drought-tolerant lines, adapted to acid soils and resistant to grain molds (TAM-124). The universities conducted research in agronomy and physiology (UNL-114), and entomology (TAM-125 and MSU-105). The El Alcaraván Foundation developed germplasm adapted to acid savannas and slightly acid soils (vegas). The Foundation was also interested in grain quality and utilization (TAM-126 and PRF-103B). Most of these research activities were conducted by scientists from ICA or the private sector, supported by undergraduate students working on their B.Sc. theses.

Collaboration with Other Organizations

International Centers

The selection of the International Center, CIAT, as the operational headquarters for the Colombian Prime Site research was ideal. The student training program and CIAT's outreach programs throughout Latin America kept INTSORMIL's sorghum and millet research very visible. Collaboration with ICRISAT Center and ICRISAT's outreach programs in Mexico (CIMMYT) and SADC in Zimbabwe contributed to the success of this project. At the time the INTSORMIL program in Colombia was terminated, CIAT, ICRISAT and INTSORMIL were attempting to get funding from the Latin American Bank for a joint acid soil research project.

Since 1982, CIAT and ICRISAT have supported International Workshops in Colombia concerning sorghum and millet research. In 1984, CIAT provided facilities and other support for the Workshop "Evaluating Sorghum for Tolerance to Al-Toxic Tropical Soils in Latin America" and in

1991 for the Workshop "Sorghum for the Future." CIAT has supported the project in several other ways: administratively, CIAT staff time, 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 breeders' 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 many 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 soil regions.

Most Latin American countries are privatizing and opening their economies to outside trade. 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.Sc.) 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 supported research in Arauca under INTSORMIL's leadership.

Planning Collaborative Research

From the beginning, a close working relationship was established with CIAT, facilitating research 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 met annually to establish work plans.

Since 1988, relations among the institutions involved in Colombian sorghum research became complex, requiring careful coordination of research activities. Specific short- and long-term goals were developed jointly with INTSORMIL Projects MSU-111 and MSU-104, ICA, El Alcaraván, FENALCE, and the Colombian universities. Formal planning meetings were held annually to discuss specific experiments, organizational funding, and individual responsibilities. Results were published annually, and distributed among those involved.

Sorghum/Millet Constraints Researched

The main overall constraint to sorghum production in Latin America is the high cost of production. Most sorghum has been grown on high value land, making production of this crop a nonprofitable enterprise. One method of reducing production costs was incorporating marginal lands into the production system. This low-value land has production constraints including the poor distribution of water, soil acidity, and high Al saturation, presence of pests and diseases, periods of excessive rainfall with high relative humidity, and other related agronomic problems. Thus, sorghum production in these areas required the development of varieties or hybrids adapted to the specific ecological problems prevalent in each region.

In spite of the constraints encountered in these marginal areas, the amount of land available is such that the acid, well-watered savannas of Latin America constitute the main potential region for sorghum production. Acid, infertile soil savannas account for more than 10% of the land area in Latin America and the Caribbean. Some 76 million hectares of well-watered savannas are currently available for more intensive cultivation in the future in Colombia alone. Farmers throughout the region require low-input technology and research information to avoid resource degradation problems; thus, work to develop sustainable agricultural systems becomes a mandate.

Research Progress

Research progress was excellent until the Colombian Prime Site was discontinued. Due to travel restrictions, this country program was the smallest within INTSORMIL in terms of number of PIs involved. Since MSU-111 and MSU-104 were both breeding projects, INTSORMIL's involvement was primarily breeding while ICA's role was more in other disciplines and included some extension activities.

ICA and the El Alcaravan Foundation, with INTSORMIL's support, released two acid soil tolerant sorghum cultivars in 1993 which are adapted to growing conditions in Arauca in the Colombian Eastern Plains. The cultivars have been named Icaravan 1 (IS 3071) and Icaravan 2 (IS 8577). Icaravan 1 is exceptionally hardy and has produced more than 3 t ha^{-1} grain under low fertilization levels and when the Al-saturation level is 60% or less. It also tolerates partial flooding after flowering - an essential characteristic in poorly drained savannas. Icaravan 2 is very tolerant to Al toxicity and has good agronomic characteristics when grown under Arauca's soil and climatic conditions.

FEDEARROZ and ICA announced the release of a hybrid for the dry Caribbean region of Colombia, which uses an A-line from the INTSORMIL MSU-104 project and an R-line from Texas A&M University. Hybrids using one or both parental lines developed in Colombia are currently being evaluated in many countries with acid and/or infertile soils. Since 1990, experimental sorghum hybrids using lines developed in Colombia have been evaluated in east Africa. The bird resistant germplasm being developed by the INTSORMIL Colombian program is similar to that used throughout many areas in Colombia and in western Kenya and throughout Uganda is used for food. Several of these hybrid combinations are in the final stages of evaluation before being released to farmers.

Egypt

The Egypt/INTSORMIL program consists of research efforts within two groups in the Agricultural Research Center (ARC). The plant pathology research group in the MSSCFC Section of the Plant Pathology Institute and the sorghum research section of the Field Crops Research Institute of ARC.

Plant Pathology

Dr. Thanaa Fahmy Ibrahim, Dr. Tawfic Abdel-Moity and Mr. Abu-Serie Ismael participated in short-term training in the Plant Pathology Department of Kansas State University during the spring semester of 1994. Dr. Ibrahim focused on classical microbiology of bacterial pathogens of sorghum. Dr. Abdel-Moity studied parameters that are involved in the use of nontoxin-producing *Fusarium* species as biological controls in sorghum. Mr. Abu-Serie Ismael conducted experiments with SDS polyacrylamide gel and agarose gel electrophoresis of proteins and DNA to determine differences between Egyptian and U.S. isolates of *Pseudomonas andropogonis*. These data were to be incorporated into Mr. Ismael's Ph.D. thesis.

Work focused on the characterization of *Fusarium* populations from Egypt and comparing these populations with those from other locations. Egyptian *Fusarium* populations from sorghum appear to be dominated by members of the D mating population (*Fusarium proliferatum)* instead of the F mating population *(Fusarium proliferatum)* as is common in the United States and Tanzania. The reasons for this difference in population composition are unknown. Members of the D mating population are known to make gibberellic acid and may be responsible for the pokkah boeng disease symptoms that we have commonly observed on Egyptian sorghum. Some members of the D mating population are known to synthesize moniliformin and fumonisin mycotoxins, and, thus, may pose a hazard to humans and animals that consume sorghum grain and/or sorghum forage.

Sorghum Agronomy

Production experiments have dealt with the effects of different water and nitrogen levels and the water x nitrogen level interactions in order to optimize water use efficiency (WUE) and nutrient use efficiency (NUE). Water and N level effects at modest input levels are almost additive. Experimentation approach and set ups are now geared up and need several years operation in a range of the "New Lands" marginal areas to come up with the best guidelines to stretch Nile water supplies and minimize N imports. Drs. Bashir and Kamal have a good start on this. Nubaria needs to be developed along with irrigation equipment for other sites.

Sorghum breeding faces challenges to tailor germplasm to the expanding marginal land areas and boost production. A good percentage of the germplasm used there is like Giza 15 and some locals which fit their conditions quite well in the traditional sorghum areas. The germplasm base related to these is probably fairly narrow and breeders are involved in widening the base. One hopefully useful approach was started last year by applying pollen from Giza 15 and many locals to sterile heads in a Nebraska midseason stress resistant tan plant population to develop a new Egypt adapted randomly mating population. Such a population should provide an easy means to incorporate new germplasm sources into a breeder working pool to be used in conjunction with conventional breeding approaches.

United States

The EEP INTSORMIL project reviews of the Texas program took place at Corpus Christi, July 12-13, College Station, July 14-15, and Lubbock, September 20-21, 1993. The EEP also reviewed the Nebraska, Kansas, and Purdue Programs in September. Excessive moisture and unusual low temperatures delayed crop development at these sites.

Research is being continued on evaluating increasing the seed size component of yield in sorghum as it may relate to (1) post anthesis stress resistance, (2) higher yields under relatively optimal conditions, (3) higher water use efficiency under stress and favorable conditions, (4) housewife preference in developing countries and (5) value added for livestock feeders through cheaper processing and greater starch release. Increasing seed size without decreasing yield (decreasing seed number) depends partly on increasing grain fill length which relates to metabolic pace Metabolic pace is being estimated by measuring grain respiration rate in the field with a portable analyzer in a nondestructive manner. Seed saved is then used for genetic manipulation which is being supported through INTSORMIL and a Nebraska Grain Sorghum Board leveraging grant.

In Texas, excellent disease, insect, drought, and adaptation sorghum nurseries were obtained this year. High rainfall contributed to high disease pressure in South Texas. A very long and continuous drought in West Texas resulted in excellent drought nurseries (both pre-and post flowering stress nurseries) in the Lubbock area.

Plots planted at Lubbock for the purpose of identifying nitrogen efficient breeding lines are in the process of being harvested. A chlorophyll meter is being investigated for use as a possible screening tool to determine nitrogen status of sorghum at various growth stages. It is also being investigated as a potential indicator of nitrogen use efficiency.

In Texas, two students supported by INTSORMIL and their major professors are measuring the control capability of natural enemies of aphids infesting grain sorghum. During the summer of 1993, they researched removal of these natural enemies from large plots of grain sorghum with the short term goal of distinguishing the mortality caused by the respective species of natural enemies. The primary objective of this work is to provide methodology and information on how to use these natural enemies more effectively in integrated pest management programs.

Darrell Rosenow and Gary Peterson traveled to China in August on a UNDP program. They evaluated sorghum research nurseries at the Sorghum Research Institute, Liaoning Academy of Agricultural Sciences in Shenyang. This travel provided information on some potentially important new germplasm from China which should be useful to INTSORMIL researchers.

Germplasm Improvement

In Nebraska, the threat of early frost hastened seed harvest. Harvest of grain yield trials proceeded well after a season of exceptionally high rainfall. Winter nursery seed was put up and dispatched. Germplasm population NPM-3 was released. This is the first public source of material available in a dwarf early maturing background that will restore male-fertility on the A_4 (monodii) cytoplasmic male-sterile system. This restorer source will now permit this new system, which has several significant advantages, to be used in making grain hybrids. The seed set on new A_4 hybrids test in 1993 was generally superior to seed set on A_1 hybrids.

David J. Andrews, PI for projects UNL-115 and 118, was awarded the International Service in Crop Science Award at the November ASA annual meeting in Cincinnati. The International Service in Crop Science Award recognizes outstanding achievement in the international area of crop science. The focus of the award is on creativity and innovation in bringing about specific changes in practices, products, and/or programs in the crops area at the international level.

In Texas, progress continued in sorghum breeding for high stable yield and resistance to stresses. One major dominant gene and one major recessive gene, controlled the ability of sorghum to stay green under drought. 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. Eight genes have been described which affect food quality of the grain. Field selections were made in south Texas for adaptation to tropical environments, disease resistance, and grain quality. F_2 populations were increased which will be used to provide materials to collaborators in Mexico, Honduras, Mali, Sudan, Kenya, and Southern Africa.

At Purdue, transgenic sorghum plants have been obtained after microprojectile bombardment of immature embryos (PRF-103A). The protocol for obtaining transgenic plants consists of the delivery of the bar gene to immature embryos and the imposition of biolaphos selection pressure at various stages during culture from induction of embryogenesis to rooting of regenerated plantlets. The presence of the *bar* and *uid*A genes was confirmed by PCR and Southern blot analysis of plant genomic DNA. Phosphinothricin acetyltransferase activity was detected in extracts of the regenerated plants and these plants were resistant to local application of the herbicide Ignite/Basta. T1 seedlings are now being evaluated. A similar protocol has been used to obtain putative transformed calli from immature inflorescences, and regenerate plants that are being tested for the presence and expression of the *bar* gene.

Sustainable Production Systems

Extensive developmental physiology research in the 70's and 80's was used to fashion a preanthesis stress screening field method. Preanthesis stress is a problem in many tropical countries as well as being the major stress period most years in temperate climates. The physiological research clearly illustrated (scanning electron micrographs) that microsporogenesis and megasporogenesis are major stress sensitive stages. Tapetal damage caused nutritional problems which lead to microspore damage during microsporogenesis. Similar translocation (nutritional) problems caused ovule abortion.

Pinpointing the developmental time of damage allowed timing stress in the field to select stable, high seed number stress-resistant (preanthesis) genotypes. Our stress screening model was tested and validated by selecting good yielding S_1 plants from a randomly mated tan plant sorghum population which were advanced to the S_3 generation, selected for stress resistance in the field using our methodology and recombined to form a new stress resistant population. The population has been or is being used in Niger, Senegal, Sudan, Mexico and Egypt. Population selections in hybrid combination are competitive with commercial hybrids and usually exceed them in stress tests.

Current research (UNL-116, Jerry Eastin) is centered on increasing seed size potential as a post anthesis stress yield compensating mechanism. Increased seed size also relates to increasing yield potential under good conditions. In addition, the developing country housewife normally prefers larger seed sizes in the marketplace. Also, livestock feeders in the U.S. prefer larger seed sorghums to decrease roller milling energy costs and improve kernel fracture to release more readily digestible starch as in perceived in the treatment and use of maize as a livestock feed. These investigations are being heavily coordinated with germplasm improvement programs by Egyptian plant breeders. A big advantage in Egypt is total water control to get good plant anthesis stress control not readily achieved in the U.S.

Experiments comparing improved Malian sorghums against U.S. types at the University of Nebraska (Ph.D. dissertation study) at low and high soil N levels showed that both Malisor 7 and S-34 ranked among the highest for NUE among 15 genotypes. A genotype by nitrogen level interaction occurred at the boot and flowering growth stages but not at maturity. Seed quality and poor stands were also a problem with the Malian types.

Irrigated experiments conducted on sorghums specifically selected for high NUE at Kansas State University and the University of Nebraska for agronomic response to N application (M.S. thesis) showed that the hybrids responded much better to N application than the high NUE parent lines as would be expected. The best hybrid at 0 kg N ha^{-1} application was Tx623/SC566, (3449 kg ha^{-1}) and the best at 100 kg N ha^{-1} was TX623/IR204 (5537 kg ha^{-1}). High NUE lines varied in their response to N, but were all responsive (UNL-114, Jerry Maranville).

Sustainable Plant Protection Systems

During the period of January 1-March 31, 1994, Richard Frederiksen (TAM-124) was able to select several DNA probes from a genomic library of *Collectotrichum graminicola* that will be used in evaluation of the population dynamics of this pathogen. Progress has been made on the laboratory identification of compatible isolates of *Sporisorium reilianum*, the fungus causing head smut of sorghum. This technique may permit the rapid identification of virulent isolates and be useful in defining some of the factors contributing to pathogenicity in the fungus. They put together a collection of 198 commercial sorghum hybrids for obtaining data sets on reactions of these hybrids to the most important diseases of sorghum. These data will be integrated into an interactive computer model for use in developing integrated sorghum production systems. Integrated production systems are the most environmentally safe and sustainable systems for both developed and developing agriculture. Sorghum disease nurseries in south Texas were planted as a part of the continuing research programs. Dr. Melville Thomas spent the academic year at Texas A&M using techniques in biotechnology as they apply to characterizing populations of *Colletotrichum graminicola*. Mr. Issoufou Kollo has begun the application process to begin graduate work at Texas A&M; however, his application has not been completed and he may not be able to begin until Spring Semester, 1995.

Crop Utilization

Purdue has two new graduate students working on the INTSORMIL project - Adam Aboubacar (Ph.D.) from Niger who is funded from the project and Charlotte Weaver (M.S.) who is funded from an outside source. A third project-funded student is in her last year of her Ph.D. studies.

The most significant finding of late concerns the poor protein digestibility of sorghum. In screening 25 selected sorghum genotypes for *in vitro* protein digestibility they found a range from 66 to 88% for uncooked values and 48 to 81% for cooked values. Two sorghum lines had notably higher digestibilities compared to the other sorghums tested. Perhaps more important, digestibility of these two sorghums did not decrease appreciably on cooking which is commonly seen with sorghum. This was verified using two *in vitro* enzyme systems. Chemical studies showed that in the two highly digestible sorghums the major storage protein (about 65% of total protein), α-kafirin, was digested much earlier than the other sorghum samples. Also, a group of high molecular weight proteins, that usually restrict the digestion of α-kafirin, was digested very rapidly. This group of sorghums is now being grown in Mexico to determine if this is a heritable trait. If this proves to be so, we believe that a rapid screening assay for digestibility can be developed based on chemical differences between genotypes.

Adam Aboubacar has set up a laboratory-scale process to make couscous and is examining physical and chemical properties of various sorghum and millet types in relation to their couscous-making ability. He is trying to better understand the controlling factors in the grains that are necessary to produce a couscous product competitive to wheat couscous.

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

L. E. Claflin and J. F. Leslie
Kansas State University

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Mr. Fabio Polania, Dr. Manual Torregroza and Mr. Jaime Bernal, INTSORMIL/ICA/FENALCE, Colombia
Dr. Guillermo Munoz, Pioneer Seed Company, San Jose, Costa Rica (formerly in Cali, Colombia)
Mr. Xu Xiude, Sorghum Research Institute, Liaoning Academy of Sciences, Shenyang, China
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Dr. Darrell Rosenow, Texas A&M Experiment Station, Lubbock, TX
Prof. D. J. Andrews, Department of Agronomy, University of Nebraska, Lincoln, NE
Dr. Martin B. Dickman, Department of Plant Pathology, University of Nebraska, Lincoln, NE
Drs. Anne E. Desjardins and Ronald D. Plattner, USDA/ARS National Center for Agricultural Utilization Research, Peoria, IL

Summary

Research funded by this project includes both disease screening of breeding material and identification of parameters underlying the populations of pathogens in agroecosystems. The All Disease and Insect Nursery (ADIN) from Texas A&M University was screened for genetic variability to covered kernel smut and bacterial diseases for the last ten years, and for rust the last two years. Three accessions, B35-6, SC 414, and Sureño were immune to the race of smut used for inoculation. Accessions rated as resistant to rust include: 87EON366, 87EON366SIS, 90CW8147, 92BD1016, 92CW5447, 86EON362, R9117, and Malisor 84. Those entries with good resistance to bacterial stripe disease include: SC326-6, 86EON361, 86EON366SIS, 90EDN328, 90CCEDN343, 90CW8147, 91CC515, 91BE7151, Sureño, BTX378, and TX7078.

With respect to agroecosystems, work has been in two main areas. First we have been identifying *Fusarium* isolates from sorghum with Pokkah boeng disease symptoms from Egypt. Numerous isolates belonging to *Fusarium* section *Liseola* have been identified, but these isolates are not cross-fertile with standard testers that we have developed for identifying such isolates. It is possible that these strains represent a new, as yet uncharacterized, mating population. In a second area, we have developed a genetic map and electrophoretic karyotype of one of the mating populations. This map will be used to select markers for screening pathogen populations for genetic variability and evidence for genetic recombination.

Objectives, Production, and Utilization Constraints

Objectives

Determine the causal agent of pokkah boeng. Ascertain the epidemiological parameters of the causal agent. Evaluate sorghum germplasm for genetic variability in resistance to the causal agent.

Develop characters for assessing the levels of genetic variability within *Fusarium* populations.

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

Continue to develop monoclonal antibodies against various bacterial pathogens of sorghum and pearl millet.

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

Constraints

Pokkah boeng is a disease of maize, sorghum, and sugar cane that is attributed to *Fusarium subglutinans*. Diseased plants have an "onion-leaf" or "rat-tailed" appearance. In essence, the whorl of the plant fails to unfold properly due either to plant or fungal exudates which bind the leaves together, or to improper growth of the plant. Plants with lesser damage often exhibit leaves with a scorched appearance; other symptoms include a "knife-cut", where the lesion appears to be cut on a transverse plane. Leaves of infected plants are often rippled and have a leathery texture. Grain loss from an infected plant is 100% since the inflorescences fail to emerge.

Fusarium stalk rot and grain mold remain serious problems that cause loss in both quantity and quality of grain sorghum. Yet these fungi appear to be endophytes (Table 1) that provide as yet undetermined benefits to the plant. We are characterizing populations of these fungi to identify fungal strains that are competitive for the plant niche, but that are unable to produce mycotoxins such as beauvericin, fumonisin and moniliformin and do not cause stalk rot. These strains could then be used to reduce the incidence of disease and, once established in a local population should be maintained in a sustainable manner.

Covered kernel smut (*Sporisorium sorghi*) and rust (*Puccinia purpurea*) of grain sorghum occur throughout the world. 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 and 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.

Research Approach and Project Output

Research Methods

Suspected pokkah boeng tissue will be disinfested of contaminants by immersing the samples in 95% ethanol for 10 seconds and then in 10% bleach for four minutes. Samples are then washed three times in sterile distilled water. Small pieces of tissue will be placed on Nash-Snyder (NS) medium, which is selective for *Fusarium* spp. and incubated at 28 C for one week.

The *Fusarium* colonies that develop will be single-spored under a microscope (100x) equipped with a micro-manipulator. These single-spore isolates will be transferred to carnation-leaf agar (CLA) and examined for morphological features such as presence of macro- and microconidia, presence of microconidia in chains or false heads, and general conidia and conidiophore morphology. The isolates will also be grown on potato dextrose agar to measure growth and pigment production. Within the *Liseola* section of the *Fusarium* genus, examination of the morphological characteristics and pigment production are insufficient to identify the isolate to species. Since most isolates from sorghum

Table 1. Percentage of *Fusarium* spp. recovered from tissues of sorghum plants from the Rocky Ford Experimental Farm, Manhattan, Kansas (1993 growing season)

Tissue	*Fusarium* spp.				Unknown[1]
	moniliforme	*proliferatum*	*graminearum*	*solani*	
Grain	40	-	18	-	42
Leaf	99	-	-	-	1
Root	69	25	4	2	-
Sheath	99	-	-	-	1
Soil	82	-	-	-	18
Stalk	89	10	1	-	-

[1] *Fusarium* spp. other than those listed above.

belong to this section we will use the isozyme diagnostic procedure described below and crosses with mating type standards to complete our identifications.

Isozyme assays. *Fusarium* isolates to be tested are grown on slants of complete medium for 3-5 days. The spores are separated from the mycelial mat with an aqueous solution of 2.5% Tween 60 and placed in a petri dish containing minimal media. A sterile cellulose membrane is placed on top of the minimal medium and incubated for 5 days at 27° C with alternating 12 hour periods of light and dark. The membrane is lifted from the medium and ground to a fine powder in liquid nitrogen. The powder and 600 µl of buffer are placed in a microfuge tube and centrifuged at 13,000 rpm for 6 minutes. One hundred µl of the supernatant is removed and placed into microfuge tubes and stored at -80 C until needed.

Small (2 x 6 mm) wicks are prepared from Whatman 3MM chromatography paper. The wicks are submerged into the thawed supernatant samples, blotted, and then inserted into a 10% starch gel. Controls consist of representatives of the seven mating populations, A-G. Isozymes are resolved by electrophoresis for 4-20 hours, depending on the buffer system, at 35 mAmps at 4-7°C.

Gels were assayed for the following isozymes: Fumarase (FUMH), Malate dehydrogenase (MDH), and Isocitrate dehydrogenase (IDH).

Electrophoretic karyotypes. Karyotypes of six *Fusarium* mating populations were resolved using CHEF agarose gel electrophoresis. In some fungi, changes in chromosome karyotype are associated with changes in pathogenicity and can be used to denote different subgroups. We also have identified polymorphic RFLP markers that can be used to make a genetic map and, potentially, as markers to characterize local populations of these fungi from a genetic perspective.

To determine if the bacterial stripe pathogen will overwinter within sorghum debris, 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 the Rocky Ford Experiment farm near Manhattan. 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 a 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 was repeated during the 1994 growing season.

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 a five-year-period (1989-1994) although not all genotypes were evaluated on a yearly basis.

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

Pokkah boeng. We have noticed a high incidence of pokkah boeng in southern Egypt that was especially severe on the major cultivar, Giza 15. The disease is more severe during humid weather or when the crops are irrigated.

Pokkah boeng is often difficult to diagnose. The rat tail symptom may be caused by herbicide injury (usually 2,4-D), particularly if the chemicals are applied after plant emergence as a lay-by treatment. The knife-cut symptom and scorched appearance at the margin of lesions may be attributed to calcium deficiency. The causal agent is related to those thought to induce stalk rot and grain mold.

Only limited research has been reported on pokkah boeng. The disease was first described in Java on sugar cane over 70 years ago. The causal agent was reported as *Fusarium subglutinans*. Our limited research efforts have shown that *Fusarium moniliforme* is almost exclusively isolated from suspected pokkah boeng lesions. We examined millet and sorghum samples from Kenya, Senegal, Egypt, China, Zimbabwe, and the U.S. From root tissues, *F. proliferatum* was the principal species recovered. Based on the symptomology it is not clear where the causal agent should necessarily be found.

F. subglutinans is a known producer of gibberellic acids (GAs), a potent plant growth stimulant. Our research has shown that sorghum seed infested with *F. subglutinans* had an earlier emergence and, at three weeks post emergence, these plants were nearly twice the height of untreated controls. Isolates of *F. subglutinans* produce varying levels of GA. We plan to survey all isolates with the intent of determining their effects on sorghum and millet emergence, growth, and yield. A closely related pathogen, *F. moniliforme*, was shown to decrease the incidence of *Aspergillus niger* in corn. Perhaps *F. subglutinans* would have a similar trait. *A. niger* is a notorious producer of mycotoxins, including aflatoxin.

Many of the *Fusarium* spp. that we recover from the pokkah boeng plants belong to the *Liseola* section, but are not cross-fertile with any of our mating type testers. It is not clear whether these isolates are all sexually sterile or whether they represent a new mating population within this species complex for which we do not yet have suitable mating testers.

Genetic variability in *Fusarium*. We examined more than 25 strains from six different mating populations within the *Fusarium moniliforme* (*Gibberella fujikuroi*) species complex. All of these species had 12 chromosomes. There were minor differences in chromosome length within a mating population, but no major changes in size or in chromosome number were observed. Overall genome sizes ranged from 45-55 megabasepairs (Mb) of DNA with individual chromosomes ranging from 0.7 to >10 Mb. Much of the size variation was associated with chromosome 2, which is known to carry the multi-copy region that encodes for the ribosomal DNA. Some of the variation we observed may be attributable to differences in gene copy number within this region. It is unlikely that karyotype variation will be useful for distinguishing the different mating populations within this species complex, with the possible exception of chromosome 12 (see below).

We assigned more than 140 RFLP markers to the 12 chromosomes and calculate that the genome size is approximately 1500 centimorgans (map units) in length. We also identified map positions for genes controlling mating type, spore-killer and fumonisin production and obtained preliminary evidence for at least one inversion chromosome rearrangement. These markers can be used to provide measures of genetic diversity of these fungal populations that are independent of the vegetative compatibility group (VCG) measures that we have used previously.

The smallest chromosome in the karyotype, chromosome 12, is approximately 700 kb in size and worthy of particular note. This chromosome varies significantly in size between mating populations and can be rearranged or deleted without a noticeable affect on the fungus in terms of laboratory growth rate and morphology, fumonisin production, or pathogenicity. From Northern analysis it is known to encode some transcribed genes, although the function of these transcripts and/or their corresponding proteins is not known. Unlike other dispensable chromosomes known in some other fungi, all of the field isolates examined carry this chromosome and there is relatively little polymorphism for this chromosome within a mating population. The function of this chromosome remains an interesting fundamental mystery.

Several ADIN entries, B35-6, SC414, Sureño, 90EDN328, 90CW8147, 92CW4572 and 92BD1016, were immune in our tests to covered kernel smut. The most susceptible accessions were TX430, BTX623, R9188, 91CC515, ICSV-LM89, and TX636 as over 50% of the plants exhibited smutted heads. With respect to rust, B35-6, TX2858, TX2862, TX2783, MB108B, 90B2662, and 92B2029 were very susceptible to rust whereas 86EDN362, 87EDN366, 87EDN366SIS, 90CW8147, 92BD1016, 92CW5447, and Malisor 84 were nearly immune.

Networking Activities

Workshops

J. F. Leslie attended the 2nd International *Colletotrichum* workshop in Lake Placid, New York, July 25-27, 1993.

J. F. Leslie and R. A. Frederiksen co-organized a workshop entitled "Application of Genetics and Biotechnology to the Characterization and Control of Fungal Pathogens: An International Sorghum and Millet Perspective" which was held at the Rockefeller Foundation's Conference Center at Bellagio, Italy from November 15-19, 1993.

Research Investigator Exchange

L. E. Claflin

China - Consulted for the United Nations Development Program at sorghum and maize institutes in Shenyang, Gong Zhu Ling, Shanxi Province and Beijing, July 11 - 28, 1993.

Kenya - Consulted for the Rockefeller Foundation at various Kenya Agricultural Research Institutes including those at Mtwapa, Kiboko, Muguga, Kitale, and Kakamega. Also discussed Ph.D. dissertation results with Mr. Chagema John Kedera and Dr. Richard Mibay, University of Nairobi, August 7 - 23, 1993.

Egypt - Grant project supported by USAID and Agricultural Research Center (Egypt) to discuss collaborative projects on grain sorghum in Giza, Sakha, and Gemmeiza, August 23 - 31, 1993.

Colombia - INTSORMIL project to evaluate sorghum accessions for disease resistance under acid soils at the ICA research station at Villavicencio, September 2 - 7, 1993.

J. F. Leslie

Egypt - Grant project supported by USAID and Agricultural Research Center (Egypt) to discuss collaborative projects on grain sorghum in Giza, Sakha, Gemmeiza, and Shandaweel, September 26-6 October 1993 and February 25 - March 8, 1994

The Netherlands - Collaborative study of genetic variability in *Fusarium* with researchers at S and G Seeds in Enkhuizen; September 23-25, 1993

Malaysia and Indonesia - Collected fungal samples from soil and plant material from peninsular Malaysia, Borneo and Sumatra, May 16 - June 15, 1994

U.S. - Development of collaborative research project on fumonisins and *Fusarium moniliforme*, Pioneer Hi-Bred International, Johnston, Iowa; October 12-14, 1993

Serve on committee for final Ph.D. oral defense of Anaclet Mansuetus in Dept. of Plant Pathology and Microbiology, Texas A&M University, College Station, Texas; October 19-21, 1993

Worked with scientists at Myco Pharmaceuticals, Inc, Cambridge, Massachusetts to develop new uses for existing culture collection and to devise optimal collecting strategies to further mutual goals; February 3-5, 1994 and June 24-26, 1994

Laboratory visitors

Colombia - Dr. Guillermo Munoz, CIAT/INTSORMIL, April 9 - 17, 1994

Egypt - Drs. Rashad Abu El-Enien and Ibrahim El-Fangary, ARC (Giza)/NARP, August 11-15, 1993; Dr. Osman El-Nagouly, ARC (Giza)/NARP, August 18-21, 1993; Drs. Nadia Dawood and Haroun El-Shafey, ARC (Giza)/NARP, October 27 - November 7, 1993; Dr. Tawfic Abd-el Moity, ARC (Giza)/NARP, February 28 - May 11, 1994; Dr. Thanaa Fahny Ibrahim and Mr. Abu-Serie Mahmoud Ismael, ARC, (Giza)/NARP, March 27 - April 23, 1994

Germplasm Conservation and Use

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.

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. A summary of the strains in this collection that have been characterized by host and mating population are included as Table 2, and by host and geographic origin as Table 3.

Assistance Given

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

Assistance was provided to Drs. Elhamy El-Assiuty, Nadia Dawood and Haroun El-Shafey, 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.

Other Networking Activities

Dr Claflin serves on the editorial board of the Kenyan Agricultural Research Institute

Dr. Leslie serves on the editorial boards of *Applied and Environmental Microbiology*, 1992-1994; *Mycologia*, 1993-1997 and ISPP Fusarium Committee, 1993-1998.

In addition to the collaborators specified above, Dr. Leslie has been collaborating with the following scientists:

James B. Anderson and Linda Kohn, Dept. of Botany, University of Toronto, Mississauga, Canada.

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Jon Duvick, Adreana Tomas and Steve Briggs, Pioneer Hi-Bred, International, Johnston, Iowa.

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

Philippe Nicot, INRA, Montfavet, France.

David D. Perkins, Barbara Turner and Namboori Raju, Department of Biological Science, Stanford University, Palo Alto, California.

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Table 2. Recovery of mating populations from different hosts based on KSU *Fusarium* strain collection.

Host	A^+	A^-	B^+	B^-	C^+	C^-	D^+	D^-	E^+	E^-	F^+	F^-	Sterile[1]
Animal Feed	■[2]	■											
Banana	■	■	■	■			■				■		■
Fig	■	■									■		
Maize	■	■		■			■	■	■	■	■	■	■
Mango							■						■
Millet													■
Muskmelon		■											
Orchid				■									
Peanut				■									
Pine	■	■					■						■
Rice	■	■	■	■	■	■							
Soil	■	■					■	■	■			■	■
Sorghum	■	■	■	■	■		■	■			■	■	■
Sugarcane		■	■	■									
Tobacco								■					■

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[1] Not fertile as a male in at least three consecutive crosses with standard tester strains from each of the six known mating populations.

[2] A "■" indicates that this class is represented by at least one isolate in the KSU Fungal Genetics collection.

Table 3. Recovery of mating populations from different geographic regions based on KSU *Fusarium* strain collection.

Location	A^+	A^-	B^+	B^-	C^+	C^-	D^+	D^-	E^+	E^-	F^+	F^-	Sterile[1]
Argentina	■[2]	■					■	■					
Brazil	■	■	■										
China	■	■					■	■	■	■			■
Dominican Rep.	■	■											
Egypt	■	■					■	■			■	■	
Germany		■											
Guatemala	■	■											
Honduras	■	■											
India		■	■	■									
Italy	■	■											
Iran								■					
Japan						■							■
Kenya	■	■											
Malaysia	■	■	■				■						
Nepal	■	■											
Philippines	■	■	■	■			■	■				■	■
South Africa	■	■		■		■					■	■	■
Taiwan	■	■	■	■	■	■							■
Thailand	■	■	■	■			■						■
Venezuela	■	■											
United States													
Alabama	■	■		■				■					
Arkansas	■	■			■		■	■			■		■
California	■	■						■			■		■
Florida	■	■											■
Georgia	■	■					■				■		■
Illinois	■	■					■	■	■	■		■	■
Indiana	■	■					■	■					■
Iowa	■	■							■				■
Kansas	■	■					■	■	■	■	■	■	■
Minnesota	■	■											■
Mississippi	■	■					■	■		■	■	■	■
Missouri	■	■					■	■	■	■	■	■	■
Nebraska	■	■					■						■
No. Carolina	■	■					■	■	■				■
Ohio	■	■					■	■	■	■	■		■
So. Carolina	■	■						■					■
So. Dakota	■	■								■			
Tennessee	■	■											
Texas											■		■

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[1] Not fertile as a male in at least three consecutive crosses with standard tester strains from each of the six known mating populations.

[2] A "■" indicates that this class is represented by at least one isolate in the KSU Fungal Genetics collection.

Publications and Presentations

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Presentations

Leslie, J.F. VIIth International *Fusarium* Workshop, University Park, Pennsylvania - July, 1993.

Leslie, J.F. VIth International Congress of Plant Pathology, Montreal, Canada - August 1993

Leslie, J.F. Plant Pathology Research Institute, Agricultural Research Center, Giza, Egypt - September, 1993.

Leslie, J.F. Pioneer Hi-Bred International, Johnston, Iowa - October, 1993.

Leslie, J.F. Department of Plant Pathology and Microbiology, Texas A&M University, College Station, Texas - October, 1993.

Leslie, J.F. International Workshop on Applications of Biotechnology to the Characterization of Fungal Pathogens of Sorghum and Millet, Bellagio, Italy - November, 1993.

Low Input Ecologically Defined Management Strategies for Insect Pests on Sorghum

Project MSU-105

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Summary

Although soil inhabiting insects, stem borers and panicle feeding insects contribute to reduced yields of sorghum and corn on subsistence farms in Honduras, the major insect pest constraint to production of these crops is foliage feeding insects. The insect pest complex, referred to as "langosta" by subsistence farmers in Honduras, annually damages or destroys sorghum and corn crop stands. The pest complex has been identified by MSU-105 to consist of four lepidopterous caterpillars, including three armyworm species and a grass looper.

Aspect of the biology, ecology, behavior and population dynamics of two of the armyworm species has identified the role of these insects in this complex. This information has contributed to the successful conduct of entomological research design to evaluate ecological relationships of the pest insects with crop and non-crop plants within various cropping systems, crop planting and management strategies, host plant resistance (evaluation of native landrace cultivars - the "maicillos criollos" planted by subsistence farmers; as well as improved varieties), influence of insecticides on pest and natural enemy populations (including insecticide resistance), and roll of naturally occurring beneficial agents (parasites and nematodes) in regulation of pest populations. Insect pest management tactics have been investigated (usually alone) in crop production systems in areas where the insects are a constraint to crop production. These tactics are now (in part) and will be (in whole) under investigation in holistic on-farm crop management systems. The research with armyworms on sorghum and corn (as most of the crop is intercropped in Honduras) will assist subsistence farmers in producing grain crops with increased yield at minimum cost for pest control and with reduced risk to human health.

Objectives, Production and Utilization Constraints

Objectives

Study the biology, behavior and population dynamics of *Metaponpneumata rogenhoferi*, a lepidopterous caterpillar in the "langosta" complex on sorghum and corn. This insect species is one of the four species responsible for damage or destruction of sorghum and corn seeds, seedlings and older plants on subsistence farms in Honduras.

Develop integrated insect pest management methods employing basic concepts of ecological sorghum and corn crop management in Honduras.

Constraints

Ninety percent of the sorghum acreage in southern Honduras is intercropped with corn because of adverse environment and agronomic conditions. In this area, tall, photoperiod sensitive, low yielding sorghum,, called "maicillos criollos" are intercropped with corn. 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.

The lepidopterous "langosta" pest complex is considered by subsistence farmers to be the principal threat to their sorghum-corn crop during the early period of crop development. Biological and ecological studies have been conducted with two of the armyworm species *(Spodoptera frugiperda* and *S. latifascia*) in different crop production areas in Honduras. Insect pest biology, ecology and seasonal populations dynamics studies elucidated the role of these two species in this complex. Non-crop plant "source habitats" and crop plant "sink habitats" have been identified and the biotic potential of the species in the crop production systems has been determined. Crop mortality factors have been partitioned in limited studies in sorghum-corn intercropped systems in southern Honduras, with insects accounting for 65% of the mortality to the crops.

Having conducted research on two of the lepidopterous caterpillar species, *S. frugiperda* and *S. latifascia*, studies now emphasize the third armyworm species (*M. rogenhoferi*) in the complex. The relationships of this species with non-crop vegetation and crop plants revealed the relative economic significance of this little researched species. The dynamics and levels of population occurrence need investigation to assist in developing a total insect pest management strategy for the "langosta" complex in intercropped sorghum and corn in specific regions of Honduras.

The international significance of *M. rogenhoferi*, and related species, particularly in relation to migration and insecticide control and resistance, has impact on sorghum production for various regions in the Latin American Ecogeographic Zone, as well as potential impact on crop production in the U.S. (specifically involving the fall armyworm, a serious pest throughout the Americas).

Alternative insect pest management practices (limiting insecticide use) which are practical for use by subsistence farmers have been evaluated in MSU-105. The sorghum breeding program with EAP/SRN is designed to develop improved maicillo varieties and photoperiod sensitive hybrids. MSU-105 is active in this program, and has identified antibiosis resistance in the native landrace cultivars, and research has elucidated the antibiosis mechanisms of resistance.

Research Approach and Project Output

Honduras

Occurrence, Host Plant Relationships and Diapause of *M. rogenhoferi*

M. rogenhoferi, like *Spodoptera frugiperda* and *S. latifascia*, is associated with non-crop vegetation upon which they feed before moving to sorghum and corn. Systematic sampling of vegetation types in and around production fields before planting in 1993 revealed that this species infests non-crop vegetation of several types beginning immediately after the on-set of the rainy season. Observations indicated that *M. rogenhoferi* appeared to have only one and possible two generations in southern Honduras. Thus, studies with this species were initiated to determine:

- The univoltine or multivoltine behavior of the species,
- Host oviposition preference for and larval development on broadleaf plants compared with sorghum, corn and other grass plants, and
- Influence of soil moisture and time on pupal diapause.

The establishment and density of *M. rogenhoferi* infestations on non-crop and crop plants was monitored in selected fields in the hills area of southern Honduras for the second year. The occurrence of larvae of various age structure was recorded from late April to late July. Agroecological data (soil preparation for planting, planting date, variety, rainfall, plant emergence, use of chemicals, etc.) were recorded. Data included host plant identification and growth stage, time of insect occurrence, age structure of insects, and plant and insect population density. Diversity of insect developmental stages and density are used to depict insect occurrence in time and with host plant growth stage.

The first appearance of *M. rogenhoferi* following the initiation of the rains prior to planting in May or June further supports the earlier observations of a pupal diapause. The ecological relationship of this species with non-crop host plants and the population structure (insect developmental stages) during May-July, as confirmed by intensive sampling in the crop production area, identified the time that this species is potentially destructive to the crops. In some years, *M. rogenhoferi* may be the most damaging species in the "langosta" complex; in other years it may appear as only a contributor to crop destruction by the "langosta". The biological and ecological relationships of this species in sorghum and corn intercropping systems needs further investigation in various ecogeographic areas and crop production systems to elucidate the specific factors responsible for the occurrence of devastating populations of this defoliator pest species at different times in Honduras.

Preliminary studies indicated that *M. rogenhoferi* diapause during the dry season is influenced by soil moisture. This relationship is being investigated in the laboratory exposing pupae (from field collected larvae) to various moisture levels over time after the pupae enter the diapause condition. Larvae are reared on specific host plants (sorghum, corn, and three non-crop plants) previously identified as important hosts for *M. rogenhoferi*. Pupae in the soil will be exposed to five soil moisture levels (0%, 10%, 20%, 30% soil saturation) and continuous moisture (10% moisture over time) at monthly intervals. These studies will be completed in 1994-95 and will provide a better understanding of environmental influence (host plant and soil moisture) on the population occurrence and dynamics during the early part of the crop growing season. This information, like that for the other species in the "langosta" complex assists the development of insect control tactics for individual species in the complex.

The role of various host plant species on the development of *S. frugiperda* and *S. latifascia* has been identified in previous MSU-105 investigations. Similar studies have been initiated in the laboratory with *M. rogenhoferi* using the most common non-crop plants (*Ipomoea* sp., *Melampodium divaricatum*, and *Amaranthus hybrydus*) and sorghum and corn. Insects fed these host plants are measured daily to determine host preference for development. Data includes larval and pupal weight, mortality, developmental rate, pupation and adult longevity and fecundity. These studies will be completed in 1994.

Integrated Crop Management

Insect pest control developed for one species, or a complex of species, involves the integration of specific management tactics, possibly applied throughout the crop growing season, in a holistic crop management system. This holds true for insect pest management in subsistence farming, as it does for high technology crop production. Host plant associations have been identified and ecological relationships defined for two of the "langosta" species; *M. rogenhoferi* investigations will provide additional information for design of integrated insect pest management systems. The use of cultural control methods (e.g.., weed management in production fields), crop varieties with insect resistance and limited and judicial use of insecticides, as previously identified in the MSU-105 project, will benefit sorghum-corn production in Honduras and other areas in Latin America having similar crop production problems. The observation of various levels of antibiosis host plant resistance in the maicillo criollos to fall armyworm can have considerable impact on sorghum insect pest control. The subsistence farmers in this region of Latin America use a wide variety of native land race sorghums, many of which may have some levels of insect resistance. The antibiosis resistance characters in these cultivars are desirable for use in the Honduran National Sorghum Breeding Program. Crop production technology, new and/or improved, is planned for validation in 1994.

Host Plant Resistance

Hondurans landrace sorghums have been identified to have moderate levels of antibiosis resistance to fall armyworms. San Bernard III, a caudatum-durra integrated race selected from the 'Liberal' landrace, expresses antibiosis through reduced fecundity. This cultivar was crossed with AF28, expressing resistance through increased larval and pupal mortality, to combine the two possible different sources of resistance. Fifty-nine F4 inbred lines derived from this cross were evaluated for fall armyworm resistance. One inbred line (AF28* San Bernardo III) - 28 was selected from this study for additional research. Additional breeding was required to test whether resistance genes were indeed inherited from both parents. Five inbred lines derived from the AF28* San Bernardo III cross were evaluated further for host plant resistance. These lines were selected in the F2 generation for photoperiod sensitivity and compact head type. These selection procedures will define the harmful effects of the resistant sorghums to the armyworm species in the "langosta" complex and advance the process for development of sorghums with insect resistance.

United States

Diapause studies will continue to emphasize *M. rogenhoferi*, investigating the factors responsible for termination of this biological characteristic. This information will assist in defining early application of specific ecological, as well as chemical control tactics.

Insecticide studies will continue to emphasize the minimum use and timely application of insecticide for control of the defoliator fall armyworm. The efficacy of biological insecticides at different application rates and times of application will be further evaluated. This information can be transferred to subsistence farming situations in the Latin American Ecogeographic Zone.

Networking Activities

Workshops

International Consultative Workshop on Panicle Insect Pests of Sorghum and Pearl Millet. ICRISAT Sahelian Center, Niamey, Niger, Africa. October 1-9, 1993. Invited paper: "Caterpillar Pests of Sorghum Panicles in the Western Hemisphere".

Assistance Given

Supplies and equipment required by graduate students in performance of research activities in the laboratory and field in Honduras is supplied by MSU-105. This includes field cage frames and covers.

Publications and Presentations

Publications

Portillo, H.E., H.N. Pitre, D.H. Meckenstock and F. Gomez. 1994. Improved chemical protection of sorghum seed and seedlings from insect pests in Honduras. Turrialba. 43(4):

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Castro, M. T., H. N. Pitre, and D. H. Meckenstock. 1994. Fall armyworm (Spodoptera frugiperda) (J.E. Smith) (Lepidoptera: Noctuidae) and neotropical cornstalk borer (Diatraea lineolata) (Walker) (Lepidoptera: Pyralidae) on sorghum and maize intercropped with legumes in Honduras. Turrialba (accepted for publication).

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Ching'oma, G. P. 1993. Relationship of oviposition response and larval development of fall armyworm, Spodoptera frugiperda (J. E. Smith), to stage of maturity of sorghum, *Sorghum bicolor* (L.) Moench. M.S. Thesis. Mississippi State University. 41 pp.

Presentations

Pitre, H. N. Caterpillar Pests of Sorghum Panicles in the Western Hemisphere. International Consultative Workshop on Panicle Insect Pests of Sorghum and Pearl Millet. Niamey, Niger. Oct. 1-9, 1994.

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 (see below) on sorghum production and utilization.

Perhaps our most significant activity in recent months is, in collaboration with Drs. Ejeta and Bennetzen, the mapping of several biochemical traits on the sorghum genome. These include *Striga* germination stimulant production, and grain and leaf content of 3-deoxyanthocyanidins (pigments), flavan-4-ols, proanthocyanidins, and a new class of materials which have unique properties similar to those expected for pro-3-deoxyanthocyanidins. We have also definitively identified the cyanogenic glucoside dhurrin, characteristically found in sorghum seedlings but not in the grain, as present in highly significant levels in the grain of sorghum line ARK 3048, which is bird resistant but has no tannin.

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 and leaf diseases for which
polyphenols play a defense role
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/or identify by screening superior sources of resistance (to birds, mold, *Striga*, etc), establish in the laboratory 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.

Project Output

Methods development: 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 using trapped wild birds, and several bioassays for chemical signals in the *Striga*-host association. We are still seeking to develop a simple and reliable bioassay for the "toxin" produced by *Striga.*

Mold and leaf disease resistance in sorghum: 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. As part of the sorghum genome mapping project (see later) we found that leaf tissue of some genotypes contains small amounts of what appear to be proanthocyanidins (tannins) previously considered to be confined to the seeds of genotypes that have a testa layer. Moreover, some genotypes also appear to contain in leaf tissue a previously unreported phenolic material which on treatment with acid at 100 degrees converts to a mixture of the 3-deoxyanthocyanidins, apigenidin and luteolinidin. Characterization of this apparent pro-3-deoxyanthocyanidin may lead to a new type of tannin.

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, has been extracted, purified and tentatively identified as the cyanogenic glucoside *dhurrin*, previously known to be found in sorghum seedlings but not in significant amounts in sorghum grain. This bird resistance factor may be of considerable importance. It can be completely inactivated by moistening the flour (in a manner analogous to the detoxification of the cyanogenic glucoside of cassava), so sorghums containing this bird-resistant factor can nevertheless be used as poultry feed. This highly nutritious tannin-free bird-resistant sorghum would be suitable for human food in all applications where it is ground, moistened, and cooked. It would not be suitable for utilization in the green roasted form because this treatment would not be likely to eliminate the cyanogenic glucoside.

Biotechnology: 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, 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. The parents of the cross being mapped differ widely in their content of polyphenols as well as many other traits. Characterization of selections from this cross is leading to evidence for polyphenolic materials never before reported (see above).

The first successful stable transformation of sorghum was recently announced at Purdue University. A gene for herbicide resistance was stably inserted 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: Ms. Cai in our laboratory has produced finely divided fast-growing suspension cultures of sorghum cells of six genotypes, some of which have been stable in culture for over four years. These culture techniques have been utilized in the sorghum transformation work mentioned above. Our second major journal report on somaclonal variation in sorghum in *in vitro* culture, as well as a major review chapter on the same subject, are in press. Our tissue culture work on *Striga* is described below.

Striga: In the field, *Striga* germination is not controlled by sorgoleone, which we previously identified as the first host-produced germination stimulant for *Striga*, but by a different set of compounds exuded by host roots. These compounds are more stable and more water soluble than sorgoleone. Bupe Siame, our SADC student from Zambia, identified the major *Striga* germination stimulant exuded by corn and proso millet roots as *strigol.* Researchers in Germany 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.*

These findings seem to close the book on the long, laborious effort to identify host-produced *Striga* germination stimulants, with the possible exception that the stimulant produced by pearl millet has not yet been identified. We have shown that it is not strigol or its analogs identified from sorghum and cowpeas, but that it is probably another strigol analog. I have recently suggested that all these strigol analogs active as *Striga* germination stimulants, all of which contain a lactone ring required for stimulant activity, be classified together under the generic name of *strigolactones.*

Unfortunately, strigolactones 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. We have recently developed a new approach based on destroying the lactone ring of these compounds, as rapidly as they are produced by host roots, by lactonase enzymes secreted from non-pathogenic bacteria growing on host roots after inoculation of the host seed. 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.

We continue to pursue host-derived signals required by *Striga* later 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 few sorghum genotypes and one of corn which produce abnormally low amounts of this signal. 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. The major problem is that the amount of haustoria inducing factor produced by the low producing genotypes is only about 1 order of magnitude less than is produced by the normal types. This difference is not nearly as great as between high and low producers of germination stimulant, and may not be great enough to result in good resistance.

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. In our attempt to isolate and identify the *Stria* toxin, we have isolated several new compounds not previously reported from *Striga*, and are characterizing them.

Networking Activities

Workshops

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

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.

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 (Intl. Soc. for Horticultural Science), Sept. 13-17, 1993, Techn. Univ. of Munich, Freising, Germany.

Cooperating scientists

Dr. Dale Hess, Millet Pathology, ICRISAT Sahelian Center, B.P.12404, Niamey, NIGER (via Paris)

Dr. J. Rutto, Deputy Director, Kenya Agriculture Research Institute, Nairobi, KENYA

Drs. Axtell (Agronomy), Bennetzen (Biology), Rogler (Animal Science), Hamaker (Food Science), Nicholson (Botany & Plant Pathology), Bressan, Woodson and Hasegawa (Horticulture), Chaney and Weeks (Forestry), all at Purdue University.

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.

Impact

This project is perhaps the most basic in nature of all INTSORMIL projects. Accordingly, the major impacts have been on our understanding of the biochemical basis for the production/utilization constraints addressed, and on the methodology we have developed for characterizing them.

As a result of our work, the role of polyphenols as antinutrients in herbivore diets is better known for sorghum than for any other feed or foodstuff. It was our work that showed the unique capacity of proline-rich proteins to bind tannins; for this and other reasons proline-rich plant proteins are of wide interest now.

In several ways, our work with Dr. Ejeta on *Striga* has profoundly affected the manner in which *Striga* research is carried out around the world. Our approach of addressing individual facets of the *Striga* life cycle independently is being widely copied, because it has proven to be more effective than the approaches previously utilized. The long search for identification of germination stimulants is essentially over. We have shown the existence of several subsequent signals in the life cycle, and the search is moving on to identify them. We have shown how tissue culture techniques can strongly contribute to our understanding of the *Striga*-host system.

Our methods for purifying, characterizing, and quantitating polyphenols are now utilized, both in the US and abroad, on crops as widely different as strawberries and *leuceana* trees, in addition to sorghum. As an example, Ralston Purina has long used our Prussian Blue test for total polyphenols in blending their sorghums to keep the polyphenol content within acceptable levels.

Publications and Presentations

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Butler, L.G. Manipulation of Developmental Signals to Control a Devastating Parasitic Weed. Seminar, Dept. of Biological Sciences, Butler University, Indianapolis, Sept. 29, 1993.
Butler, L.G. Communication/Recognition Between the Parasitic Weed, *Striga*, and Its Hosts. Symposium on Interspecific Chemical Recognition, 11th Annual Meeting of the International Society of Chemical Ecology, Syracuse, NY, June 5th, 1994.

Disease Control Strategies for Sustainable Agricultural Systems

Project TAM-124

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Summary

Cooperation with ICRISAT was continued through the joint International Anthracnose Virulence Nursery. The enhanced collaboration stems from the recognition of the importance of this disease in the more humid sorghum growing regions of the developing world. Anthracnose collaboration permits the better evaluation of the durability of host resistance and a better estimate of the variation in pathogenicity among isolates of the pathogen worldwide. Participating regions include West Africa, Mali and Niger; East Africa, Sudan; Southern Africa, Zambia and Zimbabwe; and Brazil. Our work has demonstrated that there is tremendous variation among isolates from locations and between locations. Sorghum downy mildew has become less and less of a problem because of global cooperation in the development of host resistance, characterization of isolates and through the use of highly effective fungicide seed dressings. RFLP and RAPD markers linked to head smut, downy mildew, and acremonium wilt resistance have been placed within specific linkage groups on the sorghum genome. In 1991, a new product with a mixture of pesticides was developed that has the potential of inexpensively controlling downy mildew of pearl millet. Preliminary data are remarkably impressive. Work on the product Apron® Plus is being conducted in Niger and was proposed in Sudan. In Niger, 180 on-farm tests have shown an average yield increase for pearl millet of 18% with the application of Apron® Plus.

Research Objectives

Honduras

Identify the most important disease constraints and design disease control strategies.

Initiate studies on variability of *Colletotrichum graminicola* and genetic resistance of sorghum grown in Honduras to anthracnose.

Continue to monitor the major downy mildew screening program run by the Honduran National Program to evaluate disease and host plant resistance.

India

Continue collaboration with ICRISAT on growing, distributing, and evaluating the Sorghum Anthracnose Virulence Nursery.

Mali

Continue efforts to establish a National Sorghum and Millet Disease Program.

Develop an inoculation procedure for the sooty stripe and anthracnose pathogens.

Evaluate the Texas A&M/INTSORMIL nurseries for reaction to the prevalent pathogens in Mali.

Study the interaction of mold and insects on grain deterioration.

Niger

Continue to monitor the evaluation of resistance to long smut performed by the Niger Sorghum Improvement Program, along with evaluation for resistance to head smut, Acremonium wilt, and anthracnose.

Summarize data on the survival of spores from long smut.

Summarize data on a trial on the effect of different fertilization treatments on the incidence of *Striga hermonthica* in pearl millet.

Continue the use and deployment of Apron® plus as a control for downy mildew of pearl millet.

Domestic

Identify sources of resistance to disease.

Assist in the incorporation of multiple sources of resistance to disease.

Determine inheritance of resistance.

Genetically map disease resistance traits.

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

Research Approach and Project Output

We use virtually identical approaches to domestic and international work on the control of sorghum and millet diseases. This involves the identification of sorghums with excellent resistance(s) to specific pathogens and then the incorporation of this resistance into useful cultivars. Most of this work is done cooperatively with plant breeders in the Texas programs, but also occasionally with breeders in other states, nations (NARS), or with an International Crop Research Center, specifically ICRISAT.

Disease evaluation studies are conducted primarily in large research nurseries in South Texas. An evaluation of U.S. grain sorghum hybrids for reaction to all of the significant diseases was initiated in 1994. One hundred ninety-seven hybrids are being evaluated for resistance to anthracnose, sorghum downy mildew, maize dwarf mosaic virus, grain mold, head smut, and stalk rots. Much of the data collected to-date will be incorporated into a National Sorghum Production Program using principles of integrated crop management.

Several uniform nurseries are grown in locations where sorghum/millet diseases are important. These include the International Sorghum Anthracnose Virulence Nursery (ISAVN), in collaboration with ICRISAT, the Uniform Head Smut Nursery (UHSN), the Sorghum Downy Mildew Virulence Nursery (SDMVN), the International Sorghum Virus Nursery (ISVN), and also a uniform nursery for grain mold. These nurseries provide a quick assessment of disease severity and pathotype differences among locations.

Elite sorghums are also distributed and evaluated for multiple resistances in international nurseries, which also provide a means of distributing elite germplasm from different breeding programs in INTSORMIL. The most widely grown is the International Disease and Insect Nursery (IDIN), a 30-entry test, followed by the All Disease and Insect Nursery (ADIN), a 70-entry test, which is composed in part of unreleased experimental materials that need evaluation in many different disease environments. Both of these collections represent one of the best means of comparing germplasm from region to region. Additionally, we have collected 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.

Striga

In Niger, Mr. Issoufou Kollo has conducted a trial on the effect of fertilization on the incidence of *Striga hermonthica* in pearl millet. The experiment was set up in a split-split plot design with the millet cultivars as the main plot. These were NKP, an early maturing cultivar (70 days to physiological maturity), and Zongo Kollo, a late maturing cultivar (80-85 days to physiological maturity). The subplots were three manure treatments (0, 5, and 10 T/ha). The sub-subplots were three nitrogen (urea) treatments (0, 50, and 100 kg/ha). The cultivars were planted in four-row plots, 6m long. Hills were thinned to three plants. The application of nitrogen was split; half of the rate was applied at planting, the second application was done three weeks after planting at the time of the second weeding. *Striga* was counted weekly with the highest number being taken. The data is currently being summarized.

Sorghum Head Smut

Present techniques for evaluating resistance of sorghum to infection by *Sporisorium reilionum*, 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 data because of environmental effects, whereas inoculation with sporidia is labor intensive and may bypass resistance factors that provide satisfactory levels of resistance under field conditions. Using techniques developed by Dr. J. Craig (Craig and Frederiksen, 1992) to evaluate head smut resistance at the seedling stage, Alejandro Palma, a graduate student of Dr. Fred Miller, provided additional evidence of horizontal resistance in sorghum to a new race of the pathogen from Taylor, Texas. Isolates of the pathogen from this area appear to be able to overcome what Dr. Craig described as R1 resistance in a sorghum hybrid.

A dissertation program was completed by Dr. Boung-Jun Oh concerning the identification of resistance genes in sorghum. As reported in last year's report, he was able to locate molecular markers for resistance to head smut (*Shs*), downy mildew (*Sdm*), and acremonium wilt (*aw*) using RFLP and RAPD analyses. He also studied glycoprotein changes following developmental transition in the meristematic tissue of sorghum classified according to head smut reaction as R1, R2, R3, and S1 as described by Craig and Frederiksen (1992). Changes were detected with sodium dodecyl sulfate-gel electrophoresis and protein blotting by six biotinylated lectins, *Bandeiraea simplicifolia* agglutinin (BS-I) which binds to α-D-gal, Concanavalin A (Con A) which binds to α-D-glc and α-D-man, Peanut agglutinin (PNA) which binds to β-D-gal(1-3)-D-galNAc, Soybean agglutinan (SBA) which binds to D-gal-NAc, *Ulex europaeus* (UEA I) which binds to α-L-fuc, and Wheat germ agglutinin (WGA) which binds to β-D-glcNAc. The sugar-binding specificity of vegetative and reproductive meristematic tissues in these sorghum cultivars are shown in Table 1. Although BS-I, PNA, and SBA bind to different galactose derived structures, they showed almost the same binding specificity and same banding patterns with only minor differences that were not scored. These lectins showed binding-specificity only in the vegetative meristem, not reproductive, while Con A showed binding-specificity only in the reproductive meristem. Thus, disappearance of galactose-binding specificity and appearance of glucose and mannose-binding specificity may give a clue to the dramatic increase of mycelial growth which occurs in the reproductive meristematic tissue. Since R2 and R3 classes have factors conferring resistance to *Sporisorium reilianum* in meristematic tissues, and R1 and S1 do not, it is interesting that UEA I showed α-L-fuc-binding specificity with two bands at 96 kDa and 116 kDa only in the reproductive meristematic tissues of the R2 and R3 classes. It is possible the two UEA I-labeled bands may be linked to factors conferring resistance to *Sporisorium reilianum* in R2 and R3 sorghum head smut reaction classes.

Downy mildew

The ongoing screening of sorghum materials for resistance to sorghum downy mildew was continued using our greenhouse inoculation techniques. Also, 20 sorghum en-

Table 1. The sugar-binding specificity in the vegetative and reproductive meristems of selected sorghum cultivars in response to the presence or absence of six different lectin-binding glycoproteins.

Reaction Class	Cultivar	Lectin											
		BS-I		SBA		PNA		WGA		Con A		UEA I	
		veg[a]	rep[b]	veg	rep	veg	rep	veg	rep	veg	rep	veg	rep
R1	TAM428	+[c]	-[d]	+	-	+	-	-	-	-	+	+	-
	Tx430	+	-	+	-	+	-	-	-	-	+	+	-
R2	SA281	+	-	+	-	+	-	-	-	-	+	+	+
	SC170-6-17	+	-	+	-	+	-	-	-	-	+	+	+
	Tx414	+	-	+	-	+	-	-	-	-	+	+	+
R3	FC6601	+	-	+	-	+	-	-	-	-	+	+	+
	Lahoma Sudangrass	+	-	+	-	+	-	-	-	-	+	+	+
S1	SC241-12	+	-	+	-	+	-	-	-	-	+	+	-
	Tx7078	+	-	+	-	+	-	-	-	-	+	+	-

[a] Veg = vegetative meristematic tissues

[b] Rep = reproductive meristematic tissues

[c] + = detection of sugar-binding specificity

[d] - = no detection of sugar-binding specificity

tries from Colombia were screened for resistance to downy mildew under field conditions at the Texas A&M Research Farm in Burleson County.

Anthracnose

Ms. Ute Rosewich has continued work on population biology of *Colletotrichum graminicola*, the causal organism of anthracnose in sorghum. Whereas Drs. Casela and Guthrie both worked with populations from large areas (Brazilian and mainly African isolates, respectively) and often they only worked with a few single-spored isolates from any one region, Ms. Rosewich is taking the next logical step with a close-up look at populations from small, confined areas. *C. graminicola* is also able to infect johnsongrass (*Sorghum halepense*), a common perennial weed. There have been speculations that johnsongrass might serve as a reservoir for *C. graminicola* and as an overwintering host. Her hypothesis is that johnsongrass isolates are comprised of a similar heterogeneous population which can be separated from the sorghum isolates based on RFLPs and virulence. From a commercial sorghum field in LaWard, Texas, she sampled 100 stalks infected with *C. graminicola* in transects covering an area of 5000 m^2. One single spored isolate was obtained per stalk (98 total isolates). She obtained johnsongrass isolates from two sites, one directly bordering this sorghum field, and the other three miles away, again bordering a sorghum field. At each site, 25 m were covered. A total of 95 isolates were obtained. Screening of a species specific library yielded eight probes which are useful for population genetics analysis on the basis of being polymorphic, hybridizing to fragments in suitable size ranges, and being able to distinguished alleles. So far, five of these probes have been examined for the above mentioned populations. The allele frequencies for the two populations are presented in Figure 1. The sorghum population seems to consist of one predominant clone, whereby the alternative alleles observed at two out of the five loci are very rare. In comparison, the population from johnsongrass shows a much higher degree of genetic variability, with up to seven alleles at a single locus. The alleles in the two populations do not overlap (except for one case - see pSCg40), but are fairly homogenous within each population. These data strongly suggest that the initial inoculum for the sorghum does not originate from the johnsongrass population.

Dr. Melville Thomas worked in our laboratory examining the genetic variability among many of the isolates of *Colletotrichum graminicola* from the West African region. He used four probes (pSCg3, pSCg10, pSCg23, and pSCg31) to detect polymorphisms in 20 isolates from West Africa. Based on total DNA, there was genetic variability among many of the isolates as shown by RFLP separation of isolates 1,2,3,6,14,30,31, and 32. It is worth noting that all four probes differentiated isolate 3 from the rest. This isolate also differed considerably from the others with respect to conidium production and culture characteristics. It would be necessary to sample many more isolates from given fields and from different locations and to develop many more probes to more accurately characterize the pattern of genetic variability in populations from West Africa.

Grain Mold

Dr. Anaclet Mansuetus completed his dissertation studies studying the mating populations and vegetative compatibil-

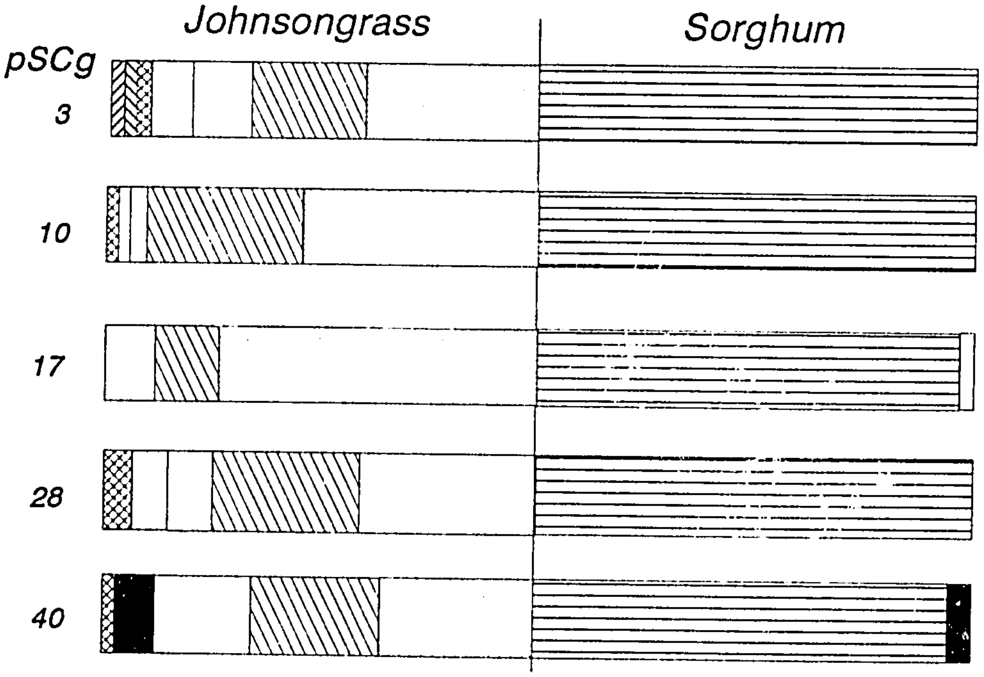

Figure 1. Allele frequencies for five Loci in populations of *C. graminicola* from sorghum and johnsongrass.

ity groups in *Fusarium moniliforme*. In *Fusarium* section *Liseola*, sexual stages are useful in the identification of mating populations that represent different biological species in the absence of morphological distinctness. Mating populations within *Gibberella fujikuroi* (*Fusarium* section *Liseola*) were identified on sorghum in Tanzania by using standard mating type testers. All mating populations A, B, C, D, E, and F were recovered on sorghum from Tanzania, but not all mating populations were recovered either at Ifakara or Kachiri. Locations did not differ significantly in mean percent of mating populations A to F.

Mating population F occurred in higher frequencies than mating population A or D and mating population C was the least frequent. Percent mating population A and F were significantly different (P>0.01) at Ilonga.

nit mutants were recovered from within both mating population A and F of *F. moniliforme* and used to determine vegetative compatibility groups (VCGs) within both populations. Pairing of *nit*1 and NitM or *nit*3 mutants resulted into heterokaryon formation when isolates were vegetatively compatible. Within mating population A, six VCGs were identified at Ifakara, five at Ilonga, and two at Kachiri. All VCGs were represented by more than one isolate except one at Ifakara. Genetic diversity, measured as the number of VCGs identified per number of isolates examined, within mating population A was relatively higher at Ilonga than at Ifakara and Kachiri. Within mating population F, three VCGs were identified at Ifakara, four at Ilonga, and two at Kachiri. All VCGs within mating population F were represented by more than one isolate. Genetic diversity within this population was higher at Kachiri than at Ilonga and Ifakara. Genetic diversity within mating population A was significantly higher (P>0.02) than genetic diversity within mating population F. Vegetative compatibility studies across the three locations demonstrated eleven VCGs within mating population A and five VCGs within mating population F (Table 2). Strains from each location appeared to be more similar genetically to each other than to strains from other locations.

Table 2. Overall vegetative compatibility groups within *Fusarium moniliforme* mating population A and F on sorghum from Tanzania.

Vegetative compatibility group	Number of isolates within population		Percent of population for mating population	
	A	F	A	F
1	12	43	20.3	59.7
2	10	12	16.9	16.7
3	8	9	13.6	12.5
4	7	6	11.9	8.3
5	4	2	6.8	2.8
6	5	-[z]	8.4	-
7	3	-	5.1	-
8	3	-	5.1	-
9	2	-	3.4	-
10	2	-	3.4	-
11	3	-	5.1	-
Total	57	72	100	100
Genetic diversity	0.19	0.1		

[z] "-" = no VCG identified; a total of five VCGs were identified within mating population F.

A major aspect of the collaborative research in Mali has been to examine the relation between head bug damage and grain mold on seed deterioration. It was observed that known mold resistant sorghums such as SC748 and Sureño develop extensive mold damage if the sorghum heads are not protected from head bugs. Protection from head bugs will be a requirement for evaluation of grain mold resistance. This is important because grain mold resistance as well as resistance to head bugs will be required in an improved sorghum cultivar for Mali.

Sorghum viruses

The primary work on viruses of sorghum performed this year was the evaluation of 197 sorghum hybrids in College Station for infection with maize dwarf mosaic under natural and inoculated conditions. A rating and incidence of the disease were assessed and these data are currently being summarized.

Networking Activities

John Leslie and R. A. Frederiksen coordinated a conference at the Rockefeller Foundation Center in Bellagio, Italy in November, 1993 on the application of genetics and biotechnology to the characterization of fungal pathogens of sorghum and millet. This program included scientists from newly developing countries, from genetics and microbiology laboratories, along with participants from INTSORMIL laboratories. R. Frederiksen also reviewed collaborative research in Mali and in Niger. Dr. Melville Thomas worked in Frederiksen's laboratory on sabbatical working with anthracnose in sorghum.

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Integrated Insect Pest Management Strategies for Sustainable Agricultural Systems

Project TAM-125

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Summary

Project TAM-125 emphasizes the development and use of insect-resistant sorghums as a foundational component of an integrated pest management approach to attain sustainable sorghum production in developing countries and the U.S. On-site collaborative research activities are in Mali and have West Africa regional application. Research in Texas is used to develop resistant cultivars and related plant resistance-to-insects technology, graduate student education, and short-term training. Cultivars are being developed and evaluated for resistance to sorghum midge, greenbug, sugarcane aphid, yellow sugarcane aphid, and African sorghum head bugs.

Collaborative research in Mali in 1993 confirmed the utility of methodology developed to screen sorghums for resistance to panicle-feeding bugs in two preliminary screening trials of 50 and 49 sorghum entries. In an advanced screening trial, entries B-Var-1 and IS21525 were most resistant to panicle-feeding bugs. Insecticide application and plastic pollinating bags used to protect kernels from bug damage provided a means for comparing bug damage to kernels of unprotected panicles with those of protected panicles. A positive correlation existed between the level of damage by panicle-feeding bugs and grain deterioration. The multi-disciplinary panicle-feeding bug program has been extremely successful, a model collaborative research program, and Dr. Y. O. Doumbia is an excellent collaborating scientist.

Insect resistance breeding and evaluation nurseries were established at Corpus Christi, College Station, and Lubbock, Texas, in 1993. Graduate students from Mali, Mexico, and the United States are pursuing graduate studies in entomology, and use field research plots at College Station. Mortality was assessed of sorghum midges infesting resistant and susceptible sorghums; this research will contribute to our understanding of the mechanisms of resistance and provide data for the population dynamics model simulation effort. Research underway to determine factors that govern sorghum midge diapause termination and overwintering survival will also contribute to the modeling effort. An asynchrony between the times when sorghum spikelets flower and sorghum midges are in the field was determined to be a factor causing some sorghums to be resistant to sorghum midge. Spikelet morphology also contributes to resistance to sorghum midge. A project using RFLP technology to map genes imparting resistance of sorghum to greenbug was begun.

Technology transfer occurred through publications, presentations, workshops, and exchange visitations. Collaboration with ICRISAT scientists has continued to be strong.

Objectives, Production and Utilization Constraints

Objectives

Mali sorghum panicle-feeding bug research: The objectives of the collaborative research project in Mali with Dr. Y. O. Doumbia are to develop practical techniques for screening sorghums for resistance to panicle-feeding bugs; relate resistance to glume, kernel, and grain-texture characteristics; cooperate with sorghum breeders to develop sorghums resistant to panicle-feeding bugs; assess the relationship of pathogen infection and damage caused by panicle-feeding bugs, to grain/food quality; and conduct on-farm surveys of abundance and severity of panicle-feeding bug.

Technology development and graduate student research: The overall objectives of research conducted in Texas are to provide a mechanism for graduate student education programs, to identify and evaluate sorghums resistant to insect pests, determine mechanisms and causes of resistance, investigate how resistant plants respond to insect pest invasion and how insects respond to resistant plants, and determine economic injury levels. Specific objectives for Year 15 were to determine the natural mortality rate of sorghum midges; determine the spikelet flowering and morphological characteristics of sorghum midge-resistant sorghums, determine the factors that affect sorghum midge diapause termination and the abundance of overwintering sorghum midges; develop population dynamics simulation models that have prediction capabilities, and construct genome maps to locate sorghum genes conferring resistance to greenbug.

Constraints

Panicle-feeding bugs are a major constraint of the sorghum improvement program in Mali and most sorghum-producing areas of West Africa. These insects are problematic in non-photoperiod sensitive, compact-panicle sorghums that yield more than currently grown, local varieties. Panicle-feeding bugs are a serious deterrent to sustainable sorghum production in an area of the world where grain yield stability across years is essential. The problem is exacerbated by pathogen infection that significantly increases when kernels are damaged by bugs. Grain damage by bugs and infection by pathogens dramatically reduce grain yield and quality, and render the grain unusable for human consumption. Insecticides can be used to control these bugs but are too expensive for most farmers that grow sorghum in subsistence systems. Sorghum cultivars resistant to bugs would be a more sustainable and safer method to manage these insect pests. The interrelationship of damage by bugs, infection by pathogens, and reduction in grain yield and quality requires an interdisciplinary approach to resolving this problem.

Insect pests in the U.S. constrain sorghum production in a different way than in developing countries. The ready availability of insecticides in the U.S. lessens the yield-reducing impact of insect pests. However, insecticides result in significantly increased production costs, occurrence of secondary pests, pest resurgence, and environmental contamination. Sorghums resistant to aphids, sorghum midge, and panicle-infesting bugs and caterpillars would enable sorghum insect pests to be managed in a more ecologically sound way and provide a more economically and environmentally sustainable agricultural system. Insect-resistant plants provide an important foundational component to an integrated pest management approach. However, development of these cultivars requires a holistic approach including identification of insect resistance genes, agronomic improvement of germplasm, and deployment into production systems. Much research is needed on the role these cultivars play in an integrated pest management program so that research progress is made, farmers understand how to properly use resistant cultivars, and expected yield levels of insect-resistant cultivars are known.

Research Approach and Project Output

Mali sorghum panicle-feeding bug research: The following summary report of research relative to the collaborative sorghum panicle-feeding bug project was provided by Dr. Y. O. Doumbia. The results of four trials are summarized here.

In one of two preliminary evaluation (screening) trials, the damage by panicle-feeding bugs was assessed for 50 sorghum lines under natural infestation at Sotuba in a search for new sources of resistance. This trial represented the third year of screening these sorghum lines. Most of the lines evaluated were progenies of crosses between Malisor 84-7 and other genotypes. A Fisher block experimental design with two replications was used with entries planted in two, 5-meter-long rows. For each entry, five panicles were covered with a plastic pollinating bag after panicle exertion to protect panicles from infestation by bugs. Data were collected from bug-protected and unprotected panicles, including a numerical rating of kernel damage by bugs and level of pathogen infection. Data on 200-kernel weight were collected from panicles protected using plastic pollinating bags and not protected from bug infestation.

Kernel ratings ranged from 1-4 for damage by bugs and 1-4.25 for damage by pathogens. Kernel weight ranged from 1.79-7.12 for 200 kernels. In 1993, genotypes that rated less than 2.0 for bug damage were 90-CZ-CS-TX-2, 90-CZ-CS-TX-12, 90L 19140-91 PR 2566 (2-5) (7-9), 90L 19225-91 PR 2579 (1-5), and 90L 19254-91 PR 273. Malisor 84-7 rated 1.0 for kernel damage by bugs. Genotypes that were consistently rated as most resistant during three years of evaluation are shown in Table 1. These sorghum lines were those that were damaged less than or about the same as the standard resistant check, Malisor 84-7.

A second resistance evaluation trial in 1993 consisted of 49 sorghum lines selected from the national sorghum breeding program. The trial was arranged in a Fisher block design

Table 1. Sorghum genotypes that consistently rated resistant to panicle-feeding bugs during evaluation each of three years at Sotuba.

	Bug damage rating			Pathogen rating			1000-kernel weight		
Genotypes	1991	1992	1993	1991	1992	1993	1991	1992	1993
90-CZ-CS-TX1	1.20	2.00	2.00	1.75	1.25	1.75	20.57	20.70	16.80
90-CZ-CS-TX2	2.50	1.62	1.50	1.25	1.00	2.50	17.97	15.70	15.80
90-CZ-CS-TX6	1.75	2.00	2.00	2.00	1.50	2.25	17.75	20.45	13.30
Malisor 84-7	1.50	1.75	1.00	1.00	1.00	2.00	18.60	17.10	14.30

Table 2. Bug and pathogen damage ratings and kernel weights of sorghum varieties evaluated for panicle-feeding bug resistance in an advanced screening trial in 1993 at Sotuba.

	Unprotected			Cage protected		Bag protected	
Variety	Bug damage rating	Pathogen rating	200-kernel weight	Pathogen rating	200-kernel weight	Pathogen rating	200-kernel weight
Malisor 84-7	1.12	1.87	2.20	2.25	2.82	2.00	2.18
87-SB-F4-54-2	1.57	2.00	2.25	2.50	3.40	2.00	3.11
IS16357	3.12	1.00	3.25	1.00	3.72	1.50	4.33
IS21468	1.12	1.25	2.16	1.12	2.31	1.00	2.61
IS21525	1.87	1.00	2.78	1.12	3.13	1.50	2.98
IS27477	3.50	1.25	3.76	1.25	3.81	1.00	4.29
R6078	2.25	2.25	2.27	2.62	2.78	2.25	2.68
B-Var-1	2.00	1.87	1.78	2.33	2.23	2.75	1.65
82-Select. hard kernel	3.62	1.62	4.16	1.25	4.51	1.50	4.70
CV	14.90%	31.30%	14.04%	24.46%	21.87%	36.53%	23.74%
Mean	2.27	1.56	2.75	1.71	-	1.72	3.22

Table 3. Damage ratings and kernel weights obtained after using different methods to protect sorghum panicles from bug infestation at Sotuba, 1993.

Treatment	Bug damage rating	Pathogen rating	200-kernel weight
Insecticide protected	1.25	1.60	4.21
Cage protected	1.70	2.40	3.93
Plastic bag protected	1.72	1.55	3.84
Natural infestation	2.90	2.45	3.20
CV	8.18%	8.82%	11.72%
Mean	1.89	2.00	3.79

with two replications. Five lines, 89-CZ-CS-F5-73AF, ICSV401, 88-BE-F4-257-3, 87-SB-F4-275-2, and 87-SB-L-F4-155, were least damaged and had bug damage ratings of 1.0-1.7.

In an advanced evaluation trial, eight sorghum varieties selected for their apparent resistance to panicle-feeding bugs in preliminary screening trials were tested using plastic pollinating bags to protect some panicles from bug infestation to compare panicles not protected with those naturally infested. The response of these varieties to bug infestation was compared to that of Malisor 84-7. Results are presented in Table 2.

Bug and pathogen damage ratings and 200-kernel weight for unprotected panicles of Malisor 84-7 were 1.12, 1.87, and 2.20, respectively. These parameters for unprotected panicles of the test entries ranged from 1.12-3.62, 1.00-2.25, and 1.78-4.16, with means of 2.27, 1.56, and 2.75, respectively. Varieties 87-SB-F4-54-2, IS21468, IS21525, and B-Var-1 appeared to be the most resistant to panicle-feeding bugs.

As during recent years, an experiment was conducted to determine the best means of protecting panicles from bug damage. Protected panicles provide a means of easily assessing the resistance level of a test sorghum because the protected panicles provide a basis for comparison to unprotected, naturally infested panicles. In that experiment, panicles protected using insecticide applications, constructed cages, and plastic pollinating bags were compared for their effectiveness in preventing bug damage and pathogen infestation. Kernel weight was used as a parameter for comparison, as were bug and pathogen damage ratings. The three methods used to protect panicles from bugs resulted in bug damage ratings less than those for the unprotected panicles (Table 3). Pathogen ratings were as high for panicles protected using cages as were those of unprotected panicles.

Table 4. Relationship between damage by panicle-feeding bugs and pathogen infection at Sotuba, 1993.

Treatment	Bug damage rating	Pathogen rating	200-kernel weight
Fungicide protected	2.80	1.50	3.62
Pollination bag protected	1.70	1.80	4.22
Pollination bag & fungicide protected	1.72	1.10	3.92
Natural infestation	3.00	2.25	3.37
CV	16.92%	9.02%	6.10%
Mean	2.31	1.66	3.78

Pathogen infection was less for panicles protected using insecticide applications and plastic pollinating bags. Kernel weights from panicles protected by insecticides were higher than those from unprotected sorghum.

A relationship between panicle-feeding bugs and pathogen infection is very apparent. However, the contribution of each type of pestilence has not been well defined. An experiment using application of a fungicide was done to remove the effect of pathogen infection on kernel damage and weight. Fungicide application reduced the incidence of pathogen infection (Table 4). Ratings of pathogen infection were lower where the fungicide was used and were lowest when panicles were protected from both bugs and pathogens. In general, the data indicate that bugs cause significantly more damage to kernels than do pathogens, but pathogens probably play a significant role in grain quality.

Technology Support and Student Training Research: Following are summaries of the results of graduate student research projects associated with INTSORMIL, or are summaries of technology development that support international research collaboration.

Technology Development

Greenbug biotype I represents a serious threat to the effectiveness of biotype E-resistant sorghum hybrids currently being grown. Sources of resistance to biotype I have been identified, and these have been reported in previous annual reports. Progress was make in 1993 to introgress resistance to biotype I greenbug into elite parent lines for production of biotype I greenbug-resistant hybrids. Biotype I resistance is being crossed into biotype E-resistant and susceptible parent lines, although some sources of resistance to biotype I are also resistant to biotype E. Resistance to biotype I appears to be simply inherited; consequently, procedures used to develop biotype C- and E-resistant sorghums are applicable to the development of biotype I-resistant sorghums. The difficulties encountered with the development of greenbug biotypes has lead to the need to better understand the genetics of resistant plants and the insect itself. For this reason, considerable effort is and will be made to use molecular genetic technologies to better understand sorghum and greenbug genetics and their interrelationships.

Selections for resistance to sorghum midge were made among agronomically improved segregating germplasm lines advanced two generations using Puerto Rico winter nurseries. Elite sorghum midge-resistant lines and parent lines in hybrid combination were evaluated at College Station. Excellent progress in developing acceptable sorghum midge-resistant hybrids continues to be made. Advanced generation A-lines appear to hold promise for making significantly improved resistant hybrids. Introgression of different gene sources to elevate the resistance level continues to be made. Plans are to soon release another group of sorghum midge-resistant parent lines.

Student Training

The sorghum midge component of the sorghum plant growth model—SORKAM was refined by using sorghum midge occurrence and abundance data, subsequent sorghum panicle damage, and yield data collected in fields in the Coastal Bend and Blacklands regions of Texas. Initial execution of the model indicated a need to refine the Johnsongrass density-sorghum midge production, sorghum midge survival, and proportion of sorghum midges surviving after insecticide application equations of SORKAM, so that initial occurrence and abundance of predicted values were decreased. Additional data on sorghum midge occurrence and abundance in the Coastal Bend and Blacklands regions were used to validate the sorghum midge component of the model. Initial predicted values of sorghum midge occurrence were decreased from approximately five to two days and abundance decreased from a mean above the actual values of 6.75 to 0.35 sorghum midges per panicle. However, 95% of the predicted damage values were less than actual values and 92% of the predicted grain yield values exceeded actual values. This inverse relationship indicated a need for further modification of SORKAM's panicle damage equations. The model could be used as a management strategy in predicting the occurrence and density of sorghum midges in relation to time of sorghum flowering.

Differential immigration pattern of sorghum midge was reassessed. Two sorghum midge-resistant sorghum lines (RTx2782 and RTx2767) and one susceptible (Tx430) were planted April 30. Sorghum midge spreader, a mixture of sorghum midge-susceptible hybrid seed of various maturities, was uniformly planted around each experimental plot. This was done to assure that the source of sorghum midge infestation was similar for each sorghum line. Before flowering, yellow sticky traps located approximately one foot above panicles were proportionally distributed in and around sorghum plots. The number of sorghum midge adults trapped was recorded daily throughout the sorghum flowering period so as to determine differences in abundance of infesting populations. Information obtained will be used to validate analysis of sorghum infestation made in 1992.

The time and duration of flowering of eight sorghum lines and hybrids with a range of resistance and susceptibility to the sorghum midge were determined in field plots planted at three different times. The spikelet flowering process was divided into six distinct stages, and the proportion of spikelets in each stage on selected rachis branches was assessed hourly from spikelet opening to closing for 11 consecutive hours every other night. Adult sorghum midge abundance was assessed hourly by counting the number of sorghum midges on the sorghum panicles from which flowering data were collected and on additional panicles. Temperature and relative humidity measurements were collected on an hourly basis and were used to assess the influence of weather factors on time of sorghum flowering and presence of sorghum midges. The number of spikelets damaged by sorghum midges were counted when the kernels were in the hard-dough stage. Analysis of the data indicated that the more resistant sorghum flowered during early morning hours, when sorghum midges were not present. Also, glumes of spikelets of the more resistant sorghums were open for a shorter time than were those of more susceptible sorghums. Spikelets of susceptible and resistant sorghum lines and hybrids were dissected and observed by using a microscope. A sample of 15 spikelets from each sorghum line or hybrid was collected and dissected each day for 10 days. Stigmas and styles of florets of susceptible sorghum were long and ovaries were small. The stigmas and styles of florets of resistant sorghum were shorter but ovaries were larger than those of florets of susceptible sorghum. Closed spikelets from the different sorghum lines and hybrids were collected and observed to determine whether the glumes of the spikelets were actually closed. Microscopic observation showed that there was a ≤1-mm wide opening either between the glumes or between the anthers and the glumes of spikelets of susceptible sorghum when the spikelets appeared closed. Glumes of resistant sorghum lines and hybrids overlapped when the glumes appeared during field observation to be closed.

Sorghum midge diapause termination is a key element in the population dynamics of the sorghum midge. Sorghum midge emergence and meteorological data are being collected for use in a model to predict when sorghum midges will terminate diapause and emerge after overwintering. Rainfall maps generated by Doppler Radar will be used to determine when model predictions should begin. The emergence of overwintering sorghum midges is monitored by using 1 m^2 pyramid traps. These traps collect adults emerging from overwintering in spikelets underneath or on the soil surface. Three treatments being used to determine the effect of rainfall/moisture on termination of sorghum midge diapause are: 1) a control exposed to natural weather conditions, 2) soil kept dry, and 3) soil kept dry initially, but water added later. Three cultural conditions that will be used to evaluate their effect on sorghum midge survival and emergence from diapause are: 1) sorghum residues shredded only, 2) residues shredded and disked into the soil, and 3) residues shredded, disked into the soil, and the soil deep plowed.

RFLP analysis is being used to map the location of greenbug (*Schizaphis graminum*) resistance genes. To simplify this process, genotypes differing in resistance to greenbug are being used as the parents for the mapping population. Crosses have been made between the biotype I-resistant PI550607 and the susceptible line Tx430, and between biotype E-resistant Tx2783 and the susceptible Tx430. An interspecific cross between Tx2783 and a susceptible *Sorghum propinquum* was also produced for this purpose. The F2 populations of these crosses have been evaluated in the greenhouse to identify those segregating for greenbug resistance. The progeny of segregating populations are then evaluated by RFLP analysis to determine the presence of polymorphisms. Locations of greenbug resistance genes will be based on DNA markers selected from a complete RFLP map of the sorghum genome produced by Dr. Andrew H. Paterson's laboratory at Texas A&M University. Determining the genetic map positions of these genes will hasten their identification and transfer into more productive sorghum genotypes.

A greenhouse study was performed to evaluate the effectiveness of imidacloprid, formulated as a seed-treatment insecticide, for control of yellow sugarcane aphid on 3-, 10-, and 31-day-old sorghum seedlings. This systemic and contact insecticide with low mammalian toxicity, was extremely effective in controlling yellow sugarcane aphid on young plants. Additional studies included the use of imidacloprid as a foliar treatment for greenbug control. Future studies will include field trials involving imidacloprid as a seed treatment for aphid control on older, more mature plants. A greenhouse insecticide trial was conducted to evaluate Lorsban, Lannate, Parathion, and Asana XL as foliar treatments for control of yellow sugarcane aphid on sorghum seedlings. Only applications of Asana XL resulted in less than complete control of yellow sugarcane aphid 1, 2, and 3 days after treatment. Another field trial was conducted to evaluate two standard insecticides, several pyrethroids, and corn oil for control of sorghum midge. Plots were planted with a mixture of hybrid seed of various maturities to simulate a typical non-uniformly flowering field. All applications of pyrethroids resulted in significant increases in yield when compared with yields from plots treated with Lorsban or Dyfonate. Plots treated with corn oil alone yielded slightly more than plots treated with either Lorsban or Dyfonate.

Networking Activities

Research Investigator Exchanges

Ten LDC scientists visited the sorghum entomology program at Texas A&M University. George L. Teetes traveled to Mali to review research progress on panicle-feeding bugs. The collaborative research conducted in Mali is reported in an earlier section of this report and is further described in the Mali country report. A major effort is needed to get the Mali panicle-feeding bug research results published in a refereed journal.

Germplasm and Research Information Exchange

Seeds were requested by nine LDC scientists, and these requests were forwarded to Dr. Gary C. Peterson. Publication reprints or copies related to sorghum entomology were sent to 35 LDC scientists. Research supplies and equipment were sent to Mali 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, Principle 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.

George L. Teetes served as a member of the organizing committee for the International Consultative Workshop, sponsored by ICRISAT, on Panicle Insect Pests of Sorghum and Pearl Millet in Niamey, Niger.

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Biological Control Tactics for Sustainable Production of Sorghum and Millet

TAM-125B

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Objectives, Production & Utilization Constraints

Objectives

Objectives of project collaborative work are (1) to assess the efficacy of natural enemies for biological control of stalk borers and the millet head miner; (2) to implement effective biological controls for pests of millet; and (3) domestically to provide graduate level training programs, develop strategies for implementing biological controls in sorghum and millet, test strategies for implementing biological control in annual crop ecosystems, investigate plant-pest-natural enemy ecology and assess potential of natural enemies as biological control agents for sorghum and millet pests, and optimize integration of effective biological controls with local crop protection and production needs.

Constraints

The insect pests of sorghum/millet addressed in this research are key pests and constraints to production in the U.S. and West Africa. Annual crops such as sorghum and millet sustain damage and control costs from infestations of key pests such as aphids, stalk borers and millet head miner. These costs are variables that must be managed each year. Ideally, each pest is managed with ecologically sound practices. To be most effective, these practices optimize the sustainability of a cropping ecosystem. Detailed ecological understanding of pests and their natural enemies is key to a sustainable pest management strategy, especially during times of the year when pests occupy noncrop portions of the agroecosystem. The project's approach includes on-site collaborative research, development of complimentary U.S. technology, evolution of necessary theory, and graduate student training. The collaborative research in Niger seeks to implement biological control of stalk borers and the millet head miner, and in the U.S. to implement biological control of aphids and spider mites. Research in the U.S. provides a platform for training graduate students, evolving theory and concepts for implementing biological controls in West Africa, conceptualizing and defining functional ecosystems of pests, developing methodologies for measuring the actual and potential impacts of natural enemies, and validating results of biological control when implemented.

Research Approach and Project Output

Niger millet stalk borer and millet head miner research. The primary goal of this project is to implement biological controls of the millet pests, enlarging on research conducted by Dr. Ousmane Youm in Niger in 1986-88. Key elements of this project are: (1) collaborative research with NARS in West Africa via the West and Central Africa Millet Research Network (WCAMRN) (i.e., Reseau Ouest et Centre Africain de Recherche sur le Mil, ROCAFREMI) and the ICRISAT Sahelian Center; (2) research training in biological control for a NARS scientist in West Africa; and (3) collaboration with scientists at the ICRISAT-SC.

Since 1992, this research has sought to initiate a new Ph.D. program to research biological control of millet head miner. For several reasons, we have been unable to achieve that goal with IER (Mali) or INRAN (Niger) in Project Years 13-15. In August 1992, we submitted a proposal to INRAN to train an INRAN scientist for future collaboration on identifying and assessing natural enemies of millet head miner (MHM). This proposal was accepted by the Director General of INRAN and the local USAID mission, but an INRAN trainee was not approved for 1992. In August 1993, this proposal was updated and resubmitted to INRAN. INRAN administrators reaffirmed that this effort is an important collaboration for Niger and INRAN, but again an INRAN trainee did not participate. To avoid continuing no progress on research, I assigned Mr. Bayoun (a Lebanese Ph.D. student in my program) to initiate the needed research in Niger, and to provide a methodological foundation for eventual collaboration with a West Africa NARS scientist.

The millet head miner (MHM), *Heliocheilus albipunctella* (de Joannis), commonly causes significant crop losses of pearl millet, *Pennisetum glaucum* L., a primary food crop in Sahelian West Africa. MHM is an excellent candidate for demonstrating a control strategy that emphasizes effective natural enemies. It occupies a predictable habitat in an ecosystem with relatively consistent annual habitats, has one generation per year, attacks several host plants including wild millet, and across West Africa supports a relatively large guild of natural enemies. Our objective in this research is to evaluate natural enemies of *H. albipunctella*, and the results will serve to appraise tactics and develop a biological control strategy for *H. albipunctella*.

Our 1993 research provides baseline methods and initial results for planning 1994 experimentation. The 1993 experimentation consisted of cage exclusion studies and population monitoring at Sadore. Exclusion experiments are essentially a series of paired plots in which natural enemies are excluded from one-half, and are allowed access to the other half (= Control or Check). Survival is measured in all plots, and the differences in surviving pests between treatments are direct measures of control by natural enemies. These treatments can be modified in various ways to collect different kinds of information on pest mortality. In 1993, we used only caged exclusions that consisted of placing a physical barrier (i.e., panicle cage) over panicles in the plots. Openings were made in one-half of these cages to permit normal natural enemy ingress and egress. Different types of cage treatments were set up to evaluate enemies occurring on different MHM stages (i.e., eggs, early and late instars) separately. Caged panicles were initially infested with similar numbers of MHM eggs or 1st stage larvae. Treatments imposed on these infested panicles included (1) cages closed throughout panicle development, which excluded all natural enemies; (2) cages opened only during the MHM egg stage, and then closed until the end of the season; (3) cages opened only when early MHM instars were present, and then closed for the remainder of the season; (4) cages opened only when late MHM instars were present, and then closed for the remainder of the season; and (5) cages opened for the duration of MHM development. At the end of the season, millet heads were cut and numbers of surviving MHM were assessed. All collected natural enemies were sent to appropriate taxonomic authorities for identification.

Our results showed that attacks by natural enemies have a very significant impact on mortality of MHM, and most of this mortality occurs during the late larval stages. Numbers of surviving MHM individuals in cages opened throughout panicle development were significantly different from those in closed cages.

Significantly, we encountered relatively few species of enemies attacking MHM during this first year of experimentation. Two predators and two parasites were the most commonly recovered natural enemies. The most common predator was *Orius* sp., a small anthocorid predator that attacks MHM eggs and early instars. The second most common was an ant that attacked full-grown larvae after they dropped to the soil to pupate. These predators will be further investigated in 1994 experiments.

The two commonly encountered parasites were both parasitic Hymenoptera. The most abundant parasite was *Copidosoma* sp., an encyrtid egg-prepupal parasite that attacks the MHM eggs and emerges the next year as an adult from the MHM prepupa. This parasite is polyembryonic, i.e., one parasite egg produces many progeny. An average of 394 (maximum = 802) adult parasites emerged from each parasitized MHM. The second most common parasite was a braconid, *Bracon hebetor*. *Bracon* is a gregarious ectoparasite that attacks late larval stages of MHM. Parasitism by *B. hebetor* occurs mostly late in the season, and can reach 80-90% of the total MHM population. Female *B. hebetor* attack late MHM instars, permanently paralyzing each. Many, but not all, attacks by *B. hebetor* result in the parasite ovipositing externally on the MHM larva. Studies in 1993 encountered many larvae killed by *B. hebetor* but without parasite eggs. Thus, *Bracon hebetor* functions ecologically as a predator and as a parasite. *Bracon hebetor* has a short generation time and is polyphagous (i.e., attacks many other host species).

During 1994-1996, these exclusion studies will be repeated on MHM developmental stages in Sadore and Maradi, and data will be used to construct life tables for MHM. Each year, the methodology will be refined. By 1996, we will be able to advocate an MHM biological control research program for NARS participating in ROCAFREMI. Ultimately, we will construct survival budgets for MHM, and characterize the portion of MHM population removed by natural enemies. Our research approach will continue to use host exposure techniques, caged exclosures and natural population monitoring.

Research on Assessing the Efficacy of Natural Enemies Attacking Greenbugs on Grain Sorghum. Experiments were conducted to develop an insecticidal check method for assessing the efficacy of natural enemies of greenbugs (GB). These initial experiments assessed an "enemy removal method" and an "enemy trap method." In the removal method, plants in the experimental plot were treated with either chlorpyrifos or malathion to remove the natural enemies. Rates of treatment were based on prior experiments, and were set to minimally affect greenbugs in these plots. In the trap method, plants in the area immediately surrounding the plot were treated and plants within the plots were undisturbed. Trap method plots were treated with the pyrethroid λ-cyhalothrin or with λ-cyhalothrin mixed with the systemic organophosphate, dicrotofos. The trap method seeks to repel or kill natural enemies of GB in the treated area and thus prevent their entry into the central experimental plots. In both methods, the enemy removal and enemy trap, numbers of aphids in a treated plot were compared with the aphid numbers in a control plot. This comparison establishes the role of parasites and predators in reducing aphid population growth.

The mean GB population trends were similar in both the enemy trap and enemy removal experiments (Fig 1 & 2). The population increase began after panicle exertion (early August) and peaks were observed by mid-August. In both experiments, parasites suppressed the GB population by the end of August (Fig 3 & 4). Predator activity was greatest before crop maturity and then declined. Species of natural enemies recovered from samples included *Lysiphlebus testaceipes* (Cresson), *Aphelinus asychis* Walker, *Aphelinus albipodus* Hyatt & Fatima, *Hippodamia convergens* Guerin, *Hippodamia sinuata* Mulsant, *Coccinella septempunctata* L. and *Coleomegilla maculata lengi* Timberlake.

Data from 1993 experiments showed that frequencies of insecticide application did not prevent natural enemies from entering the experimental plots. In trap experiments, plots were sampled on six different dates for numbers of Greenbugs/plant, predators/plant, and parasites/plant. At the 95% confidence interval, numbers of greenbugs in plots treated with λ-cyhalothrin once per 15 days and in those treated with λ-cyhalothrin and bidrin once per 15 days were different from numbers of greenbugs in control plots on August 5 and September 2. However, these differences were not statistically significant. At the 95% confidence interval, removal plots treated at different frequencies with malathion and chlorpyrifos were not significantly different from untreated control plots on four sampling dates. However, these differences were statistically significant at the 90% confidence interval. Using nonparametric statistics, data from the natural enemy plots (both enemy trap and enemy removal plots) were not significantly different from the untreated control plots.

In summary, the trap method was a more effective suppressor of the parasite population. However, differences among plots were not large enough to separate the treatments for either enemy trap plots or enemy removal plots. Variability among plots is one of the key problems that must be overcome in 1994 research. Much of the variation was probably due to sample size being too small, and to insufficient replication. Modifications in experimental design and sampling will be made for 1994 experiments.

Networking Activities

Invited participant in the 3rd Biennial West and Central Africa Millet Research Network (WCAMRN) (i.e., Reseau Ouest et Centre Africain de Recherche sur le Mil, ROCAFREMI), April 4-8, 1994. The meeting was held at the ICRISAT Sahelian Center near Niamey, Niger. The primary activities were participation in the network meetings; improving collaboration and partnerships between INTSORMIL, NARS and ICRISAT-ISC; and finalizing plans for 1994 collaborative research program with INRAN and

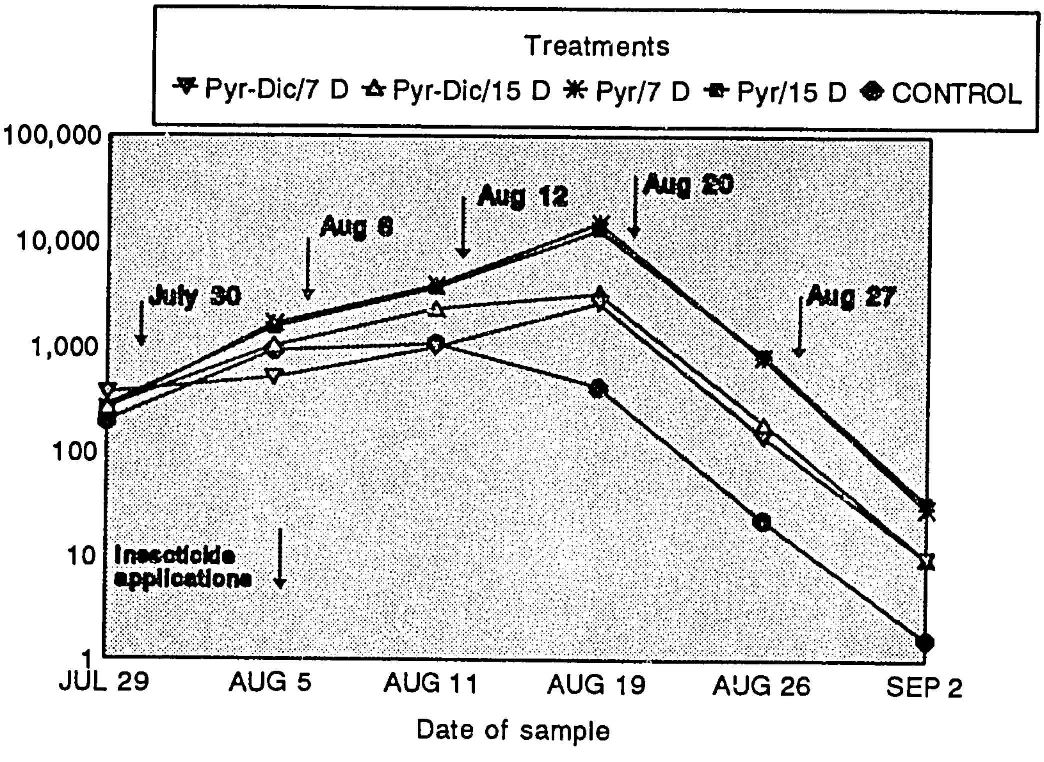

Figure 1. Numbers of greenbugs per plant in Trap Method.

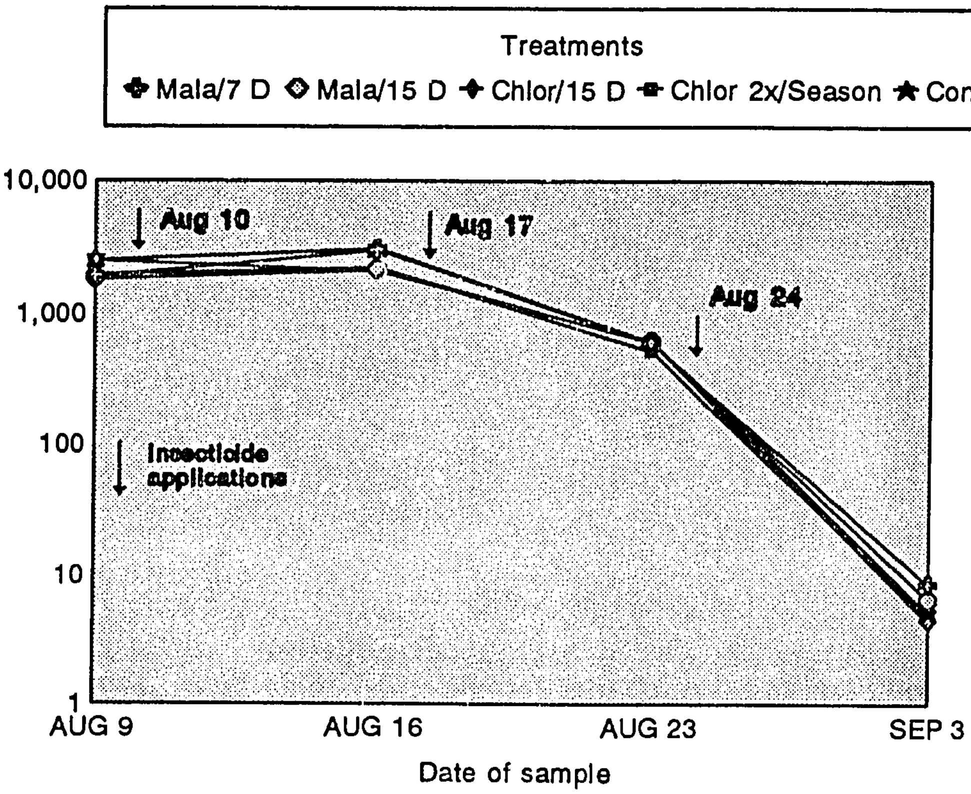

Figure 2. Numbers of greenbugs per plant in Removal Method.

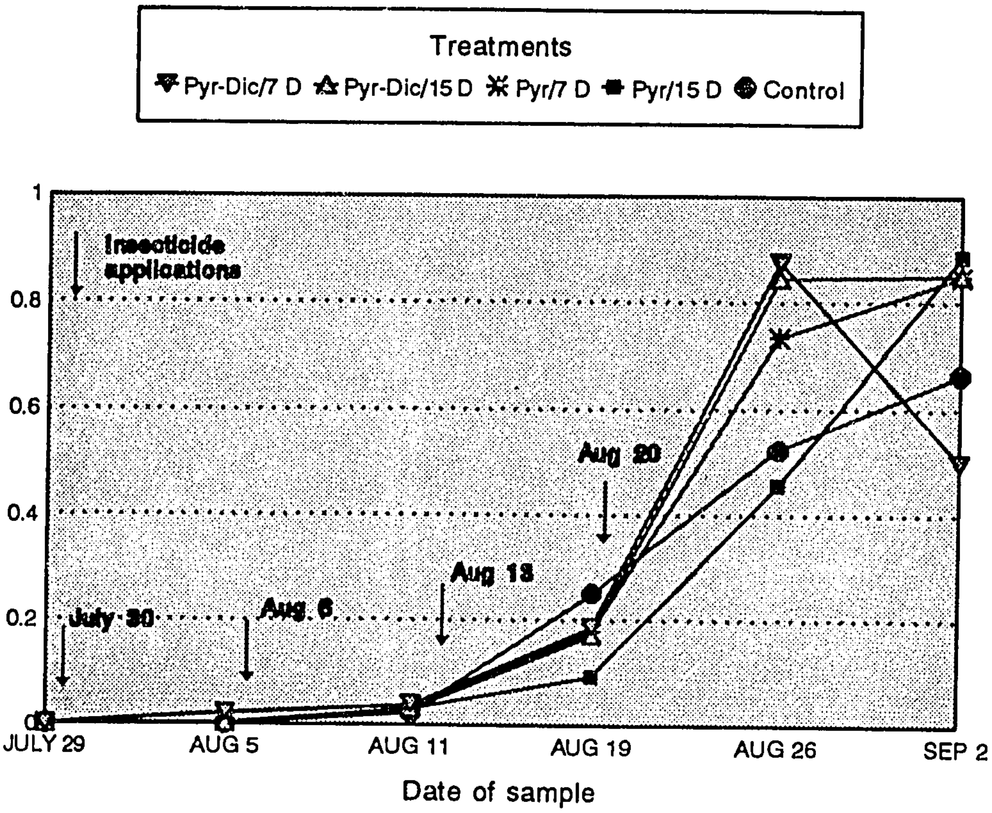

Figure 3. Numbers of parasites per greenbug in Trap Method.

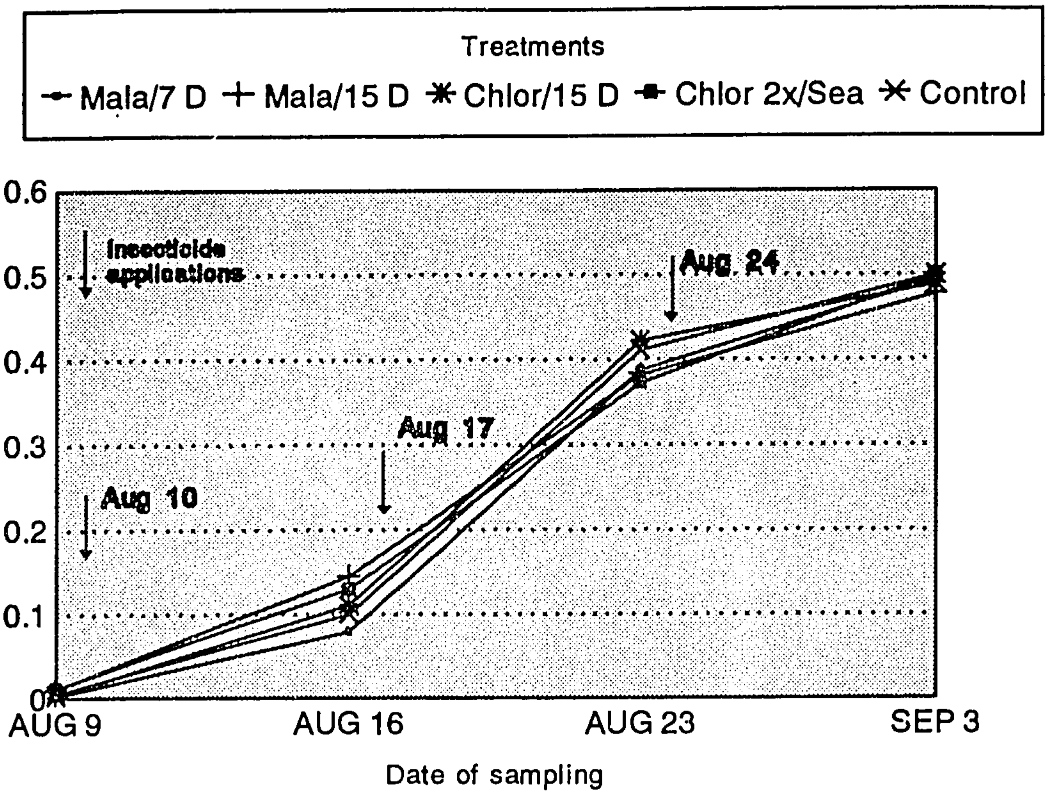

Figure 4. Numbers of parasites per greenbug in Removal Method.

ICRISAT on millet head miner. Participants in ROCAFREMI requested that INTSORMIL scientists collaborate in millet research with expanded INTSORMIL roles in training, specialized short-courses, mini-workshops or other associations. This request resulted in invitations for three teams of INTSORMIL scientists to lead 1-2 day short-courses conducted coincident with three ROCAFREMI Annual Project Meetings in 1995.

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Development of Plant Disease Protection Systems for Millet and Sorghum in Semi-Arid Southern Africa

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Summary

In 1993-94, two sorghum nurseries were planted at two locations in Zambia and two locations in Zimbabwe to evaluate response to anthracnose and leaf blight. These two nurseries, called Anthracnose Resistant Germplasm Nurseries (ARGN-1, 33 entries and ARGN-2, 41 entries), consisted primarily of entries that had excellent anthracnose (*Colletotrichum graminicola*) resistance, good adaptation to the region, and good to excellent leaf blight (*Exserohilum turcicum*) resistance in previous SADC testing over one or more years. At the Henderson Station in Zimbabwe, the average leaf blight incidence (percent leaf area destroyed) in these nurseries was 21% across all 74 entries, 75% in the most susceptible cultivar (R8601), and ≤10 % in the 25 most resistant entries at 103 days after planting. Sooty stripe (*Ramulispora sorghi*) incidence was rated in these same ARGN nurseries at Golden Valley, Zambia and at Panmure Station, Zimbabwe. The average incidence of sooty stripe was 24% and 19% across all cultivars and 80% and 58% on the most susceptible cultivar (R6956) at Golden Valley and Panmure, respectively. Twenty-seven entries had an incidence of sooty stripe ≤ 20% at both locations. Ten of the seventy-four entries demonstrated high resistance to both leaf blight and sooty stripe at these three locations and in previous years had demonstrated good resistance to anthracnose. One of these ten entries was SC326-6 and five others had SC326-6 in their genetic background. A virus disease was observed at the Pandamatenga station for the second consecutive year and the incidence/severity of virus response in the International Sorghum Virus Nursery was most consistent with MDMV-A but that remains to be confirmed. Similar virus symptoms were noted this year at the Mt. Makulu station in Zambia where MDMV-A was

confirmed in previous years. Drought response of sorghum cultivars in two nurseries planted at two locations in Southern Zimbabwe (Matopos and Lucydale) indicated the need for pre-flowering drought tolerance in this region. Entries with post-flowering drought tolerance often had partial to full blasting of the head, especially as stress occurred earlier in maturity and with increased severity. All mating populations (A, B, C, D, E, F) of *Gibberella fujikuroi* (*Fusarium* section Liseola) were recovered from sorghum grain collected in Tanzania with mating population F occurring in the highest frequency. Studies of preharvest aflatoxin in sorghums, with differing pericarp genetics, exposed a recurring problem of false positive aflatoxin readings when using a popular commercial immunoclonal assay system for aflatoxin determinations.

Objectives, Production and Utilization Constraints

Identify stable adapted sources of resistance to major foliar pathogens through field screening nurseries at strategic locations: Zambia, Zimbabwe, Botswana

Identify pathotypes of *Colletotrichum graminicola* from southern Africa using differential cultivars: Zambia, Zimbabwe

Characterization of *Fusarium* spp. on sorghum grain: Tanzania

Characterization of *Macrophomina phaseolina*: Zambia, Zimbabwe, Botswana, U.S.

Ecology and economic impact of *Exserohilum turcicum*, specific and general leaf disease resistance: Zimbabwe

Identfy sources of late season drought tolerance with adequate charcoal rot and other disease resistance: Botswana, Zimbabwe

Evalate potential for preharvest aflatoxin in sorghum grain: U.S.

Research Approach and Project Output

Foliar Diseases (Anthracnose, Leaf Blight, Sooty Stripe)

In 1993-94, two sorghum nurseries were planted at two locations in Zambia and two locations in Zimbabwe to evaluate response to anthracnose and leaf blight. These two nurseries, called Anthracnose Resistant Germplasm Nurseries (ARGN-1, 33 entries and ARGN-2, 41 entries), consisted primarily of entries that had excellent anthracnose resistance, good adaptation to the region, and good to excellent leaf blight resistance in previous SADC testing over one or more years. New entries in these nurseries usually had some genetic relationship to the best of the previously evaluated cultivars.

Incidence of leaf blight (caused by *Exserohilum turcicum*) was evaluated at the Henderson Station in Zimbabwe at 72 (2/24/94) and 103 (3/27/94) days after planting. Average incidence of leaf blight (percent leaf area destroyed in two reps) across all 74 entries of the ARGN nurseries was 9% at 72 days after planting and 21% at 103 days. The most leaf blight susceptible entry (R8601) had 33% and 75% average incidence of leaf blight at 72 and 103 days, respectively. Table 1 shows entries in the ARGN nurseries that had an average incidence of leaf blight ≤10 % at 103 days after planting. Also shown in Table 1 for these 25 resistant entries is their average incidence of leaf blight at 72 days after planting and their average agronomic desirability rating (1 to 5, 1=best, 5=worst) at 103 days after planting.

Late planting and late development of anthracnose at Mansa and Golden Valley, Zambia precluded definitive anthracnose ratings on the ARGN nurseries at these sites. At Mansa, anthracnose had developed to high levels in an adjacent earlier planted nursery from which we systematically sampled the population for RFLP analysis by U. Rosewich, R.A. Frederiksen's graduate student, working on Project TAM-124.

Sooty stripe incidence and severity were sufficient to rate the ARGN nurseries at Golden Valley and at Panmure Station, Zimbabwe. The average incidence (percent leaf area destroyed in two reps) of sooty stripe (caused by *Ramulispora sorghi*) was 24% and 19% across all cultivars and 80% and 58% on the most susceptible cultivar (R6956) at Golden Valley and Panmure, respectively. The most resistant cultivars (average incidence of sooty stripe ≤20% at both sites) are shown in Table 2.

Ten of the 74 entries in the ARGN-1 and ARGN-2 had high resistance to both leaf blight and sooty stripe (Table 2). Of those ten resistant entries, one was SC326-6, four were derived from the same cross of R5646*SC326-6, and one had SC326-6 in its genetic background. The variable incidence and severity of anthracnose, leaf blight, and sooty stripe at these nursery sites across the years, especially at Golden Valley, indicate the need for cultivars to have some general leaf disease resistance. SC326-6 continues to be a good source of overall leaf disease resistance including anthracnose in Zambia where many of the above materials demonstrated good resistance in previous years (1992, 1993).

Virus

Disease evaluations done at Pandamatenga, Botswana in early April 1994 indicated the presence of a virus disease similar to that observed in 1993. Red and tan leaf necrosis were the most common symptoms with only a minimal amount of viral mosaic observed. Reaction of sorghum entries from the International Sorghum Virus Nursery (ISVN) planted at this site were most consistent with the response of MDMV-A. Entries New Mexico 31, BTX378 (Redlan), TX7000 (Caprock), and BTX3048 had heavy red

Table 1. Sorghum entries of the ARGN-1 and ARGN-2 resistant to leaf blight (≤10%) at Henderson Station, Zimbabwe in 1994.[a]

Genotype or Designation	Henderson		
	LB-Avg		Agron-Avg
	2/24/94	3/27/94	3/27/94
SC146	0	0	2.8
SC326-6	0	0	3.8
86EON374((TX432*CS3541)*SC326-6)deriv	0	2	2.5
[92L24-BK] R9109	1	3	2.5
86EON362 (R5646*SC326-6)deriv	0	4	2.3
[89CW2929] (R8505*(((Tx432*CS3541)*SC326-6)-HF69	1	4	3.3
[89BE8236] (R2241*(R5646*SC326-6))-HD11	4	4	3.0
82BDM499 (SC173*SC414-12E)deriv	0	5	2.5
[92C4782BK] (77CS2*SC326-6)deriv-C1	0	5	2.8
[90C241BK] ((SC120*Tx70000*Tx7000)-10deriv-T1	2	5	2.3
SC991	2	5	3.3
[92C2422BK] (Tx2817*EBA-1)deriv-B1	3	5	2.5
[92C631] (80C2241*R4224)deriv-B1	1	6	2.5
[87L3452] 86EON362sel	1	7	2.0
[90C2132-BK] (ADN55*B8204)deriv-T2	2	7	2.5
SC574	2	7	2.8
SC647	0	8	3.5
91C28521](((SC120*Tx7000)*Tx7000)deriv*R6956)deriv-C2	1	8	3.0
[91CC673] (R8505*((TX432*CS3541)*SC326-6))-HF59	2	8	2.8
[87BH8351] 86EON361sel	4	8	2.3
[87BH8341] 86EON361sel	4	9	2.0
R6956	5	9	2.8
[87L3450] 86EON362sel	2	10	2.5
[92C2494-BK] ((Tx414*SC108)deriv-OP*R6956)deriv-C1	4	10	2.3
[91C643]84C7730	6	10	2.5

[a] Average incidence of leaf blight (LB-Avg, percent leaf area destroyed) from two reps is shown for two dates which are 72 and 103 days after planting. Only entries with an incidence of leaf blight ≤10% on 3/27/94 are shown. Cumulative number of entries for both tests was 74. Average agronomic desirability (Agron-Avg, 1 to 5, 1=best, 5=worst) from two reps is shown for the latter date. Evaluations on 2/24/94 were done by Mtisi, Benza and on 3/27/94 by Odvody, Mtisi, Benza.

Table 2. Cultivars from ARGN-1 and ARGN-2 with resistance to sooty stripe (SS) at Golden Valley, Zambia and Panmure Station, Zimbabwe. Average incidence ≤20% at both locations.[a]

Genotype or Designation	Golden Valley SS-Avg 3/26/94	Panmure SS-Avg 3/28/94	Henderson LB[b]
SC748	5	0	
SC326-6	5	2	*
SC146	5	13	*
SC748-5	8	2	
[89PR1688] (SC173*SC414)deriv	13	1	
TAM2566	13	8	
[91CC673] (R8505*((TX432*CS3541)*SC326-6)-HF59	13	15	*
[91C562] B9006	15	6	
ATx638*R8602 hybrid	15	8	
[87BH8351]86EON361sel	15	13	*
SC647	15	13	*
[93BD2455]Sureño*87BB396deriv	15	13	
[90CCEON362] R1183*(SC120xTX7000)deriv	15	15	
SC726	18	0	
[89PR1679] (SC173*SC414)/499	18	0	
(SC173*SC414)/413	18	5	
SRN39 (Striga Resistant)	18	8	
[87L3450] 86EON362sel	18	8	*
[92L4341] 90CCEON362/(R1183*(SC120*TX7000)deriv	18	8	
[87BH8341]86EON361sel	18	13	*
[92BD1908] PL2120*86EO361 deriv	18	15	
86EON374 ((TX432*CS3541)*SC326-6)deriv	18	15	*
86EON362 (R5646*SC326-6)deriv	18	15	*
SC414-12E	20	9	
[92C2494-BK] ((Tx414*SC108)deriv-OP*R6956)deriv-C1	20	13	*
[92BD1916] PL2120*86eo361deriv	20	18	
[92BD1016] R5647*(SC414*SC326-6)deriv	20	20	

[a] Average incidence of sooty stripe (SS-Avg, percent leaf area destroyed) from two reps is shown for two locations on the date ratings were made. Cumulative number of entries for both tests was 74. Evaluations at Golden Valley were done by Odvody and Kaula and at Panmure by Odvody, Mtisi, and Garutsa. Planting dates were mid-December at both Golden Valley and Panmure.

[b] Asterisk (*) indicates cultivar also had resistance to leaf blight (LB) at Henderson Station (Table 1).

leaf necrosis and SA394 had heavy tan leaf necrosis (only in one of three reps). Further evaluations are being conducted by DAR pathologists on virus specimens collected and transferred to the Sebele Station in Gaborone. MDMV-A is suspected also because of its previous identification at the Mt. Makulu station in Zambia. In late March 1994, the incidence of MDMV-A(?) and associated red- and tan-leaf necrosis (depending on host pigmentation) were quite heavy at Mt. Makulu in some released sorghum inbreds, especially at one location where virus mosaic symptoms were also observed in a few plants of a grassy weed bordering the field plot.

Drought Stress and Charcoal Rot

In early April 1994, the drought response of sorghum in the Drought Line Test (DLT) and Preliminary Drought Line Test (PDLT) at two locations in Southern Zimbabwe (moderate to severe drought stress at Matopos and early, severe drought stress at Lucydale) indicated the necessity for pre-flowering drought tolerance in sorghum cultivars for this region. The inclusion of some post-flowering drought tolerance along with pre-flowering drought tolerance would probably be valuable for the SADC region but not as the primary drought response mechanism. Sorghums primarily possessing post-flowering drought tolerance developed moderate to complete blasting of the head as pre-flowering stress increased in severity and earliness. Environmental stress and crop maturation appeared to be conducive to charcoal stalk rot development at Matopos but the disease was observed externally in only a few definitive instances.

Grain Mold

Anaclet Mansuetus completed his dissertation research on characterization of *Fusarium* species, section Liseola from samples of sorghum grain collected in Tanzania in 1991. Sexual stages are useful in differentiating mating populations that are actually separate biological species but do not have distinct morphological characters. Mating populations within *Gibberella fujikuroi* (*Fusarium* section Liseola) were identified by using mating type testers. All mating populations (A, B, C, D, E, and F) were recovered from sorghum grain at Ilonga, Tanzania but not at Ifakara or Kachiri. Locations did not differ significantly in mean percent of mating populations A to F. Mating population F occurred in higher frequencies than mating population A or D and mating population C was the least frequent. Percent mating population A and F were significantly different ($P>0.01$) at Ilonga. Female fertile strains were significantly more common ($P>0.02$) within mating population A than F (Table 3). Genetic diversity and other information about mating populations A and F as determined by vegetative compatibility groups are summarized in the TAM-124 report.

Preharvest Aflatoxin in Grain Sorghum

Grain sorghums of the Genetics of Pericarp Nursery representing various pericarp types were evaluated for vulnerability to naturally-occurring preharvest aflatoxin in South Texas. The measurements of aflatoxin content with a commercial immunoclonal antibody system (Aflatest 10, VICAM, Somerville, MA, U.S.) were often confusing because sorghum pericarp and grain pigments and other grain factors interfered with the aflatoxin assay. False positive readings for aflatoxin content were sometimes obtained when no aflatoxin was present or additive false positive readings inflated the actual aflatoxin content. Modifications to the current assay procedure are being developed to eliminate false positive aflatoxin readings in sorghum. Because some of the sorghums in this nursery are very diverse, the false-positive aflatoxin problem may be limited to only certain types of sorghum not generally utilized in the grain trade. However, we will determine if the basic factors contributing to false positive aflatoxin readings in this study may also affect aflatoxin measurements conducted on sorghums in commercial production.

Table 3. Female fertility within mating types and populations of *Gibberella fujikuroi* (*Fusarium* section Liseola) on sorghum from Tanzania.

Location/	Female fertility (%) within											
female fertility[a]	A^+	A^-	B^+	B^-	C^+	C^-	D^+	D^-	E^+	E^-	F^+	F^-
Ifakara												
Types	41	70	50	0	Absent		100	50	Absent		23	19
Populations	48		50		Absent		66		Absent		22	
Ilonga												
Types	38	100	0	50	0	50	100	44	0	50	14	21
Populations	46		25		33		50		50		17	
Kachiri												
Types	50	75	0	67	Absent		50	30	50	40	0	43
Populations	60		25		Absent		33		43		15	

[a] Female fertility was determined by placing testers on complete media slants and wildtypes on carrot agar prior to fertilization.
Locations did not differ significantly in their female fertility within *G. fujikuroi*.
Mating populations A and F were significantly different ($P>0.02$) in their percent female fertility. Populations A and D were also different ($P>0.05$) in percent female fertility.

Networking Activities

Germplasm Exchange

Over 420 lines and cultivars were evaluated in the SADC region in 1993-94 (collaborative with TAM-121, TAM-122, TAM-123, and TAM-124)

Eleven sorghum accessions were brought into the U.S. from the SADC region in 1993. All had good drought response characteristics except one which had specific susceptibility to sorghum downy mildew.

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.

Publication

Mansuetus, A.S. B. 1993. Mating populations and vegetative compatibility groups within *Gibberella fujikuroi* (*Fusarium* Section Liseola) on sorghum in Tanzania. Ph.D. dissertation. Texas A&M University, College Station, Texas. 96 p.

Sustainable Production Systems

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

Project MSU-111

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Summary

This is a terminal report for MSU-111. This project was terminated June 30, 1994 by INTSORMIL primarily because of USAID travel restrictions to Colombia and not because it was considered ineffective in the development of acid soil technology related to sorghum and pearl millet production or lacking in the development and release of acid soil tolerant varieties. This report will summarize the need for acid soil research and will discuss some of the project's productivity since its inception in 1981.

Over two billion hectares of land with acid soils are distributed throughout the tropics. Tropical South America has over 860 million hectares of these problem soils with their various chemical constraints to agricultural production. Average yield of grain sorghum has decreased in the last two decades due to more marginal acid soil lands being brought into production. The lack of available sorghum and pearl millet germplasm, with reasonable tolerance to aluminum (Al) toxicity and low levels of phosphorus (P), has prevented national research programs from exploiting these acid soil areas.

The need to develop crops with tolerance and adaptability to soil acidity has increased in many South and Central American countries due to food and feed grain deficits. However, methods and approaches to accomplish this objective were either not available to scientists in the region or not well defined because of lack of research in the area. The development of a reliable field screening technique to screen for Al tolerance by this project has resulted in the selection of several hundred Al-tolerant sorghum lines from the World Collection. About 50 promising lines have been identified with potential grain yield of three tons per hectare under acid soil conditions with minimum fertilization practices.

Before INTSORMIL began this project, sorghum could not be grown on soils with levels of Al saturation higher than 60%. Since 1982, five sorghum cultivars have been released as the result of collaboration between ICA, INTSORMIL, and commercial companies. These cultivars produce profitably in soils with 60% Al saturation, immediately making more than 200,000 hectares of marginal farm land available for sorghum production in Colombia alone.

INTSORMIL strengthened ICA's Acid Soils Research Program through training, literature, equipment, germplasm, and operating funds. Several international Workshops were organized by MSU-111 PIs and were successfully conducted in Colombia. A number of graduate students from Colombia and other countries earned advanced degrees by conducting research on acid soil-plant interactions at INTSORMIL universities, adding significantly to the literature. Breeding output and technology

generated for the acid soil complex by this project has and will continue to stimulate research in many countries with acid soils around the world.

Objectives, Production and Utilization Constraints

Objectives

To screen and evaluate sorghum and millet germplasm at different 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 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 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 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 sorghum is grown on high value lands, making production noncompetitive with high value crops. One way of reducing production costs is to incorporate acid soil marginal lands into the cereal production system. South America has the worlds 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 if it is not managed properly. 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 relatively near to population centers. Stress tolerant cultivars, crop rotation, improved fertilization and soil preparation practices, and integrated pest and disease management must become part of the research package for the future.

Research on acid-soil constraints would benefit both developing countries and the U.S. 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 if a large enough demand develops. This may occur in Latin America and Central Africa, both areas that lack cereal grains for food and feed.

Research Approach and Project Output

In the 1970s, reports started appearing 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 for 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 project was an attempt to provide the acid soil regions of the world, represented by 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.

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 a 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 1970s, 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 equal in stress manifestation 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 level 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.

Using the field screening developed for sorghum, preliminary trials showed that pearl millet has excellent adaptation to acid soils even under low phosphorus conditions. Several pearl millet varieties, synthetics, and populations showed potential grain yields of 2-3 tons per hectare. Pearl millet tolerates a higher level of Al toxicity than sorghum.

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. 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, Monteria).

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).

In close cooperation with MSU-104, the main breeding and evaluation research was conducted in Colombia at CIAT-Quilichao, CIAT-Palmira, ICA-La Libertad, and Arauca, and in the U.S. at Mississippi State University. ICA conducted breeding research 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.

Breeding material has been generated from crosses among Al-tolerant sources, agronomically elite lines, and new tolerant breeding lines. Different sets of segregating material were sent from MSU-104 to be screened in Colombia under different levels of Al saturation. 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 Al-tolerant lines were conducted by ICA at three different levels of Al saturation.

All research conducted by INTSORMIL MSU-111 follows the low-input technology approach. Dolomitic limestone at 300 kg ha^{-1} is used more as a source of calcium and magnesium than for correcting the acidity of the soil. Fertilizer applications of 30 kg ha^{-1} each of N, P, and K is used.

By using first-generation Al-tolerant lines from the world collection, uniform regional yield trials were conducted at sites determined by National Programs in Colombia, Venezuela, Peru, and Brazil. As the breeding effort progressed, hybrid observation nurseries were evaluated at different locations in Colombia, Mississippi, and in Kenya from seed produced by hand-pollinated crosses made by MSU-104 in Mississippi or in winter nurseries in Colombia. Advanced hybrid yield trials were being evaluated at the termination of this project.

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

Research Progress

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. 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 and Mali, 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 four Al-tolerant varieties. The first two varieties released in 1991, Sorghica Real 60 (MN 4508) and Sorghica Real 40 (156-P5-Serere 1), 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, 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 4 to 5 range.

ICA and the El Alcaravan Foundation, with INTSORMIL's support, released two acid soil tolerant sorghum cultivars in 1993 which are adapted to growing conditions in Arauca in the Colombian Eastern Plains. The cultivars have been named Icaravan 1 (IS 3071) and Icaravan 2 (IS 8577). Icaravan 1 is exceptionally hardy and has produced more than 3 t ha^{-1} grain under low fertilization levels and when the Al-saturation level is 60% or less. It also tolerates partial flooding after flowering - an essential characteristic in poorly drained savannas. Icaravan 2 is very tolerant to Al toxicity and has good agronomic characteristics when grown under Arauca's soil and climatic conditions.

FEDEARROZ and ICA have announced the release of 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. In 1994 the Kenya Seed Company, a partially government owned organization, entered two sorghum hybrids in the Kenya National Performance Trials. These hybrids are made by using an A-line from Texas A&M University and two acid soil tolerant R-lines from MSU-104 germplasm developed in Colombia. Also, world collection sorghum lines identified as being superior in Colombian trials are currently being used in a commercial hybrid in the U.S. and in southern Africa, as reported in the recent EEP review.

A SEPON line developed by ICRISAT and taken through U.S. quarantine by MSU-104 has been released as a high yielding sorghum variety in Niger. In collaboration with INTSORMIL breeders at Purdue University, the line was selected from the MSU-104 winter nursery grown at CIAT and sent to Niger for evaluation and eventual release.

Collaborators working with EMBRAPA at Sete Lagoas, Brazil have evaluated 279 lines developed by MSU-104 from segregating populations in which only one parent was acid soil tolerant. After preliminary evaluations, five of the best yielding 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 INTSORMIL genotypes matured earlier and were shorter than the Al-tolerant material currently available for the Cerrado environment. 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.

Hybrids using one or both parental lines developed in Colombia are currently being evaluated in many countries with acid and/or infertile soils. Since 1990, experimental sorghum hybrids using lines developed in Colombia have been evaluated in East Africa. In Western Kenya and throughout Uganda, the bird resistant germplasm used throughout many areas in Colombia is used for food. Several of these hybrid combinations are in the final stages of evaluation before being released to farmers.

In summary, the land area with infertile soil is growing throughout the world due to nutrients not being replaced after they are removed in the harvested grain and stover. This INTSORMIL project has been very successful in developing a theory about the possibility of finding genetic diversity for tolerance to low pH soils and incorporating this tolerance into sorghum cultivars which are now in the hands of farmers trying to support their families on these marginal lands.

The credit for the success of the MSU-111 project should go to the INTSORMIL Board of Directors and committees which supported this project through funding for 11-1/2 years, the National Program ICA, the International Center CIAT, and to the PIs who lived and conducted the research throughout Colombia. The project was initiated by Dr. Lynn M. Gourley who served as PI from November 1982 until December 1984 and again from March 1987 until June 1988. Dr. Catalino I. Flores was PI from January 1985 until February 1987 and Dr. Guillermo Munoz from July 1988 until the project was terminated at the end of June 1994.

Networking Activities

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, networking activities in many other Latin American countries are weak.

Workshops

The 1984 international workshop, "Evaluating Sorghum for Tolerance to Al-Toxic Tropical Soils in Latin America", laid the foundation for a regional effort to help solve problems of sorghum and millet production on the acid soils of Latin America. The enthusiasm and cooperation of National Program administrators and scientists in South America helped INTSORMIL initiate a collaborative research network.

In January 1991, the second international sorghum meeting for Latin America, was organized by ICA, El Alcaraván, FENALCE, and INTSORMIL, and 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 third 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 fourth 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.

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 Foundation 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 in this workshop.

Research Investigator Exchanges

Many sorghum and millet researchers and administrators from national and international institutions and private seed companies have visited the acid soil field screening nurseries at CIAT-Quilichao, ICA-La Libertad, and El Alcaravan and ICA-Arauca. The many visitors at CIAT get an opportunity to see the INTSORMIL sorghum and millet breeding nurseries at CIAT-Palmira. This project has also been instrumental in providing support for Colombian and other Latin American scientists to attend meetings and workshops outside of Colombia.

Germplasm and Research Information Exchange

This project is informally linked with many countries in South and Central America and in Africa in which CIAT conducts research. Over the years we have established cooperative research linkages with the national research programs of ICA-Colombia, EMBRAPA-Brazil, CENIAP-FONAIAP-Venezuela, INIPA-Peru, and IDIAP-Panama. These countries are in the major acid soil areas and are conducting research to solve soil acidity problems. This collaborative linkage network unifies INTSORMIL researchers and host country scientists to solve a common problem in the region through exchange of germplasm, research result dissemination, technical consultation, training, and workshops.

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 planned to 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.

In Africa, germplasm from this project and MSU-104 has been used in Zambia, Zimbabwe, Niger, Mali, Kenya, Tanzania, Uganda, Egypt, and South Africa. Germplasm bred and screened in Colombia has demonstrated its superiority in acid soils in many parts of the world, but many of the lines and hybrids compete very well on infertile soils where acidity is not a problem. Stress breeding on very acid soils appears to have resulted in the development of sorghum germplasm which will tolerate other soil induced fertility stresses.

Because four varieties have been released by ICA from sorghum lines developed by MSU-104 and MSU-111, considerable effort has been directed toward semi-commercial fields with the specific levels of Al saturation for which each variety was released and fields for seed production of the varieties.

Publications and Presentations

Since this is a terminal report, a summary of the publications, theses and dissertations, and presentations from the initiation of this project in 1981 until its termination in 1994 will be discussed.

Since this project was initiated, approximately 28 theses and dissertations of research conducted on sorghum and millet have been published by students from Colombia or other nationalities completing their research in Colombia. In addition, 2 books, 11 chapters in books, the proceedings of 6 International Workshops, and 46 other publications on sorghum and millet relevant to the activities of MSU-111 PIs or their collaborators have been published.

Approximately 22 invitational papers and 40 other presentations, mostly concerning the acid soil research, have been made by MSU-111 PIs or their collaborators at professional meetings.

Training Output

At the time this project was terminated, 17 Colombian students had conducted their thesis research using sorghum and millet and received their B.S. degrees from National Universities with INTSORMIL's assistance. An additional five students were collaborating with INTSORMIL and will complete their B.S. degrees with the assistance of CIAT senior staff. Postgraduates from Colombia or those who conducted research in Colombia include four M.S. and seven Ph.D. students, which were granted their degrees from INTSORMIL Universities. The number of Colombian graduate students currently in INTSORMIL universities and conducting research on sorghum and millets is unknown.

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

Project PRF-105

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Summary

In the Sudan we have intensively studied actual and potential technology adoption in both the Gezira and the mechanized rainfed regions. The rapid present diffusion of Hageen Dura 1 is associated with the water control and the increasing consumption of chemical fertilizer. Prices for sorghum have also stayed high with the continuing civil war and irregular rainfall. Consumer tastes are apparently shifting as the price discount for Hageen Dura 1 has been declining over time according to farmer interviews.

In the next five to ten years it will be very important to increase sorghum productivity in mechanized rainfed zone as more profitable activities are expected to displace sorghum in the irrigated schemes. With chemical fertilizer (nitrogen) and new cultivars, yields can be substantially increased and stabilized at approximately 1.5 mt/ha according to simulation model results. In contrast traditional sorghum practices without chemical inputs lead to declining yields and increased variability in yields over time. An important start on a sustainability strategy is then setting up the input supply system so that the mechanized rainfed producers have access to the nitrogen. An important component of this technology shift to higher and more stable yields is to modify public policies so that intensive or yield increasing technologies are encouraged, rather than continuing to promote extensive or area increasing technologies with deleterious effects on deforestation and land degradation.

In Burkina Faso, substantial gains to both agricultural and household technologies were demonstrated for family and female incomes. There is some evidence that family decision making becomes more equitable and that more bargaining takes place at higher income levels. With family bargaining, women can substantially benefit from new agricultural technologies. Moreover, both women and the family benefit from the introduction of the household technologies.

Objectives, Production, and Utilization Constraints

Objectives

Sudan

Identify farm level and other factors associated with the diffusion of Hageen Dura 1 in the Gezira. This project also included a preliminary analysis of the performance of the seed and fertilizer supply sectors. Suggest policy measures to accelerate diffusion of this new cultivar.

Evaluate long term economic and sustainability effects of present and potential technologies in the mechanized rainfed region. Recommend policy changes and future research needs.

Burkina Faso

Estimate the effects of new agricultural and household technologies on farm and female incomes. Make policy suggestions to insure that agricultural and other technologies also increase the welfare of women.

Mali

Estimate potential farm level effects of actual and potential technologies in the Sudanian and Guineo-Sudanian zones. The technologies to be considered are techniques to increase water retention and to improve soil fertility combined with adoption of new cultivars.

Identify constraints to new technology introduction in the two regions.

Constraints

We have emphasized the combined effects of water availability and soil fertility. Frequently, in this improved agronomic environment there is a substantial response to new cultivars. We have also identified the importance of policies to offset the price collapses associated with good rainfall years. Recent field research in Sudan and Niger has indicated the importance of the improved performance of the input industries (seed and fertilizer) in facilitating a more rapid diffusion of new technologies. More recently, we have been focusing our attention on land degradation and the necessary elements for more sustainable technologies and on the constraints to increasing the effects of technological changes on the welfare of women.

Research Approach and Project Output

Research Approach

Our approach varies with the state of technology introduction. Where the sorghum technology is being adopted by farmers, we utilize various types of diffusion methodologies such as the Probit and Tobit methods discussed below for Hageen Dura in the Gezira. Where there is only potential technology available on the experiment station and from regional and farmer trials, we utilize various types of programming models and now simulation (see the results for the mechanized drylands of Sudan below). The simulation and dynamic programming are necessary tools to evaluate the long run effects of present and potential technologies to respond to the concerns of sustainability as well as profitability. Finally, in more recent studies to calculate the national benefits from specific research activities we estimate consumer and producer surpluses. Our analyses are based on farm level and experimental data supplemented with national level statistics.

Research Findings

Introduction of a New Sorghum Hybrid in the Gezira of the Sudan

In the early '90s the diffusion process for the sorghum hybrid, Hageen Dura 1, was accelerating in the primary irrigated scheme of the Sudan, the Gezira project. The greater Gezira scheme includes approximately 875,000 ha and is 12% of the total cultivated area in the Sudan and 46% of the irrigated area. In the 1991-92 crop year approximately 12% of the sorghum area (38,000 ha) were planted to this hybrid.

In the mid-'80s there had been a temporary decline in interest due to the price collapse of good rainfall years and the initial discount for this hybrid for taste reasons. Over time this price discount disappeared and the majority of farmers interviewed in the Gezira in 1990 asserted that the taste of Hageen Dura 1 was equal to or better than the other traditional sorghum cultivars. Apparently, with cultivars of high yield potential consumers can change their taste preferences.

The principal constraint to a more rapid introduction of the high yielding cultivar according to the farmers interviewed in 1992 is the ability of input suppliers to produce adequate quantities of high quality seed and to provide sufficient fertilizer. There were complaints about the quality of the seed. Moreover, there would have been 51% more adopters if all those who wanted to buy seed had been able to obtain it. The reentry of the private seed producers is presently occurring and that should increase the responsiveness of the seed sector to the rapidly increasing farm demands. It should be noted that the public seed sector played a critical role in maintaining the diffusion of Hageen Dura 1 since the private firms pulled out of the market when the price of sorghum collapsed in the 1985-86 crop year.

In diffusion models, entirely misleading results can be obtained if no adjustment is made for supply shortages. If no adjustments are made for the failure of the seed and fertilizer firms to provide seed and fertilizer to all who would buy it, we get the conventional results for diffusion studies (Table 1). The statistical significance of farmers with certain characteristics is generally interpreted that the probability of purchase is greater for the more educated and wealthier farmers and therefore extension and other diffusion programs should be aimed at them. However, if we adjust for seed and fertilizer shortages by treating all, who said they would buy, as adopters these farmer characteristic variables no longer influence the rate of diffusion. Rather diffusion is only determined by the taste variable (whether the farmer likes the taste of Hageen Dura 1) and by the number of extension visits. Apparently, the farmer characteristics such as greater size, wealth and higher education determine the ability of farmers to obtain a rationed, subsidized input. The policy implication is not to concentrate extension efforts on this wealthier group of farmers as implied in many other diffusion studies, that do not adjust for this inability of the input sector to respond, but rather to take various policy measures to improve the functioning of the input industries. In the input industries there is also a difficult pricing issue for public firms. A subsidy on the price can be justified for equity or welfare reasons but the consequence of a subsidized input is that there will be excess demand and then rationing of the input. When rationing occurs, the principal beneficiaries are usually the larger, more influential farmers. Hence, a measure ostensibly designed to improve income distribution can in practice make income distribution worse. Moreover, a subsidized price for the hybrid in the public sector will make it more difficult to develop a private seed sector.

Table 1. Determinants of the farm level adoption decision (probit model) with and without adjustments for the input supply shortages.

Variable	No adjustment for input supply restrictions	Adjustment for input supply restrictions
Experience	0.011 (1.0)	-0.001 (0.1)
Education	0.089 (2.0)**	0.03 (0.7)
Family Size	-0.002 (0.1)	0.02 (0.4)
Farm Size	0.035 (2.8)***	0.19 (1.6)
Indebtedness	0.0000096 (1.6)*	0.000006 (1.0)
Extension	0.20 (4.5)***	0.11 (2.8)***
Taste	0.84 (2.5)***	0.62 (2.1)**

Source: Nichola, 1994, pp.70,73

Note: The asterisks indicate asymptotic t values of 10, 5, and 1% respectively for one to three asterisks.

Technological Change and Sustainability in the Mechanized Rainfed Region of Sudan:

In the previous section we pointed out the accelerating diffusion of Hageen Dura 1 in the Gezira of the Sudan. The irrigated regions provide a safety valve for when the conditions for cereal production are adverse in the drylands. In the '80s, except for two drought years, the mechanized rainfed region was responsible for 55 to 75% of the sorghum production in the country. The cultivation of the mechanized rainfed sector began during World War II. Area expansion here has been promoted by the government and is a remarkable success story. From 1964 to 1993 the area cultivated in sorghum increased from 850,000 to 5 million ha. In this extensive, almost monoculture sorghum system with no purchased inputs except labor, sorghum yields have been stagnant and now declining. Aggregate yields vary substantially with the weather and with crop movement into new and out of old areas. In normal rainfall years, regional yields would be 500 to 700 kg/ha. In contrast, mean irrigated yields are more than 1.2 mt/ha.

However, in the long run the mechanized rainfed region needs to be the center for sorghum production. Basic food cereals, outside of rice and wheat, are generally not produced under irrigation except under circumstances of duress or with substantial governmental subsidies. In recent years with the continuing civil war and some poor rainfall years the irrigation authority has allowed farmers to relax the area limitations on sorghum. However, with increasing incomes over time the opportunity costs of keeping high value irrigation land in low value cereal crops will become too high and sorghum is expected to be replaced there by fruits, vegetables and other high value crops.

Presently, the extensive policy promotion by the government of subsidizing land, machinery and interest costs is being reexamined. The social costs of rapid area expansion with the resulting deforestation and land degradation are an increasing concern of the government. Even more serious for the long term food security situation of the Sudan are the low and declining sorghum yields in the mechanized rainfed zone. Sorghum is the principal staple in the Sudan. To increase and stabilize yields will require shifts to more intensive or yield increasing technologies.

With a simulation model, the long-run potential effects on yields and sustainability of various new technologies on the mechanized rainfed area were evaluated. Introducing only a new cultivar would increase yields approximately 13% over the 16-year period, with the yield advantage declining over time as soil fertility decreases (Figure 1). Combining the new cultivar with 47 kg/ha/yr of urea increased yields 58% over the improved cultivar alone, doubling yields, and these yields are sustainable in contrast with traditional practices and introduction of a new cultivar alone. This combination of moderate fertilizer use, combined with an improved cultivar, increased profits 95%. Doubling yields is a surprising increase for a low fertilizer rate combined with a new cultivar. However, these heavy soils have adequate levels of other nutrients and rainfall, so increasing nitrogen has a large effect.

Doubling the fertilizer level increases the yield levels 30% more than the lower fertilizer level, but the additional effect of the tied ridges is minimal, only 6.5% (Figure 1). This is unexpected since a water-retention technique is already used by many traditional producers. Small traditional producers on these vertisols in other regions use "teras," a hand-constructed series of bunds built on three sides on the contour to prevent runoff. This region (Sim Sim) of the mechanized rainfed zone is definitely semi-arid at a mean rainfall of 630 mm. However, the greater water-holding capacity of these heavy clay, cracking soils evidently makes the additional water-holding capacity of tied ridging insufficient to be profitable and therefore is not adopted by farmers. At higher absolute yield levels, as on the vertisols of the Texas high plains or at lower rainfall levels, the tied ridges may become a profitable activity. At the present, the addition of nitrogen and new cultivars on these vertisols are the critical innovations and do not need to be combined with a water-retention technique.

In summary, in the rainfed vertisols, the introduction of a new variety alone would increase yields 13% but was not a sustainable long-run strategy. When combined with moderate fertilization, the two practices doubled yields and maintained them at approximately 1.5 mt/ha, according to the simulation model. Once soil fertility is improved, a new cultivar needs to be used since new cultivars respond better to inorganic fertilizer than traditional land races, such as the Feterita sorghums. Moreover, these are preliminary results for long run sustainability since the simulation model does not include biotic factors, potassium or micro nutrients.

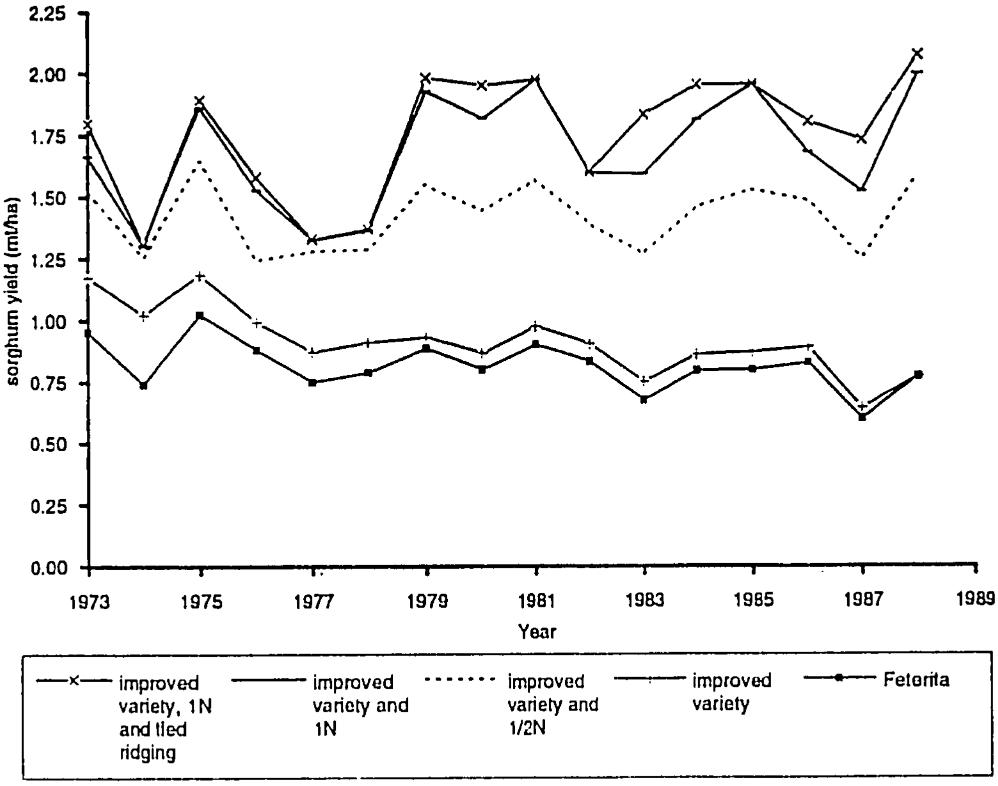

Figure 1. Simulated sorghum yields of actual and potential technologies in the mechanized rainfed zone. Source: M. Ahmed, 1994.

Some or all of these would be expected to become future constraints to the maintenance of these 1.5 mt/ha yields. Agriculture is a dynamic system and good research systems are necessary to respond to new constraints as they emerge.

Burkina Faso: Impacts of Household and Agricultural Technologies on the Household and on Women

We did fieldwork in 1989 in one of the regions of most rapid technological change in agriculture in Burkina Faso, the Solenzo region. This area had been recently cleared of river blindness and has been experiencing very rapid in-migration and income growth. The technologies being introduced have been associated with the cotton zone to which this region is contiguous. These technologies include chemical fertilizer, new cotton and maize cultivars, improved agronomic practices of higher densities, pesticides and animal traction. There is also a residual effect of the fertilization on the sorghum included in the rotation with cotton.

We were concerned in this fieldwork with the impacts of new agricultural technologies on the welfare of women (and children). It has been frequently observed that with the introduction of new agricultural technologies women have reduced their labor on their own private plots. Women have control of the output coming from their private plots and the household head controls the disposition of the proceeds of the income from the farm. Therefore the question was raised whether the household head could exploit the women and actually make them worse off after the new agricultural technology was introduced.

Various empirical studies including our modeling (Gupta Lawrence, 1993) demonstrated that improved agricultural technologies increased the welfare of women. The available evidence indicates that household decision making is often characterized as a bargaining process in which to get the women to increase their labor contribution to the family holdings, they have to share in the higher revenue being generated from agriculture. Moreover, we expect that the bargaining position of women will be improved as family incomes increase. In 1995 we will be doing fieldwork in Mali to evaluate household decision making and investment in the process of rapid technological change. Moreover, the previous modelling has shown that the bargaining position of the women is improved when the opportunities for off-farm labor are increased.

In the process of intensive or yield increasing technological change in agriculture, further pressure is put on one of the scarcest commodities in the African village, the time of women. Household tasks, children and agriculture are already very time intensive. Moreover, many women also work off the farm. Hence, the next critical investments for African households, once new agricultural technologies are introduced, are household technologies. More fuel efficient stoves and grain processing improvements are available in these countries though the decision to invest in them is generally that of the household head.

Table 2 shows the effects on family incomes and on the incomes of the individual female members of new agricultural and household technologies. In these families there can be up to four wives. Moreover, other unmarried adults also have the right to farm the private lands. The household technologies release the labor time of the women so that there is more time for working on the farm or for other activities. Hence, the combined agricultural and household technologies increase household incomes by 75% and the incomes of the individual female by 85%. Agricultural technologies alone increase household income by 57% and adult female income by 67% Adult female wages do not go up here with the addition of household technologies since their effect is only to make more labor time of the female available. The household technologies are a combination of the stoves, parboiling, grain processing, and an improved well or pump technology. All except the last are individual family investment decisions whereas the wells are a community decision. There was a 58% increase in female wages with the introduction of new agricultural technologies. The above are modelling results but they are consistent with our field data and with the other empirical studies cited in Gupta Lawrence (1993).

Mali-Improved Agronomy and New Cultivars in the Sudanian and Sudano-Guinean Zones

Two of the principal constraints in southern Mali to increasing sorghum and millet yields are declining soil fertility and the fluctuation of rainfall. Most farmers in southern Mali already utilize the water retention technique of ridging. The ridges are not closed, however, as with tied ridging. Chemical fertilizer is widely used in the Guineo-Sudanian zone but in the Sudanian zone farmers principally utilize organic fertilizers.

In this study, we are modeling the interaction of higher soil fertility and new cultivars. In the Sudanian zone, chemical fertilizer at moderate levels increase the yields but is not profitable on traditional sorghum cultivars. The same fertilization levels were highly profitable on the new sorghum and millet cultivars. In the Sudano-Guinean zone the chemical fertilizer was profitable on both the traditional and the new cultivars. Programming is presently being undertaken to consider the on-farm and off farm constraints to these new technologies.

Networking Activities

Workshops

Papers were presented in Uganda and in the Gambia for regional groups planning research in the fall of 1993 and the spring of 1994, respectively. These were both three day workshops. Participants included the NARS, the IARCs, the World Bank, USAID, and other bi-lateral donors. The papers given are cited below.

From June 6-10 Will Masters and I conducted a workshop on impact analysis to 22 economists and administrators selected by their NARS from the West African French speaking countries. The workshop will be followed up in 1995 with another one, this time for the previous trainees to report the results from their impact analysis in their countries. We are creating a network of West African economists and other scientists, who are engaged in the economic analysis of new technologies.

Research-Investigator Exchanges

Joao Carlos Garcia, the former administrator of the EMBRAPA Corn-Sorghum Center in Sete Lagoas, Brazil spent a year's sabbatical with our program. He had been working the previous year with Miguel Lopez-Pereira, an INTSORMIL graduate then working with CIMMYT, on a comparative study of the development of the seed industry in Mexico and Brazil. Joao Carlos helped us with the seed aspects of Tennassie Nichola's thesis in the Sudan and also made suggestions on the future expansion of our program into the analysis of the performance of the seed industry.

In the spring of 1994, Yeshi Chiche came to spend a few months with our program. She is an economist with the sorghum program in Ethiopia. We developed some ideas for future collaboration on the impact of new sorghum cultivars and the evolution of the seed industry in Ethiopia. While she was at Purdue, I visited Ethiopia and went out into the field with her husband, who is the principal sorghum breeder of the IAR in Ethiopia (Ph.D. from Oklahoma State).

Table 2. Farm and female worker incomes before and after the introduction of new agricultural and new household technologies.

	Traditional agriculture technology	Introduction of new agricultural technology	Introduction of new agricultural technology and household technology
Total farm income (U.S. $)	704	1,111	1,235
Income per female	100	167	185
Wages/hour for females	.24	.38	.38

Source: Gupta, Lawrence, 1993, p. 92.

Note:These households are hand traction ones. Moreover, the women are paid according to their productivity (their marginal value product). Elsewhere we have considered the exploitation and bargaining cases. The above is considered an altruistic case though altruism could be specified differently as not only a reward for higher productivity but also giving women a share in the profits as well. The previous bargaining framework is analogous to the factory worker-management negotiation whereas a share in profits is comparable with a cooperative.

Research Information Exchange

The bulletin on the commodity networks (including sorghum-millet) of SAFGRAD (cited below) evaluated impacts of new technologies and of the networks and made recommendations for the NARS and USAID on future technology development. This report was distributed to the NARS and to the USAID offices all over Sub-Saharan Africa by USAID/Africa.

Publications and Presentations

Publications

Gupta Lawrence, Pareena, 1993. Household Decision Making and Introduction of New Agricultural and Household Technologies in the Solenzo Region of Burkina Faso. Ph.D. Dissertation, West Lafayette, IN. Purdue University, Department of Agricultural Economics.

Lopez-Pereira, Miguel A., John H. Sanders, Timothy G. Baker, and Paul V. Preckel. 1994. Economics of Erosion Control and Seed-Fertilizer Technologies for Hillside Farming in Honduras. Agricultural Economics. (In press).

Nichola, Tennassie. 1994. The Adoption of Hybrid Sorghum at the Farm and Regional Levels in the Gezira Irrigated Scheme of Sudan. Ph.D. Dissertation, West Lafayette, IN. Purdue University, Department of Agricultural Economics.

Sanders, John H., Taye Bezuneh and Alan C. Schroeder. 1994. Impact of the SAFGRAD Commodity Networks. USAID/AFR, OAU/STRC-SAFGRAD, Department of Agricultural Economics, Purdue University, West Lafayette, IN. 111 pages.

Sanders, John H., Barry I. Shapiro, and Sunder Ramaswamy. 1995. The Economics of Agricultural Technology in Semi-Arid Sub-Saharan Africa. Johns Hopkins Press, Baltimore, Maryland. (In press).

Sanders, John H. and Joao Carlos Garcia. 1994. The Economics of Stress and Technology Development in the Sahel and the 'Cerrados' of Brazil. p. 28-47. Proceedings of a Workshop on Adaptation of Plants to Soil Stresses, INTSORMIL, University of Nebraska, Lincoln, Nebraska.

Presentations

Sanders, John H. and Joao Carlos Garcia. The Economics of Stress and Technology Development in the Sahel and 'Cerrados' of Brazil. Invited paper presented at a Workshop on Adaptation of Plants to Soil Stress, INTSORMIL, Lincoln, Nebraska, August 2, 1993.

Sanders, John H. Technology Development for Semi-Arid Sub-Saharan Africa: Theory, Performance, and Constraints. Paper presented at a pre-conference Workshop on Agricultural Development at the Annual Meetings of the American Association of Agricultural Economists, Orlando, Florida, July 30, 1993.

Sanders, John H. Economic Impact of New Technologies in Sub-Saharan African Agriculture. Presented at a seminar of the World Bank, Washington, DC, Oct.7, 1993.

Sanders, John H. Measuring Agricultural Research Impact: Some Results and Implications for Sub-Saharan African Agriculture. Invited paper presented to the Workshop for Regional Research Planning of the NARS of East Africa, IARCs, World Bank and USAID, Kampala, Uganda, Nov. 23, 1993.

Masters, William A. and John H. Sanders. The Impact of Agricultural Research in West and Central Africa: Concepts and Evidence. Invited paper for the SPAAR/USAID Workshop on Regionalization of Agricultural Research, Banjul, Gambia, March 15, 1994.

Resource Efficient Crop Production Systems

UNL-113A

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Summary

Emphasis has been directed towards principles and practices that enhance the availability and use of water and nutrients, nitrogen and more recently phosphorus by sorghum and millet. These major natural resources must be increased so the improved varieties and hybrids can express their yield potential. Research in Sudan shows that 2.5 times more nitrogen is removed if the residue is harvested than just the grain. This typically occurs in developing countries, and thus, more rapidly leads to depletion of soil fertility.

The application of nitrogen or use of a soybean/sorghum rotation resulted in more heads and seeds per m^{-2}, and larger seeds higher in nitrogen content as compared to continuous sorghum with no inputs.

The ability of the landrace sorghum (maicillo) to survive when intercropped with maize does not seem to be because of a lower compensation point. It may involve the efficiency of the photosynthetic light-gathering system.

A greenhouse water and nitrogen study showed that water will increase grain yield regardless of nitrogen status. Although grain yield increases with nitrogen with adequate water, nitrogen will intensify water stress if water becomes limiting as the more vigorous plants will quickly utilize what little water there is. This is why many farmers on these marginal lands are not very concerned about using nitrogen.

Objectives, Production and Utilization Constraints

Objectives

Study the "rotational effect" in sorghum-soybean and millet-soybean rotations by evaluating: 1) nitrogen and phosphate contribution of legumes and, 2) soil water relationships.

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

Constraints

Emphasis has been directed towards principles and practices that enhance the availability and use efficiency of water and nutrients, especially nitrogen and more recently phosphorus. These major natural resources limit grain sorghum and pearl millet production worldwide. Cropping systems research is needed to increase these resources so that improved varieties and hybrids can express their higher yield potential. However, this requires special considerations since they are long-term investments. Crop rotation or intercropping systems experiments must be continued for several seasons or cycles. Thus, a host scientist must be genuinely interested in these long-term projects, and stable funding over time. Also, 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 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 nutrients is becoming even greater with more intensive cropping practices being used, removal of the entire crop (grain and residue), and limited availability of new land. 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 require improved genetics combined with production practices to provide adequate water and fertility.

International

Sudan - Grain Sorghum as Affected by Crop Rotation and/or Applied N

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 - 1990 cropping seasons.

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

Both legumes as previous crops greatly increased sorghum yield over that of continuous sorghum (INTSORMIL Annual Report 1993). Grain harvest removes some N without inputs (Table 1), but much more is removed when fertilizer is applied or after the legumes indicating increased availability. The N that is removed in the grain will have to be replenished either from existing soil N, from applied fertilizer or use of a sustainable cropping system. Loss of N from the systems became more critical if the stover is included, (Table 2). Harvest of stover results in about 2.5 times more N being removed than if only grain is harvested. This is generally what occurs in the developing countries. Other nutrients, such as P, are also removed which may be even more critical as they are not renewable. Greater emphasis on management is needed for improving N, P and water levels so that high yielding varieties and hybrids can express their higher yield potential.

Table 1. Grain N uptake in sorghum as affected by previous crop (Sudan).

Applied N	Continuous sorghum	After Phillipesara	After Clitoria
	----------	kg ha^{-1}	----------
1989			
0	27	38	36
43	39	53	50
86	34	36	47
1990			
0	25	30	42
43	32	39	4[illegible]
86	34	48	[illegible]8

Table 2. Plant N uptake of sorghum as affected by previous crop (Sudan).

Applied N	Continuous sorghum	After Phillipesara	After Clitoria
	----------	kg ha^{-1}	----------
1989			
0	67	82	87
43	84	102	90
86	92	111	122
1990			
0	72	94	109
43	93	112	113
86	112	125	140

Honduras - Grain Yield and Photosynthesis of Landrace Sorghum

Land race sorghum cultivars can be characterized by low but stable grain yields. In Central America, a group of photoperiodic land races called maicillos criollos are intercropped with maize to reduce drought risk. Twelve sorghum cultivars (three maicillos, three temperate varieties, and six enhanced maicillo cultivars or DMV), were evaluated at Mead, NE and El Zamorano, Honduras in collaboration with 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.

The photosynthetic measurements of these sorghums indicated the adaptation of maicillo to reduced irradiance during vegetative growth (INTSORMIL Annual Report 1993). Therefore, greenhouse studies were used to study further the response of these cultivars to low irradiance. The response of six sorghum cultivars planted in the greenhouse under low irradiance was comparable to the response obtained in *aporque* intercropping. The assimilation response of the cultivars at irradiance below 300 *u*E m$_{-2}$ is shown in

Table 3. The influence of applied nitrogen and legume/soybean/sorghum rotation on some agronomic and yield components of grain sorghum (1978-1993).

Cropping system	N level kg ha^{-1}	Days to flower	Heads per ha	Height (cm)	Kernel wt. (g/100)	Kernel N (%)	Kernels per meter sq
Continuous	0	81.4	124,700	108.5	2.310	1.04	15,736
	57	77.3	130,000	114.8	2.546	1.27	23,758
	114	76.1	131,000	115.9	2.635	1.57	25,858
	171	75.4	132,700	116.7	2.699	1.74	26,767
Rotation	0	75.8	134,600	114.3	2.569	1.20	23,775
	57	74.8	135,500	114.7	2.679	1.47	25,368
	114	74.8	134,300	114.2	2.729	1.66	25,843
	171	74.9	134,700	113.1	2.663	1.73	25,201
# Years		13	12	11	16	9	16

Table 4. Parameters for the linear regression of six sorghum cultivars planted in the greenhouse at Lincoln, NE.

Cultivar	Type	Parameter Intercept	Slope	R²
Cacho de Chivo	MC	0.904	0.11	89.65
San Bernardo III	MC	-0.962	0.12	84.65
Billy	MC	-1.005	0.143	91.42
DMV179	DMV	-1.73	0.138	83.25
DMH	DMV	0.044	0.132	93.42
TAM428	IL	-1.057	0.151	96.19

Table 3. Linear regression was used instead of a rectangular hyperbola because of the linear relationship under low light. As with *aporque*, the slope of TAM 428 (0.151) was steeper than the slopes for Cacho de chivo (0.110) and San Bernardo III (0.120).

No significant difference in light compensation point was found between the cultivars in the field or in the greenhouse. The results of these experiments do not support the hypothesis that, in the process of adaptation to intercropping, *maicillo* cultivars have developed lower respiration rates. Instead, an increase in the efficiency of the photosynthetic light-gathering system appears to be involved.

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.

Domestic

Crop Rotation - Grain Sorghum

A sorghum/soybean rotation study has been in progress for over 15 years. This rotation has focused on determining the "rotational effect". This rotation experiment includes nitrogen rates to allow study of grain yield and quality, and nitrogen dynamics.

The influence of applied nitrogen and legume/sorghum rotation on sorghum grain yield has been well documented. However, various yield components and agronomic characters are also affected by these management practices (Table 4).

Days to 50% Flowering —Nitrogen stress delays flowering of grain sorghum. On average in this study it was delayed 6 days. With each increasing increment of N the time to 50% flowering was shortened. The greatest effect was with the addition of the first 57 kg ha^{-1} increment of N. Sorghum grown after soybean remained about the same even if additional N was applied.

Heads Per Hectare —There is a trend for more harvestable heads per hectare with increased applied N. However, the largest difference occurs with the first increment of N. In general, a greater number of harvestable heads occurred with sorghum grown after soybean.

Plant Height —Sorghum tended to be the shortest when grown continuously with no nitrogen. Sorghum with the higher three levels of N were somewhat taller than the sorghum grown after soybean.

Kernel Weight —Kernel weight increased with increased level of N. The greatest increase (10%) was with the first increment of N. Kernel weight of sorghum grown after soybeans with no N, as compared to continuous sorghum with no N was increased 11%.

Kernel Nitrogen —Kernel N concentration increased with increased applied N regardless of being grown continuously or in rotation. At the highest level of N, Kernel N was the same in both cropping systems.

Kernels m^{-2} —More kernels m^{-2} were obtained with increased N. Again the greatest change occurred with the first increment of N.

In general, N or soybean rotation resulted in the improvement of the agronomic characteristics and yield components. Sorghum after soybean, especially with no applied N, resulted in a response equal to about 57 kg ha^{-1} applied N. In most cases, 57 and 114 kg ha^{-1} rotation equated to 100 and 171 kg ha^{-1} continuous, respectively. However, when 171 kg ha^{-1} was applied to sorghum after soybean the response was generally less than when 171 kg ha^{-1} was applied to continuous sorghum. The high application rate is above the recommendation amount for the yields being attained. Thus, probably residual N remained in the profile and the sorghum had access to N even if the top soil dries limiting root activity. This suggests the previous soybean crop used the residual N and the N was not available lower in the profile where active roots would generally be present.

Crop rotation research in this project is continuing to generate basic knowledge about the rotation effect, and is providing results for use in extension education programs. It also is serving as a long-term "laboratory" for training graduate students.

Water and Nitrogen Stress - Grain Sorghum

In many environments where sorghum is grown, severe water stress can occur. Application of nitrogen needed for growth may result in a yield reduction. Because of the possible negative effect, many farmers in developing countries are reluctant to increase soil fertility. The objective of this study is to determine the nitrogen by water stress affect on sorghum grain yield.

The experiment was conducted in the greenhouse. Six liter pots were used. The bottoms were sealed. Four water stress levels were maintained. No-stress (32 495 ml water pot^{-1}), moderate stress (18 350 ml pot^{-1}), severe stress (12 350 ml water pot^{-1}) and very severe stress (8650 ml water pot^{-1}). Nitrogen rates were 0.30, 1.45, 2.90 g-N pot^{-1}. Water was added based on reading of a moisture meter. Grain was harvested at maturity.

Grain yield of sorghum increased with all N rates when water was adequate. (Table 5). With 2.91 g-N pot^{-1} application, grain yield for both genotypes showed practically no response to the two lowest water applications, as the sorghum plants were practically barren. This occurred because sorghum plants failed to develop beyond the boot stage. However, with 0.30 and 1.47 g-N pot^{-1} grain yield apparently increased even with 12 350 ml-water-pot^{-1}. This indicates that high-N application did not favor grain yield under water stress. With 0.30 and 1.47 g-N pot^{-1}, apparently grain yield response to 12 350, as compared to 8650, ml-water-pot^{-1} was much higher with DK48 than with Segaolane. With 1.47 and 2.91 g-N pot^{-1} applications, grain yield (especially for DK48) increased sharply with 32 495 ml-water-pot^{-1} (as compared to 18 350 ml-water-pot^{-1}). Although grain yield increases with nitrogen under adequate water, nitrogen will intensify water stress if water becomes limiting as the more vigorous plants will quickly utilize what little water is present.

Networking Activities

Workshops

Plant Adaptation to Soil Stress. Aug. 1-4, 1993. University of Nebraska, Lincoln, NE.

Table 5. Grain yield as affected by water application, nitrogen application and genotype for sorghum plants grown in 1991 in the Agronomy greenhouse at Lincoln, Nebraska.

	Genotype									
	DK48					Segaolane				
	Water application (ml-water pot^{-1})					Water application (ml-water pot^{-1}				
Nitrogen	8650	12 350	18 350	32 495	Mean	8650	12 350	18 350	32 495	Mean
g N pot^{-1}					g plant^{-1}					
0.30	0.007	0.854	2.041	3.978	1.7200	0.019	0.157	2.751	4.053	1.7450
1.47	0.000	0.208	2.081	13.030	3.8297	0.000	0.166	2.471	9.864	3.1252
2.91	0.000	0.000	0.860	14.187	3.7617	0.000	0.033	1.668	9.829	2.8825
Mean	0.0023	0.3540	1.6607	10.3983	3.1038	0.0063	0.1187	2.2967	7.9153	
Contrast					p-level					
					Nitrogen comparisons					
High-N vs. 0.30†	0.99	NC‡	NC	<0.01		0.98	NC	NC	<0.01	
2.91 vs. 1.47	1.00	NC	NC	0.17		NC	NC	NC	NC	
					Water comparisons					
	At 0.3 g-Npot		At 2.91 g-N/pot			At 0.3 g-N/pot		At 2.91 g-N/pot		
High vs low water§		<0.01		<0.01		<0.01		<0.01		
12 350 vs 8650ml		0.31		1.00		NC		NC		
					Genotype comparisons					
	At 32 495 ml	At 8650 ml		At 32 495 ml		At 18 350 ml		At 12 350 ml		At 8350 ml
Dk 48 vs. SEG	0.93	0.99		<0.01		0.34		0.97		1.00

† High-N is mean of 1.47 and 2.91 g-N pot^{-1}

‡ NC means no contrast was tested

§ High water is mean of 18 350 and 32 495 while low water is mean of 8650 and 12 350.

American Society of Agronomy Meetings, November 7-12, 1993. Minneapolis, MN.

Publications and Presentations

Publications

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 1:25-32.

Clegg, M.D. and C.A. Francis. 1994. Crop Management, Chapter 5, p135-156. In J. L. Hatfield and D.L. Karlen (ed) Sustainable Agriculture Systems. Lewis Publishers, Boca Raton, Florida.

Maliro, Charles E. 1993. Nitrogen stress environments on the physiology and yield of grain sorghum. p 279. Ph.D. Dissertation. University of Nebraska, Lincoln, NE 68583-0817.

Gutierrez, Patricio F. 1994. Physiologic response of landrace sorghum to light intensity and intercropping. p 79. M.S. Thesis, University of Nebraska, Lincoln, NE 68583-0817.

Mohamed, Mirghani S. 1994. Quantitative nitrogen and growth models of grain sorghum (cv. Sm-39) as influenced by mineral and/or bio-nitrogen from preceding forage legumes in Sudan. p. 227. Ph.D. Dissertation. University of Nebraska, Lincoln, NE 68583-0817.

Gutierrez, P.F. and M.D. Clegg. 1993. Photosynthetic response of landrace sorghum to intercropping. p 113. Agron. Abst., Cincinnati, Ohio.

Mohamed, M.S. and M.D. Clegg. 1993. Models of sorghum N as affected by previous legumes and/or applied N in Sudan. p 141. Agron. Abst., Cincinnati, Ohio.

Onyango, R.M. and M.D. Clegg. 1993. Maize-soybean rotation residue interaction on maize grain yield. p 143. Agron. Abst. Cincinnati, Ohio.

Presentations

Clegg, M., M. Mohamed, and P. Gutierrez at the American Society of Agronomy Meetings, November 7-12, 1993, Cincinnati, Ohio.

Resource Efficient Crop Production Systems

Project UNL-113B

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Summary

Cropping system research has been conducted in INTSORMIL UNL-113B 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. Crop rotation with either cowpea or peanut in Mali increased grain yield of sorghum by 0.7 Mg/ha and pearl millet by 0.3 Mg/ha, and also substantially increased stover yield of both crops. Leaving crop residues on the soil surface reduced yield of both pearl millet and grain sorghum in 1991, 1992, and 1993. Residue incorporation for three years increased yield of pearl millet in 1993, but had no effect on sorghum grain yield. Preliminary results in Nebraska indicate that nitrogen fertilizer application, narrow rows and weed control lowered leaf temperatures, indicating less plant water stress.

Introduction

Water, nitrogen, and phosphorus are the major natural resource constraints limiting grain sorghum and pearl millet production in West Africa. During the past eight years, INTSORMIL Project UNL-113B has focused on development and extension of cropping systems that are water use efficient, enhance grain and stover yields, and utilize nitrogen fixation by legumes to reduce need for N fertilizer. Research efforts in Nebraska, Mali and Niger have studied continuous, intercropping and crop rotational systems. This effort has been slowed by the limited number of trained production agronomists in West Africa and the long-term nature of cropping systems studies. Efforts to improve the human resource base has been made by providing graduate training of students from Mali, and mentoring these students upon return. Future training is planned for collaborators in both Mali and Niger. Presently a trainee from Ethiopia is working with project UNL-113B.

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, crop residue management and weed competition for water and nitrogen.

Objectives, Production and Utilization Constraints

Objectives

Study the "rotational effect" in grain sorghum-soybean rotation by evaluating: 1) grain and stover yields, 2) nitrogen contribution of legumes, 3) nitrogen use efficiency, and 4) soil water relationships.

Continue long-term studies to determine grain sorghum/peanut and pearl millet/cowpea cropping systems (monoculture, rotation, intercropping) by nitrogen fertilizer rate interaction effects on grain and stover yields and nitrogen use efficiency at three locations in Mali.

Continue long-term studies to determine the influence of crop residue removal, incorporation and leaving on the surface on grain and stover yield at two locations in Mali.

Determine the genetic variances of grain sorghum lines for emergence potential in crusted soils.

Initiate studies to determine difference in competitive ability of pearl millet and grain sorghum with weeds for water and nitrogen.

Constraints

This project has focused primarily on crop production systems which increase the probability of obtaining higher grain and stover yields. This involves systems which increase nutrient and water availability to growing crops, and produce desired uniform stands. Present efforts emphasize crop rotation, intercropping, fertilization, residue management interactions with traditional and improved cultivars. These cropping systems research efforts require long-term investments of well-trained, interested scientists and stable funding. Training of additional scientists in crop production and continued support of their work after return to their home countries is needed to improve cropping systems.

Research Approach and Project Output

Grain sorghum and pearl millet are usually grown in stressful environments with high temperatures, lack of a predictable water supply, and often on fragile soils with low nutrient status. Generally, lack of water is considered to be the most critical environmental factor controlling plant growth and yield in most environments, but a source of nitrogen and/or phosphorus often is more critical. The importance of these elements is becoming recognized as more intensive cropping systems using improved cultivars are adopted. The unavailability of "new" land due to population growth and land degradation has heightened awareness of this constraint. The rotation or intercropping of legumes becomes a viable alternative for providing nitrogen for yield enhancement when fertilizer availability is limited or the cost is excessively high. Increased nutrient availability also improves water use efficiency of grain crops, indicating that major increases in grain sorghum and pearl millet yields requires improved cultivars combined with production practices that provide adequate water and fertility. The complex interaction of water, N, P and cultivars is the focus of Project UNL-113B's research efforts.

International

Research in Mali has shown clear grain and stover yield advantage to rotation of grain sorghum with peanut, and pearl millet with cowpea, and a smaller yield advantage following intercropping (Tables 1 and 2). This yield increase is impressive considering that all peanut/cowpea grain and residue were removed from the field. Crop rotation appears to be the only viable alternative to supply needed N for grain and stover yield if commercial fertilizers are unavailable or are too expensive. Increased stover yields are often overlooked, but they are important to provide additional livestock feed during the dry season and are a key component in maintenance or improvement of soil quality.

Long-term studies in Mali were initiated in 1990 to study the effects of residue removal, incorporation or leaving residues on the soil surface on sorghum and pearl millet grain yield, and maintenance of the soil natural resource. After three years no differences in grain or stover yield had been found either in the sorghum or millet studies, but in 1993 grain yield differences occurred for the first time (Table 3). In both studies, leaving the crop residues on the soil surface reduced grain yields which contrasts to research previously conducted in Niger and the United States. At Samanko, removal and incorporation of crop residues resulted in the best sorghum grain yields, while at Cinzana, incorporation of crop residues increased pearl millet grain yield by 0.2 Mg ha^{-1} over residual removal treatments. Crop residue management in sustainable crop production deserves much greater attention in the future, and obviously in Mali, positive results occur only after several years.

Projects UNL-113B and UNL-114 became more closely associated with the entire pearl millet research team through preparation of a grant proposal for the McKnight Foundation. This proposal integrated breeding, physiology, agronomy, and socioeconomics to tackle the complex interactive

Table 1. Previous crop effect on sorghum grain and stover yield in 1991, 1992 and 1993.

Previous Crop	1991 Grain	1991 Stover	1992 Grain	1992 Stover	1993 Grain	1993 Stover	Average Grain	Average Stover
	Mg ha^{-1}							
Grain Sorghum	1.4	3.1	1.4	6.2	1.3	7.3	1.4	5.5
Grain Sorghum/Peanut Intercrop	2.0	4.9	1.5	6.2	1.4	7.9	1.6	6.3
Peanut	2.4	6.9	2.0	7.7	1.8	11.0	2.1	8.5

Table 2. Previous crop effect on pearl millet grain and stover yield in 1991, 1992 and 1993.

Previous crop	1991 Grain	1991 Stover	1992 Grain	1992 Stover	1993 Grain	1993 Stover	Average Grain	Average Stover
	Mg ha^{-1}							
Pearl Millet	1.1	3.7	2.0	4.0	1.1	2.8	1.4	3.5
Pearl Millet/Cowpea Intercrop	1.1	3.2	2.2	3.6	1.2	2.8	1.5	3.2
Peanut	1.4	4.4	2.4	4.6	1.4	3.7	1.7	4.2

Table 3. Crop residue management influence on grain yield of sorghum and pearl millet.

	Grain sorghum			Pearl millet		
Residue treatment	1991	1992	1993	1991	1992	1993
			Mg ha^{-1}			
Removed	1.9	1.4	2.4	1.3	1.5	1.4
Incorporated	2.2	1.3	2.4	1.4	1.7	1.6
Surface	1.7	1.3	1.8	11.5	1.7	1.1

effects of water, nitrogen and phosphorus which are viewed as three of the most serious constraints to pearl millet production in Mali. Although the grant proposal was not funded, the proposal will serve to provide direction for research efforts with pearl millet in Mali. Planning efforts in 1994 will result in increased research efforts on nutrient cycling, residue management, nitrogen and phosphorus fertilization, and nutrient use efficiency. Collaborators are actively involved in on-farm trials with the extension service to test improved cultivars, plant populations, fertilizer rates, and use of the fungicide, Apron Plus, for control of downy mildew.

Contacts have been made with INRAN in Niger and ROCAFREMI (West and Central Africa Pearl Millet Regional Research Network) during 1993-94 regarding agronomy research on pearl millet. It is planned to initiate new agronomy research in Niger during the coming year, and to become involved in ROCAFREMI network activities.

Domestic

Crop Rotation - A grain sorghum soybean-rotation study was established in 1990 to help understand the "rotational effect". This experiment includes nitrogen and manure treatments, and has been used to study grain yield, soil water extraction, root distribution, microbial biomass and mycorrhizal infection. Long-term residual effects of manure nitrogen and cropping systems is presently being studied. Efforts to establish nodulating and non-nodulating soybean histories has been delayed due to seed contamination problems, but will continue next year. Plots will be split into grain sorghum and pearl millet to allow characterization of their response differences.

Genetic Variances for Emergence Potential in Crusted Soils - Stand establishment of grain sorghum is a major concern since many environments have low organic matter, poorly structured soils which often crust. This research was conducted to develop a technique for estimating emergence potential of genotypes in crusted soils, and to determine genetic variances.

Studies were conducted using grain sorghum kernels of 16 hybrids produced from four distinctly different A and R lines. 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.

Studies found that genetic variances for piston displacement and coleoptile diameter were large, 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 Competition for Water with Pearl Millet and Grain Sorghum - A study was initiated to study the effects of weed level (velvetleaf and foxtail species), row spacing, and nitrogen fertilizer application on seasonal leaf temperatures (measured with Infra-red thermometer) and grain yield of pearl millet and grain sorghum. Preliminary results indicate that nitrogen fertilizer application, narrow rows, and weed control resulted in lower leaf temperatures, indicating less water stress for both species. Leaf temperatures of pearl millet were more sensitive to weed competition than was grain sorghum. In a related study, past manure application (in 1980 to 1987) and higher rates of nitrogen fertilizer resulted in lower grain sorghum leaf temperatures than in unfertilized plots.

Networking Activities

Workshops

American Society of Agronomy Meetings, November 7-12 , 1993. Cincinnati, Ohio

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, February 8-15, 1994. Helped prepare grant proposal for the McKnight Foundation.

Ms. Berhane Biru, Physiologist from Ethiopia, is receiving training in water-nitrogen relations using infra-red thermometers, June 11-Sept 11, 1994.

Research Information Exchange

Equipment purchased for Malian collaborators/IER included:

Soil Water Capacitance Probe
Printer Power Source

Membership for collaborators in the American Society of Agronomy.

Pass-through funds to assist with conduct of experiments and costs of soil testing.

Publications and Presentations

Publications

Kasalu, H., S.C. Mason, and Gebisa Ejeta. 1993. Temperature effects on germination and seedling emergence of grain sorghum genotypes. Trop. Agric. (Trinidad) 70: 368 - 371.

Mason, S. C., J. Lasschuit, and J. M. Lasa. 1994. Interrelationship of sorghum coleoptile morphology with emergence potential in crusted soils. Eur. J. Agron. 2: 17 - 21.

Mason, S.C., K.M. Eskridge, B. Kliewer, G. Bonifas, J. Deprez, C. Medinger Pallas, and M. Meyer. 1994. A survey: Student interest and knowledge of international agriculture. NACTA J. 38: 34 - 38.

Mason, S.C., J.M. Lasa, and K.M. Eskridge. 1994. Number of samples, replication and measurements for a screening technique of sorghum emergence potential in crusted soils. Investigaciones Agrarias (In Press).

Bagayoko, M., S. Traore, B. Coulibaly, and S.C. Mason. 1994. Grain and stover yields of pearl millet-cowpea cropping systems in Mali. Agron. Abst., p. 74

Bagayoko, M., S. Traore, A.W. Toure, B. Coulibaly, and S.C. Mason. 1994. Grain and stover yields of grain sorghum-peanut cropping systems in Mali. Agron. Abst., p. 74

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.

Nutrient Use Efficiency in Sorghum and Pearl Millet

Project UNL-114
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Summary

Studies on root morphology in sorghum indicated that genotypes differ in distribution. Genotypes WSV387 and Naga white had the greatest root branching capacity and TX631 the lowest. A hybrid TX631B x WSV387 was intermediate for root branching. Temperate sorghums exhibited maximum root branching in the top 35 cm of soil while the tropical types generally had more branching in the lower profile. Highly branched sorghums have potential to more effectively exploit the soil for nutrients and water.

A greenhouse study on two exotic Chinese sorghum varieties placed under combined water and N stress, as compared to CK60 indicated that these may have potential importance in areas of low or medium soil N if water is not limiting. Moisture stress seemed to negatively affect the China lines much more than N stress as shown by reduced head dry matter and grain. Grain yield was reduced with high N when moisture was limiting.

Seven diverse sorghums were compared for $(NO_3)N$ reductase activity in two environments with the objective of better understanding N use efficiency characteristics of the sorghums. In the field, those varieties previously found to be high for N use efficiency were also high in N reductase activity. This indicated a possible relationship between N reductase activity and N efficiency which may be exploited. Another study on sorghums of known N use efficiency indicated that all varieties generally responded positively to applied N. There was no genotype by N rate interaction over a range of 0 to 100 kg ha^{-1} applied N. Hybrids generally produced greater grain yields than the parents with or without N.

Studies conducted in Mali, West Africa on several Malian varieties planted at different dates with different soil fertility levels, indicated large differences for biomass and harvest indices between locations. Planting date appeared to influence biomass production at one location but not harvest indices. Harvest indices were not greatly influenced by fertility level. Some of the newer Malian lines out of the current breeding program had very good biomass production and harvest indices. It was also determined from a companion study that Guinea sorghums had decreased planting to PI intervals when planting was delayed in contrast to Malisor varieties which were less sensitive or not affected by planting date regarding this parameter.

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 fertility levels (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

Research Related to Student and Scientist Training

Root morphology of diverse sorghums. Cassim Masi - Zambia. The specific goals of this study were to: (1) evaluate the branching pattern of several sorghum genotypes by fractal analysis; and (2) determine whether fractal dimension can objectively be used to describe the rooting systems of the sorghum genotypes and/or be used to group the genotypes according to their rooting characteristics. Ten sorghum genotypes were grown in three replications in wooden boxes filled with a mixer of 20% fine and 80% sand by weight in the greenhouse. Spacing between boxes was about 0.10 m apart and this was adequate to provide a spacing of 0.15 m between plants. Initially, 2-3 seeds were sown in the middle of the root box and later thinned to one plant per box. The nails inside on the side of the box were used to support and retain the natural pattern or geometry of the roots and at the same time, maintain their relative position after the box was opened.

At the 10 - 11 leaf stage, one side of the box was removed and the soil and sand mixture carefully washed with tap water from the roots. The shoot was carefully detached from the roots, and the roots were sprayed with 0.5% (wt/vol) solution of Janus Green dye which was allowed to penetrate for one minute before rinsing with water. When the roots were partially dry, the boxes were turned down on a 1.2 by 1.2 m white formica board in such a way as to allow the roots to fall on the board in the same geometry as they were in the box. The roots were trisected both horizontally and vertically with a black elastic string which provided nine square sections (350 x 350 mm each). Photographs were taken from each section with ISO 25 Kodachrome slide film. The roots and shoots were dried, and total dry matter was determined for each sample.

The fractal dimension, D, was determined for each genotype and root segments or sections within the root-box in the greenhouse. Mean fractal dimensions, log K values, root dry matter and root to shoot ratio among sorghum genotypes are presented in Table 1. Analysis of variance indicated significant differences among the genotypes in fractal dimension, log K (intercept), root dry matter, and root-shoot ratios.

The genotypes were found to be different in root distribution and dry matter as shown by variations in fractal dimension values. The fractal dimensions (D) of all genotypes except TX631 (D=1.62) were greater than 1.65. The genotype WSV387 had a particularly high fractal dimension of 1.84. Naga white performed equally the same as WSV387 with a value of 1.80. The hybrids TX631 x WSV387 and TX631 x M9037R did not differ significantly from each other and average response performance of their parents. D values for M90378, CE-151-262 and IR204 ranged from 1.70 to 1.77 while, TX631, PI8358 and KS57 had the lowest D values in the range of 1.62 to 1.66.

The results demonstrate that these genotypes have root systems that differed in branching magnitude. Root systems that have high D values are considered to have highly branched structures. This means that higher fractal dimen-

Table 1. Estimates and contrasts of root fractal dimension (D), root abundance (log K) and root/shoot for sorghum genotypes grown in the root boxes in the greenhouse.

Genotype	Fractal dimension D	Root abundance (log K) matter	Root dry wt. g/plant	Root/shoot ratio
TX631	1.62	5.08	16.03	1.04
KS57	1.66	5.07	4.90	1.25
PI8358	1.67	5.32	29.90	0.93
TX631 x WSV387	1.78	5.56	97.12	0.62
TX631 x M90378R	1.72	5.35	42.23	0.72
Naga white	1.80	5.59	61.40	0.74
M90378R	1.77	5.52	57.38	0.52
CE-151-262	1.77	5.47	40.13	0.62
IR204	1.70	5.40	33.83	0.82
WSV387	1.84	5.63	117.70	0.45

sion values are associated with those genotypes that exhibit root systems which are more complex and highly branched; the more complex root systems have fractal dimensions closer to 2 than to 1. In contrast, those with lower values may be expected to be simple with less branching. Patterns of root distribution were different among genotypes (Table 2).

Table 2. Mean values for root distribution (% root counts of 6.35-square size) of ten sorghum genotypes at 0-35, 35-70, and 70-105 cm soil depth when grown in a root-box in the greenhouse.

Genotype	Root-box depth 0-35 cm	 35-70 cm	 70-105 cm
		%	
TX631	49.60	33.97	16.00
KS57	41.84	33.18	24.98
PI8358	46.37	35.89	17.74
TX631 x WSV387	36.71	30.25	33.04
TX631 x M90378R	39.92	31.77	28.56
Naga white	38.49	30.59	30.93
M90378R	36.28	33.90	29.83
CE-151-262	33.63	38.05	28.24
IR204	36.92	34.09	29.00
WSV387	38.46	34.01	27.53

The temperate sorghum genotypes such as TX631, PI8358 and KS57 exhibited maximum root distribution in the top 35 cm of the soil profile. These same genotypes were observed to have lower fractal dimensions (1.15 to 1.58) at the depth of >70 cm. On the contrary, the hybrids TX631 x WSV387, TX631 x M90387 and genotype Naga white showed maximum root distribution both in the root sections 0 - 35 and 35 - 70 cm of the root box. M90387, CE-151, IR205 along with WSV387 appear to have similar rooting patterns, which were abundant in the upper as well as lower profiles as indicated by fractal dimension values and log K. A higher log K at different rooting depth may reflect maximum lateral spread of roots. The genotypes with higher fractal dimension at each section of a profile tended to occupy more surface area and exploit more soil volume to a greater degree than other genotypes.

Variation of fractal dimension between genotypes provides some insight into their sensitivity to branching patterns. In the context of fractal analysis, the rooting pattern of two genotypes may be considered similar, but with the addition of log (K), which refers to root abundance, such differences can be used to separate the genotypes. Furthermore, roots exhibiting high capacities for growth and branching become long and thick, enabling soil exploration and water and nutrient transport, while roots with low capacities remain short and thin with potentially less effective exploitation of the soil.

Effect of water and nitrogen levels on exotic sorghums high in stress tolerance. Teshome Regassa, Visiting Scientist - Ethiopia. A greenhouse experiment was conducted at UNL to determine the growth potential and N use characteristics of two Chinese (San Chi San and China 17) compared to CK60 under combined N and water stress. Another objective was to explore physiological and morphological traits associated with stress tolerance. Seeds were planted in pots containing 25% soil and 75% sand that was analyzed for initial NO_3-N and water holding capacity. The varieties were factored over three levels of N: 10 mg NO_3- kg^{-1} soil (low), 20 mg NO_3 kg^{-1} soil (medium), and continuous N supply (high). Two water levels were also imposed, those being fully watered to field capacity, and those stressed at the tenth leaf stage. Each pot was suspended on a hanging scale and watered to a field capacity until tenth leaf stage. After the tenth leaf stage water was withheld from plants to be stressed until a level when partial turgidity was not regained early in the morning. The low and medium N levels were applied once after complete seed emergence while the high N was applied until maturity in the form of solution with other essential nutrients. Zero N solution was concurrently added to the low and medium N plots for essential nutrients other than N. A field experiment is in progress to substantiate the results obtained under greenhouse conditions.

Summary of some of the measured variables are shown in Tables 3 and 4. The amount of water applied to stressed plots was significantly ($P < 0.01$) lower indicating less total water use and the China lines used more water. Nitrogen increased the amount of water required per pot.

Leaf area was increased by N and the China lines had highest leaf area. At the tenth leaf stage, even if N had increased leaf area of all varieties, leaf area of CK50 had dropped significantly at the high N level.

Leaf density (g cm^{-2}) was significantly increased by high N. The difference between mean leaf density at the low and medium N was not significant. No significant difference was found between moisture and varietal mean leaf densities.

Significant difference was observed between varieties and the N levels for SPAD-50 chlorophyll meter reading at the eleventh leaf stage and heading. Both China lines gave lower readings than CK60. The SPAD reading and leaf chlorophyll content have a direct relationship, therefore, these lines have lower chlorophyll compared to CK60. Nitrogen also increased leaf chlorophyll content.

Stressed plants produced significantly ($P < 0.01$) higher leaf and stem dry matter but significantly (P < 0.01) lower head dry matter and grain. The China lines exceeded CK60 in head dry matter and grain formation under fully watered conditions. Under water stress and high level of N, however, the China lines produced significantly lower head dry matter and grains. This could possibly be attributed to the difference observed among the varieties in tillering behavior (both auxiliary and basal) and difference in recovery growth after moisture stress was relieved. After the shock of stress the China lines tended to lose their leaves and developed auxil-

Table 3. Means of water applied, leaf area and leaf density for three sorghum lines grown at three N levels and two moisture regimes in a greenhouse experiment

Treatments	Water applied (L/pot)	Leaf area (cm^2)		Leaf density (g cm^{-2})
		5th leaf	10th leaf	
Moisture				
Fully watered	26251	125.1	909.5	5.82×10^{-3}
Stressed	22747	124.2	919.2	5.93×10^{-3}
Variety				
San Chi San	25048	157.9	1118.0	6.0×10^{-3}
China 17	24877	145.4	974.5	5.75×10^{-3}
CK60	23572	70.7	650.6	5.86×10^{-3}
Nitrogen				
10 mg NO_3 kg^{-1}	23491	119.9	847.6	5.47×10^{-3}
20 mg NO_3 kg^{-1}	24076	118.0	885.5	5.55×10^{-3}
High nitrogen	25929	136.0	1010.0	6.60×10^{-3}

Table 4. Means of morphological and physiological traits for three sorghum lines grown at three N levels and two regimes in a greenhouse experiment.

Treatment	Leaf color		Total chl. Grain fill	Plant height (cm)	Dry matter (g/plant)			Grain (g/plant)
	11th leaf	Heading			Leaf	Stem	Head	
Moisture								
Fully watered	36.6	33.7	5.37	115.6	8.6	22.6	21.0	15.5
Stressed	34.8	32.3	6.21	92.7	9.7	23.4	9.6	5.5
Variety								
San Chi San	32.7	30.5	5.6	100.8	10.6	24.2	16.3	11.2
China 17	34.6	31.2	4.3	132.0	8.0	24.0	18.1	12.6
CK60	36.7	37.3	8.2	79.6	8.9	20.8	11.5	7.7
Nitrogen								
10 mg NO_3 kg^{-1}	26.8	23.3	3.2	107.5	5.8	18.2	11.2	7.7
20 mg NO_3 kg^{-1}	29.6	26.1	3.7	106.6	6.5	21.1	13.8	9.7
High nitrogen	47.7	49.6	11.3	98.2	15.3	29.8	20.8	14.1

iary and basal tillers that reduced or stopped the growth of the head. CK60 tend to stop shoot extension under stress but recovered both shoot and leaf growth after the stress was removed. It also developed less auxiliary tillers. The stockiness of CK60 might influence its performance, especially in its water economy. Moisture stress reduced plant height while N application increased it.

In general, combined effects of moisture stress and high N had negative effects on the China lines possibly by creating certain unbalanced physiological processes and unfavorable morphological structures such as increased basal and auxiliary tillers, leafness and other factors which could make them more vulnerable to moisture stress. Compared to the control (CK60) the China lines also produced more stem and leaf dry matter. Grain yield of these lines under stress was reduced with each level of added N. Under better moisture, however, the reverse was true. Moisture stress and high N resulted in hording of their dry matter in stem and leaves resulting in very low grain yields. From this information, it can be inferred that the China lines are more prone to moisture stress than N stress. Under limited moisture, high N could result in haying-off of these lines. The information obtained also suggests potential importance of these lines in areas of low or medium soil N where moisture is not the main limiting factor of sorghum production. It is also suggested that if certain breeding manipulations for drought stress tolerance is done on these varieties, they may have great potential for low and/or medium N soils.

Nitrate metabolism in diverse sorghum cultivars. Abdoulaye Traore - Mali. As part of an ongoing Ph.D. study, seven sorghum genotypes grown at two soil N levels (low and optimum) in the field were tested for NO_3- reductase activity (NRA) and compared to earlier controlled condition greenhouse studies. Samples were taken from leaves of random plants (approximately 2 g fresh weight) using leaf punches of known area and placed on ice for processing in the laboratory. Standard procedures were used for the enzyme assay.

Table 5 shows the enzyme activity comparison for the two environments. Generally, field activities were much lower than those of the greenhouse most likely because of the more optimum conditions of water and nutrients of the greenhouse environment. Previous experiments showed that Malisor-7, S-34 and M35.1 were very high in N use efficiency (g DM S^{-1} N). The field NRA activities were also the greatest for these genotypes along with P720, a high lysine type from Purdue. The ranking of genotypes was the same

Table 5. Nitrate reductase activity (NRA) from seven sorghum genotypes grown in the field and in the greenhouse.

	NRA	
Genotype	Field	Greenhouse
	n mole NO_2 cm^{-2} hr^{-1}	µmole NO_2 g^{-1} hr^{-1}
Malisor-7	62.6	1.97
P720	59.6	3.77
M35.1	58.8	2.88
S34	45.1	2.83
VG146	42.3	2.59
HH640	38.3	2.50
CK60	36.4	2.34

in field and greenhouse except for Malisor-7 which ranked lowest in the greenhouse. There was no significant interaction between N level and genotype. Genotypes were significantly different ($P = 0.05$) indicating a potential relationship between NRA and N use efficiency as determined on these genotypes from earlier work (Ann. Report 1992/93).

Response of nitrogen efficient sorghums to nitrogen fertilizer. Samuel Buah - Ghana. Twenty-nine sorghum genotypes previously selected for high nitrogen use efficiency (g DM g^{-1} N) were grown in the field at the University of Nebraska and Kansas State University in 1993 at three N rates (0, 50, and 100 kg/ha). The objective was to determine agronomic responsiveness to applied N and characterize physiological factors that contribute to improved NUE. The genotypes did not interact with N rates. However, there was significant yield response due to the different N rates. Mean grain yield increased with increasing rates of N (1.8, 2.2, and 2.4 t/ha for 0, 50, and 100 kg/N/ha, respectively). The average response of the genotypes to 50 and 100 kg N/ha was 22 and 33%, respectively. The hybrids generally produced significantly higher grain yield than their parents with or without N fertilizer. Five top hybrids in terms of yield were TX623/IR204, KS9/DR50, TX7000/SC566, KS9/SC279, and TX7000/1R204 which produced 4.0, 3.8, 3.3, 3.1 and 3.0 t/ha, respectively. This experiment is being repeated in Nebraska during the 1994 growing season.

International Research (Mali).

Date of planting and fertility responses of Malian sorghums - Abdoul Toure. Fourteen local Malian varieties and an IRAT released variety were planted at different dates and fertilizer levels at Katibougou to compare biomass production and harvest indices. In this study, date of planting and fertilizer were non-significant for the parameters measured. There was no date of planting x fertilizer interaction. Varieties Seguetanal, Foulatieba 2 and Seguetana 9 produced the greatest biomass of 4769, 4685 and 4705 kg ha^{-1}, respectively. Varieties Seguetanafing 3, Foulatuba 3 and N'Gonewoule 8 had the highest harvest indices of 0.325, 0.307 and 0.303, respectively.

At Samanko, ten new Malian varieties were compared to four local and an ICRISAT release for the same parameters. Planting data influenced biomass production but harvest indices were not altered by either planting date or fertilizer level. Varieties producing the greatest biomass were 90-C2-CS-F5-107, 90-C2-C5-F5-111 and 90-C2-CS-F5-60 at 11,321, 8839, and 7926 kg ha^{-1}, respectively. Variety 90-C2-CS-F5-111 had the greatest harvest index. At the latest planting date, varieties 90-C2-CS-F5-180, 90-C2-CS-F5-96 and 90-C2-CS-F5-107 had the greatest biomass production. Variety 90-C2-CS-F5-80 had the greatest harvest index.

Determination of adaptation zone for Malian sorghums - Abdoul Toure. Three Guinea (CSM388, Nazongala, CSM63) and three Malian sorghums (Malisor 84-7, Malisor 92-1, Malisor 92-2) were planted at six planting dates from May 17 - July 27 in 15 day intervals at Samanko to determine adaptation according to rainfall pattern. Days from planting to panicle initiation and mean crop growth rate were recorded. The study showed that as planting is delayed, the time to panicle initiation (PI) decreases. Generally the CSM varieties had decreased planting - PI time with each planting delay whereas the Malisor varieties were less sensitive or were not affected at all by delayed planting. Mean crop growth rate was generally higher in the Guinese types, especially for the earlier planting dates. However, there was quite a lot of variation in this parameter.

Networking Activities

UNL-114 supplied $7000 to Mali for collaborative research in nitrogen agronomy and physiology.

UNL-114 purchased a new $4500 soil moisture probe for use at Sotuba.

Traveled to Mali on UNL-114 funds to plan new collaboration in agronomy and physiology.

Publications

Gardner, J.C., J.W. Maranville and E.T. Paparozzi. 1994. Nitrogen use efficiency among diverse sorghum cultivars. Crop Sci. 34:728-733.

Physiologically Derived Cultural and Genetic Enhancements of Water and Temperature Stress Induced Limitations

Project UNL-116

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Summary

Mr. Gandoul I. Gandoul's stress screening training has been completed and his Ph.D. dissertation is being written. His emphasis was on developing legume stress screening capabilities because of nitrogen deficiency problems in most semiarid tropic countries and the inability of many farmers to finance N fertilizer purchases. He also gained stress screening experience with sorghum. However, nutrient deficiencies and cultural practices without a legume component are frequently, if not predominately, greater production constraints in Africa than is suitable germplasm. That is the reason for the legume component emphasis in his research on sorghum production constraints. He has done an excellent job of analyzing the contributing effects of dense pubescence in ameliorating water stress induced effects on physiological processes such as photosynthesis (Ps; the energy source for N fixation), transpiration level (as it influences water use efficiency = WUE), respiration (drives essential syntheses of carbohydrates, proteins, oils, etc.) and other essential physiological/biochemical processes which drive growth and associated N fixation which potentially benefits a rotational sorghum crop. Compared to normal pubescence, the dense pubescence character improves Ps, reduces leaf temperature and transpiration, increases WUE, maintains a higher water potential, promotes more rapid growth (which is presumably associated with greater N fixation) and gives higher grain yields. Some of these measurements should be useful in stress screening. In addition, some of the Ps - stomatal resistance analyses were informative. He demonstrated the expected normal heavy influence of stomatal control on Ps and also demonstrated an increasing CO_2 concentration as stress increased and stomatal resistance increased. This suggests some stress induced biochemical limitation in dark CO_2 fixation reactions which is a consideration for future research evaluation. Overall Mr. Gandoul's training and experience will permit him to screen germplasm effectively in real world environments.

Part of Mohamed Hovny's training for stress research and screening in sorghum involved testing in two dry and one wet environments. His research involved using a block within replication design with and without two checks included. The analyses were with block adjustments based on check yield and without adjusted means. The top 20 lines were to be chosen for advancement in the program. When the top 20 were selected based on adjusted means, 8 or 9 lines in the adjusted mean list were different from the 20 lines in the other unadjusted set, despite the fact that rank correlations between adjusted and unadjusted means were on the order of 0.9. The value of known checks for visual observation through the season, as well as for block adjustments in stress experiments, is quite high. This experience was an eye opener for Mr. Hovny and will serve him well in his work in Egypt.

Seed size yield component research at Nebraska seems to be progressing well. There is a germplasm manipulation component to this work which is financed by the Nebraska Grain Sorghum Board. We are close to having medium seed sized R lines generated which are reasonably well adapted to the Great Plains. Very preliminary data suggest that hybrids can now be made with seed sizes up to the 3.2 to 3.6 g/100 range (compared to 2.5 to 2.9 g/100 in good commercial hybrids) without sacrificing yield at least up in the 8000 kg ha^{-1} range. The influence of seed size on roller milling, steam flaking and starch release properties will be tested some time in the future. The immediate concern is determining whether or not we can generate a positive impact on yield under good conditions and also get yield compensation, through attaining larger seed size during grain filling, if preanthesis stress has materially reduced the seed number component of yield. Determining the influence of grain fill length on seed size attained is a key investigation area.

Objectives, Production and Utilization Constraints

Sudan

Enhance water use efficiency (WUE) in both sorghum and nitrogen fixing legumes in sorghum based cropping systems where N and H_2O deficiencies are serious.

Egypt

Conduct a joint breeding/physiology water stress screening program at Fayoum and Shandoweel.

Assist Egyptian breeders in developing sorghum populations for Egyptian water/salt stress conditions.

Determine crop water use efficiency and nutrient use efficiencies at different water levels, particularly in the New Lands areas.

United States

Continue stress screening.

Expand research on stress resistance mechanisms through heat shock protein and mitochondrial analyses.

Evaluate the relationship between grain fill length, metabiotic pace and seed size.

Research Approach and Project Output

Sudan

The current political situation in Sudan precludes travel and interaction with Dr. S. Farah. Research was confined to Mr. Gandoul's Ph.D. thesis research which is summarized below.

Water is usually, if not always, the most limiting production constraint in the semi-arid tropics (SAT). Nutrients, particularly nitrogen (N), run a close second. Efficient use of both water and N is absolutely imperative. Developing cultural systems to maximize WUE and nutrient use efficiency (NUE) requires understanding the nature of the water x nitrogen (W x N) interaction in a given production situation. When soil N is very low, water and N effects are often additive or greater than additive. In these kinds of farming situations, credit is often unavailable putting commercial N fertilizer out of the farmer's reach. Under these circumstances inclusion of a legume in the rotation or an intercropping system is critical. To be more succinct if you want to increase sorghum production under such conditions it is often smart to increase legume production since growth level is a good indicator of N-fixation level. Besides increasing N availability for the associated cereal crop, legumes generally recycle other nutrient elements from lower soil depths and often help suppress cereal grain pests. If the legume is a grain legume, it often generates cash which can be used to purchase phosphorus fertilizer (to enhance legume growth) which is normally considerably cheaper than commercial N fertilizer for the cereal crop.

Mr. Gandoul's legume stress performance work was initiated with these facts in mind and with a view toward screening measurements which could be made quickly as opposed to slow N (acetylene reduction) measurements. Again the thought was that if growth was rapid then N fixation should be reasonably good in low N-limited water soils. Screening evaluation measurements made were growth (leaf expansion) and essential physiological processes or parameters necessary for growth such as photosynthesis (Ps), respiration (R), transpiration (TR) and water potential maintenance. The experimental legume used was soybean since it is adapted to Nebraska and has near isogenic normal and dense pubescence isolines available. Since dense pubescence is reputed to impart more favorable stress responses than the normal pubescence character, the influence of pubescence on N fixation related characters (Ps, TR, R, growth, assimilate partitioning, etc.) was determined hoping to relate some of the measurements to stress resistance. A summary of the results follows:

A growth function (leaf expansion) will be considered first since growth (cell expansion and cell division) is ordinarily influenced by stress sooner than most other easily measured attributes. Figure 1 illustrates the growth responses to temperature of greenhouse stressed and fully watered normal and dense pubescent isolines of Clark and Harosoy soybeans. Under no stress there was a positive leaf expansion rate (LER) up to about 26C after which LER declined. The differences between the dense and normal pubescent pairs under no stress were modest. By contrast LER in stressed plants declined as temperatures rose above 21C. Furthermore the LERs of the dense pubescent isolines were higher than the normal pubescence lines between 21 to 25C. The difference tended to decline between 25 and 30C as overall LERs declined.

Field growth data were similar as noted in Figure 2. Weather was unfavorable in 1991 and superiority of the dense pubescence isoline was much greater than in 1992 when weather was favorable. Higher field production in 1991 for the dense pubescent isoline follows the higher net carbon exchange rates of the dense compared to normal pubescent isoline (Figure 3). Note the much smaller differences between the isolines under the wet, cool 1992 conditions. While NCE was higher in the dense pubescent isoline, transpiration (TR) tended to be lower so instantaneous water use efficiency (IWUE = NCE/TR) tended to be higher in the dense pubescent isoline (Figure 4). Higher IWUE is definitely a plus under limited water conditions. The dense leaf hair layer apparently increases the boundary layer resistance to water flow out of the leaf. Night respiration in 1991 tended to be higher in the normal pubescent isoline under both wet and dry conditions, especially dry (Figure 5). Perhaps the higher respiration was due to a higher maintenance respiration component due to the higher stress level (higher TR water loss and higher stress) in the normal pubescent isoline. The final superior attribute of the dense pubescent isoline was its greater percentage of reproductive mass/total mass under both wet and dry conditions (Figure 6). Almost always when a plant experiences increasing stress the reproductive mass declines faster than the vegetative mass. The normal was more stressed than the dense pubescent line in this case.

A mechanistic analyses of Ps differences between the dense and normal pubescent isolines shows (Figure 7) that as stomatal resistance increases, a decline in Ps is forced, suggesting a normal heavy stomatal control influence on Ps. However, the fact that the internal concentration of CO_2 (Ci) in the stomatal cavity increases, also suggests there are other biochemical limitations in dark reactions, in addition to stomatal control which merit evaluation as part of a stress screening development and evaluation program.

Egypt

One component of Mr. Mohamed Hovny's dissertation research in the U.S. was an experimental design choice experiment on how to maximize the amount of information which can be gleaned from stress testing experiments. One difficult problem in stress testing is how to get reliable data because of the high level of soil variability which is exposed under stress conditions. A replication in blocks design with two checks was used to test sorghum population S_1 families and their S_2 progeny for heritability and stress selection for advancing generations. Previous experience suggested using seven S_1s and two S_2 selections from each S_1 family plus two checks in each replication. There were 2 replications per block and 13 blocks. When the checks were used to adjust block means 8 or 9 of the top 20 S_2 families changed (depending on which of three environments was involved) despite high rank correlations (generally 0.8 to 0.9) between adjusted and unadjusted means. Since the rank correlation were done across all entries in the experiment, it is not surprising that 8 to 9 discrepancies among the top 20 surfaced. Rank correlations obviously can be deceiving. The advantages of seeing known checks beside S_1 or S_2 families during the selection process outweigh the loss of higher screening numbers of S_1 or S_2 families due to space required by the checks in the soil environment of this test. Each field used for tests should be evaluated independently.

Networking Activities

Research Investigator Exchanges

Mohamed Hovny and Mr. El-Bakry (Egypt) training.

Germplasm and research information exchange from USAID/CRSP/NARP Project buyin to INTSORMIL. Three populations, 12 L-lines, 2 A-lines were sent to Egypt and 15 lines were received from Egypt. Over $25,000 was sent to Egypt to purchase research equipment (LiCor 6250 photosynthetic system, psychrometors, two computers, 2 balances, dewpoint generator and many other items), supplies and/or other support.

Publications

Abstracts

Ngulube-Msikita, R., J.D. Eastin and F. Zavala-Garcia. 1994. Grain sorghum panicle respiration and length of grain filling. Agron. Abstr. p.

Gandoul, G.I., J.D. Eastin, and M.D. Clegg. 1994. Responses of soybean leaf growth to water stress. Agron. Abstr. p. 149.

Zavala-Garcia, F., M. Chisi, P.J. Bramel-Cox, J.D. Eastin and C.G.S. Valdes Lozano. 1994. Reciprocal recurrent selection in sorghum. Agron. Abstr. p. 107.

Kubik, K.K., J.D. Eastin, and M.D. Clegg. 1994. Supersweet (Shrunken-2) sweet corn: Combining strategies for improved stand establishment. Agron. Abstr. p. 151.

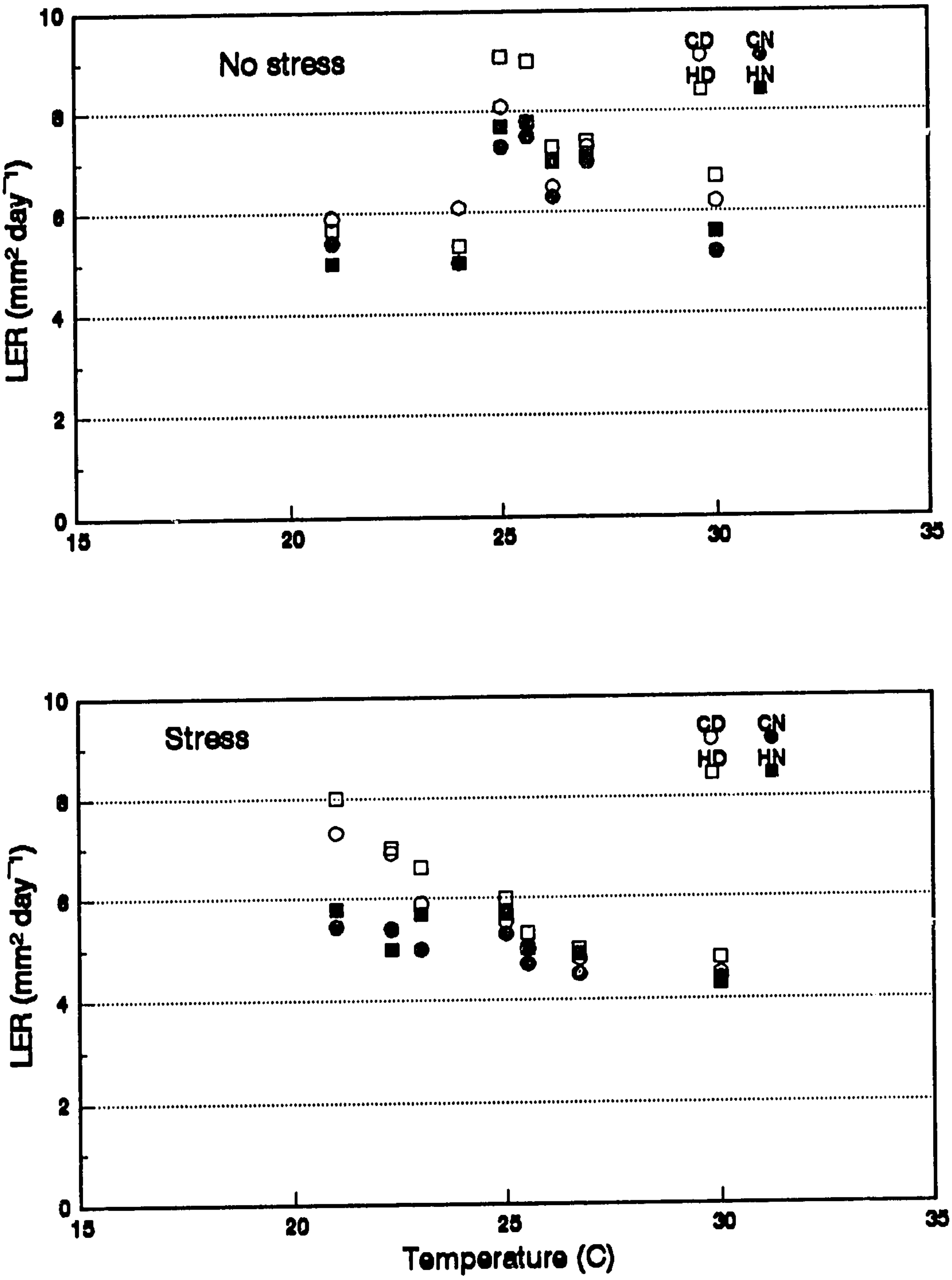

Figure 1. Relationship between temperature (C) and leaf expansion rate (LER) for dense Clark (CD), normal Clark (CN), dense Harosoy (HD) and normal Harosoy (HN) under non-stress and stress conditions.

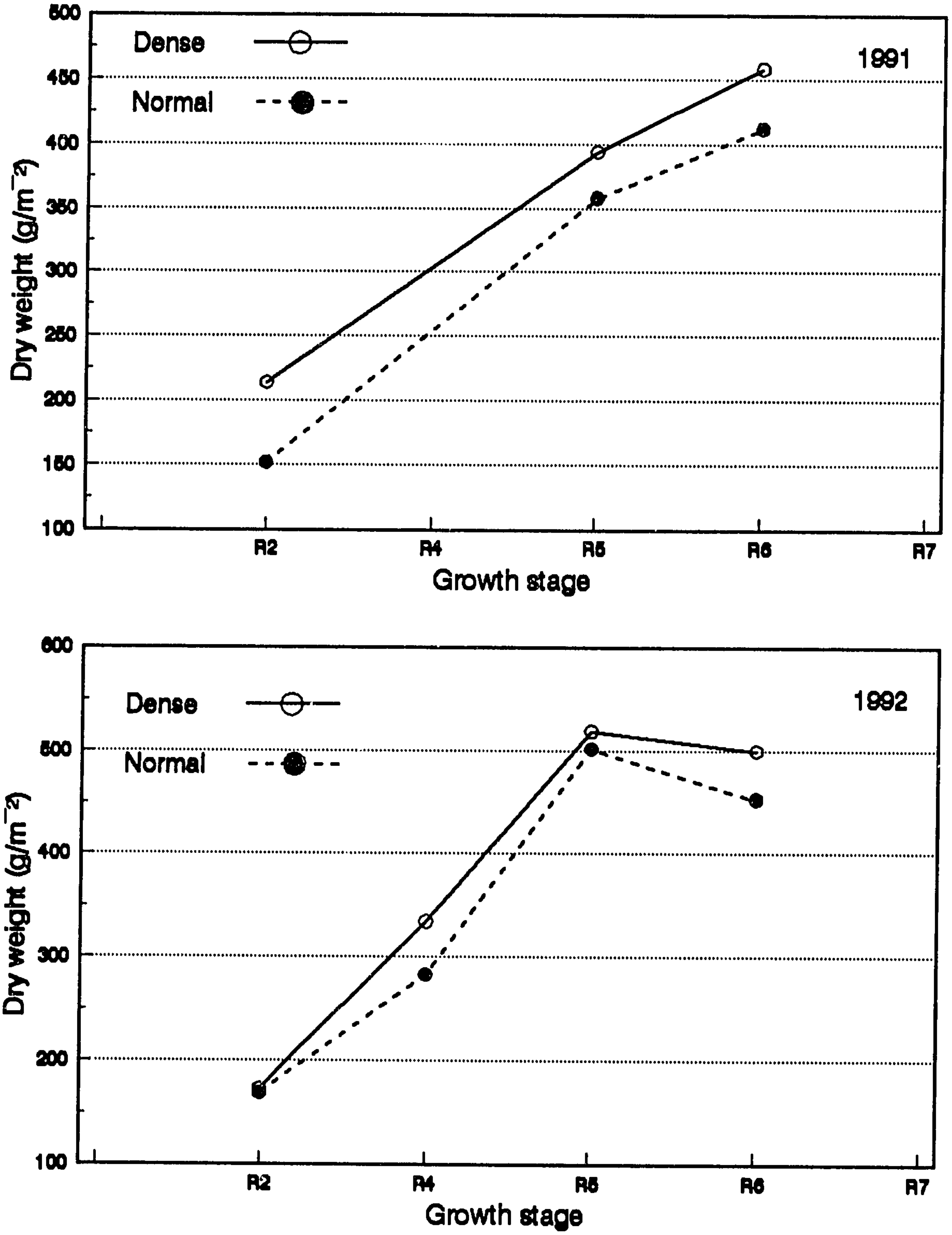

Figure 2. Seasonal patterns of dry mater accumulation of dense and normal pubescent Clark soybean isolines during 1991 and 1992 growing seasons.

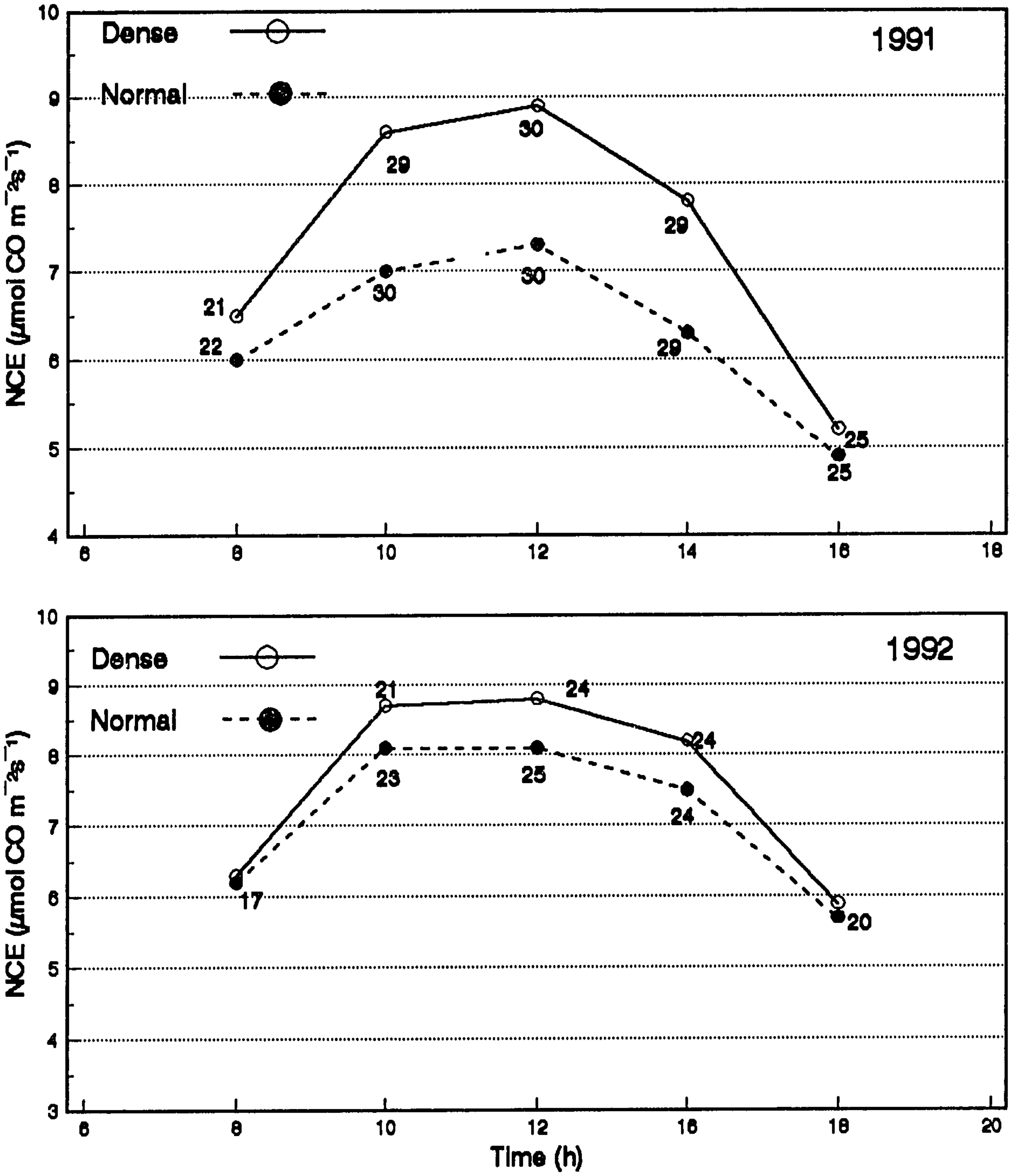

Figure 3. Canopy net carbon exchange (NCE) of dense and normal pubescent Clark soybean isolines at R2 growth stage during 1991 and 1992 at Lincoln, NE. Numbers at each point are canopy temperature (C).

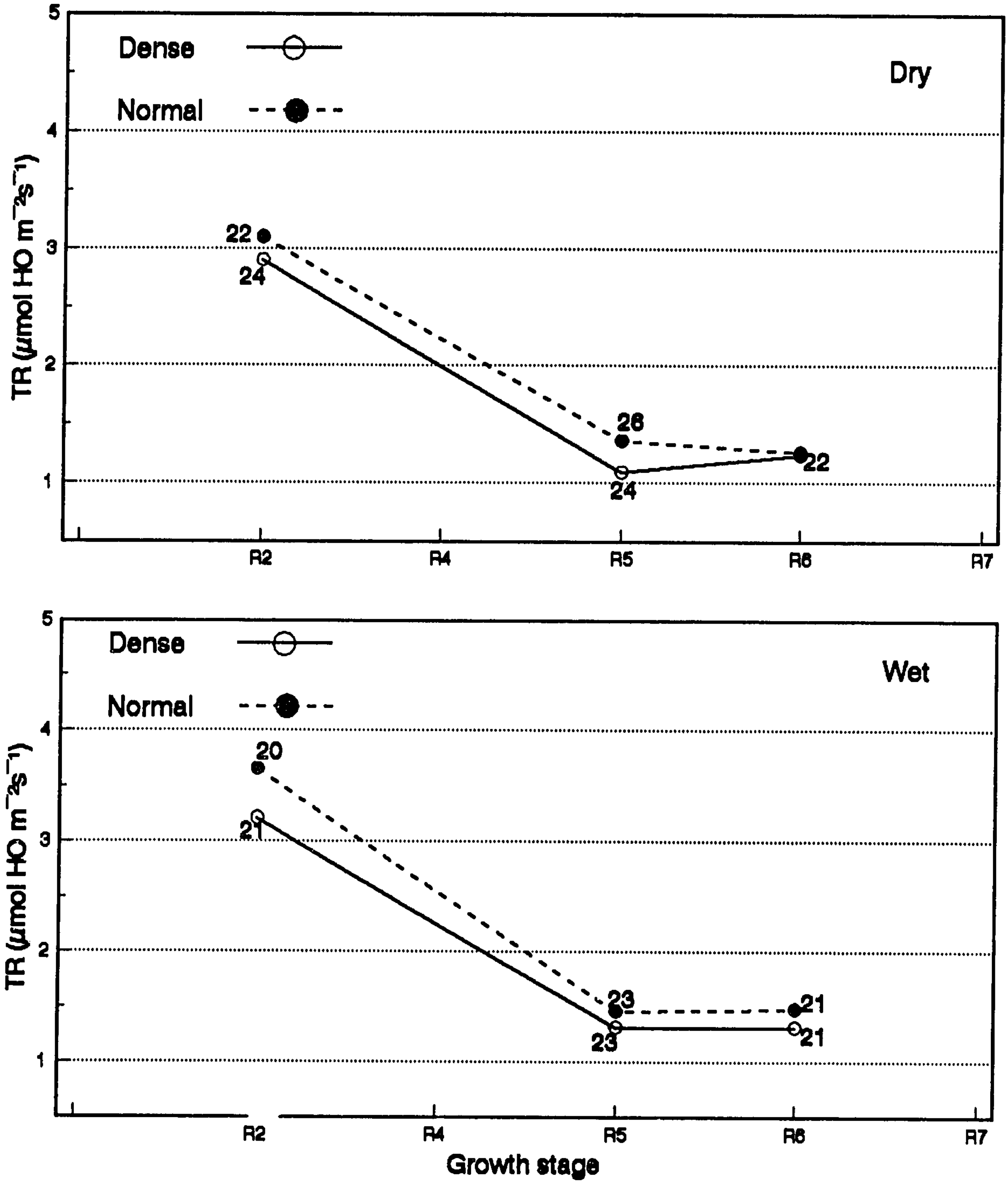

Figure 4. Seasonal patterns of transpiration (TR) of normal and dense pubescent Clark soybeans under dry and wet conditions at R2 at Lincoln, NE. Numbers at each point are canopy temperature (C).

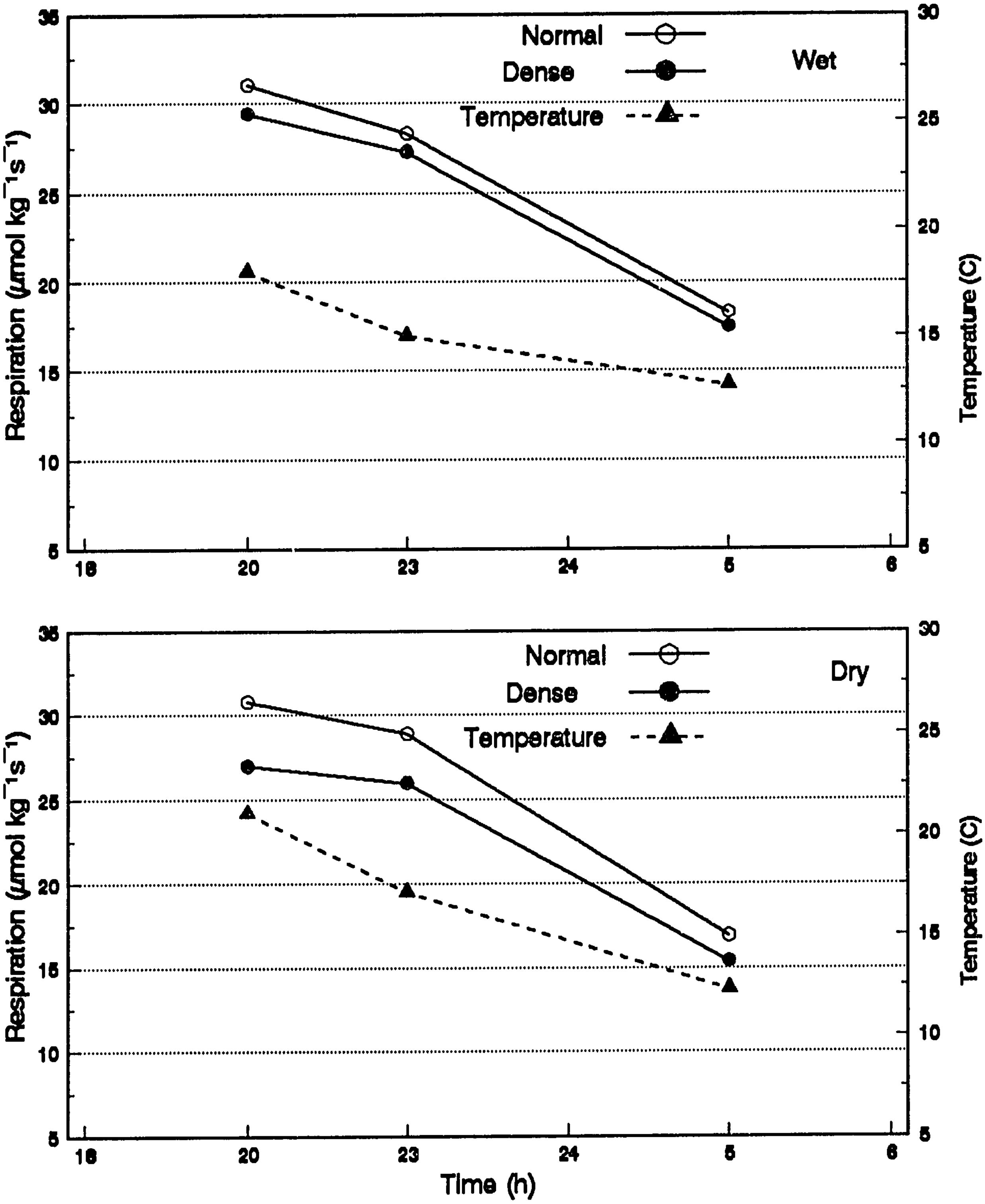

Figure 5. Changes in canopy respiration and temperature of normal and dense pubescent Clark soybean isolines at the R5 under wet and dry conditions during 1991 at Lincoln, NE.

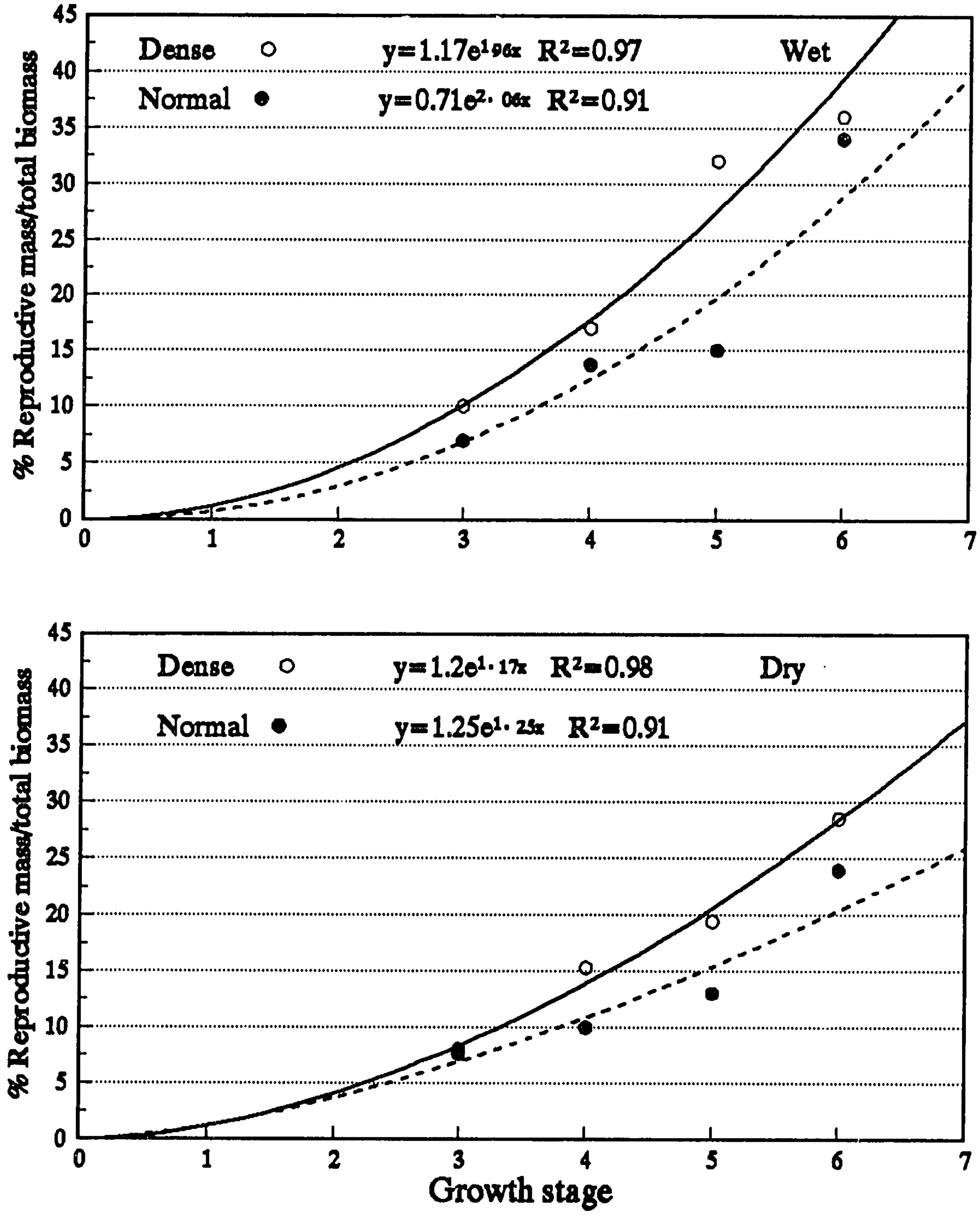

Figure 6. Partitioning coefficient for dense and normal pubescent Clark soybean isolines under wet and dry conditions during 1991.

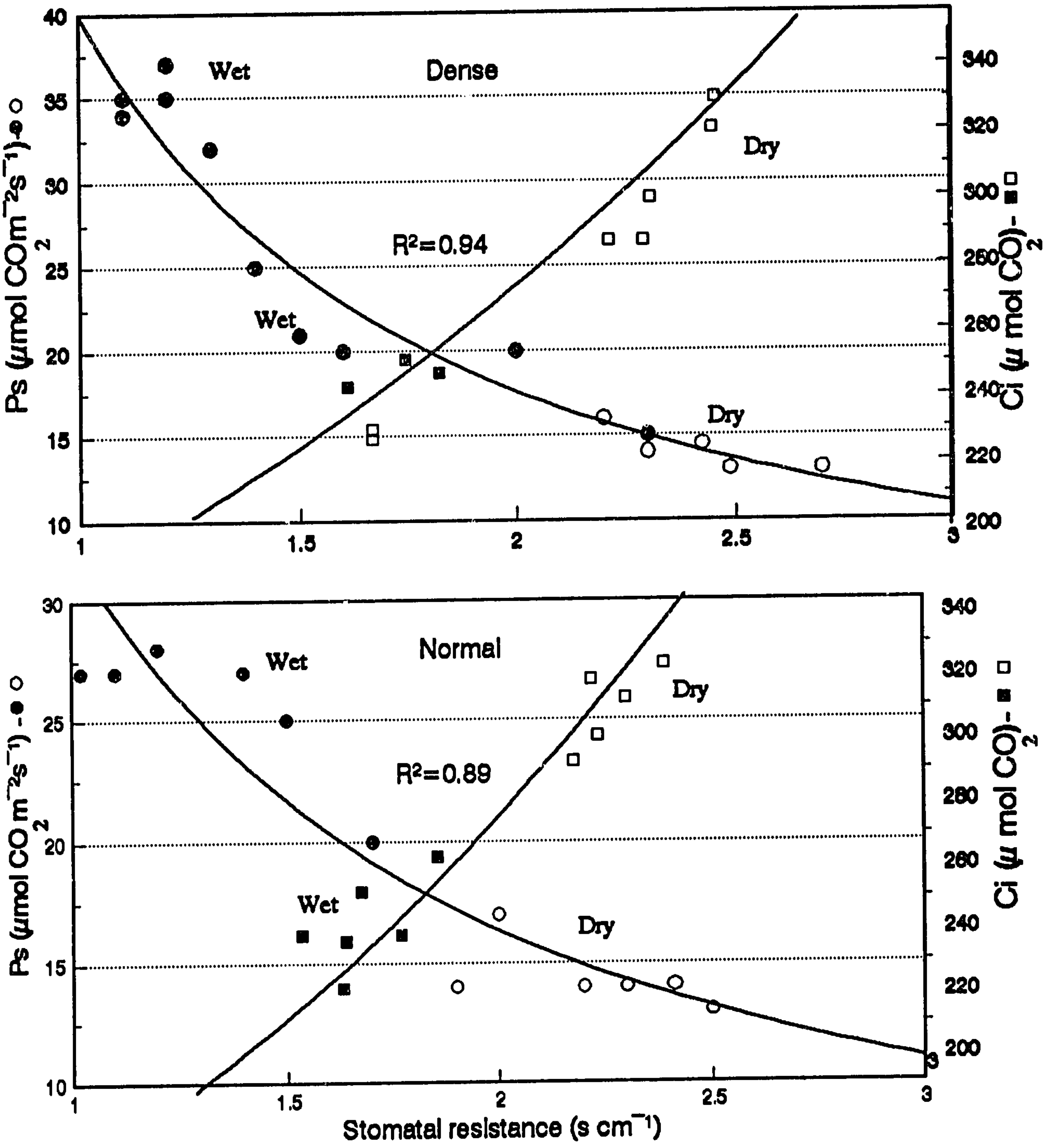

Figure 7. Relationship between photosynthesis (Ps), stomatal resistance (Rs) and Internal CO_2 concentration (Ci) of dense and normal Clark soybeans at R3.

Germplasm Enhancement and Conservation

Pearl Millet Germplasm Enhancement for Semi-Arid Regions

Project KSU-101
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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 millet germplasm result in improved ranges of adaptability, HI, stand establishment, drought stress tolerance, and lodging resistance. These have been successfully exploited in India through collaboration with ICRISAT personnel but have been difficult to incorporate into African millet germplasm. Downy mildew (DM) disease susceptibility of KSU-101 materials has been the main obstacle in the transfer of US 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

Mali

To determine the efficacy of alternate cycles of crossing and selection in the western U.S. Great Plains and Mali for seed and plant characteristics enhancing stand establishment, drought tolerance, and wider adaptation. A germplasm presumed to be *Striga*-resistant will be evaluated in hybrid combinations with several Malian varieties.

Niger and Zimbabwe

To enhance and enlarge the germplasm base of collaborative projects by the exchange of materials possessing superior plant and seed characteristics.

ICRISAT/India

To continue the enhancement of A_1, A_4, B, R_1 and R_4 inbred lines by cycling improved materials between projects followed by crossing and selection at Patancheru and KSU/Agricultural Research Center at Hays.

U.S.

To continue the development of pearl millet materials with improved characteristics affecting productivity and to determine the mode of inheritance of seed, seedling, and plant characteristics affecting productivity and agronomic responses.

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 plant breeding. Drought and heat stress are the primary constraints in much of the dry tropics since millet is grown in areas receiving limited erratic amounts of precipitation. Drought and heat stress influence 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_1s 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 longer 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

Precipitation amounts received in 1993 were 73 percent above normal. All low-lying areas of the station were flooded in mid-July to depths of two meters or more for periods of two to five days causing severe damage to about 50 percent of the breeding program materials. All performance tests of populations, population topcross hybrids, and experimental testcross hybrids were abandoned. Thirty of 33 small (60 to 100m^2) isolated crossing blocks and seed increases were abandoned. Variable damage levels were observed within five of the larger (0.2 to 0.4 ha) blocks planted to random-mating populations.

Emphasis is being placed on developing a population of breeding materials, elite inbred lines, and genetically broad based populations useful to collaborators in LDCs 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

Twenty-four accessions from Mali were grown in quarantine and crossed to elite KSU-101 lines to produce 77 F_1 hybrids. Seven of the Mali lines were crossed to a line from Yemen that was reported to be resistant to *Striga*, producing 13 hybrids.

A total of 72 Malian millet cultivars and synthetics have been imported since 1991 and crosses to elite KSU-101 breeding materials have produced 369 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 occur 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 to F_5 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. Two of these hybrids have produced heads intermediate in length

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. 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 stalks 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 for mechanized agriculture, the taller plant heights would be acceptable for Malian intercropping situations. For this purpose, several elite, tall (150-175 cm) d_2 dwarfs were crossed to accessions from Mali to generate segregating materials for selection in Mali.

Improved stand establishment characteristics have been obtained by selecting for increased mesocotyl length by planting to depths of 100 mm in the greenhouse and 75-80 mm depths in the field and identifying early emerging seedlings with rapid rates of mesocotyl elongation. When placed at normal planting depths seedlings of lines having long and rapidly elongating mesocotyls emerge 0.5 to 2 days earlier than unselected lines. Limited data indicates lines with improved emergence capability produce larger plants with 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 their 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 290 A/B pairs. Another group of 132 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 tentatively identified six restorer lines for the A_4 system within this program but more than 314 lines have been crossed to A_4 lines for evaluation in 1994. 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 Tables 1 and 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 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. 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 male-fertility restorer lines derived from crosses involving 1985 to 1988 introductions are presently producing experimental hybrids with improved plant and agronomic characteristics and with yield potentials as shown in Table 2.

Lodging

Lodging stalk 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

Table 1. Agronomic and grain yield performance of advanced experimental A_1 cytoplasmic male-sterile lines in hybrid combination with tester males (averages of two tests grown at Kansas State University, Agricultural Research Center at Hays, 1992, 1993).

	Grain yield kg ha⁻¹	Bloom days	Plant height cm	Lodging percent
Funk's 550 Sorghum	6280	68	130	5
90-0240 / 89-0093	6110	63	185	35
90-0302 / 89-0093	5800	61	185	50
90-0205 / 89-0093	5470	60	160	25
90-0189 / 89-0093	5460	56	160	30
90-0207 / 89-0093	5440	63	165	30
90-0080 / 89-0083	5440	63	165	30
90-0240 / 89-0083	5430	62	168	25
90-0197 / 89-0093	5430	59	163	25
90-0328 / 89-0093	5400	61	155	25
90-0127 / 89-0093	5390	58	160	45
90-0021 / 89-0093	5320	56	152	30
90-0070 / 89-0093	5280	55	150	35
91-1150 / 89-0083	5220	58	147	30
90-0025 / 89-0093	5190	57	155	25
90-0030 / 89-0093	5090	59	150	25
79-2068 / 89-0083 Check	3540	59	140	60

Table 2. Grain yield and agronomic performance of advanced R1 male-fertility restorer lines in hybrid combination with tester female lines of similar maturity. (From Test 5, Hays, 1993.)

	Grain yield kg ha⁻¹	Bloom days	Plant height cm
90-0240/91-1047	7660	66	157
79-2068/92-1123	6920	57	119
Funk's 550 sorghum	6640	66	119
90-0240/92-1063	6340	68	152
81-1056/92-1091	5850	61	142
90-0328/92-1107	5640	63	147
81-1056/92-6166	5610	56	122

into hardpan and the B horizon of the soil. These plants are easily uprooted in severe wind storms. Breakage at a stalk node appears to be inherited as a simple recessive trait 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 stalk 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 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 stalk rind. 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 trait 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 were 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.

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. 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 has been applied to populations HMPBR d_2 and PI185642 d_2 by planting alternating four row blocks within their isolations at 75 to 85 mm in 1992 and the entire populations at that depth in 1993.

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 tests at FHES each year. Phenotypic variability for grain yield (62 to 140 percent of the test mean in 1993) was greater than expected considering the narrow base of the population. A 20 percent selection factor in cycle 2 gave a 14.73 percent selection differential for the 16 entries selected for the cycle 3 polycross. When compared to the 14.87 percent SD obtained from cycle 1 testing it indicates minimal decrease in genetic variability within the population as a result of previous selection. The low correlation coefficients involving grain yield and plant height (+0.25) may indicate possible trends.

Networking

Research Investigator Exchanges

Oct. 6-7, 1993. Traveled to Lincoln and Mead, Nebraska to view UNL-118 program and evaluate KSU-101 materials.

Oct. 16-25, 1993. Traveled to Mali.

Jan. 28-Feb. 18, 1994. Conducted breeding operations in the Mexico winter nursery.

Germplasm Exchange

Germplasm conservation use

Twenty-four cultivars and germplasms were obtained from Malian collaborators, 145 lines from ICRISAT/Patancheru, and a total of 70 items from UNL-118.

Thirty F_1 hybrids of KSU-101 X Mali lines and Yemen (*Striga* resistant) X Mali lines and nine S_2 selections from the Yemen source were sent to Mali. Materials sent to ICRISAT/Patancheru included 50 elite inbred lines and 150 half-sib selections from population HMP BR d2.

Domestically, a set of the ICRISAT and Mali introductions and several inbred lines were sent to UNL-118

Breeding Sorghum for Tolerance to Infertile Acid Soils

Project MSU-104
Dr. Lynn M. Gourley
Mississippi State University

Principal Investigators

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Dr. Guillermo Munoz, Plant Breeder, former MSU-111, (currently with Pioneer Hi-Bred International)
Dr. Henry Pitre, Entomologist, MSU-105, Department of Entomology, Mississippi State University, Mississippi State, MS
Dr. Jerry Maranville, Plant Nutritionist, UNL-114; and Mr. David Andrews, Sorghum and Pearl Millet Breeder, UNL-118, Department of Agronomy, University of Nebraska, Lincoln, NE
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Summary

The latter part of Year 15 was a time of reorganization for MSU-104. The MSU-104 PI returned to Mississippi State University from Kenya after working four and one-half years as a sorghum and millet technical advisor to the Kenyan Agricultural Research Institute (KARI) through an INTSORMIL buy-in. The INTSORMIL Colombian Prime Site was terminated due mainly to travel restrictions imposed by the U.S. Embassy in Bogota.

This project will now be focused on the production constraints in the East African region. Kenya is currently the logical choice as the country within the region which could serve as a center to develop and transfer sorghum and millet technology throughout the region. Kenya is centrally located, geographically representative of the area, has demonstrated long-term stability, is a communications center used by many NGOs and PVOs operating in the region, and has operational seaport, rail, road and international airport facilities. With KARI, INTSORMIL now has many U.S trained collaborators.

In 1994, two sorghum hybrids were entered in the Keny National Performance Trials by Kenya Seed Company, partially government owned organization. This is unusua in two respects. First, they are the only hybrids in the tria and second, the inbreds used to produce these hybrids wer developed in the INTSORMIL Colombian acid soil breeding program. Stress screening for tropical acid soil toleranc appears to impart tolerance and stability to sorghum growing in low-input environments. In subsistence agriculture stable performance under low-input production practices i more important than high yields.

Hybrids have many advantages over inbred varieties i the infertile-soil environment: hybrid seedlings exhibi more vigor during emergence and early plant growth; hy

brids 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.

Inbred lines which produce high yielding hybrids, tolerant to 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 infertile soil complex appears to be dominate in sorghum, either tolerant pollinator or seed parent lines can be used to produce commercial cytoplasmic-genic hybrids in tropic or temperate zones.

Objectives, Production and Utilization Constraints

Objectives

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 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. To ensure that the end product of the breeding program is useful, yield and yield stability, disease and insect resistance, and acceptable grain quality must also be addressed.

Research Approach and Project Output

Pearl Millet Breeding in Kenya

One cycle of divergent phenotypic recurrent selection for seedling root length was conducted within each of two genetically diverse pearl millet populations. Early Dwarf Synthetic (EDS) is a subpopulation with very early (blooms in approximately 45 days) dwarf plant type (about 60 cm in height) and four or more erect uniform tillers having complete selfed seed set which was derived from the original Nebraska Dwarf Pearl Millet Population (NDMP), as identified in a progeny test conducted in 1985 and released as NPM-2. NDMP originated from a dwarf population of pearl millet obtained in 1977 from Dr. A. J. Casady, Kansas State University, Manhattan, Kansas. The dwarf population was composed of breeding material from the pearl millet breeding programs at Serere, Uganda and Bambey, Senegal. The seed used in this study was provided by Professor David J. Andrews, University of Nebraska, Lincoln, Nebraska.

Tift #2 S-1 is a bulk of equal quantities of seed from 740 accessions, most of which originated from Africa. Seed were bulked from 20 or more selfed plants of each accession. Tift #2 S-1 is a source of both dominant and recessive qualitative and quantitative genes. In a random sample of 300 plants, plant height and inflorescence length ranged from 90 to 370 cm and from 15 to 66 cm, respectively. Tift #2 S-1 was developed cooperatively by USDA-ARS and University of Georgia, Coastal Plain Experiment Station, Tifton, Georgia. Seed of S1 was provided by Dr. Wayne W. Hanna, USDA-ARS, Coastal Plain Experiment Station, Tifton, Georgia.

Selection for seedling root length in sand culture was conducted in the greenhouse at Mississippi State University. Paper cups (10 cm diameter by 16.5 cm deep) were filled with washed sand, arranged in metal trays on a greenhouse bench, and watered to field capacity with tap water. Four plants were established in each cup. Plants were fertilized and watered for seven days as required. A total of 180 cups were prepared and 720 plants of each population evaluated.

Seven days after planting, each cup was slit open on the side and the seedlings were carefully washed in a water filled bucket to clean sand from the roots. Seedlings were then placed on moist paper towels, and their roots were straightened. Root length of each seedling was measured from the point where the primary root was attached to the seed to the root tip.

The longest and the shortest 15% of the seedlings with respect to root length within each population were evaluated, selected, and replanted in a cup that was filled with moist sandy soil. One selected seedling was planted in each cup. The cups were then put in trays on the greenhouse bench. These plants were transplanted to the field six weeks after selection. Two divergent populations selected for seedling root length in sand culture were derived from each parent population.

Seedlings of the four selected populations were transplanted in isolation blocks 12 by 12 m with seedlings on 1 m centers within each block. After maturation, each plant was harvested, threshed, and weighed separately. Seed of each plant within a given block were bulked in equal quantities to constitute the cycle one populations.

The test locations in Kenya were Katumani and Kiboko in Eastern Province of Kenya in semi-arid agroecological zone IV with bimodal rainy seasons. The long rain (LR) season begins in March and ends in May. The second or short rain (SR) season begins in October and ends in December. The SR season is more reliable for crop production than the LR season, thus, most pearl millet and sorghum are grown in the SR season. Katumani is 1575 m and Kiboko 975 m above sea level. Soils at both location are alfisols.

The tests were planted in November during the 1991 SR season and in April during the 1992 LR season. Both locations were dry planted in the 1991 SR season, irrigated on day 1 to initiate the study, and received 289 and 294 mm of rainfall in the next 100 days at Katumani and Kiboko. The Katumani test was wet planted and the Kiboko test dry planted for the 1992 LR season. Both trials were irrigated on day 1, and received 261 mm. No recorded rainfall occurred in the next 100 days at Katumani and Kiboko. The Kiboko test was irrigated sparingly during the 1992 season; however, rainfall was poorly distributed and there were intra-seasonal water stress periods at both locations.

The experimental design was a randomized complete block with four replications in which populations derived from each parent population were planted together to prevent shading of dwarf EDS populations by the taller S1 population. Each plot consisted of three rows, 4.8 m long and 0.9 m between rows. Seeds were hill planted 60 cm apart within the row and thinned to one plant per hill, two weeks after planting. Each row contained eight plants. Measurements were made on the eight plants in the middle row where possible. The objective of the experiment was to evaluate the effects of selection for seedling root length on yield and yield components.

Retesting the selected populations after random mating showed that selecting for longer roots in sand culture was effective. The cycle one LR populations for EDS LR and S1 LR were both significantly longer than their parent populations. Population S1 SR was significantly shorter than S1; however, EDS SR was not different from EDS. Realized heritability for S1 LR was 0.23 and 0.29 for S1 SR. Realized heritabilities for EDS SR and EDS SR populations were 0.60 and 0.00, respectively.

In a Kenyan test not reported here, seedling emergence of S1 LR was significantly greater than that of the S1 parent, but this trend was not observed for the EDS LR population. Seedling shoot height, a measure of growth and vigor, for the S1 parent population was significantly shorter than S1 LR at Kiboko for four of the five dates of measure for 1991 and for all five dates in 1992. There were few differences among the EDS populations. For the S1 population, selection for longer seedling root lengths also had faster shoot elongation. Selection for long seedling root length may have promise as a means of improving seedling vigor and emergence.

Mean plant grain and stover weight of parental and selected pearl millet populations grown at Katumani and Kiboko, Kenya in 1991 and 1992 are shown in Table 1. Nearly all S1 population means were larger than those for EDS populations. This was due to the generally taller plants in the S1 populations and the positive association of height on yield.

The S1 LR population produced more grain than the S1 parent population at Katumani in 1991 and more grain and stover at Kiboko in 1992. The trend of more grain and stover production of S1 LR than for the S1 parent and S1 SR populations for both locations and years can be seen from the means. Due to the limited plot size (8 plants), error was high and differentiation of mean differences was limited.

Few differences were observed among the EDS populations for either location or year. There was some indication that the EDS parent population produced more grain than the EDS LR population. The few differences observed among the EDS populations was probably due to overall uniformity of the EDS populations in general.

Table 1. Mean plant grain and stover weight (g) of parental and selected pearl millet populations grown at Katumani and Kiboko, Kenya in 1991 and 1992.

	Katumani				Kiboko			
	1991		1992		1991		1992	
Populations[1]	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover
				S1 Populations				
S1 Parent	102.5b	167.8a	60.4a	236.6ab	93.4a	188.9a	57.2b	80.6b
S1 LR	174.3a	188.3a	88.9a	318.3a	124.0a	255.8a	112.1a	174.6a
S1 SR	135.0ab	197.0a	75.5a	168.1b	115.4a	189.0a	59.1b	88.2b
				EDS Populations				
EDS Parent	80.4a	52.8a	62.2a	57.1a	72.5a	64.9a	49.0a	30.0a
EDS LR	67.6a	44.8a	38.6b	47.1a	58.0b	64.5a	45.3a	32.0a
EDS SR	63.1a	46.7a	58.6a	61.9a	67.0ab	68.4a	36.9a	21.8a

Means within a column and a population set (i.e., S1 or EDS) followed by the same letter are not significantly different according to the t-test ($P<0.05$).

[1] Populations designated S1 are from Tift #2 S-1 (parent), a bulk of equal quantities of seed from 740 mostly African accessions (Hanna, 1990). Populations designated EDS are a subpopulation called Early Dwarf Synthetic which was derived from the original Nebraska Dwarf Pearl Millet Population (NDMP) (Andrews et al., 1992). The longest (LR) and shortest (SR) 15% of the seedlings selected for root length in sand culture from parent populations in a divergent selection procedure were random mated and consistute cycle one populations in this recurrent selection scheme.

Adapted from Ph.D. Dissertation of Dr. Lawrence M'Ragwa. Divergent selection for seedling root length and coleoptile length in pearl millet [*Pennisetum glaucum* (L.) R. Br.] and effects on seedling emergence, seedling vigor, and agronomic traits.

The EDS populations were of interest for direct use by farmers in the semi-arid areas of Kenya. Local pearl millet cultivars tend to be too tall and late. Farmers are interested in these early dwarf types for several reasons. Drought avoidance is the key to survival in semi-arid areas where rainfall is poorly distributed and unreliable. Farmers are willing to sacrifice yield for yield stability. Shorter plants lodge less, require less total water and fertility, and appear to be more bird resistant than taller and later maturity local cultivars. Birds are more visible in the shorter plants and perhaps are more vulnerable to predators and man when feeding close to the ground. Both the S1 and EDS populations will add a tremendous amount of genetic variability to the Kenyan pearl millet breeding program.

Sorghum Breeding in Kenya

Thirty-four genotypes consisting of six cytoplasmic genetic male sterile (A-lines), represented by their respective maintainer (B-lines), as female parents, four restorer (R-lines), as male parents, and their 24 F_1 hybrids from a North Carolina Mating Design II were utilized in this study. The low pH tolerant lines used were from the MSU-104 breeding research conducted in Colombia and had not been tested in Kenya before.

The Obambo location in which this study was conducted is about 1200 m above sea level, has soil of about pH 5.2-5.5 with low fertility, and is where sorghum is an important crop in the subsistence farming systems. The trial was conducted on a farmer's field which had no history of farmyard manure or fertilizer applications.

Trials were grown in 1990 and 1991 during the long rain seasons. The experimental design was a randomized complete block with four replicates. Plots consisted of a single row 5 m in length with 75 cm between rows. After emergence, seedlings were thinned to 20 cm between plants within rows. Pre-emergence herbicides and fertilizers were not used. This was done to simulate typical sorghum management practices of Western Kenya. Periodic sprays of recommended insecticides were used to control major insect pests and birds were scared from the plot from the grain filling period through harvest. The trial was maintained weed-free throughout the growing period.

Mean grain and total dry matter yields and harvest index of the 24 sorghum hybrids grown at Obambo, Kenya in 1990 and 1991 are shown in Table 2. The analyses of variance showed that genotypes, parents, and F_1s were significantly different for all variables for both years. Within F_1s, males, females, and the M x F interactions were significant for all variables for both years except total DM in 1991 for males and the M x F interaction; and harvest index for females in 1991.

Grain yields, total DM yields, and harvest indexes ranged from 819-4020 kg ha^{-1}, 2673-9300 kg ha^{-1}, and 17-53%;

Table 2. Mean grain and total dry matter yields and harvest index of 24 sorghum hybrids grown at Obambo, Kenya in 1990 and 1991.

	1990			1991		
	Yield		Harvest index	Yield		Harvest index
Hybrid	Grain	Total DM		Grain	Total DM	
	---- kg ha^{-1} ----		x 100	---- kg ha^{-1} ----		x 100
Tx623 x IS 7254C	1611	4018	37	1905	6218	38
Wheatland x IS 7254C	2210	5560	41	789	3061	29
B-Yel PI x IS 7254C	1247	6913	18	1206	3891	31
AT152 x IS 7254C	2321	6020	40	886	3977	20
AT210 x IS 7254C	886	5120	17	505	1927	33
AT136 x IS 7254C	819	2673	30	1086	3799	32
Tx623 x IA 28	2981	7033	42	2535	5558	47
Wheatland x IA 28	2659	7067	38	2326	4315	61
B-Yel PI x IA 28	2671	7453	39	2381	4307	55
AT152 x IA 28	3797	9300	41	3636	6324	57
AT210 x IA 28	2375	5067	47	1741	3692	47
AT136 x IA 28	1741	4587	38	2817	5287	54
Tx623 x Tx430	1813	5153	39	2153	5039	43
Wheatland x Tx430	2750	8020	36	2007	3803	56
B-Yel PI x Tx430	1317	4927	27	1607	3661	46
AT152 x Tx430	3745	7433	53	2423	3757	70
AT210 x Tx430	2891	7127	41	2332	4500	55
AT136 x Tx430	1364	4113	34	2243	4915	44
Tx623 x Tx432	1661	4927	35	3031	6598	47
Wheatland x Tx432	3493	7893	46	1156	3262	35
B-Yel PI x Tx432	2528	5713	49	2497	5171	49
AT152 x Tx432	4020	8273	50	1275	3314	39
AT210 x Tx432	1769	6600	28	1555	3127	51
AT136 x Tx432	3330	6980	48	1747	4669	38
Mean	2333	6188	38	1910	4340	45
$LSD_{0.05}$	1672	3248	22	1489	2334	24

Adapted from Ph.D. Dissertation of Dr. Vincent Makumbi Zake. Inheritance of tolerance to soil acidity and effects on agronomic characteristics and leaf mineral element concentrations in sorghum [*Sorghum bicolor* (L.) Moench].

and 505-3636 kg ha^{-1}, 1927-6598 kg ha^{-1}, and 20-70% for 1990 and 1991, respectively. Grand means for grain yield of the hybrids were 2333 kg ha^{-1} in 1990 and 1910 kg ha^{-1} in 1991, which was indicative of the better growing season in 1990. From the overall variable means in Table 2, it can be seen that grain and total DM yields were higher in 1990 than in 1991. Proportionately more stover than grain was produced in 1990 than 1991, resulting in a lower average harvest index for 1990.

In general, hybrid arrays with Tx623, Wheatland, and AT 152 as female parents; and IA 28 and Tx432 as male parents were superior in grain yield than other inbreds. General and specific combining ability effects for grain yield of the 24 hybrids grown at Obambo, Kenya in 1990 and 1991 are shown in Table 3. The GCA effects for males and females were significantly different from zero in 1990 except for male Tx430; and in 1991 except for male Tx432 and females B-Yel PI, AT 152, and AT 136. Among the males, IA 28 consistently produced high positive GCA effects and IS 7254C consistently produced high negative GCA effects. The other males produced inconsistent GCA effects. Among the females, AT 152 consistently produced positive; and AT 210 negative GCA effects. The GCA effects for the other females were inconsistent.

Hybrids producing positive SCA effects significantly different from zero in 1990 were At 136 x Tx432 (1050), At 210 x Tx430 (931), and Tx623 x IA 28 (594); and in 1991 were AT 152 x IA 28 (918), Tx623 x Tx432 (658), B-Yel PI x Tx432 (607), and AT 210 x Tx430 (581). Most of the highest yielding hybrids produced their high yields by means of both positive GCA and SCA effects.

IA 28 was the best combiner in both years as indicated by its high positive GCA effects. The female AT 152 was also a good general combiner. These results suggest that additive genetic variance was important in the control of grain yield. When these two inbred were combined, the resultant hybrid produced high yields both years. The existence of both additive and non-additive genetic variance for grain yield were indicated by these data.

Both IA 28 and AT 152 were selected in the Colombian breeding effort as being tolerant to infertile low pH soils. Both inbreds are tropically adapted and combine well with other inbreds to produce tough, high yielding hybrids. Together they produce a superior hybrid with high grain yield, high harvest index, and is bird resistant. In Western Kenya, as in Colombia, high tannin grain is preferred due to the large numbers of grain eating birds and grain mold tolerance. In Western Kenya and Uganda, farmers have used techniques to neutralize tannins with wood ashes or eliminate the testa by pounding and removing the seed coat for many years.

Hybrid AT 152 x IA 28 has performed well in Colombia and at Mississippi State University. It produced high yields of grain at Tarna, Bengou, and Konni, Niger as reported in the INTSORMIL 1990 Annual Report, pages 52-59. Kenya Seed Company, a partially government owned seed company, has entered two hybrids in the Kenyan sorghum National Performance Trials using inbreds developed by this project. One of these hybrids appears to be AT 152 x IA 28.

Networking Activities

Workshops

Dr. Susana Goggi was an instructer for the 37th Seed Improvement Course (T.C. 130-3), Seed Technology Laboratory, Mississippi State University, May 31 - July 31, 1993.

The MSU-104 PI presented a paper at the Workshop on Adaptation of Plants to Soil Stresses, University of Nebraska, Lincoln, Nebraska, August 1 - 4, 1993.

Table 3. General and specific combining ability effects for grain yield of 24 sorghum hybrids grown at Obambo, Kenya in 1990 and 1991.

Females	Year	Males								GCA effects females	
		IS 7254C		IA 28		Tx430		Tx432			
		1990	1991	1990	1991	1990	1991	1990	1991	1990	1991
		SCA Effects									
Tx623	1990	412	--	594**	--	-184	--	-822**	--	-317*	--
	1991	--	346	--	-534**	--	-471*	--	658**	--	496**
Wheatland	1990	250	--	-489*	--	-8	--	248	--	445**	--
	1991	--	66	--	94	--	220	--	-381	--	-340**
B-Yel PI	1990	124	--	360	--	-604**	--	120	--	-392**	--
	1991	--	130	--	-205	--	-533**	--	607**	--	13
AT152	1990	-332	--	-45	--	294	--	83	--	1137**	--
	1991	--	-322	--	918**	--	150	--	-747**	--	145
AT210	1990	-276	--	24	--	931**	--	-678**	--	-353**	--
	1991	--	-181	--	-455*	--	581**	--	55	--	-378**
AT136	1990	-177	--	-443	--	-429	--	1050**	--	-520**	--
	1991	--	-40	--	181	--	52	--	-193	--	64
GCA effects Males		-817**	-847**	371**	663**	-21	218*	467**	-34	--	--

*,**Significantly different from zero according to the t-test at the 0.05 and 0.01 levels of probability, respectively. Adapted from Ph.D. Dissertation of Dr. Vincent Makumbi Zake. Inheritance of tolerance to soil acidity and effects on agronomic characteristics and leaf mineral element concentrations in sorghum [*Sorghum bicolor* (L.) Moench].

Dr. Susana Goggi was an instructor for the 1993 International Fertilizer Development Center (IFDC) Training Course, Muscle Shoals, Alabama, August 2 - September 3, 1993.

A paper on advances in the selection and breeding of acid-tolerant plants was co-authored by the MSU-104 PI and presented at the Third International Symposium on Plant-Soil Interactions at Low pH at Canberra, Australia, September 12 - 16, 1993.

Five papers were co-authored by the MSU-104 PI and presented at the American Society of Agronomy Meetings, Cincinnati, Ohio, November 7 - 12, 1993.

The MSU-104 PI attended and participated in a KARI-MIAC-USAID Research Planning Workshop held in Nairobi, Kenya, May 18 - 19, 1994.

The Small Ruminant and INTSORMIL CRSP activities in Kenya were reviewed June 7 -10, 1994. The MSU-104 PI assisted in the coordination of this review since KARI receives assistance from both CRSPs.

The MSU-104 PI assisted in the organization and participated in a National Performance Trial Data and Design Review Workshop for all KARI sorghum and millet Research Officers held at Machakos, Kenya, June 9 - 10, 1994.

The MSU-104 PI assisted in the organization and gave the opening address at a KARI Technical Assistant's Training Course held at Machakos, Kenya, June 13 - 18, 1994.

Research Investigator Exchanges

Dr. Robert Hudgens consulted with MIAC in Kenya concerning research in systems agronomy. The MSU-104 PI escorted Dr. Hudgens in visits to KARI Centers and in meetings with KARI and USAID administrators, July 7 - 10, 1993.

The MSU-104 PI assisted in the completion of the KARI cereal crops 10-year Strategic Plan.

January 10 - 31, 1994 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.

Dr. Charles Campbell, MIAC Coordinator, visited Mississippi State University and consulted with Kenyan students and their Major Professors.

Dr. Susana Goggi left the MSU-104 Project on February 1, 1994 for a position at Iowa State University. Dr. Goggi conducted project research at Mississippi State University while the MSU-104 PI was in Kenya.

Dr. Clarence Watson, Plant Breeder and Statistician at MSU, consulted with MIAC in Kenya from May 25 - June 20, 1994. He and the MSU-104 PI are co-Major Professors for several of the KARI graduate students currently at MSU.

Dr. Larry Butler, Purdue University Biochemist, consulted with MIAC in Kenya on sorghum food science and Striga research from June 8 - 25, 1994. Together with Drs. Watson, Hudgens, M'Ragwa, and the MSU-104 PI, several KARI Centers and Sub-Centers were visited in the dryland areas of Eastern Kenya.

The MSU-104 PI and his wife left Kenya on June 28, 1994 after completing a 4 1/2 year long-term assignment with MIAC. This assignment as a sorghum and millet technical advisor to KARI was the result of an INTSORMIL buy-in by MIAC. The investment of time spent trying to improve the KARI S/M Research Program was considered rewarding and worthwhile.

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

Dos Santos, F. G., G. V. E. Pitta, L. M. Gourley, and A. S. Goggi. 1993. Introduction and evaluation of Al-tolerant sorghum germplasm in Brazil. p. 188. In Agron. Abs. November 7-12, 1993. Cincinnati, OH.

Goggi, A. S., C. H. Andrews, H. O. Catano, and L. M. Gourley. 1993. TZ staining patterns in sorghum for artificially induced freeze damage. p. 151. In Agron. Abs. November 7-12, 1993. Cincinnati, OH.

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 17(1):1-11.

Goggi, A. S., J. C. Delouche, and L. M. Gourley. 1994. The effects of seed specific gravity on stand establishment and production in sorghum. Journal of Seed Technology (in review).

Gourley, L. M. 1994. Breeding sorghums for infertile, acid soils. Proceedings of the 8th EARSAM Regional Workshop on Sorghum and Millet Improvement. ICRISAT (in press).

Gourley, L. M. 1994. Success in acid/low fertility soils in Colombia. p. 221-233. In Proceedings of the Workshop on Adaptation of Plants to Soil Stresses, INTSORMIL Publication No. 94-2. The University of Nebraska, Lincoln, NE.

M'Ragwa, L. R. F., C. E. Watson, and L. M. Gourley. 1993. Effects of selection for seedling root length and coleoptile length on field seedling emergence and shoot height in pearl millet. p. 95. In Agron. Abs. November 7-12, 1993. Cincinnati, OH.

Ortegon, J., L. M. Gourley, C. E. Watson, Jr., and N. Zummo. 1993. Pathogenicity of *Fusarium moniliforme* on sorghum genotypes in aluminum supplemented low pH nutrient culture. p. 96. In Agron. Abs. November 7-12, 1993. Cincinnati, OH.

Saadan, H. M., L. Gourley, and C. Watson. 1994. Inheritance of manganese tolerance in sorghum. Proceedings of the 8th EARSAM Regional Workshop on Sorghum and Millet Improvement. ICRISAT (in press).

Zake, V. M., C. E. Watson, Jr., L. M. Gourley, and R. B. Clark. 1993. Combining ability for leaf mineral content of sorghum on infertile, acid soils in Kenya. p. 106. In Agron. Abs. November 7-12, 1993. Cincinnati, OH.

Zeigler, R. S., S. Pandey, J. Miles, L. M. Gourley, and S. Sarkarung. 1994. Advances in the selection and breeding of acid-tolerant plants: rice, maize, sorghum, and tropical forages. Plant and Soils (in press).

Presentations

Dos Santos, F. G., G. V. E. Pitta, L. M. Gourley, and A. S. Goggi. 1993. Introduction and evaluation of Al-tolerant sorghum germplasm in Brazil. ASA Meetings. November 7-12, 1993. Cincinnati, OH.

Goggi, A. S., C. H. Andrews, H. O. Catano, and L. M. Gourley. 1993. TZ staining patterns in sorghum for artificially induced freeze damage. ASA Meetings. November 7-12, 1993. Cincinnati, OH.

Gourley, L. M. 1993. Success in acid/low fertility soils in Colombia. Presented at the Workshop on Adaptation of Plants to Soil Stresses, August 1-4, 1993, Lincoln, Nebraska.

M'Ragwa, L. R. F., C. E. Watson, and L. M. Gourley. 1993. Effects of selection for seedling root length and coleoptile length on field seedling emergence and shoot height in pearl millet. ASA Meetings. November 7-12, 1993. Cincinnati, OH.

Ortegon, J., L. M. Gourley, C. E. Watson, Jr., and N. Zummo. 1993. Pathogenicity of *Fusarium moniliforme* on sorghum genotypes in aluminum supplemented low pH nutrient culture. ASA Meetings. November 7-12, 1993. Cincinnati, OH.

Zake, V. M., C. E. Watson, Jr., L. M. Gourley, and R. B. Clark. 1993. Combining ability for leaf mineral content of sorghum on infertile, acid soils in Kenya. ASA Meetings. November 7-12, 1993. Cincinnati, OH.

Zeigler, R. S., S. Pandey, J. Miles, L. M. Gourley, and S. Sarkarung. 1993. Advances in the selection and breeding of acid-tolerant plants: rice, maize, sorghum, and tropical forages. Presented at the Third International Symposium on Plant-Soil Interations at Low pH, September 12-16, 1993, Canberra, Australia.

Breeding Sorghum for Increased Nutritional Value

Project PRF-103A
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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.

This report notes for the first time that a genetic solution may be possible for the digestibility problem. Bruce Hamaker in the Food Science Department (PRF-112) has been collaborating on studies of new genetic lines with protein digestibility equivalent to corn. Studies are in progress to determine the inheritance of this important trait in sorghum.

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 five 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 erratic 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 semi-arid 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 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.

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. 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 seeds men from both the U.S. and from developing countries to meet and discuss with scientists and government policy makers in Niger 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.

Objectives, Production and Utilization Constraints

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 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 (QPM) 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 were conducted at several locations beginning in 1992 and will continue through 1995 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 present 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 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.

Drought Research

A major drought occurred across a section of the corn belt, including West Lafayette, Indiana, in 1992. 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 a 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.

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 spend 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 three 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 first 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, 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

Sorghum Protein Digestibility

Recent research in collaboration with Bruce Hamaker has identified sorghum cultivars with significantly improved digestibility. Hamaker's results show that these cultivars have protein digestibilities comparable to corn and wheat.

The genetic source of these lines trace back to crosses between P-721 opaque and improved food grain lines from the Purdue program. Selections are being evaluated by Dr. Hamaker's laboratory using some new and very efficient *in vitro* laboratory tests which he developed. Agronomic performance of these lines is quite good since they were first selected for agronomic performance and yield and then subsequently tested to identify those high yielding lines with good protein digestibility.

Tagging Genes for Early Maturity in Sorghum with Molecular Markers

Issoufou Kapran is studying the inheritance of early maturity in sorghum and the identification of molecular markers which will allow selection for earliness using a marker assisted backcross program. The source of early maturity include very early lines from Niger and Sudan. Earliness is a much desired trait by farmers because they guarantee a crop even under erratic rainfall conditions. This study will allow a more efficient selection of very early sorghums with good yield potential and good food grain quality for farmers who live under these eratic rainfed conditions.

Cold Tolerance in Sorghum

Sorghum cultivars in general lack the ability to grow well under cool early spring conditions in the central cornbelt. However, excellent sources of cold tolerance are known to exist and have been collected from Northern China where sorghum has historically been grown under cool temperate conditions. Unfortunately, most of these Chinese lines have undesirable agronomic traits in respect to disease, insect resistance, and yield potential. We have initiated a long-term recurrent selection program using the Chinese source of cold tolerance in an intergression program with elite sorghum germplasm from the INTSORMIL program. Each cycle is subjected to a cold test using procedures similar to those used by corn breeders for several decades. Early results suggest that progress can be achieved but that the process will be slow. The results however could provide useful germplasm for semi-arid tropical, high elevation locations, and also for the central cornbelt.

Development and Characterization of Epicuticular Wax Mutants in Sorghum bicolor

Sorghum is a major grain crop throughout the world. Because it is relatively drought tolerant, sorghum can be grown in areas where conditions are too harsh for corn and it is therefore one of the primary food staples in the semi-arid tropics of Africa. Epicuticular wax (EW) has previously been associated with drought resistance in sorghum. This may be the result of reduced cuticular transpiration and/or increased dispersion of heat by reflection of light caused by the waxy bloom on normal sorghum plants. Our studies developed sets of near isogenic lines of normal, bloomless (no visible EW), and sparse bloom (reduced visible EW) mutants using chemical mutagenesis of two drought resistant sorghum cultivars, P898012 and P954035. Near isogenic *Sorghum bicolor* mutants for epicuticular wax (EW) production provide a model system for interdisciplinary analysis of EW genetics, morphology, physiology, and biochemistry. Mutants were characterized phenotypically and tests for pleiotropic effects of EW mutations were conducted. Segregation ratios indicate nuclear single gene recessive inheritance for 30 of 38 putative mutants. Allelism tests distinguished at least six loci involved in EW production among 31 mutants and Txbm1. Differences in leaf blight, *Exserohilum turcicum*, and leaf rust, *Puccinia purpurae*, susceptibility between EW mutants and normal isolines were associated with quantitative and qualitative differences in EW chemical composition and structure. An inverse relationship between EW amount and leaf disease susceptibility was found which suggests these waxes may play an important role in disease resistance.

During the past year considerable progress was made in characterizing the chemical composition of the epicuticular waxes of sorghum sheaths. The major constituents of wild-type sheath waxes were found to be free carboxylic acids of chain length C_{28} and C_{30}. Certain of the "bloomless" mutants with visibly altered wax loads were found to have carboxylic acids of much shorter chain length (C_{22}-C_{26}). The latter mutants include bm18. One mutant (bm28) exhibited carboxylic acids of longer chain length than wild-type, accumulating significant amounts of C_{32}. The hybrid between bm18 and bm28 exhibited normal epicuticular wax carboxylic acid profiles. However, the F_2 segregated in a manner consistent with mutations in two separate genes in two discrete elongate pathways of epicuticular carboxylic acid synthesis. The double mutant exhibits a markedly different carboxylic acid profile than either parent (bm18 or bm28) and wild-type.

We examined the influence of epicuticular wax on the reflection of solar radiation and its affect on crop growth. Hollow epicuticular wax filaments, which are present on the sorghum sheath, reflect photosynthetically active and infrared radiation. The amount of reflected radiation was directly proportional to the area of the sheath covered with wax filaments. Field comparisons between normal sorghum and a near-isogenic mutant which lacked epicuticular wax filaments were made to test the hypothesis that "bloom" in sorghum reduces canopy energy flux and enhances productivity. No significant differences were measured. Canopy reflectance and the extent of light penetration into the canopy were essentially identical.

A mutant line having alterations in both epicuticular waxes and reduced cuticle thickness was identified. The mutant with reduced cuticule exhibited increased epicuticular water conductance (i.e., it lost more water) and increased susceptibility to the fungal pathogen *Exserohilum turcicum*. To our knowledge, this is the first description of a cuticle mutation in plants. The identification of this mutation in a near-isogenic background provides a unique system to study both cuticle biogenesis, and the role of the cuticle in plant performance.

Epicuticular Wax Morphology of Bloomless (bm) Mutants in Sorghum bicolor

Sorghum bicolor mutants for cuticular wax production provide a model system for analysis of epicuticular wax (EW) physiology, biochemistry, and genetics. Mutants produced from seeds treated with the chemical mutagens diethyl sulfate (DES) and ethyl methanesulfonate (EMS) were selected in the M_2 generation and self-pollinated to produce near-isogenic mutants of two classes; bloomless (lacking visible EW) and sparse bloom (possessing little visible EW). Scanning electron microscopy was used to further divide 33 selected lines into 14 unique classes based on altered EW structure. Mutations have affected the structure of cork silica (CS) cell associated EW or both CS cell and cuticle EW. The resulting spectrum of altered EW structure indicates unique alterations in EW biosynthesis or deposition which may correlate with specific EW alleles and loci within the *Sorghum* genome.

Transposable Element in Sorghum

Transposable elements have been used to tag "Epicuticular Wax Genes" in sorghum. Several sorghum [*Sorghum bicolor* (L.) Moench] lines that exhibit variegated pericarp color have been collected. We selected one of these lines, referred to as candystripe, for genetic characterization. We found that the gene involved in the candystripe phenotype is not only associated with red pigment variegation in the pericarp layer of the seed, but also determines variegated red pigmentation in chlorophyll-bleached leaves and yellow pigmentation in the stigmas of mature flowers. Inheritance tests indicated that the candystripe trait is monogenic, and allelism tests showed that it is encoded by an allele of the sorghum *Y* locus, which we call *y-cs*. Segregation studies suggested that *y-cs* instability is autonomous and without extreme dosage effects. Molecular and mapping data demonstrated that the *Y* gene of sorghum is not homologous to any of the several (>12) cloned genes from maize that are known to be involved in flavonoid synthesis. We have observed germinal instability of *y-cs*; apparent reversion to a stable *Y* phenotype occurred at frequencies varying from <1% to >20%. The behaviors of *y-cs* are indicative of the type of transposable element-induced systems that, in maize and other plant species, have proved invaluable as tools for molecular, genetic, and developmental studies.

Genetic Analysis of Mutable Phenotypes Associated with Candystripe Sorghum

A candystripe cultivar in sorghum shows a high frequency of somatic and germinal instability for pericarp pigmentation resulting in the characteristic phenotype. This type of instability is associated with the presence of a transposable element. To date, no molecular evidence exists to show that a transposon is causing the candystripe phenotype. An alternative way to demonstrate the presence of a transposable element is through its somatic and germinal instability. The pericarp color is controlled by the Y locus and the candystripe phenotype is designated y-cs. Excision and reinsertion of transposon at the Y locus results in a red head with a small variegated sector. In addition, these red heads when grown produce mutations based on where the transposon has moved to and these mutants in turn exhibit mutability indicative of transposon induced mutations.

Several putative transposon induced mutants have been obtained from red heads, each red head representing an independent excision event, of the candystripe cultivar. These mutants include a chlorophyll deficient, brown midrib color, bloomless (lack of epicuticular wax), wilty seedling, virescent seedling, dwarf growth habit and yellow stripe mutant similar to yellow stripe in maize. An overall mutation frequency of 10 in 3,000 was seen. Of the mutant types, chlorophyll deficient mutant showed reversions to the wild type green phenotype at different stages of plant development, and a morphologically normal plant in a row segregating for the brown midrib phenotype shows tiller expression for brown midrib trait. This demonstration of mutable phenotype provides additional suggestive evidence of a transposable element in sorghum. The putatively transposon tagged bloomless mutant will provide a source of genes for epicuticular wax which could be transferred to other crop species by transformation.

Sorghum Transformation

Transgenic sorghum plants have been obtained after microprojectile bombardment of immature zygotic embryos of a drought-resistant sorghum cultivar, P898012. DNA delivery parameters were optimized based on transient expression of *R* and *Cl* maize anthocyanin regulatory elements in scutellar cells. The protocol for obtaining transgenic plants consists of the delivery of the *bar* gene to immature zygotic embryos and the imposition of bialaphos selection pressure at various stages during culture, from induction of somatic embryogenesis to rooting of regenerated plantlets. One in about every 350 embryos produced embryogenic tissues that survived bialaphos treatment; six transformed callus lines were obtained from three of the eight sorghum cultivars used in this research. Transgenic (T_0) plants were obtained from cultivar P898012 (two independent transformation events). The presence of the *bar* and *uidA* genes in the T_0 plants was confirmed by Southern blot analysis of genomic DNA. Phosphinothricin acetyltransferase activity was detected in extracts of the T_0 plants. These plants were resistant to local application of the herbicide Ignite/Baste, and the resistance was inherited in T_1 plants as a single dominant locus. This is the first report of stable transformation in sorghum.

Physiology of Drought Resistance

Two contrasting sorghum lines (K886 and CS3541), differing sharply in their pre-flowering tolerance to drought and in their capacity for osmotic adjustment, were subjected to water deficit, and their solute accumulation patterns were characterized by Drs. Joly and Premachandra. Line K886, a drought tolerant accession, exhibited substantially greater accumulation of solutes over the whole range of leaf water potentials induced. Of interest is the fact that this pattern was observed for virtually every solute analyzed, including glycinebetaine, sugars, amino acids, potassium, calcium, magnesium, phosphorus and chloride. The single exception to this pattern was for proline. Sugars, K^+, Cl^- and amino acids were the major contributors to osmotic potential in both lines, but the extent to which they affected osmotic adjustment varied between lines and with stress development. Water-stressed plants of line K886 maintained higher leaf turgor as well as higher rates of CO_2 assimilation, stomatal conductance and transpiration than CS3541. Future work will involve characterization of high- and low-accumulating lines and their hybrids in order to critically evaluate the genetic aspects of this character.

Epicuticular Vax Load and Water-Use Efficiency in Bloomless and Sparse-Bloom Mutants of Sorghum bicolor (L.).

A mutation breeding approach use utilized to obtain near-isogenic lines of sorghum [*Sorghum bicolor* (L.) Moench] with altered epicuticular wax. Seeds of three bloomless mutants (bm-15, bm-22 and bm-38) and one sparse-bloom mutant (h-19) were obtained from M_4 generation, and responses of mutants were compared to their corresponding normal, non-mutant sib lines (designated N-15, N-22, N-38 and N-19). Net CO_2 assimilation rate, stomatal conductance, transpiration rate and water-use efficiency were measured on the uppermost, fully expanded leaves in irrigated and non irrigated 43-day-old plants using a LiCor LI-6200 portable photosynthesis system. Epicuticular wax load (EWL) and cumulative water loss from excised leaves (CWL) were measured, and the relationships among EWL, CWL and water-use efficiency were assessed. Differences in response to irrigation level varied among the four lines. Among irrigated plants, h-19 exhibited a higher water-use efficiency than N-19. Among non irrigated plants, bm-15, bm-22 and h-19 exhibited lower water-use efficiency than N-15, N-22 and N-19, respectively. Water-use efficiency measured in non irrigated bm-22, a mutant line with no visible wax structures on the abaxial leaf surface, was more than 40% below that measured in N-22. The water loss from excised leaves was greater in bloomless and sparse-bloom lines than in normal lines. Water-use efficiency varied linearly with epicuticular wax load under irrigated (r=0.72) and non irrigated (r=0.94) conditions.

Leaf Water Relations and Gas Exchange in Two Grain Sorghum Genotypes Differing in Their Pre- and Post-Flowering Drought Tolerance

Two grain sorghum [*Sorghum bicolor* (L.) Moench] lines (TX7078 and B35) of similar maturity, but known to exhibit differences in sensitivity to drought in pre- and post-flowering growth stages, were evaluated in order to quantify the physiological basis for differences in drought tolerance between lines and growth stages. The relationships among leaf water status, osmotic adjustment, leaf gas-exchange characteristics, and epicuticular wax load were characterized for irrigated and non-irrigated plants during pre- and post-flowering growth stages. Osmotic adjustment during pre-flowering stress did not differ between lines, and average adjustment was approximately 0.42 MPa. In contrast, osmotic adjustment occurred only in TX7078 during post-flowering stress, and the extent of adjustment relative to irrigated plants was only 0.16 MPa. Neither osmotic adjustment nor epicuticular wax load appeared to be related to the relative drought tolerance of these genotypes during pre- or post-flowering growth stages. A reversal in the ranking of water-use efficiency (WUE) of TX7078 and B35 occurred between pre- and post-flowering growth stages. Nonirrigated plants of TX7078 exhibited significantly higher WUE than B35 at the pre-flowering stage, but the opposite was true in the post-flowering stage. The reason for the reversal in WUE is not known, but there was no significant relation between osmotic adjustment and WUE. TX7078 and B35 showed a contrasting response for intercellular CO_2 concentration (C_i) in both pre- and post-flowering experiments; C_i was strongly reduced by water deficit in TX7078, but it was not significantly affected in B35, suggesting that these genotypes may differ fundamentally in their photosynthetic response to low leaf water potential.

Leaf Water Relations, Gas Exchange and Solute Accumulation in Two Grain Sorghum Lines Exhibiting Contrasting Drought Tolerance

A drought-tolerant grain sorghum line (K886) maintained significantly higher relative water content (RWC), osmotic potential at full turgor [$\psi\pi_{(100)}$], turgor pressure (Ψ_p) and leaf gas-exchange rates than did a drought-susceptible line (CS3541) when the two genotypes were grown in containers and subjected to severe water stress prior to anthesis. Leaf area expansion was inhibited to a greater extent by water deficit in line CS3541 than in K886. Both the basal $\psi\pi(_{100})$ potential and the capacity to accumulate solutes upon exposure to stress appear to play important roles in the measured genotypic differences in leaf water relations. Sap osmolarity was greater in line K886 than in CS3541 throughout the entire range of water potential induced. With the exception of proline, the baseline concentrations of each of eight solutes were higher in K886 than in CS3541. Further, when water deficit was imposed, K886 exhibited larger increases in sap osmolality than did CS3541. The concentrations of K^+, sugars, Cl^- and P, predominant solutes contributing to osmotic adjustment, increased with increasing stress in K886 but remained essentially constant in CS3541. The two lines exhibited large differences in the relative contributions of individual solutes to osmotic adjustment, and these contributions changed markedly during stress development both within and between lines. The most notable differences between genotypes were with respect to the contributions of sugars and K^+ ions.

Networking Activities

Workshop

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 and Millet Program, Bulawayo, Zimbabwe

Dr. Vartan Guiragossian, Sorghum Breeder, ICRISAT, Nairobi, Kenya

Dr. Darrell Rosenow, Texas A&M Agriculture and Research Center, Lubbock, TX 79401

Dr. Lloyd Rooney, Soil and Crop Science, Texas A&M University, College Station, 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/Sudan, ICRISAT/SADC Zimbabwe, plus numerous seed lots in response to specific requests by both private and public sector institutions. Several Purdue varieties are being increased for release in Kenya.

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Development and Enhancement of Sorghum Germplasm with Sustained Tolerance to Drought, *Striga*, and Grain Mold

Project PRF-107 and 107B

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Dr. Abdeljabar T. Babiker, *Striga* Specialist, ARC, Sudan
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Mr. Issoufou Kapran, Sorghum Breeder, INRAN, Niamey, Niger
Dr. Ouendeba Botorou, Millet Breeder, INRAN, Niamey, Niger
Dr. Sam Mukuru, Sorghum Breeder, ICRISAT, Kenya
Dr. John Axtell, Agronomy Department, Purdue University, West Lafayette, IN
Dr. Larry Butler, Biochemistry Department, Purdue University, W. Lafayette, IN
Dr. Bruce Hamaker, Food Science Department, Purdue University, West Lafayette, IN
Dr. Darrell Rosenow, Texas A&M Univ. Agricultural Research Center, Route 3, Lubbock, TX
Dr. Jerry Eastin, Department of Agronomy, University of Nebraska, Lincoln, NE
Mr. David Andrews, Department of Agronomy, University of Nebraska, Lincoln, NE
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Dr. Kay Porter, Pioneer HiBred International, Plainview, TX

Summary

Breeding sorghum varieties and hybrids for use in developing countries requires proper recognition of the major constraints limiting production, knowledge of germplasm and appropriate physical environment for evaluation and testing. Successful breeding efforts also require knowledge of mode of inheritance and association of traits that contribute to productivity as well as tolerance to biotic and abiotic stresses. Research and germplasm development activities in PRF-107 attempt to address these essential requirements.

PRF-107 addresses three major constraints, namely drought, *Striga*, and grain mold that limit productivity of sorghum in many areas of the world. Over the years significant progress has been made in each of these areas. Superior raw germplasm have been identified, mode of inheritance established, chemical and morphological traits that contribute to productivity and stress tolerance have been identified, and gene sources have been placed in improved germplasm background, many of which have already been widely distributed.

In year 15 we report on progress made in molecular mapping of the *Striga* resistance gene in SRN39 and the result of our further screening for sources of *Striga* resistance. We have identified sorghum germplasm that are resistant to *Striga* because they produce low amounts of the haustorial initiation factor. Our previous sources of resistance have been low producers of the germination signal.

We also report on the result of an extensive international testing that clearly demonstrated the superior performance and stability of sorghum hybrids over open-pollinated varieties. The experiment showed that the superiority of hybrids over varieties is even greater under low yield (stress) environments than under optimum (high yield) environments.

Finally a brief report is given on the introduction, characterization, cataloguing, and distribution to public and private institutions of over 3000 sorghum accessions from Sudan.

Project 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 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 Genetics.

The training, networking and institutional development efforts of PRF-107 have been provided through graduate education, organization of 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.

Project Output

Research Findings

Striga - Molecular mapping of a gene conferring *Striga* resistance in sorghum - Yohan Weerasuriya

Previous studies conducted in our program have shown the stability of *Striga* resistance found in the widely adapted sorghum lines, SRN-39. We have shown that resistance in SRN-39 is due to low production in the host of the chemical signal required for initiating *Striga* germination. We have also established low stimulant production in SRN-39 is inherited as a single recessive gene. However, its location on the sorghum linkage map has not been known. Marker-based linkage maps provide essential tools for convenient transfer of genes by plant breeders as well as for tagging and isolation of genes by molecular biologists. As part of his Ph.D. dissertation, Yohan Weerasuriya (a graduate student from Sri Lanka) generated a sorghum molecular linkage map with the use of RFLP (restricted fragment length polymorphism) and RAPD (random amplified polymorphic DNA) markers. One hundred, highly homozygous and highly heterogeneous, recombinant inbred lines derived from a cross between a *Striga* resistant, low stimulant producer parent, (SRN-39) and a susceptible, high stimulant producing parent (Shanqui-Red) were used as the mapping population. About 150 RAPD and 50 RFLP markers were used to genotype the RI lines. In addition to the low stimulant production phenotype, several biochemical, morphological and disease resistance traits were also assessed and identified. Resistance to the leaf diseases anthracnose, downy mildew, and rust were evaluated. Levels of phenols (flavonoids and tannins) in leaf, sheath, and seed were measured on all the RI lines and parents. Morphological traits characterized include leaf width, leaf length, midrib color, plant height, plant color, panicle length, panicle width, panicle shape, peduncle length, pericarp color and presence or absence of awns. The map maker computer program was used to generate linkage groups for each of the marker-traits associations.

Striga - The use of simple laboratory assays to identify mechanisms of *Striga* resistance in sorghum - Yohan Weerasuriya

Methods that have been available to evaluate *Striga* resistance in crops have been rather slow, cumbersome, and tended to confound an array of environmental influences that affect *Striga* infestation in the field. Alternative and more efficient laboratory procedures were necessary for efficient germplasm assessment and evaluation. An agar gel assay recently developed in our laboratory was used to screen a collection of landraces and improved sorghums known to have been resistant and tolerant to *Striga*. Sorghum germplasm were assembled on the basis of published reports on their field resistance to *Striga*. Seed samples of these entries were obtained from ICRISAT the United States National Seed Storage Laboratory, and from our own collection of accessions at Purdue University. Several genotypes that produced low amounts of *Striga* germination stimulants or haustorial initiation factor were identified. These genotypes can be used as useful sources of *Striga* resistant germplasm in a breeding program geared to pyramid gene sources for durable resistance to *Striga*.

Drought - Performance and stability of drought tolerant lines and hybrids - Yahia Ibrahim

Several years of breeding efforts have resulted in a collection of drought tolerant inbred lines of sorghum. The combining ability and the stability of performance of these lines per se or in hybrid combination have not been thoroughly evaluated, however. Yahia Ibrahim, a graduate student from Sudan, undertook a study to address this issue as part of his M.S. thesis project. He pooled an array of drought tolerant lines from our program at Purdue (PRF-107) and the Texas A&M program at Lubbock, (TAM-122). Twenty-five pollinator lines with a range of yield potential and their hybrids on three seed parents were tested in 15 different environments. The lines and hybrids were evaluated for yield and yield stability in a cooperative international testing program. Grain yield data were combined and analyzed according to Finlay and Wilkinson's model of stability analysis. For each genotype a regression coefficient (b_i) was calculated and used as a measure of stability. Environmental mean yields ranged from 2323 to 9524 kg/ha. Overall, experimental hybrids yielded significantly higher than selected inbred lines and the yield superiority of hybrids was greater under low-yield (86%) environment than at high yield (32%) locations. The lines as a group had b_i significantly different from unity, and mean yield lower than the population mean. whereas hybrids had b_i not significantly different from unity, but yielded higher than the overall mean. The stability response of hybrids for each R-line varied with the seed parent on to which the hybrid was made. This study has identified several inbred combinations (hybrids) with the desired attributes of high yield and stability of performance across a range of environments.

Drought - Combining ability and QTL x Environment interaction of sorghum RI lines derived from crosses between two drought tolerant parents - Edwin Grote

Although drought tolerant sorghum inbred lines exist, their reaction in hybrid combinations is often poor. A study was conducted to evaluate the combining ability of 100 recombinant inbred (RI) lines, previously characterized for drought tolerance. Each line was crossed onto two testers, A4R and Wheatland The resulting hybrids and their parents were evaluated in two environments in Indiana and three environments in Texas in generalized randomized complete block designs. Within and among environment analysis of variation was performed. Significance of GCA for each line was tested. Significant variation exist for grain yield among crosses in four of the five environments. General combining ability (GCA) for males was significant in each of the four environments and accounted for 48% to 52% of the variation due to crosses in Texas and 66% to 75% in Indiana. Several of the RI lines with high significant GCA had superior drought tolerance. Such lines may provide a source of drought tolerance suitable for use in hybrid combinations.

Efficacy of selection for combining ability based on agronomic performance is dependent upon the environment in which selection is practiced. Analysis of marker environment interaction for testcross performance should allow a better understanding of this selection. We conducted a study geared to identification of quantitative trait loci (QTLs) associated with testcross performance across contrasting environments. A set of recombinant inbred (RI) lines derived by single seed descent from the cross between TX7078 and B35, two inbred lines uniquely contrasted for their drought responses, was used in this study. The RI lines have been genotyped with over 100 RAPD markers. Each line was crossed onto two testers, A4R and Wheatland A. The resulting hybrids and their parents were evaluated in two environments in Indiana and three environments in Texas. Grain yield, height, flowering, and various other agronomic variables were measured and analyzed within and among environments. Significant variation among crosses for grain yield exists in four of the five environments. General combining ability (GCA) for males contributed at least 50% of the variation. QTLs for testcross performance in each environment were associated with several RAPD markers. Some

QTLs accounted for 10% of the variation in GCA, but were not consistently associated across environments.

Diseases - Grain mold resistance in sorghum - Abebe Menkir

Sorghum germplasm accessions with diverse physical and chemical kernel attributes were evaluated for grain mold resistance at different days after flowering in Lafayette, Indiana, for two years. Fungal pathogens invading sorghum kernels were monitored. Visual rating identified highly susceptible accessions as early as 40 days after flowering. However, rating a few weeks after physiological maturity was more reliable to identify genotypes with higher levels of resistance to grain mold. The predominant fungal species recovered from sorghum kernels were consistent across different sampling dates and years at this test location. A multiple regression model involving all fungi isolates accounted for 63% of the variation in the final visual grain mold rating. Gibbrella zea, Fusarium moniliforme, and Alternaria Spp each accounted for 42, 22, and 15% of the variation in the final visual grain mold rating. Some sorghum accessions were free from infection of certain, but not all, fungal species across the three sampling dates. Higher level of resistance to grain mold was associated with increased concentration of flavin 4-ols and tannin, kernel hardness, kernel density, and intensity of pericarp color.

Nutritional Quality - Characterization of a new brown-midrib sorghum line - Renée Vogler

Low lignin concentration in brown midrib (bmr) mutants of maize, sorghum, and pearl millet has been associated with increased in vitro digestibility. We recently identified a new brown midrib mutant in a M3 population of chemically treated (DES, 1.5 ml/1000 ml water) grain sorghum variety P898012 (bmr-P898012). Allelism tests with three previously identified bmr sorghum mutants indicated the new bmr-P898012 is allelic to bmr-12 and bmr-18, but not allelic to bmr-6. Mutants bmr-12 and bmr-18 have been known to be allelic. Sequential fiber analysis of the new bmr-P898012, and bmr-12, their F1 hybrid, and their normal counterparts (N-P898012 and N-12) showed significant differences between the bmr-normal pairs, with significant decreases in mean permanganate lignin percentages from 16% to 34% for whole plant, stem, sheath, and panicle tissues of the bmr lines. Correspondingly, mean in vitro dry matter digestibility (IVDMD) percentages increased between 3% to 17% for sheath and panicle tissues in the bmr lines compared to the normal lines, although the increases were not significant. Leaf tissue of bmr-P898012 and whole plant tissue of bmr-12 also had non-significant increases of 8% and 5% in IVDMD percentages, respectively. Regression analyses of the five fiber fractions (neutral detergent fiber, acid detergent fiber, permanganate lignin, cellulose, and hemicellulose) on digestibility showed that per unit decreases in lignin percentages were associated with the largest increases in IVDMD percentages for whole plant, stem, and leaf tissues.

Networking Activities

Workshops and Program Reviews

Attended the First Crop Science Conference for Eastern and Southern Africa. June 14-18, 1993.

Participated at the Summer Institute for African Agricultural Research, University of Wisconsin. June 20-25, 1993.

Visited the University of Hoenheim, Germany, October 1993. Presented a seminar to faculty and students about our *Striga* research at Purdue University.

Traveled to IER-Mali and INRAN-Niger, and worked with collaborators on ongoing collaborative field research. October 1993.

Attended the American Society of Agronomy Annual Meetings at Cincinnati, Ohio. November 7-11, 1993.

Participated in a Rockefeller Foundation in-house retreat on future Rockefeller Foundation plans for Research and Development program support to Africa. November 11-15, 1993.

Research Investigator Exchange

Interactions with public, private and international sorghum research scientists continues to be an important function of PRF-107. The following individuals visited our program or worked in our laboratory during this last year.

Dr. Paula Bramel-Cox, Sorghum Breeder, Kansas State University spent three months on sabbatic. Nov. - Jan. 1994.

Dr. Fran Bidinger, ICRISAT Sorghum Breeder-Agronomist, October 1993.

Dr. Bruce Maunder, DeKalb, October 1993.

Dr. Gene Dalton, Pioneer, October 1993.

Dr. Kay Porter, Pioneer, October 1993.

Dr. Yilma Kebede, Pioneer, August 1993.

Dr. Sam Mukuru, ICRISAT-Kenya, August 1993.

Dr. Osman Obeid, ARC-Sudan, August 1993.

Germplasm and Research Information Exchange

An effective mechanism has been developed for germplasm exchange with cooperators both in Sudan and Niger. Type and extent of germplasm introductions to both Sudan and Niger from our collection is decided upon either by specific request from the collaborators or based on preliminary evaluation of small sets of nurseries introduced the previous season. Such an approach has been found to be satisfactory and workable. A number of early generation as well as advanced breeding sorghum lines were introduced in both Sudan and Niger. Such germplasm constitutes a significant part of the core breeding program in both INRAN and ARC. Likewise, useful local sorghums from Niger and Sudan have also been introduced for initial intercrosses to be made in the winter nursery in Puerto Rico.

A significant networking activity involving information exchange is developing through the efforts of this project and its collaborators. Using information accumulated on germplasm and environmental data from the INTSORMIL collaborative effort in Sudan, varieties and hybrids that showed potential in Sudan are suggested for testing in similar environments in Niger. Research methodologies (on drought tolerance for example), as well as results, therefore, are also shared across countries and zones.

Information and germplasm is routinely contributed to national and international sorghum research programs. A major undertaking in the area of germplasm in Year 15 has been the finalization of characterization, cataloguing, and seed increase of over 3000 Sudanese sorghum accessions that we introduced in cooperation with the USDA and ARC/Sudan. The collection was grown in its entirety at the USDA quarantine station in St. Croix during the winter 93/94 season. Sorghum breeders from most public and private U.S. institutions were invited to walk through the nursery to evaluate and select specific accessions for use in their respective programs. The quality of the germplasm and its potential use for further improvement of sorghum, particularly in the area of drought tolerance and grain quality, has been appreciated by the participating scientists. Arrangements have been made to distribute samples of the collection on a request basis. The USDA Plant Introduction Station at Griffin, Georgia will be responsible for distribution of seed samples. A complete set of samples is also to be sent back to Sudan coded with exactly the same accession numbers assigned by the U.S. National Seed Storage Laboratory. The purpose of doing this is so that ARC/Sudan can request seed samples for NSSL in case their samples are lost or found unviable as a result of poor storage facilities. This cooperative project involving INTSORMIL, USDA, and ARC that undertook the assembly, characterization, cataloguing, and storage of the Sudan Sorghum Collection has been a significant activity with mutual benefit to both U.S. and Sudan.

Publications

Publications

Babiker, A.T., M. Mana, G. Ejeta, L.G. Butler, T. Cai and W.R. Woodson. 1994. Ethylene biosynthesis in *Striga* seeds and its possible use as a probe for germination stimulants. Proc. of the Third International Workshop on Orobanche and Related *Striga* Research. A.H. Pietersee, J.A.C. Verkleig, and S.J. ter Borg (eds.) Amsterdam, The Netherlands, Royal Tropical Institute, 1994.

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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.

Objectives, Production and Utilization Constraints

Objectives

Develop environmentally stable, higher yielding, agronomical desirable sorghums with disease, insect, and environmental stress resistance, with high grain quality and weathering resistance.

Develop specific germplasm pools and resources for use in impacting productivity in Latin America, South America, and Africa.

Distribute improved lines, hybrids, and early generation populations possessing superior productivity and diversity to collaborating LDC and domestic programs.

Determine existence of heterotic pools and magnitude of heterosis and combining abilities in sorghum.

Sorghum improvement is dependent upon the availability of useful germplasm in both varietal and hybrid programs. The TAES/INTSORMIL sorghum research program has and continues to develop and enhance germplasm for utilization in sorghum breeding programs. A blend of practical field evaluations, with basic research endeavors, identification, and utilization of exotic germplasm with protection traits, strengthens enhancement of traits to make products more useful and economical for the grower and consumer.

Greater genetic diversity is an increasingly important goal for the maintenance of stability and productivity. Materials from the TAES/USDA Sorghum Conversion Program have been crossed with elite higher yielding breeding lines and have been selected to respond to the constraints of production. Greater stability of yield, greater stress resistance and pest resistance as well as food quality materials evolve from this project and are distributed to collaborators. As these elite, more broad based lines and hybrids emerge they are selected for use in Meso-America, South America, Africa, and Asia. Successful crop production systems require genotypes that possess potential which can be expressed over a wide range of environmental conditions. Sorghum as a major food resource commodity is used in much of the arid and semiarid regions of the world. Very little is known about the genetics of objective food quality. Even though sorghum has been used for many thousands of years as a food source, selection for quality has been largely subjective. Although the sorghum caryopsis is well described, very little is known about those characteristics which impact quality, especially in the variety of food systems for which sorghum serves as the base raw material.

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 superiority of end-products, hence there must be preservation and expansion of collections. Adequate evaluations of existing collections, new introductions, and converted lines are needed to determine usefulness of genetic stocks in solving or impacting worldwide sorghum productivity constraints.

Drought stress is a major constraint to sorghum production. Even in those areas where rainfall is higher or irrigation is available on a limited basis, there is need for improved drought tolerance. Large differences exist among sorghum cultivars in their reaction to drought and performance under drought stress. Texas has a semiarid environment and high temperature during the growing season and is ideal for large scale field screening and breeding for improved drought tolerance. Materials selected in Texas have performed well in other countries, including Sudan, Mali, Niger, Paraguay, and Honduras.

Diseases are often region or site specific, and on-site evaluations are 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, grain weathering, head smut, head blight, and MDMV. Many other diseases such as anthracnose, leaf blight, rust, zonate, gray leaf spot, and acremonium wilt also are present in Texas. The south Texas environment is ideal for screening and selecting sorghums (populations, improved breeding lines, and parental stocks) with high levels of resistance to most internationally important diseases.

Food quality characteristics are both cosmetic and organoleptic. Using local cultivars as controls for acceptability, genetic improvement of yield and stability characteristics can be added in breeding program. Tan plant color, straw color glumes, round seeds, easily decorticated pericarps, and reduced phenols impact food quality. These traits are assembled in breeding stocks that also possess yield potential, stable performance, and pest resistance.

Whether the constraints that this project interact with are addressed in Mali, Niger, Sudan, Cameroon, Zambia, Mexico, Honduras, Paraguay, or the People's Republic of China, there are germplasm resources available for use. However, there is a continuing need for adequate evaluations of existing collections, development of enhanced breeding stocks, and distribution to collaborating scientists.

Research Approach and Project Output

Existing breeding materials were crossed in a winter greenhouse crossing program with converted or partially converted lines, other improved stocks, and introductions. Those materials were grown in a summer F_1 transplant nursery for seed increase. Previously generated materials were screened and evaluated for recombinations of disease resistance, grain quality, and yield potential in cooperation with pathologists and cereal chemists. Disease screening was done in large field nurseries in south and central Texas utilizing natural infection and supplemented with artificial inoculations for downy mildew, anthracnose, head smut, and MDM virus.

Crosses were made to generate populations among various disease resistant sources, agronomically superior lines, and those possessing drought tolerance. These materials were screened in field nurseries at locations in the U.S., other countries, and in the laboratory. Where possible, replicated trials were used for critical evaluations.

Crosses were developed to intergress superior previously identified food quality traits into high yield, nonsenescent, disease resistant inbred lines. These materials were then selected in large field nurseries at several locations with diverse climatic patterns. Elite inbred lines and F_1 hybrids have been used for further screening in cooperative trials. Special trials have been used for evaluation, i.e., ITAT (International Tropical Adaptation Trial) and IFSAT (International Food Sorghum Adaptation Trial). Advanced generation lines and hybrids were incorporated into various standard replicated trials for more critical and extensive evaluations at several locations in Texas, other states, and in other collaborating countries where these constraints need to be addressed.

Cytoplasmic diversity and heterotic pools among taxonomic groups of sorghum were tested in trials at several locations in Texas and in Kenya. Representatives of the major groups were crossed to different sterility systems. Parents and F_1 (single cross, three-way, and double-cross) hybrids were grown in replicated trials representative of tropical and temperate climatic regimes.

Productivity is a summation of a program to include genetic, physiologic, pathologic, and cultural results into a delivered crop cultivar. This project utilizes the concept of enhancement of productivity to deliver improved sorghum germplasm to collaborating programs. While results from related CRSP projects and germplasm resources from collaborating NARs are combined both new knowledge and recombinations of useful germplasm result. Large nurseries in field settings are utilized in areas of significant climatic variation to identify desirable recombinations for yield, stability, drought tolerance, disease resistance, and grain quality. Emphasis has been placed upon development of tropically adapted cultivars with nonsenescence, high yield, and food quality grain. This project draws information and material from INTSORMIL Projects TAM-122, TAM-124, and TAM-126. Whether used in breeding or directly in F_1 hybrids these results are beneficial to each program and to INTSORMIL.

This project is involved in development of populations to identify the specific sites of $\underline{dw}_1$, $\underline{dw}_2$, $\underline{dw}_4$, and $\underline{dw}_4$ height genes; $\underline{ma}_1$, $\underline{ma}_2$, $\underline{ma}_3$, $\underline{ma}^{R}_{3}$, and $\underline{ma}_4$ maturity genes; $\underline{r}$, and $\underline{y}$ pericarp color genes; and several other genes of known agronomic importance.

Materials from the Sorghum Conversion Program and selected breeding cultivars from other INTSOMIL projects are evaluated regularly for resistance to internationally important diseases and insects in a cooperative/collaborative program throughout the sorghum growing world. An All Disease and Insect Nursery (ADIN) with 70 entries and two replications includes critically chosen materials from several TAES sorghum projects to monitor changes in pest problems and to provide germplasm to collaborators. Additional specific nurseries are developed cooperatively with the same basic objectives. Primarily, these germplasm evaluation nurseries are used to collect critical data on genetic/environmental/pest responses which can be used in INTSORMIL breeding activities. Secondly, the nurseries provide useful materials for collaborators wherever grown.

Research Findings

The basic goal of this project is to create a base yield among elite sorghums that is sustainable across varying environmental conditions, and to add mechanisms and traits that increase value and performance. There is substantial interaction between TAM-122 and TAM-124 for germplasm and information. The intensive cooperation and evaluations from TAM-126 insures the inclusion of new sources of food quality and types for new uses.

In 1993, there was the normal early season wet cycle followed by significant drought across much of Texas. Plant expression and disease reactions were good. South Texas adaptation and disease nurseries allowed selection of more than 10,000 panicles from advanced and early generation materials (Corpus Christi, Robstown, and Beeville). The breeding and testing site at College Station was very good. Yield potential expression was excellent and grain quality high because of the summer drought. Approximately 13,000 items were selected from the College Station site in 1993. Selected advanced new females were top crossed to elite tester males for evaluation in F_1 hybrid combinations. Similarly selected advanced new males were top crossed to tester females for F_1 hybrid evaluations. Hybrids were produced for use in the IFSAT and ITAT for 1994.

F_1 crosses made in the 1993 winter greenhouse using RTx430 and RTx436 as recipient parents and sources of *Striga* resistance, aphid resistance, and drought resistance obtained from Kenya were grown to produce F_2 seeds for selection. (Materials were described in 1992 Annual Report).

Experiments were designed to estimate stability, heterosis, and performance of single, three-way, and double-cross hybrids across a wide range of environments. Three groups of trials were conducted between 1990 and 1993 in Texas, and in Kenya by Dr. George Ombakho. Trials were grown under irrigation at College Station (semi-tropical) and Halfway (temperate); and dryland at Corpus Christi (semi-tropical) and Chillicothe (temperate), Texas. Trials were conducted in Kenya during 1992/93 at four locations (Kibos, Kiboko, Kakamega, and Alupe) with two season crops at Kakamega. Hybrids uniformly out performed parental lines and single crosses out performed three-way crosses and double-crosses. There was evidence of stability increasing from parental lines to the single crosses, three-way crosses, and finally double-crosses as the most stable type. Within plot variability for plant height, panicle length, and panicle exsertion for the different hybrid types indicated that differences were minimal and not of agronomic importance. However, limits of variation that might be tolerated would differ among sorghum growers. Single crosses exhibited greater heterosis than did three-way hybrids. Negative heterotic values were preponderant in the three-way crosses.

The most appropriate three-way cross for commercial production should have a male-sterile F_1 and a fertility-restoring male. Crosses involving SC103-12E exhibited high heterotic values in single crosses.

Predication of three-way cross mean grain yields using Jenkins' Method B indicated highly significant correlation with observed grain yields. These results when compared with others previously reported, especially in maize, indicate that the nonparental single crosses can be appropriately used in the prediction of three-way cross performances in sorghum. The identification and utilization of A_1 and A_2 cytoplasmic sterility, with appropriate restorers, allows the production of not only single-cross hybrids but three-way and double-crosses in sorghum with increased environmental stability.

In Kenya, 1992/93 mean yield of three-way crosses was significantly higher than for single crosses, especially in the better environments of Kibos and Kakamega (short rainy season). Three-way crosses were considered most stable under conditions of these studies, while single crosses were unstable. The variabilities of agronomic traits in single crosses and three-way crosses were nearly similar in most instances. A problem of excessive variability in Kenya might not be as important as is the case in Texas since harvesting is done by hand.

While this extensive study showed three-way hybrid stability of production and limited variability of agronomic traits, it also demonstrated the earlier harvest of F_1 female seed and reduced seed drying costs. The reduced seed production costs due to increased yields of the male-sterile single-cross would indirectly benefit the farmer. Three-way hybrids introduce variability to the cultivated population. From the evidence of this study, three-way crosses combine greater stability with substantial performance and should prove beneficial to the farmers of Kenya and similar regions.

A study was conducted by Sergio J. Gouveia (Mozambique) on the effects of chemical desiccation and seed maturity upon germination of sorghum hybrid production. The study was conducted at College Station and Lubbock, Texas in 1992 and 1993. Sorghum plants representing 10 A-lines were desiccated in the field at 35, 30, 25, and 23% grain moisture and then harvested at 12% moisture. The same lines were desiccated in a separate study 30, 35, 40, 45, and 50 days after anthesis.

Response of the 10 A-lines to desiccation with sodium chlorate showed that when seed moisture had reached 35% (physiolic maturity) germination 21 days after harvest was 95% or greater. However, if the desiccant was applied at 30% to 25% grain moisture, germination was 95% or greater 7 to 14 days following harvest. The duration of dormancy after harvest was reduced as the percentage of seed moisture content decreased prior to application of the desiccant. When application of the desiccant was delayed until grain moisture was 23%, germination at harvest was optimized. ATx399 appeared to be the most responsive to early desiccation because no improvement in % germination was made as grain moisture decreased. ATx3042 germination increased until grain moisture was 25% at application of the desiccant. In general, when seeds were 40 days old germination did not increase significantly following application of the drying agent. Dormancy was maintained in the brown seeded A Combine Sagrain until 50 days past anthesis. There were differences between the A-lines for response to desiccation. There were differences between A-lines tested for ability to germinate when harvested following desiccation at 30 to 50 days past anthesis.

A basic study was conducted by T. Clint Nesbitt (U.S.) to determine heterotic patterns among diverse sorghum hybrids. The study utilized 12 female inbred lines from three cytoplasmic sterility groups (5=A_3, 3=A_2, and 4=A_1), 9 male lines from the TAES-USDA Sorghum Conversion Program, and 108 hybrid combinations. In the past, sorghum hybrids have been produced on kafir females and durra and caudatum males. Our exclusive reliance upon such a narrow base fails to utilize the great diversity which exists within the species, and overlooks the possibility of hybrid combinations which provide greater heterosis or other stability traits. Dependence upon a single cytoplasm (milo) creates a potential genetic vulnerability problem. The creation of new male sterility systems greatly increase the diversity of parents from which hybrids can be produced.

Evidence obtained for combining ability and percent heterosis suggests the presence of heterotic "patterns" among the hybrids. Hybrids of less closely related parents demonstrated better heterotic effects than those of related groups. The Caffrorum working group demonstrates strong heterotic effects with Zerazera, Caudatum/Kaura, Nigricans/Feterita, and Nigricans groups, and these should be used in the production of hybrids with A_1 females. Nigricans/Feterita cultivars were shown to produce exceptional yields and strong heterosis with Caudatums. Females of the A_2 sterility system displayed good heterosis when crossed with Caudatum/Kaura, Zerazera, and Nigrican/Feterita males. Males from groups Caudatum, Caudatum/Kaura, and Durra/Dochna had high heterotic effects with A_3 females. The heterotic patterns discerned in this study should facilitate the utilization of hybrid vigor in producing successful hybrids. New hypotheses may be developed to further evaluate the patterns suggested by this study.

Human food quality sorghum types developed in this project performed well in a wide range of environmental conditions. Data presented in Table 1 show performance of 40 hybrids in the 1993 IFSAT (International Food Sorghum Adaptation Trial). ATx378*RTx430, a red seed feed grain type hybrid, ranked 16th in the trial. The top six hybrids over all locations were of similar pedigrees. RTx436 and 80C2241 were the male parents of the top six hybrids. These top six hybrids averaged 739 kg/ha more than the check, ATx378*RTx430. The yield advantage of the tan plant color, white grain types is significant. In addition to the yield

Table 1. Performance in kg/ha of white grain food quality sorghum hybrids at selected U.S. and international locations using the 1993 IFSAT.

No.	Entry	Pedigree	CC	CS	H	W	A	PR	CH	R $\bar{x}$
1	13	ATx631*80C2241	2935	5930	8700	5417	12800	6891	10836	7644
2	7	A155*RTx436	2748	5995	8025	5211	12420	6621	12021	7577
3	8	ATx631*R8511	3252	6228	8360	5802	14290	5988	8473	7485
4	6	ATx635*RTx436	4027	7607	9673	4736	12300	5680	8088	7444
5	15	ATx635*80C2241	3227	7038	9654	5259	14070	7308	5214	7396
6	9	A8606*RTx436	2928	4944	8004	5116	12650	6754	10540	7277
7	31	ATx631*((SC120*Tx7000)*Tx430-4-1-1-2-OP-2*Tx435)-	2839	6366	8494	4495	11780	7384	9429	7255
8	17	A8606*80C2241	2937	5818	7595	3881	13830	6019	9673	7108
9	11	A9009*RTx436	3771	6051	7593	4483	12430	5898	10377	7086
10	10	A8610*RTx436	2599	6733	8380	5021	11330	6158	9347	7081
11	19	ATx631*R8504	2371	5935	7747	4150	10580	6568	12036	7055
12	40	ATx631*90M47	2678	6098	8377	5861	10560	7205	8488	7038
13	4	ATx631*RTx436	2661	5916	8636	5687	11900	7084	6577	6923
14	16	A8610*80C2241	2927	5604	8570	4055	13180	6365	7688	6913
15	34	ATx631*87EON361	2996	6337	8093	6431	10460	6184	7155	6808
16	32	ATx378*RTx430	3069	6433	8569	5670	10390	5201	7792	6732
17	26	ATx631*Dorado	2581	6656	8489	4499	8790	6274	9643	6705
18	22	A8610*R8504	2694	6089	6680	5275	10450	5315	10266	6681
19	37	ATx631*87EON366 SIS	2495	5566	8682	4736	8110	7216	9934	6677
20	12	A9017*RTx436	2283	6100	7449	4926	11350	5693	8503	6615
21	5	ATxARG-1*RTx436	2751	5015	7770	5196	9410	5630	10066	6548
22	21	ATx635*R8504	3345	5986	7947	4530	9430	5547	9045	6547
23	35	ATx631*87EON366	3227	6200	7768	4609	8810	6730	8132	6497
24	36	ATx631*87EON366 SIS	3330	5775	7819	3754	8590	6098	10089	6694
25	24	ATx631*R8510	2061	5353	7252	4657	11390	6064	8607	6483
26	29	ATx631*$B_2$9110	2100	5832	7501	4736	7590	6258	9512	6218
27	18	A9009*80C2241	2970	5775	8092	2075	10350	5824	8273	6194
28	33	ATx635*86EON361	3562	6158	8081	4166	8470	5583	9897	6170
29	39	ATx631*90M41	2575	5550	7773	5005	9170	5521	7576	6167
30	25	ATxARG-1*R8510	2319	5720	7308	3406	8090	5801	9821	6066
31	1	Sureño	3086	6089	6007	4562	8220	4530	8770	5896
32	14	ATxARG-1*80C2241	2251	5461	7375	4752	8230	4154	8384	5801
33	28	ATxARG-1*84C7730	2091	5054	7432	5037	7060	5081	8844	5800
34	27	ATxARG-1*Dorado	3593	6461	8844	5908	6900	5983	7584	5723
35	38	ATx635*RTx2816	1552	4581	7188	3152	10030	5290	7592	5626
36	30	ATx631*(EBA1*RTx433)-C4-C1-CBK	1901	5850	6820	4182	8660	5320	5962	5528
37	23	ATxARG-1*R8511	2506	5975	7702	4455	9740	4585	5992	5422
38	2	Dorado	2172	5003	5159	4752	7160	4963	8140	5336
39	20	ATxARG-1*R8504	2038	5428	6370	---	5950	4498	7136	4489
40	3	ICSV-LM89-520-?20	1126	2363	4328	---	6350	1623	7777	3824

CC - Corpus Christi
CS - College Station
H - Halfway (2 reps)
W - Weslaco

A - South Africa
PR - Puerto Rico
CH - China
R - Rank/Mean

advantage of these hybrids there is increased leaf quality, disease resistance, and drought tolerance. In 1993 there were 20 IFSATs grown throughout the U.S. and internationally. ATx631, ATx635, and other females from the project are producing high yielding hybrids when crossed to a wide array of good R-lines. The new tan plant color, red or red translucent seed color hybrids are proving to have yield, grain quality, and weathering resistance. Data from these trials will be used to justify release of several new R-lines during 1994.

In 1993, 25 ITAT's (International Tropical Adaptation Trials) were distributed to U.S. and international collaborators. This trial is designed to allow collaborators to quickly recognize useful materials in either inbred line or hybrid form. Table 2 provides yield performance data from selected locations. The highest yielding hybrids in College Station, Texas (ATx635*80C2241=8132 kg/ha); Klerksdorp, South Africa (A155*RTx436=13680 kg/ha); Mayaguez, Puerto Rico (ATx631*Dorado=8542 kg/ha); and Shenyang, China (ATx626*R9025=12791 kg/ha) show a range of type. There are seven hybrids that rank higher in yield than the best overall locations check hybrid (ATx2752*RTx430). Five of these top seven hybrids are white grain types with tan plant color. This trial allows us to provide basic yield and adaptation in an array of hybrids that collaborators can use in their own programs.

A set of inbred lines was sent to the Summer Grain Centre at Potchefstroom, South Africa for evaluation. The best six inbred lines are listed in Table 3. These inbred lines have shown wide adaptation and presented good leaf disease resistance when exposed to different environments.

TAM-121 is designed to enhance germplasm and deliver that material in a form that can be quickly used by collaborators. Food quality grain and resistances to biotic and abiotic stresses have been major focus of the project. Sig-

Table 2. Performance in kg/ha of grain sorghum hybrids and parental lines at selected U.S. and international locations using the 1993 ITAT.

No.	Entry	Pedigree	CS	H	A	PR	CH	R $\bar{x}$
1	23	ATx631*Dorado	7368	9797	10440	8542	9534	9136
2	19	A155*RTx436	5941	8125	13680	6450	9646	8768
3	20	ATx635*80C2241	8132	9458	13490	6435	6313	8766
4	33	ATx638*R8503	6199	7887	11020	6513	11036	8531
5	18	ATx631*RTx436	6190	8255	12710	6851	7850	8371
6	11	ATx2752*RTx430	6611	8624	12210	5733	8645	8365
7	14	ATx378*RTx434	7583	8629	10640	7011	7882	8349
8	25	ATx631*((SC599-6*SC110-9)*Tx2816)-3-3-2-	6468	8249	9640	6724	9824	8181
9	28	ATx631*((SC120*Tx7000)-4-1-1-2-OP-2*Tx435)-	6618	6879	11810	6836	8610	8151
10	15	ATx626*R8503	6380	7971	9830	6757	9635	8115
11	43	ATx635*86EON366 SIS	5967	8860	10730	7206	7633	8079
12	17	ATx638*RTx2783	5690	8317	9990	6418	9389	8061
13	13	ATx378*RTx7000	5641	7681	12570	4599	9575	8013
14	32	ATxARG-1*R8922	5181	7825	8510	6104	12428	8010
15	12	ATx378*RTx430	6110	8406	11310	6509	7614	7990
16	41	ATx638*(R4244*R6956)-C13-C4-C2-C1	6280	6884	10160	5788	10704	7963
17	46	A1*RTx430	6518	6994	9860	6684	9689	7949
18	35	ATx631*((Tx430*Tx2816)-1-1-5-3*Tx433)-C1-B2-T3-CBK	6699	7123	9490	8152	8121	7917
19	49	ATx631*86EON361	6232	8794	11450	5524	7059	7812
20	50	ATx631*90M37	5823	7357	10600	8025	7254	7812
21	44	ATx635*86EON361	7154	8717	10140	6996	6005	7802
22	27	ATxARG-1*(ADN55*SC103-12E)-C1-B14-B2-CBK	5575	7912	10660	5152	8943	7684
23	39	ATx626*R9025	5647	5022	9460	5476	12791	7679
24	42	A8616*RTx430	5445	7163	10370	5857	9264	7660
25	30	ATxARG-1*((SC120*Tx7000)*Tx430)-*Tx435)-1-?3-L5-	5556	8802	8130	5959	9699	7629
26	48	A1*R8503	5847	7811	10480	7052	6866	7611
27	29	ATx631*((Tx430*77CS1)-1-1-5-3*SC326-6)-CF2-B6-B2	5461	8158	11210	6170	7011	7602
28	37	ATxARG-1*R8903	4678	6841	8550	4632	12205	7581
29	26	ATx631*(((Tx2816*SC326-6)*Tx430)-*Tx435)-	5993	7637	9300	6185	8383	7500
30	22	ATxARG-1*Dorado	6766	7931	8270	7500	6713	7436
31	47	A4R*RTx430	6085	7373	10880	5401	7235	7395
32	45	A1*RTx436	6039	7309	12370	4702	6545	7393
33	16	ATx638*RTx434	5303	7633	10760	6205	6562	7302
34	40	ATx626*(Tx7000*R9188)-C7-C2-C1-C4-C3-C2-C1	5550	8139	11190	4942	5706	7105
35	36	ATx631*(EBA-1*Tx433)-C4-C1-T2	5503	6870	9770	6322	6125	6918
36	31	ATxARG-1*R8925	4911	6760	8330	4289	9842	6826
37	21	ATxARG-1*R8504	4971	6909	7420	5172	9553	6805
38	24	ATx631*R9021	5029	6549	8410	6183	7613	6757
39	7	R.Tx7000	4161	6271	9790	4338	7543	6421
40	34	ATx638*(Tx434*SC326-6)-1-B10-B2-B1-CBK-CBK-CBK	5118	5984	7980	4235	7819	6227
41	1	B.Tx378	4679	7091	9420	3980	5139	6062
42	2	B.Tx631	2618	5791	8360	5366	6882	5803
43	3	B.Tx635	5413	4108	7150	4986	7225	5776
44	9	Dorado	4888	5014	5470	6064	7137	5715
45	10	80C2241	1510	5102	9030	4216	8057	5579
46	5	R.Tx430	3098	5445	7750	5043	6503	5568
47	6	R.Tx436	3489	4045	9660	4558	6082	5567
48	38	ATxARG-1*((Combine Shallu*Rio)-*Tx430)-1-B8-B1-B1-	4909	6776	6420	3416	5586	5421
49	8	R.Tx434	2507	3713	7740	1444	5577	4196
50	4	B.TxARG-1	3053	4757	3700	4167	5044	4144

CS - College Station	PR - Puerto Rico
H - Halfway	CH - China
A - South Africa	R - Rank/Mean

Table 3. Response of selected recent releases of *Sorghum bicolor* at Summer Grain Centre, Potchefstroom, South Africa.

No.	Designation	Reaction
1	Tx2820	good leaf disease resistance, yield potention
2	Tx2823	good leaf disease resistance, yield potention
3	Tx2835	good leaf disease resistance, yield potention
4	Tx2836	good leaf disease resistance, yield potention
5	Tx2839 (best)	best leaf disease resistance, yield potention
6	Tx2853	good leaf disease resistance, yield potential and good combining ability

nificant progress has resulted from the distribution of a large amount of superior germplasm to many collaborating programs.

Networking Activities

Workshops

South Texas Nursery and Evaluation Panel presentations - Corpus Christi, TX, July 12-15, 1993

Farmers Field Day and Tour - (White Food Sorghums) - Garden City, TX, September 9, 1993

Honduras Collaborative Nurseries and related activities, December 6-11, 1993

Research Investigation Exchanges

President Yoweri Museveni, President of Uganda

Mr. Dries Booyens, PANNAR Seed Company, Klerksdorp, South Africa, August 30 - 31, 1993

Mr. Enrique Morgan, Morgan Seed Company, Colon, Argentina, September 19, 1993

Mr. Victor R. Poggi, Morgan Seed Company, Colon, Argentina, September 19, 1993

Carmine Laserna, Bogota, Colombia, June, 1993

Mr. Antonio Cristiani, Guatemala, June 1993

Dr. Francisco Gomez, Zamorano, Honduras

Dr. A. Toure, Bamako, Mali

Dr. Vartan Guiragossian, Exec. Consultant, Fundacion Tecnologica de Sinaloa, Mexico

Mr. Tony McCosker, DPI, Queensland, Australia

Germplasm and Research Information Exchange

In 1993, this project distributed a large amount of germplasm in the form of breeding stocks, F_2 populations, and hybrids to both domestic and international collaborators. These materials are listed in summary form in Table 4. We distributed more than 3000 accessions and 101 trials during the reporting period. These materials included many old and new germplasm stocks, plus enhanced materials possessing resistance to various diseases, insects, drought stress, temperature stress, genetic stocks for maturity, height, pericarp color, endosperm type and texture, plant colors, tropical adaptation, and other traits. Included in the 101 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. Sorghum advanced breeding selections were made and entered into cooperative international trials including the ADIN, IDIN, GWT, IDMN, IAVN, UHSN, and several drought nurseries. Large amounts of germplasm were sent to collaborators in Honduras, Paraguay, Mexico, Mali, Zimbabwe, Sudan, and People's Republic of China.

Developed lectures for presentations in field nurseries for international and domestic exchanges in Weslaco, Corpus Christi, Robstown, Beeville, College Station, and Lubbock, Texas.

Prepared three separate release proposals for inbred lines (17) and A_3/B_3 germplasm stocks (12). Approval for release is pending as of this date.

Publications and Presentations

Publications

Collins, S.D., R.A. Frederiksen, D.T. Rosenow, and F.R. Miller. 1993. Registration of Tx2891 sorghum germplasm line. Crop Sci. 33:1109

Collins, S.D., R.A. Frederiksen, G.N. Odvody, D.T. Rosenow, and F.R. Miller. 1993. Disease resistant converted sorghum lines. p 151. Proc. 18th Biennial Grain Sorghum Research and Utilization Conference. Lubbock, TX, Feb 28 - March 2.

Esele, J.P., R.A. Frederiksen, and F.R. Miller. 1993. The association of genes controlling caryopsis traits with grain mold resistance in sorghum. Phytopathology 83:490-495.

Table 4. Seedstocks distributed from College Station, Texas in 1992-1993 to collaborating programs within the U.S. and internationally.

Materials	International	Domestic
Breeding Stocks	424	974
F_2 populations	95	79
Hybrids	420	1038
(Sum)	(939)	(2091)
	Trials	
ITAT	16	9
IFSAT	12	8
Experimental hybrids	4	32
Texas State Performance	- -	10
Regional Performance	- -	10
(Sum)	(32)	(69)

Gouveia, S.J., F.R. Miller, and D.T. Rosenow. 1993. The effect of different rates of glyphosate on development of charcoal rot (*Macrophomina phaseolina*) on some sorghum cultivars. p. 35. Proc. 18th Biennial Grain Sorghum Research and Utilization Conference. Lubbock, TX, Feb 28 - March 2.

Harrison, R.L and F.R. Miller. 1993. Registration of 'Della' sweet sorghum. Crop Sci. 33:1416.

Khizzah, B.W., F.R. Miller, and R.J. Newton. 1993. Inheritance and heritability of heat tolerance in several sorghum cultivars during the reproductive phase. African Crop Sci. J. 1:81-85.

Miller, F.R. and F.L. Green. 1993. How to raise sorghum in a semi-arid area. Mississippi/Zimbabwe Partnership, Jackson, MS.

Miller, F.R., and G.G. McBee. 1993. Genetics and management of physiologic systems of sorghum for biomass production. In Biomass and Bioenergy. 5(1):41-49.

Morgan, P.W., C-J He, K.L. Childs, K.R. Foster, J.I. Sarquis, M.C. Drew, W.R. Jordan, J.E. Mullet, J-L Lu, J. Cairney, and F.R. Miller. 1993. Hormones as components of plant regulartory systems: examples from tropical grasses. p. 18. Proceedings of the Plant Growth Regulator Society of America. August 6-9. St. Louis, MO.

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Rooney, L.W., F.R. Miller, D.T. Rosenow, and R.D. Waniska. 1993. JOWAR, a new cereal for food utilization. p. 63. Proc. 18th Biennial Grain Sorghum Research and Utilization Conference. Lubbock, TX, Feb 28 - March 2.

Sanderson, Matt A., Fred R. Miller, Mark A. Hussey, Ronald M. Jones, and G. Ali. 1994. Quality of forage sorghums: Response to genetics and management. p.55. National Conference on Forage Quality, Evaluation, and Utilization. April 13-15. Lincoln, NE.

Sanderson, Matt A., G. Ali, Mark A. Hussey, and Fred R. Miller. 1994. Plant density effects on forage quality and morphology of four sorghum cultivars. Proc. American Forage and Grassland Council. 3:237-241.

Tarpley, L., D.M. Victor, and F.R. Miller. 1993. ^{14}C-assimilate export from upper leaves of sweet and grain sorghum hybrids. p. 139. Proc. 18th Biennial Grain Sorghum Research and Utilization Conference. Lubbock, TX, Feb 28 - March 2.

Tarpley, L., J.A. Dahlberg, D.M. Victor, and F.R. Miller. 1993. Batch anion exchange and quantification of ^{14}C hexose and ^{14}C sucrose. Crop Sci. 33:338-341.

Tenkouano, A., F.R. Miller, R.A. Frederiksen, and D.T. Rosenow. 1993. Genetics of nonsenescence and charcoal rot resistance in sorghum. Theoretical and Applied Genetics 85:(5):644-648.

Germplasm Enhancement for Resistance to Pathogens and Drought and Increased Genetic Diversity

Project TAM-122

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Summary

The principal objectives of TAM-122 are to identify and develop disease resistant and drought resistant sorghum germplasm in genetically diverse backgrounds for use by host county and U.S. scientists, and to collaborate with host country scientists, especially those in Mali, Honduras, and Sudan, in all aspects of their crop improvement programs.

The disease and drought resistance breeding program continued to develop excellent germplasm for use in the U.S. and host countries. New cultivars were introduced into the U.S. and evaluated for useful traits. New breeding germplasm was developed from new crosses. This new segregating material plus other sorghum lines, germplasm, and hybrids was used in the U.S. and distributed to LDC collaborators.

New white seeded, tan plant derivatives of crosses of the line, BTx635, looked very good for drought resistance, head smut resistance, and lodging resistance. These should prove very useful as parents of white seeded and food-type sorghum hybrids both in the U.S. and host countries.

A few sorghum lines were identified with the dominant type of stay green, a post-flowering drought resistance trait. These lines, SC35-14E, B35, SC56-14E, and some SC33 derivatives should be useful breeding sources for the stay green trait.

Some F6 white-seeded, tan-plant Guinea type breeding progeny involving the Guinea, Bimbiri Soumale germplasm looked outstanding for yield and adaptation in Mali. They may be very useful in Mali and West Africa as an improved guineense type sorghum for enhanced utilization.

Two non-guineense Malian developed lines, Malisor 92-1 and Malisor 92-2, were selected for increase and on-farm trials in 1994.

Objectives, Production and Utilization Constraints

Objectives

Enhance the germplasm of LDCs by developing and distributing early generation breeding germplasm involving genetically improved disease and drought resistance and other desirable traits for use by host countries with emphasis on Honduras, Sudan, Mali, and Niger.

Develop high yielding cultivars for LDCs and the U.S. with enhanced resistance to downy mildew, charcoal rot, grain mold/weathering, anthracnose, head smut, head blight, and foliage diseases.

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 LDCs.

Collect and evaluate new sorghum germplasm 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, particularly West Texas, has a semiarid environment with high temperatures and is ideal for large scale field screening and breeding for improved resistance to drought. Sorghums with identified high levels of specific types of drought resistance in Texas, specifically pre- or post-flowering, perform similarly under drought response in other countries of the world, including Sudan, Mali, Niger, and Honduras. However, other adaptation traits such as grain quality, disease resistance, and grain yield must be combined with drought resistance to make a new cultivar useful.

Diseases are important worldwide but some 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 production 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, pre- and post-flowering drought tolerance, 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 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. Head bugs are the major constraint for the use of nonguineense 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, because 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 in both host countries and the U.S. for new diverse germplasm sources with resistance to pests, diseases, and environmental stress. New collections can provide 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. Selected advanced materials are then sent to host countries for evaluation and incorporated into standard replicated trials for evaluation at several locations in Texas and host countries.

New breeding crosses among various sources of pre- and post-flowering drought resistance and elite, high yielding lines are made. Progeny are selected under field conditions for pre- and post-flowering drought resistance, yield, and adaptation at several locations in West Texas. 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 evaluation at several locations 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 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 and used in germplasm enhancement programs. Assistance is provided in developing smaller working or core collections for the NARS to actively maintain and use in their improvement programs.

Research Findings

Breeding, selection, and screening for drought resistance continued, using field drought screening nurseries at Lubbock, Halfway, Lamesa, and Chillicothe. The hot, dry summer contributed to excellent post-flowering stress at Halfway, and pre-flowering stress at Lubbock and Lamesa. The "stay-green" line, B35, appears to be the best source of post-flowering drought resistance in breeding progeny. The male sterile parental line, A35, continued to show outstanding post-flowering drought resistance in hybrids with little, if any, premature death, charcoal rot, or lodging. Breeding derivatives of the parental line, B1, a derivative of B35, showed good stay-green, and many had outstanding lodging resistance. Advanced generation drought tolerant breeding A and R lines were tested statewide in hybrid combinations. Progeny from drought tolerant breeding lines were backcrossed and intercrossed with agronomically elite lines and were evaluated at several locations. Sterilization of new females (B-line material) continued and new experimental hybrids produced and evaluated. Thirteen new A-B line pairs were assigned codes for extensive testing. New breeding materials, as well as early generation F_2s and F_3s, involving drought tolerant introductions, converted lines, and U.S. elite lines, were grown under field drought stress conditions and selected.

The derivatives of new white seeded, tan plant female parental line, BTx635, showed a significant level of stay green (post-flowering drought tolerance), especially in combinations with B1, plus outstanding lodging resistance and head smut resistance. Sterilization of several of these was initiated.

New disease resistant breeding materials were developed, screened, and selected along with advanced generation breeding materials for improved agronomic types with high levels of disease or multiple disease resistance. Screening and selection was done primarily in large disease screening nurseries, mostly in South Texas. Major diseases involved were charcoal rot, grain mold/ weathering, downy mildew, head smut, anthracnose, and foliar diseases such as rust, zonate, and leaf blight. Derivatives involving the white, tan B-line, BTx635, showed outstanding resistance to head smut in South Texas. The line appears to be an excellent source of resistance to head smut in B-lines.

Several new advanced generation breeding lines were identified for release as germplasm stocks. These lines contain various desirable traits, including resistance to downy mildew, head smut, grain mold/weathering, anthracnose, charcoal rot, both pre- and post-flowering drought resistance, food type grain quality, and lodging resistance.

Recombinant inbred (RI) F7 lines of (B35*Tx430) and (B35*Tx7000) for RFLP and RAPD genome analysis were grown and evaluated for pre- and post-flowering drought resistance with excellent post-flowering drought stress obtained. Genetic variation for drought was great among the RI lines in both populations. RFLP linkage maps have been developed for 110 loci in B35*Tx7000 and for 60 loci in B35*Tx430. New crosses were made for RFLP analysis involving other sources of drought resistance, grain mold resistance, and anthracnose resistance, and progenies will be advanced for future use. Another graduate student study involved the evaluation of various germplasm and parental lines and their F1s for grain mold/weathering resistance across diverse locations around the world.

Hybrids among various released parental and experimental male sterile (A) and restorer (R) sorghum lines were used to study the nature of the dominance of the stay-green post-flowering drought resistance trait. There was a wide variation in the expression of the trait in F1 hybrids. Excellent post-flowering moisture stress occurred at both Lubbock and Halfway test sites. Only a few stay-green lines showed strong dominance of the trait. These were SC35-14E(IS12555C), SC56-14E(IS12568C), A35 (a BC1 derivative of IS12555), some SC56*SC33 derivatives, 1790E and 1790L, and an SC33 (IS12553) derivative, (P407x?) (Table 1 and 2). SC33 and 35 are Durras from Ethiopia, while SC56 is a Caudatum/Nigricans from Sudan. The stay green in some lines was completely recessive, while several showed partial dominance of the stay green trait. The stay green in some derivatives of B35 such as B1, A2-1, A2-2(B), and A4 was completely recessive. The stay green in most Rio selections and derivatives was recessive. In Table 3, the stay green ratings and percent lodging of selected hybrids is presented. The data show the strong relationship of good stay green with resistance to stress-type stalk loging.

Many new crosses and new breeding material was generated primarily for use in Host Countries. Important traits include head bug resistance, *Striga* resistance, grain mold/weathering resistance, lodging resistance, sugarcane aphid resistance, as well as drought and disease resistance. Some of the lines used in crosses were Malisor 84-7, ICSV1089BF, Sureño, Dorado, SRN-39, Sepon82, Macia, WSV387, SV1, B.BON34, BTx635, MR732, 86EON361, and 87EON366, all of which are white seeded, tan plant types.

Some new Australian B and R lines with stay green and/or midge resistance were introduced and crossed to elite lines. These include A&BQL41 (stay green), B86815-1-3 (stay green and midge), and R90562 (stay green and some midge).

In Mali, some white seeded, tan plant Guinea type F6 breeding progeny from crosses involving Bimbiri Soumale (a late maturing southern Mali Guinea) looked outstanding in Preliminary Yield Trials. These were given the highest priority in the breeding program for advance, evaluation off station, and for use in evaluating the potential of grain from white seeded, tan plant Guineas for enhanced utilization products. Two new non-guineense Malian developed lines were selected for increase and on-farm trials in 1994. The two lines, R6078 and BTx635, continued to show excellent head bug resistance.

In Sudan, numerous F3 derivatives of Ajabsido (a drought resistant Sudan Feterita), were received from TAM-122 and evaluated. The objective was to obtain Ajabsido-like cultivars with shorter plant height, tan plant color, and/or absence of testa. In Honduras, a sorghum-sudan forage sorghum, Ganadero (ATx623*Tx2784), is ready for release. The downy mildew resistant male parent of this hybrid was developed jointly by TAM-124 and TAM-122.

Networking Activities

Workshops

Participated in and presented paper at Workshop on Adaptation of Plants to Soil Stresses, Aug. 1-4, 1993, Lincoln, NE.

Participated and chaired the African INTSORMIL Country Coordinators Strategic Plan Conference, October 17, 1994, Niamey, Niger.

Table 1. Classification of male sterile A-lines of sorghum for stay green and dominance of the stay green trait in hybrids.

Designation	Pedigree	Stay Green* of line	Dominance** classification in hybrids
A35	IS12555der	VG	Dom
A1	(BTx625*B35)	G	Rec
ATx635		M	S-Dom
ATx638		M	Rec
A4R	(B406xRio)	G	P-Dom
A2-1	(BTx625*B35)	G	Rec
A2-2(B)	(BTx625*B35)	G	Rec
A4	(BTx625*B35)	G	Rec
A6	(BTx624*B35)	G	P-Dom
A7	(BTx624*B35)	G	P-Dom
A1778	(SC56*SC33)	VG	P-Dom
A1887	(SC599*SC134)	VG	P-Dom
A599	Rio Der.	G	Rec
A803	(BTx3042*(BTx625*B35))	M	S-Dom
AQL41	Australian line	G	P-Dom
Non-stay green A lines			
ATx623	(BTx3197*SC170)	P	-
ATx399	Wheatland	P	-
A807	(BTx3042*(BTx625*B35))	P	-
ATx378	Redlan	P	-

* Classification of A line for stay green, based on previous data where: VG = very good; G = good; M = moderate; P = poor.

**Overall classification of the dominance of the expression of the stay green trait in F1 hybrids where: Dom = strong dominance; P-Dom = partially dominant; S-Dom = slightly dominant; Rec = complete or nearly complete recessive.

Table 2. Classification of restorer sorghum lines for stay green and dominance of the stay green trait in hybrids.

Designation	Pedigree	Stay green* of line	Dominance** classification in hybrids
SC35-14E	IS12555C/Durra	VG	Dom
SC56-14E	IS12568C/Cau Nig	VG	Dom
NSA 440	Karper/Gaines/Kafder	VG	S-Dom
1790E	(SC56*SC33)	VG	Dom
1790L	(SC56*SC33)	VG	Dom
R9188	Rioder, SC599-6	VG	Rec
SC599-11E	Rioder, BC3	G	S-Dom
R1922	(SC56*SC110)	G	P-Dom
R1584	(SC56*SC170)	VG	Rec
(P407*?)UC	(SC33 der.)	VG	Dom
KS19	Kansas Release	G	P-Dom
R8503	(SC599-6*Tx430)	G	Rec
88V1080	(Tx430*R9188)	G	Rec
R3224(sh)	(TAM428*(GbTx7000der))	M	S-Dom
R3224(t)	(TAM428*(GbTx7000der))	M	S-Dom
82BDM499	(SC173*SC414)	M	P-Dom
R90562	Aust. Line	G	P-Dom
88B1016	(Tx430*Rio)UC	VG	Dom-P-Dom
Tx430		F	Rec
Tx436		F	Rec
Tx433		F	Rec
Tx432		M	Rec
Tx435		G	Rec
88BE2668	(Tx2783*(SC748*SC630))	F	Rec
850G4300-5	(Gb430*(SC170*4671))	P	-
88B943	(Rio*CS3541)	P	-
86EO361	(Tx432*CS3541)*SC326-6))	P	-
87EO366	(TAM428*(Tx432*CS3541))	P	-
P37-3	(Tx2794*K22/35)	P	-
R7730	(77CS1*Tx430)	P	-

* Classification of restorer line for stay green based on previous data where: VG = very good; G = good; M = moderate; F = fair; P = poor.

** Overall classification of dominance of the expression of the stay green trait in F1 hybrids where: Dom = strong dominance; P-Dom = partially dominant; S-Dom = slightly dominant; Rec = completely recessive.

Research Investigator Exchanges

Traveled to Mali Oct. 7-16, 1993 to help plan and participate in the INTSORMIL EEP Review, evaluate the INTSORMIL/IER collaborative research program, and plan future collaborative research with the IER National Program.

Traveled to Niger Oct. 16-20, 1993 to participate in and chair the African INTSORMIL Country Coordinators Strategic Plan Conference, Oct. 17 at Niamey, and participate in the EEP Review of the INRAN/INTSORMIL program.

Traveled to Honduras Dec. 6-10, 1993 to evaluate the INTSORMIL/SRN/EAP collaborative sorghum research program, and plan future collaborative research for Honduras and networking possibilities for Central America.

Traveled to St. Croix, U.S.Virgin Islands, Jan. 13-21, 1994 to assist in classification, characterization, taking descriptive notes, and checking correctness of the 3,160 item Sudan Sorghum Collection grown out in quarantine, and select a smaller working collection.

Coordinated a six-week sorghum breeding training for Aboubacar Toure, Mali sorghum breeding technician at Lubbock, July-September, 1993.

Served as coordinator and host for Study Leave for Dr. Samy M. Beder, Egyptian sorghum breeder, at Lubbock, October, 1993 thru March, 1994.

Coordinated sorghum training and research in sorghum breeding, drought resistance, and germplasm for two visiting scientists, Tony McCosker (sorghum breeding Research Associate from Australia) and Geremew Gebeyehu (Sorghum Breeder from Ethiopia), April - September, 1994.

Participated in Sorghum Commodity Advisory Committee (CAC) as Ad Hoc Member at ASA Meeting (Nov. 1993), and in St. Croix (Jan. 1994).

Other Collaborating/Cooperating Scientists

Cooperation or collaboration with the following scientists in addition to the collaborating scientists previously listed was important to the activities and achievements of Project TAM-122.

Table 3. Stay green (LPD rating) and lodging of selected sorghum hybrids under post-flowering stress.

Hybrid/Pedigree	LPD rating*	Lodging %
A1*Tx430	3.9	31
A35*Tx430	2.7	2
ATx635*Tx430	3.9	26
ATx638*Tx430	4.3	50
A2-2(B)*Tx430	4.1	28
A4R*Tx430	3.3	11
A35*Tx7000	3.4	11
A4*Tx7000	4.2	60
A2-1*Tx7000	4.4	52
A1*TAM428	4.2	23
A35*TAM428	3.0	4
A1*Tx436	4.1	7
A35*Tx436	2.7	1
AQL41*Tx436	3.1	5
A1*Tx433	3.8	27
A1*SC35-14E	2.7	1
A4R*SC35-14E	2.7	2
A1*SC56-14E	2.9	2
A35*SC56-14E	2.0	2
A1*R9188(Rio Dcr)	4.2	27
A35*R9188(Rio Dcr)	2.6	2
ATx623*R9188(Rio Dcr)	4.1	40
A1*NSA440	3.3	2
A35*NSA440	2.6	0
A1*R3224(sh)	3.7	6
A35*R3224(sh)	3.0	0
AQL41*R3224(sh)	3.3	1
A1*R8503	4.7	76
A35*R8503	3.1	4
AQL41*R8503	3.7	40
A807*R8503	4.6	93
A2-2(B)*R8503	4.4	77
A1*88V1080(Tx430*R9188)	4.3	54
A35*88V1080(Tx430*R9188)	2.2	0
AQL41*88V1080(Tx430*R9188)	3.2	9
A1*88BE2668	4.0	22
A35*88BE2668	2.7	4
AQL41*88BE2668	3.5	10
A4R*88BE2668	2.9	2
A803*88BE2668	3.1	6
A807*88BE2668	4.1	26
ATx399*88BE2668	3.7	6
A1*(Tx430*Rio)UC	2.9	9
A35*(Tx430*Rio)UC	2.5	1
A1*(P407x?)UC	2.4	1
A35*(P407x?)UC	2.3	1
A1*82BDM499	3.8	14
A35*82BDM499	2.6	2
A1*1790E	2.9	2
A35*1790E	2.2	0
A1*R1922	3.1	3
A1*87EO366	4.3	68
ATx635*87EO366	4.5	62
A1*86EO361	4.5	38
A35*86EO361	2.9	3
ATx635*86EO361	4.0	35
A1*P37-3	4.7	62
A35*P37-3	2.4	3
A1*R90562	3.4	15
A35*R90562	2.3	5
AQL41*R90562	2.8	2
ATx399*Tx430(Check)	4.2	41
ATx2752*Tx430(Check)	4.0	27
ATx378*Tx430(Check)	4.3	55
DK46(Check)	3.2	8

* Leaf and plant death rating: 1=completely green; 3=50% of leaf area dead; 5=entire plant dead. Ratings are mean of Lubbock and Halfway.

Mr. Issoufou Kapran, Sorghum Breeder, INRAN, Maradi, Niger.

Dr. A. Tunde Obilana, Sorghum Breeder SADC/ICRISAT, Bulawayo, Zimbabwe.

Dr. Chris Manthe, Entomologist, DAR, Gaborone, Botswana.

Dr. El Hilu Omer, Pathologist, ARC, Wad Medani, Sudan.

Dr. Sam Z. Mukuru, Sorghum Breeder, ICRISAT, Nairobi, Kenya.

Mr. Ben Kanyenji, Sorghum Breeder, Katumani Station, Machakos, Kenya.

Ing. Rene Clara, Sorghum Breeder, ICRISAT/CIMMYT, El Batan, Mexico.

Dr. Guillermo Munoz, INTSORMIL/CIAT, Cali, Colombia.

Dr. Manuel Torregroza, Director of Annual Crops, ICA, Bogota, Colombia.

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Dr. J.D. Eastin, Physiologist, UNL-116, University of Nebraska, Lincoln, NE.

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Dr. John H. Mullet, Biochemist, Texas A&M University, College Station, TX.

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Dr. A.B. Onken, Soil Scientist, Texas A&M University, Lubbock, TX.

Dr. Henry Nguyen, Geneticist, Texas Tech University, Lubbock, TX.

Germplasm Conservation and Use

Seed of the Sudan Sorghum Collection of approximately 3,160 cultivars of Sudanese origin was introduced into the U.S. and grown out and seed increased under quarantine in St. Croix, U.S. Virgin Islands during the winter 1993-94. Each entry was checked for correctness, purity, and classified using the Harlan Race system and the Modified Murty Working Group system. Over 30 other plant and grain descriptors were also taken on each line. A tentative Working Collection was selected representing genetic diversity, agronomic eliteness, and diversity of origin. Twenty-five of the Sudanese cultivars were selected for entry into the Sorghum Conversion Program. This was a joint effort with USDA/ARS Puerto Rico and St. Croix, USDA Regional Plant Introduction Station, Griffin, GA. INTSORMIL (Purdue-Gebisa Ejeta; Texas A&M - Darrell Rosenow; Sudan, ICRISAT, ARC), and the Sorghum CAC. Seed was sent to the National Seed Storage Lab, Sudan, ICRISAT, to interested sorghum workers, and all data was entered into the USDA GRIN System. Some very unique (high yielding Guinea - Caudatum derivatives) sorghums from Southern Sudan were discovered in the Sudan Collection.

Thirty new introductions, primarily from Mali and Zambia, were evaluated and seed increased in Puerto Rico. A few showed excellent agronomic potential and disease resistance: (1) 92SBF4DT-79(M84-7*TRPSS49CC); (2) 90CZF4-117(ICSV1063*M84-5), and (3) 91PreGp1#24 (87E0366*ICSV1086). Nineteen new sorghums from Mali (17) and Niger (2) were identified and introduced into the U.S. in 1993. These included improved breeding lines and a *Striga* resistant Guinea landrace, 'Seguetana Cinzana'.

A total of 56 new exotic sorghums were selected from evaluation in Texas and Puerto Rico for entry into the cooperative TAMU/TAES-USDA/ARS Sorghum Conversion Program in the fall of 1994. These included 5 downy mildew resistant lines from Ethiopia (Frederiksen), 4 fall armyworm resistant lines from Sudan (Pitre), 3 acid soil resistant lines from Zambia (Duncan), 17 elite agronomic or unique lines (J. Dahlberg) from various Puerto Rico and St. Croix increases and 25 Sudan Collection lines. Twelve of these lines being similar to or appeared to be derivatives of the midge resistant line, AF28, and are suspected to possess midge resistance.

Seed Production and Distribution

A large number of sorghum breeding and germplasm lines, including F2 to advanced generation breeding progeny, A,B, and R lines, converted lines, and experimental hybrids were increased and distributed to numerous international and domestic collaborators. These contained sources of desirable traits such as disease resistance, pre- and post-flowering drought resistance, grain mold and weathering resistance, and lodging resistance. Seed was increased and many sets of standard replicated trials containing elite germplasm and source lines were 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), CLAT (Converted Line Anthracnose Test), and the UHSN (Uniform Head Smut Nursery). Countries to which large numbers of germplasm items were distributed include Mali, Sudan, Honduras, Kenya, Zimbabwe, Botswana, and ICRISAT/LASIP.

Assistance Given

Evaluation of germplasm was done collaboratively with national scientists in Mali and Honduras. This included training in disease and drought screening and rating methodology, as well as information on sources of new useful germplasm and sources of desirable traits. Similar training was provided to LDC graduate students in the Texas breeding and disease nurseries in the Lubbock and Corpus Christi areas. Short term training was given at Lubbock to Aboubacar Toure, a Malian sorghum breeding technician, Samy Beder and Geremew Gebeyehu, sorghum breeders from Egypt and Ethiopia, respectively, and Tony McCosker, research associate from Australia. Pollinating bags and breeding supplies were provided to the Mali breeding program.

Publications and Presentations

Publications

Walulu, R.S., D.T. Rosenow, D.B. Wester, and H.T. Nguyen. 1994. Inheritance of the stay-green trait in sorghum. Crop Sci. 34:970-972.

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Rosenow, D.T. Sorghum conversion and germplasm. Liaoning Institute, Shenyang, China, August 24, 1993.

Rosenow, D.T. Breeding for disease resistance. Liaoning Institute, Shenyang, China. August 25, 1993.

Rosenow, D.T. Drought resistance - Concepts and breeding procedures. Liaoning Institute, Shenyang, China August 26, 1993.

Rosenow, D.T. Mapping and evaluation of the stay green drought resistant trait in sorghum. Annual TAES Staff Conf. Biotechnology Group, January 11, 1994.

Rosenow, D.T. New sorghum parental lines for South Texas. San Patricio County Farm Tour, June 22, 1994.

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

Sorghum midge (*Contarinia sorghicola*) is the most widespread insect pest of grain sorghum. It is also among the most devastating insect pests and sorghum midge infestation results in direct economic loss. At anthesis, sorghum midge oviposit in the flowering floret. The larvae feed on the developing kernel causing aborted development and a 'blasted' appearance of the sorghum panicle. Genetic resistance to sorghum midge has been used in a breeding program to develop elite germplasm with excellent resistance and agronomic characteristics. All known resistance sources are poor agronomically and difficult to use in a breeding program, the resistance being inherited as a recessive quantitative trait. Use of sorghum midge resistant hybrids has been restricted due to lack of A-lines with excellent yield and resistance in hybrids.

Four new A-lines have been identified which possess excellent resistance as lines and in hybrids. When evaluated as the female parent in hybrids, grain yield is significantly better than that of the standard resistant check (ATx2755 x Tx2767). When compared to susceptible checks grain yield is significantly better, the experimental hybrids producing several times more grain.

Seed quantities of the new lines will be increased in the next year for release. Large quantities of hybrid seed will also be produced to test performance and stability of resistance in larger sized fields.

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 sorghums resistant to selected insects including the sorghum midge and greenbug.

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 many biotic and abiotic stresses. Insects pose a production risk in all areas of sorghum production, severity of damage depending on the insect and local environment. To reduce stress impact, research to develop crop genotypes with enhanced environmental fitness for use in more sustainable production systems is needed. Development of a single genotype with genetic resistance to multiple stresses will provide additional reductions in environmental risk and contribute to improved LDC and DC productivity. This is important as local production ecosystems (cultivars and technology) experience induced change, the natural balance between cultivars and biotic stresses also change and insect damage becomes increasingly severe.

Host plant resistance to insects is a continual effort in response to a dynamic evolving production agroecosystem. Genetic resistance may be used to meet the demands of increased food production in an economically profitable, environmentally sustainable production system with no additional producer inputs. To accomplish this task a multidisciplinary research program to integrate resistant hybrids into the management system is needed. Cultivars and hybrids resistant to insects readily interface with other inputs as part of an ecologically sound integrated pest management and stress control strategy with large potential benefits to subsistence and mechanized agriculture.

Depending on the environment many other insects, including aphids, head bugs, and borers damage grain sorghum. For each insect pest genetic resistance exists and may be integrated into the production system in an ecologically safe, economically inexpensive, and environmentally sustainable manner. Sorghum midge, *Contarinia sorghicola*, is the only cosmopolitan insect pest of sorghum and is among the most destructive. As LDC research programs introduce exotic germplasm with superior agronomic traits into indigenous genotypes, progeny and eventually cultivars will be developed which are more photoperiod insensitive. Due to the wider range in time of anthesis, damage due to sorghum midge should become increasingly severe.

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. Interaction of these factors frequently results in food shortages. Solutions to these problems must meet site specific needs of soil, rainfall, resources, labor and capital. 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 nursery locations in Texas. Collaborative research has focused on evaluation of sorghum lines and hybrids resistant to sorghum midge. In the U.S. 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 LDCs 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 LDCs 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 LDCs. 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 is 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 is determined by neutron probe. Particular attention is given to determination of soil chemical and physical characteristics for nurseries in Mali.

Research Findings

Research continued in the objective of developing elite sorghum midge resistant lines suitable for hybrid seed production. Major emphasis was to broaden the genetic base of the breeding program, incorporate additional sources of resistance into elite lines, identify new superior R-lines, and identify new A-lines with excellent resistance and yield potential. Elite advanced lines were evaluated for resistance to sorghum midge and agronomic desirability in the midge line test. Data on performance of superior lines are presented in Table 1. Sixty lines were evaluated with twenty-three selected for further evaluation and testing. Eighteen of the selected lines (designated as 'MB') are B-lines (A1 cytoplasm) and in the sterilization program to develop new seed parents. A major constraint to production and use of sorghum midge resistant hybrids has been the lack of superior A-lines that possess excellent resistance and yield potential under pest infestation, and excellent yield potential in the absence of the pest. The usefulness of ten of the lines as female seed parents in hybrids is under investigation and four of the lines, designated MB104-B91NF6, MB104-B92NF9, MB110-B92NF3 and MB110-B93NF6, have been selected for release.

Forty experimental hybrids representing new hybrid combinations were evaluated in the midge hybrid test (Table 2). The test included new R-lines and A-lines evaluated in hybrid combination for resistance and yield potential. When compared to the standard sorghum midge resistant hybrid, ATx2755 x Tx2767, several experimental hybrids expressed significantly better yield potential and pest resistance under high population density at Corpus Christi. Each of these superior hybrids had as a parent a new A-line that has been in development. Based upon results from two years of evaluation, as lines and in hybrid combination, four new B-lines, listed above, have been selected for release. The lines will produce a sorghum midge resistant hybrid with excellent resistance under high population density and acceptable agronomic traits. 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.

A replicated fifteen entry trial containing sorghum midge resistant lines and standard resistant check was provided to IER, Mali. The lines were to be planted in replicated trials in at least one location in Mali to evaluate for sorghum midge resistance. The trial will be evaluated during an on-site visit in October 1994.

Research was conducted to develop germplasm resistant to biotype E greenbug. Advanced hybrid trials were conducted to test new R- and A-lines in hybrid combination. Data from the yield trial was used to identify superior lines for additional evaluation in 1994. Several potentially useful R- or B-lines were identified for further testing. Selections were made in breeding populations to develop elite germplasm resistant to biotype I greenbug. Many crosses were made to introgress the resistance gene(s) into an array of elite germplasm in both R- and B-line genetic backgrounds. A major emphasis is to backcross the resistance genes into elite genes already widely used. It was determined that PI550607 will restore fertility (is an R-line) in

Table 1. Midge damage rating and selected agronomic traits in the 1994 Midge Line Test, Corpus Christi, Texas.

Line	MDR†	DES‡	Height§	Exsertion¶	IB#	LPD††
Tx3042 (S-CK)‡‡	9.0	3.0	105	16	2.9	50
Tx623 (S-CK)	8.3	2.4	115	9	2.6	40
Tx430 (S-CK)	8.3	2.2	108	1	2.3	33
TAM2566 (R-CK)	8.0	3.1	93	6	3.2	70
MB110-B93NF6	5.7	2.6	102	9	3.3	37
Tx2755 (R-CK)	4.3	2.7	82	3	2.8	50
Tx2880 (R-CK)	4.3	2.8	98	8	2.9	43
MB104-B91NF6 (R-CK)	3.7	2.8	95	11	2.4	47
(Tx2872*Tx2880)-BM5	3.7	2.5	98	8	2.9	53
(Tx2887*Tx2890)-BM2-LMBK	3.7	2.9	110	18	2.8	63
(860362*MR106-1/Tx2883)-SM6-CM1	3.3	2.5	105	2	1.5	53
(Tx2880*Tx2882)-BM1-LMBK	3.3	2.6	102	7	2.5	47
MB104-B92NF9	3.0	2.6	92	7	2.3	47
MB110-B92NF3	3.0	2.6	93	6	2.8	37
MB120A-BM57-CC1-BM1-LMBK-CMBK	3.0	2.5	95	6	2.4	88
(MB110-21-L1-BM2-CC1*Tx623)-CM8-CM1	3.0	2.4	107	9	1.9	60
(Tx2782*Tx2876)-BM13-CM2	3.0	2.4	108	6	2.2	58
(Tx2872*Tx2880)-SM10	3.0	2.6	102	1	2.5	60
(Tx2877*86PL2;19,20)-BM22-LMBK-CM2-CM1	2.7	2.4	108	7	2.0	60
(Tx2782*Tx2878)-BM28-LMBK	2.7	2.5	117	4	1.8	70
(Tx2782*Tx2878)-SM6-LMBK	2.7	2.6	107	8	2.3	63
(MR114-90M11*Tx2767)-SM8	2.7	2.5	115	7	2.7	53
((SC228-14*Tx2767)-2-B2-BM2-LM2*Tx2876)-CM4-CM2	2.7	2.5	97	5	1.6	40
Tx2767 (R-CK)	2.3	2.5	120	4	1.9	53
Tx2782 (R-CK)	2.3	3.1	78	4	2.4	60
MR114-90M11	2.3	2.6	102	7	2.6	43
MR126-BM5-BM2-LMBK-CM2-LMBK	2.3	2.6	97	9	1.5	40
(MR114-90M11*6EO361/(R5646*SC326-6))-SM6-CM1	2.3	2.3	108	5	1.4	37
Tx2882 (R-CK)	2.0	2.4	98	5	2.6	60
$\bar{x}$	4.0	2.6	105	8	2.4	5.2
LSD.05	1.1	0.2	10	4	0.4	16

† MDR = Midge damage rating. Rated on scale of 1 = 0-10% blasted seed, 2 = 11-20% blasted seed,..., 9 = +81% blasted seed.
‡ Des = Desirability. Rated on scale of 1 = most desirable to 5 = least desirable.
§ Measured in cm from base of the stalk to top of peduncle.
¶ Measured in cm from flag leaf to peduncle base.
# IB = Insecticide phytotoxicity causing leaf discoloration. Rated on scale of 1 = no discoloration to 5 = 100% discoloration
†† LPD = Leaf and plant death. Percent of leaf tissue dead at maturity.
‡‡ S-CK = Susceptible Check; R-CK = Resistant Check.

A1 cytoplasm and that PI550610 will not restore fertility (is a B-line) in A1 cytoplasm. Based on the fertility analysis, it was decided that PI550607 would be used only in R-lines and PI550610 would be used only in B-lines. This should improve the genetic diversity of sorghum hybrids and maintain yield potential. It was also determined that both biotype I resistance sources were also resistant to biotype E.

Selections were made to develop F3 populations in the sorghum midge, and greenbug biotype E and I breeding programs suitable for use in mapping and identifying the resistance genes. For the sorghum midge, populations with resistance derived from either TAM2566 (SC175-9) or SC423-14 have been developed. For the greenbug, Tx2783 (resistance derived from Capbam) will be used for biotype E and PI550607 will be used for biotype I. A team composed of a sorghum breeder (TAM-123), an entomologist (TAM-125), and two molecular geneticists (a mapping specialist, and a marker-assisted selection specialist) has been assembled and graduate students recruited. Two small grants have been obtained to fund start-up costs. There is the need during the INTSORMIL 1994-95 year to identify funds to fully support the graduate student portion of the research. It is anticipated that when completed the research will have identified the gene(s) for resistance to sorghum midge or biotype E or I greenbug and determined genetic differences at the molecular level between resistance sources.

Research continued for the introgression of genes for resistance to yellow sugarcane into elite adapted material. Evaluation of F5 progeny derived from PI457709 resulted in identification of progeny with a useful level of resistance. The germplasm is currently undergoing additional further crossing with adapted germplasm and selection to develop elite resistant lines. The initial F1s and F2s derived from PI453951 were planted. Selection in the F2 populations will emphasize short, early genotype that may be screened for presence of the resistance gene(s).

Table 2. Grain yield, midge damage rating and selected agronomic characteristics in the 1994 Midge Hybrid Test, Corpus Christi, Texas.

Hybrid	Grain yield lbs/A	MDR†	DES‡	Height§	Exsertion¶	IB#	LPD††
A93NF6(MB110)*Tx2880	2573	2.7	2.3	112	9	3.0	37
A92NF3(MB110)*Tx2882	2031	4.3	2.4	108	13	2.9	33
A91NF6(MB104)*Tx2882	1958	3.7	2.4	115	15	2.7	33
ATx2755*Tx2880 (R-CK)‡‡	1931	4.7	2.5	115	13	3.4	43
A92NF9(MB104)*Tx2882	1734	3.7	2.5	112	13	2.7	37
A93NF6(MB110)*Tx2882	1695	4.3	2.4	105	11	2.9	30
A91NF6(MB104)*Tx2880	1651	4.7	2.6	120	14	2.9	30
A92NF9(MB104)*Tx2767	1585	4.7	2.6	123	15	2.4	40
ATx2755*Tx2767 (R-CK)	1383	6.0	2.5	122	11	2.7	40
A92NF9(MB104)*Tx2880	1379	5.7	2.8	120	12	3.1	43
ATx2801*Tx2882 (R-CK)	1251	5.3	2.5	117	12	2.7	30
ATx2755*MR114-90M11	1196	6.7	2.6	117	15	2.7	37
A91NF6(MB104)*Tx2767	1169	6.0	2.6	128	13	2.6	37
ATx2755*Tx2882 (R-CK)	1104	6.0	2.5	105	9	2.8	40
ATx2752*Tx2783 (S-CK)	289	8.7	2.7	127	9	2.3	27
ATx2755*Tx430 (R&S-CK)	217	9.0	2.4	120	9	2.7	40
ATx2801*Tx430 (R&S-CK)	152	9.0	2.4	133	9	3.1	37
ATx2752*Tx430 (S-CK)	50	9.0	2.4	123	11	2.1	30
ATx3042*Tx2737 (S-CK)	48	9.0	2.5	125	19	2.6	30
$\bar{x}$	1060	6.2	2.5	124	13	2.7	36
LSD.05	379	1.3	0.2	6	4	0.4	11

† MDR = Midge damage rating. Rated on scale of 1 = 0-10% blasted seed, 2 = 11-20% blasted seed, ..., 9 = +81% blasted seed.
‡ DES = Desirability. Rated on scale of 1 = most desirable to 5 = least desirable.
§ Measured in cm from base of the stalk to top of peduncle.
¶ Measured in cm from flag leaf to peduncle base.
# IB = Insecticide phytotoxicity causing leaf discoloration. Rated on scale of 1 = no discoloration to 5 = 100% discoloration.
††LPD = Leaf and plant death. Percent of leaf tissue dead at maturity.
‡‡CK = Resistant check; S-CK = Susceptible check; R x S-CK = Resistant x Susceptible check.

Twenty breeding lines and four 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.

We have previously found and reported that transpirational water use efficiency is linearly related to harvest index. Changing harvest index through plant breeding and/or cultural practices could significantly affect water use efficiency. We measured the harvest index of 10 breeding lines at two levels of nitrogen fertilization. Harvest index increased with nitrogen fertilizer application and was significantly different between breeding lines at both levels of nitrogen fertilization. A highly significant relationship was found between harvest index at low nitrogen and high nitrogen which had the form of $y=ax^b$. Grain yield was related to harvest index within and across both levels of nitrogen fertilization. These relationships also had the form of $y=ax^b$. A significant interaction was found between breeding line and nitrogen level on harvest index. This interaction effect (genotype X nutrient level) has also been found, in the past, to affect grain weight, nitrogen uptake, nitrogen translocation, metabolic nitrogen use efficiency, grain produced per unit of nitrogen supply, transpirational water use efficiency based on grain weight and evapotranspirational water use efficiency. These studies have shown that plant breeding can be used to improve these plant characteristics important to improving production efficiency. They also show the necessity of quantifying the interaction of genotype and nutrient supply for any given set of production conditions.

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. Checks used were Bagoba (resistant) and Malisor 84-5 (susceptible). 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. The nursery was planted again during the 1994 growing season.

To evaluate the U.S. acid soil response of African sorghums with good response to soil toxicity or acids soils (in Africa), a two-hundred-ten entry two replication test was sent to Dr. R.R. Duncan at the University of Georgia. The lines will be evaluated under conditions of known pH and nutrient concentration to identify their response to U.S. acid soil conditions. This will increase the opportunity to identify genotypes with resistance or tolerance to a range of acid soil conditions throughout the world.

Networking Activities

Workshops

G.C. Peterson. International Consultative Workshop on Panicle Insect Pests of Sorghum and Pearl Millet, 4-7 Oct 1993, Niamey, Niger.

Research Investigator Exchanges

G.C. Peterson. Oct. 1-8, 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. Oct. 8-16, 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.

Mr. Sun Guihuang, Sorghum breeder, Liaoning Acadamy of Agricultural Sciences, Shenyang, P.R.C. conducted research on resistance in grain sorghum to aphids, July 1, 1993 - March 31, 1994. Toured sorghum nurseries at Corpus Christi, Beeville and College Station.

Mr. Tony McCosker, Queensland Department of Primary Industries, Australia, conducted research on resistance in grain sorghum to sorghum midge, biotype E greenbug and drought at Lubbock, April 15, 1994 - September 31, 1994. Evaluated germplasm generated for research activities at College Station and Lubbock. Toured and worked in sorghum nurseries at Corpus Christi.

Other Cooperators

Dr. B.R. Wiseman, Entomologist, Insect Biology and Population Management Research Lab., P.O. Box 748, USDA-ARS, Tifton, GA 31793-0748

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Germplasm Exchange and Conservation

G.C. Peterson participated in classification and description of the Sudan sorghum collection when it was grown at the USDA Quarantine Center, St. Croix prior to introduction of the collection into the U.S. plant germplasm system. Approximately 1,353 introductions from the Sudan sorghum collection are being grown in research plots at Lubbock to evaluate for photoperiod sensitivity and to cross to A-lines for fertility restoration analysis.

Seed samples were sent to the following countries including, but not limited to: Australia, Mali, China, Colombia and Egypt.

TAM-123 also provided seed for entries in the ADIN (All Disease and Insect Nursery), which is grown in many locations throughout the world, and the TAT (Tropical Adaptation Test).

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, including ATx2752, Tx2737, Tx2783, Tx2864, and Tx2862. It has been estimated that the net social benefit to the U.S. 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 selected for release have the potential to significantly increase use of sorghum midge resistance hybrids.

Assistance Given

Provided computer software to Honduras.

Provided technical support to Dr. A. Toure (Mali) on computer software for breeding programs, and on computer operation.

Publications and Presentations

Abstracts

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. 1994. Sorghum and plant resistance to insects problems. Annual Plant Resistance to Insects Newsletter 20: 3-5.

Peterson, G.C., G.L. Teetes, R.M. Anderson, and B.B. Pendleton. 1994. Yield and selected traits of sorghum midge-resistant sorghum hybrids. Annual Plant Resistance to Insects Newsletter 20: 30-31.

Peterson, G.C., G.L. Teetes, and B.B. Pendleton. 1995. Resistance of sorghum to sorghum midge in the United States. Sorghum Newsletter 35: (in press).

Refereed Journal

Teetes, G.L., R.M. Anderson, and G.C. Peterson. 1994. Exploitation of sorghum nonpreference resistance to sorghum midge (Diptera: Cecidomyiidae) using mixed plantings of resistant and susceptible sorghum hybrids. J. Econ. Entomol. 87:826-831.

Pendleton, B.B., G.L. Teetes, and G.C. Peterson. 1994. Phenology of sorghum anthesis. Agron. J. 86: (in press).

Presentations

Peterson, G.C., J. Dahlberg, D.K. Mulitze, D.T. Rosenow, and F.R. Miller. 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. 7-12 Nov. 1993. Cincinnati, OH.

Dahlberg, J., G.C. Peterson, and D.K. Mulitze. Sorghum pedigree management using Agrobase/4™. Annual meeting of the American Society of Agronomy/Crop Science Society of America/Soil Science Society of America. 7-12 Nov. 1993. Cincinnati, OH.

Breeding Sorghum for Stability of Performance Using Tropical Germplasm

Project UNL-115

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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. T. Rosenow, Sorghum Breeder, TAM-122, Texas A&M University, Lubbock, TX
Dr. Paula Bramel-Cox, Sorghum Breeder, Kansas State University, Manhattan, KS
Dr. Jerry W. Maranville, Physiologist, UNL-114, University of Nebraska, Lincoln, NE

Summary

Most sorghum is grown for food in low resource semi-arid (LRSA) 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 LRSA 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. This is a fertile breeding area, therefore, this project seeks to exploit crossing of 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 LRSA 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, Niger, 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. Further hybrids were sent in 1993, together with parents, so that seed of these hybrids could be increased in Senegal.

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. Initial hybrid tests were promising. SADC/ICRISAT has produced three seed parents from University of Nebraska-Lincoln germplasm.

Multilocation tests in Kansas and Nebraska showed yields of hybrids made with several new tan-plant seed parents equalled or exceeded commercial hybrid checks. One of these was released in March 1994 as N148 A and B. Earlier work on seedling vigor identified non-destructive methodology, located several good sources, and showed that there is good potential for improving this trait through breeding. Research on determining the most efficient way to assess combining ability early in the selection process continued.

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. 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 preceeding F_2s of crosses between appropriately adapted exotic lines are provided to host-country breeders to initiate collaborative selection programs. At F_4/F_5, 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, student research is on methodology for determining combining ability. Both selection and testing in the UNL-115 project is conducted without added fertilizer (about 50 kg N/ha is available from the proceeding soybean crop), since most LDCs use little chemical fertilizer on dryland cereals but can use rotations with legumes.

Research Findings

Thirty-four 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 six 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.

With assistance from the Nebraska Grain Sorghum Board, 115 new seed parents in 28 family groups, were evaluated for their combining ability. Each was mated with two testers and the resulting hybrids divided among five trials, all of which contained the same three check hybrids. Many individual hybrids equalled or exceeded the yields of the best checks. However the best combining ability was shown by 15 seed parents where the mean of both their hybrids equalled or exceeded, by 3-17 %, the average of the three checks (Table 1). One of these seed parents, 524A, a derivative of a cross between a U.S. cold tolerant line and an ICRISAT food quality introduction, had been tested earlier and hybrids with it had equalled or exceeded checks in Kansas and Nebraska tests. In 1993, Nebraska State tests hybrid 524A x RTX2737 averaged 7% more yield than the mean of 34 or more commercial hybrids in five locations. Seed parent 524A was released as N148A & B in March, 1994.

Fabien Jeutong from Cameroon, in the first part of his dissertation research on evaluating combining ability, tested 5 female lines against 14 male testers. Results indicated that seed parents N122A and 538A (a sister selection of 524A) were superior in general combining ability to two of the other three seed parents. Among the male testers various differences existed, but three of those tested had combining

Table 1. New sorghum seed parent hybrid tests, Mead, 1993. Grain yields (kg/ha) of best hybrid, mean of best pair of hybrids with same seed parent, and average of three check hybrids.

Test #	Best hybrid		Mean yield	
	Parentage	Yield	Best pair of hybrids	3 checks
1	901A x TX2737	7520	7020	5640
2	363A x TX2737	7840	6870	5880
3	857A x TX7000	7270	6770	6580
4	919A x TX7000	7460	7020	6710
5	759A x TX2721	7520	6770	6270

abilities equal to RTX430, a male parent well known for its general combining ability.

Networking Activities

Botswana

A number of sorghum hybrids and varieties have been identified for multilocation testing, and demonstration plots prior to possible release. Most likely for release are SDSH48 (ICSA12 X SDSR 6013) and Macia, especially as the latter has been released elsewhere in the region. Eleven seed parents developed from UNL-115 material are in BC_4. The first testcrosses on these looked good at Sebele and were as early as Segeolane. The sorghum program at the SADC/ICRISAT Center has also developed three seed parents from the same source material. Further production of hybrids on the Botswana seed parents was planned in the off season with the help of the SADC/ICRISAT Center to enable more extensive hybrid tests to be conducted in 1994/1995. Selections were made in new material sent from UNL-115 and TAM-121.

Other Countries

Two of 32 seed parents sent to Nigeria had sufficient disease resistance and grain quality to be selected for producing hybrids. No report was received of a similar set sent to Zambia.

Seven hybrids made on these and other similar seed parents were sent to Niger and Senegal, together with each of the parent lines so any suitable hybrid could be reproduced on site.

Germplasm Exchange

Nineteen sorghum lines were sent to Botswana

Seven hybrids and 7 parental lines were sent both to Niger and Senegal

One seed parent to China

Ninety-six lines were supplied within the U.S. and three received

Publications

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Breeding Pearl Millet for Stability Performance Using Tropical Germplasm

Project UNL-118
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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. produce the adapted plant type needed to grow pearl millet as a combine-harvested feed crop. Finally, to provide students thesis topics from the on-going research 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 third year. Based on prior collaborative research with INTSORMIL, seed was produced in Senegal of hybrid KS2068A x 086, for the Senegal River Valley. Opportunities for INTSORMIL collaboration in the areas of food quality, agronomic and breeding research were determined in Namibia, where research on pearl millet has been stimulated by the widespread adoption of variety Okashana-1 from ICRISAT. The male sterility identified in mutated finger millet by F.R. Muza and S.C. Gupta in Ph.D. research in Zimbabwe is apparently controlled by a single recessive nuclear gene, and is easily recognizable at maturity. This male sterility will be important to finger millet breeding on a world wide basis.

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 new A_4 cytoplasmic male sterility system which has several major advantages over the A_1 system, and may also be useful in developing agriculture. Since pearl millet lacks resistance to commonly used herbicides, recurrent selection in several populations was continued to develop resistance to propachlor. Up to five cycles of selection have been completed with evident increases in tolerance. Recurrent selection continued on a Nebraska population in conjunction with ARS, Tifton, GA, and the 1993 pearl millet regional test was expanded to nine locations and included two experimental commercial hybrids.

Objectives, Production, and Utilization Constraints

Objectives

The objectives of the breeding program, with slight modifications remain as in previous years:

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. 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 delay and restrict 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. Methods and operational techniques being developed will be equally transferable.

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 sixth year of the regional grain yield test coordinated.

Pedigree Breeding

One hundred and fifty eight new exotic x adapted and adapted x adapted F_1's were grown and 1500 F_2 to F_6 lines evaluated. New introductions were made from Yemen and ICRISAT India. Selection emphasis continued on performance and lodging resistance for material intended for the U.S. 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 (Table 1) and yield testing confirmed the usefulness of seed parents 293A, 378A, 413A, and 442A. Further new seed parents were identified.

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

Table 1. Pearl millet advanced A_1 hybrid test. Plant height, lodging, and grain yield of 10 of 25 hybrids at Mead, NE and Hays, KS in 1993.

	Height (cm)		Lodging (%)		Yield (kg ha^{-1})	
Hybrid	Mead	Hays	Mead	Hays	Mead	Hays
68A x 58057R	128	120	43	3	3060	4240
293A x 58058R	123	112	22	2	2930	4430
413A x 58058R	104	96	11	2	2900	4510
378-1A x 58058R	128	108	29	7	3500	3951
378-1A x 0183R	137	124	23	29	2700	5060
68A x 60007R	120	127	38	11	3360	4130
68A x 60015R	112	116	18	2	3580	4600
219A x 60015R	109	104	18	1	3060	4460
68A x 086R	111	118	21	1	2700	5730
68A x NPM-1	123	108	25	5	2780	3590
Mean (25 entries)	119	112	24	6	2770	4400
LSD (0.05)	10	15	18	10	860	1400

lines can be converted to seed parents). The first yield tests on A_4 hybrids were conducted in 1993. Table 2 shows that some hybrid combinations between potential A_4 seed parents and two R_4 pollen parents gave yields equivalent to A_1 check hybrids. Male fertility restoration continued to be excellent by known restorer (R_4) lines, and more R_4 lines have been discovered in very different genetic backgrounds. The first nine confirmed R_4 restorer lines were intermated and released as NPM-3 in October 1993.

Recurrent Selection

Recurrent selection for improved restoration on A_1 cytoplasm was continued on NPM-1 in 1992 with half-sib families derived from 10 S_1 families which showed full restoration on $23DA_1E$. Selection for increased panicle size and lodging resistance was made on NPM-1 in 1993. The second cycle of half-sib selection was also continued on NCD2 (Nigerian Composite Dwarf) with emphasis on obtaining dwarf, stiff-stalked, long panicle types of medium maturity. This population reported to be a source of R_4 restorers.

Recurrent selection in population NTPC continued in collaboration with Dr. Glenn Burton, Tifton, GA. Eighty-one progeny in the third cycle of recurrent restricted phenotypic selection were planted at Mead in 1993. Unfortunately the experiment was damaged by heavy rains after planting and no useful results were obtained. Arrangements are being made to replant the progeny of this cycle in 1994.

Selection for Herbicide Tolerance

Although most pearl millet germplasm tolerates reduced rates of atrazine, pearl millet has always lacked tolerance for other grass herbicides utilized in corn and sorghum cropping systems. Selection for tolerance to 5.04 kg ha^{-1} propachlor (150% of recommended rate) with 1.12 kg ha^{-1} atrazine was continued in 1993 on S_1 and half-sib selections derived from the original MLS population which had previously undergone five cycles of mass selection in propachlor and atrazine. One hundred and fifty-four half-sibs were obtained for recombination and 75 S_2 selections were advanced to S_3s in the winter greenhouse for testcrossing and field evaluation in 1994. Fifteen S_2 families from a new population, SSPxPTL (Stiff Stalk Parents x Propachlor Tolerant Lines) were field screened in propachlor and atrazine and S_3 selections were testcrossed with A_1 and A_4 cytoplasms for parental line evaluation. Mass selection for propachlor and atrazine tolerance was also begun in 1993 field isolations on two other populations with 104 tolerant selections obtained from CLP (Collaborative Line Parents population) and 120 tolerant selections obtained from LP (Late Parent population).

Regional Test

The Pearl Millet Regional Grain Yield trial was continued and planted in 1993 at ten locations in nine states. Results were received from six locations. Mean yields ranged from 5180 kg/ha at Hays, Kansas to 2740 kg/ha at Hermiston, Oregon. The average yields of six pearl millet entries, and two sorghum checks grown in both 1992 and 1993 at five sites are shown in Table 3.

Networking Activities

Senegal

Variety tests were again planted at Bambey and Kaolack. Seed was sent to Bambey of BC_1 A_4 cms lines so that Senegalese germplasm can be searched for the presence of R_4 restoration genes.

Zimbabwe

Grow-outs of sibs of the male sterility discovered by F.P. Muza and S.C. Gupta of SADC/ICRISAT Bulawayo in mutated finger millet indicate that this new trait is under the control of a single nuclear recessive gene. Seed set in natural conditions on male sterile plants is not complete, by which they can be clearly recognized at harvest, and do not, therefore, require identification and tagging at flowering. This male sterile will be of considerable use in facilitating crossing in this species, which has been a major constraint to breeding new cultivars.

Table 2. Pearl millet B_4-line x R_4-line hybrids. Anthesis, height, lodging, and grain yield of 10 of 25 hybrids at Mead, NE in 1993.

Hybrid	Anthesis	Height	Lodging	Yield
$92P1361B_4$ X $2R_4$	68.5	115	14	2610
$92P1365B_4$ X $2R_4$	68.5	111	11	2680
$413B_4$ X $1R_4$	70.5	99	16	2890
$92M57233B_4$ X $4R_4$	67.0	121	16	3420
$92M57261B_4$ X $4R_4$	69.5	121	17	2930
$57026B_4$ X $4R_4$	66.5	136	20	3000
$92P1392B_4$ X 58016R	67.5	112	21	3080
$92P1425B_4$ X 58016R	67.0	108	17	3130
$68A_1$ X 58016R	64.5	113	18	2010
$68A_1$ X NPM-1	64.5	124	14	2720
Mean (25 entries)	67.7	108	17	2481
LSD (0.05)	2.5	12	18	1120

Table 3. Pearl millet regional grain yield trials. Mean grain yields (kg/ha) for 1992 and 1993 at five locations.

Entry	Georgia Tifton	Indiana Purdue	Kansas Hays	Nebraska Mead	Texas Plainview
NPM-1 Variety	2820	2730	3690	2730	3000
68A x NPM-1	3310	4120	4560	3580	4550
68A x 086R	3730	3380	5120	3840	4530
79-2068A/89-0083	4370	4240	5870	3650	5180
RR23DAE X 8677	4100	1800	3800	2520	4060
YM261	4370	2920	5170	3110	5680
DK 18 Sorghum	3810	7050	6400	6190	6900
DK 39Y Sorghum	3730	5100	6150	5190	6690
Millet Mean	3780	3210	4700	3240	4500
LSD 0.05	1030	1820	1520	1650	1550

Namibia

A trip was made in April 1994 at the invitation of the Ministry of Agriculture, Water and Rural Development to look at the millet research situation in northern Namibia. Variety Okashana-1 (ICMV 88908=a version of ICTP 8203) has very successfully been extended over about 20% of the millet area. INTSORMIL can assist Namibian research in the areas of food preparation, agronomy, and breeding strategy.

It was evident that while Okashana -1 was very successful, it was very early in relation to local cultivars, and lacked stay-green and lodging resistance. Morphologically desirable progenies were evident in a naturally introgressed population between Okashana-1 and a local cultivar. Breeding procedures were planned to extract and test these progenies.

Germplasm Exchange

Nine lines were sent to SADC/ICRISAT, Zimbabwe, 13 to Senegal and 11 to Niger. Twenty-one were sent domestically. Forty-seven germplasms were received from ICRISAT, India and 27 from Hays, Kansas that were originally from Yemen.

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Crop Utilization and Marketing

Chemical and Physical Aspects of Food and Nutritional Quality of Sorghum

Project PRF-112

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Summary

The principal objectives of PRF-112 are 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 to assist the cereal quality programs in Niger and Sudan. Our major achievement in the past year was the discovery of a sorghum genotype with substantially higher *in vitro* protein digestibility than normal sorghum types. The highly digestible genotype has, using two *in vitro* systems, uncooked and cooked digestibility nearly that of wheat and higher than maize or rice. Sorghum protein digestibility normally rates lower than other cereals, especially when cooked. Biochemical studies showed that the major storage protein of sorghum, α-kafirin (comprising about 65% of total protein), in the highly digestible type was rapidly digested. In normal types this protein is very slowly digested due to its encapsulation inside protein bodies. Further evidence from scanning electron microscopy showed that the protein bodies appeared smaller and pitted suggesting that α-kafirin in the highly digestible sorghum is easily accessible to digestive enzymes.

In a collaborative study with INRAN (Niger) researchers we have begun to study grain components that relate to couscous quality. Viscosity profiles were found to differ in flours of sorghum varieties of almost equal particle size distribution and kernel hardness. Differences in starch gelatinization properties between varieties may be a method to find a superior genotype for couscous production. Our efforts are focused on identifying the grain properties necessary to obtain the best couscous product and to better understand the chemical basis of these traits. Our longer range goal is to test these products commercially using a small scale village processing unit or units in Niger. We have begun pursuing avenues for funding such a project.

In another study, we found that actual amount of kafirin in sorghum are markedly higher than those reported in the literature. Kafirin content was as high as 80% of total protein for sorghum endosperm and was significantly higher than comparable zein content in maize. This higher kafirin content, and correspondingly lower content of the nutritionally superior non-kafirins, may explain some poorer quality traits that sorghum grain exhibits. On the other hand, variability in kafirin/non-kafirin contents among genotypes could be a method of improving quality.

Objectives, Production and Utilization Constraints

Objectives

Develop an understanding of traditional village sorghum and millet food processing and preparation procedures and determine the grain characteristics that influence the functional and organoleptic properties of traditional food products.

Determine the relationships among the physical, structural, and chemical components of the grain that affect the food and nutritional quality of sorghum and millet.

Determine the biochemical basis for the relatively poor protein and starch digestibility of sorghum grain and many cooked sorghum products.

Develop laboratory screening methods for use in developing country breeding programs to evaluate and improve the food quality characteristics of sorghum and millet grain.

Constraints

Research on the food and nutritional quality of sorghum and millet grains is of major importance in developing countries. Factors affecting milling qualities, food quality, and nutritional value 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, breeding grains that have specific and 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. The overall goal of this project is to improve food and nutritional quality of sorghum and millet through a better understanding of the structural and chemical components of the grain that affect quality. This knowledge will be applied to develop useful methodologies for screening germplasm for end-use quality, develop techniques to make the grain more nutritious, and improve grain utilization through processing.

Research Approach and Project Output

Sorghum/Millet Couscous

Couscous, a major staple food product of the Sahel, is prepared from agglomerated and steamed sorghum, millet, or durum wheat flour. It is usually produced by the housewife and can be eaten fresh or can be kept for a long time before being consumed. In Niger, although couscous is consumed by the majority of the population, it is rare to find a locally produced couscous in the urban, as well as rural, markets. No known commercial sorghum or millet couscous products are available. In urban areas imported wheat couscous is readily available or in some cases imported maize semolina is bought and consumed in the form of couscous. Traditional couscous processing methods already exist and need only be improved by the introduction of new technologies. In this project our goal is to identify the characteristics that are needed to make the best sorghum or millet couscous to compete with imported wheat couscous. Information generated will also be used to aid breeders in their selections. Other funds are being sought to put in place one or two small village-based couscous processing operations.

A recent survey in Niger by the INRAN Cereal Quality Laboratory indicated that there are three different methods for traditional couscous preparation. A method in which dough is pressed through a sieve was more adaptable to small scale commercial production and was used in the laboratory. The same survey also indicated that texture and color were the two most important attributes that determine couscous quality. It is ultimately important to understand the biochemical basis for the differences in textural characteristics of different sorghum and millet varieties in order to identify superior genotypes for processing and to develop laboratory screening techniques for breeders. Studies have begun on seven sorghum varieties to understand the changes and interactions that the starch and protein components undergo during cooking and how these affect the texture of the final couscous product. Seven sorghum varieties (IRAT 204, SC 283-10, SEPON 83, Mota Maradi, P 721N, P 721Q, and NAD-1) were used in this study. Close attention was given to varieties that have comparable hardness and particle size. The Stenvert hardness values for IRAT 204, SEPON 82, P 721N, and NAD-1 were similar (22.1, 22.1, 22.4, 23.7, respectively). Particle size distribution of flours from these varieties were almost identical. The cooking properties of the grains were investigated using the Brabender Visco/Amylograph. In 10% suspensions significant differences were found in viscosities between flours of almost equal particle size distribution and hardness. NAD-1 gave the highest hot paste viscosity and SEPON 82 the lowest value. Couscous was prepared from 80% decorticated grain flours. Flours were made into dough and pressed through a #7 (2830 μm) and a #10 (2000 μm) sieve. Figure 1 shows couscous yields obtained from the four sorghum varieties. Passing the dough through a #10 sieve gave a much higher couscous yield for all varieties. NAD-1 gave the lowest yield in both cases. This was due to a higher amount of large pieces formed during steaming. NAD-1 also tended to give stickier couscous than the other varieties. Sepon 82 was found to make the best couscous of those tested. Sorghum varieties appeared to have less gelatinized starch than similarly processed wheat couscous. Variability in starch gelatinization temperature and degree of gelatinization among sorghum genotypes may be a method that could be used to select for improved couscous types. Studies are currently underway to evaluate the textural characteristics of sorghum, and then millet, couscous and to determine the effects of flour components on these characteristics.

Digestibility of Sorghum Proteins

Although sorghum grain is a staple food for many millions of people and has comparable composition to maize, its digestibility (of tannin-free sorghum) in humans is known to be somewhat inferior to other cereal grains. Increased protein content in the diet can make a difference in nutritional well being of persons consuming diets marginal in protein, if a rather low level of complementary protein is present to give a well balanced amino acid intake. Our major recent finding in this area was the discovery of a small number of closely related sorghum genotypes from Dr. Axtell's high-lysine breeding project that have markedly higher protein digestibility compared to normal types. Of these genotypes one parent (P 721Q) was originally developed from a chemically-induced mutation study. *In vitro* pepsin digestibility values for two highly digestible lines was 87 and 88% for uncooked flour and 81 and 78% for cooked flour. Normal vitreous sorghum (P 721N) was 78% digestible uncooked and 58% cooked, and a normal floury

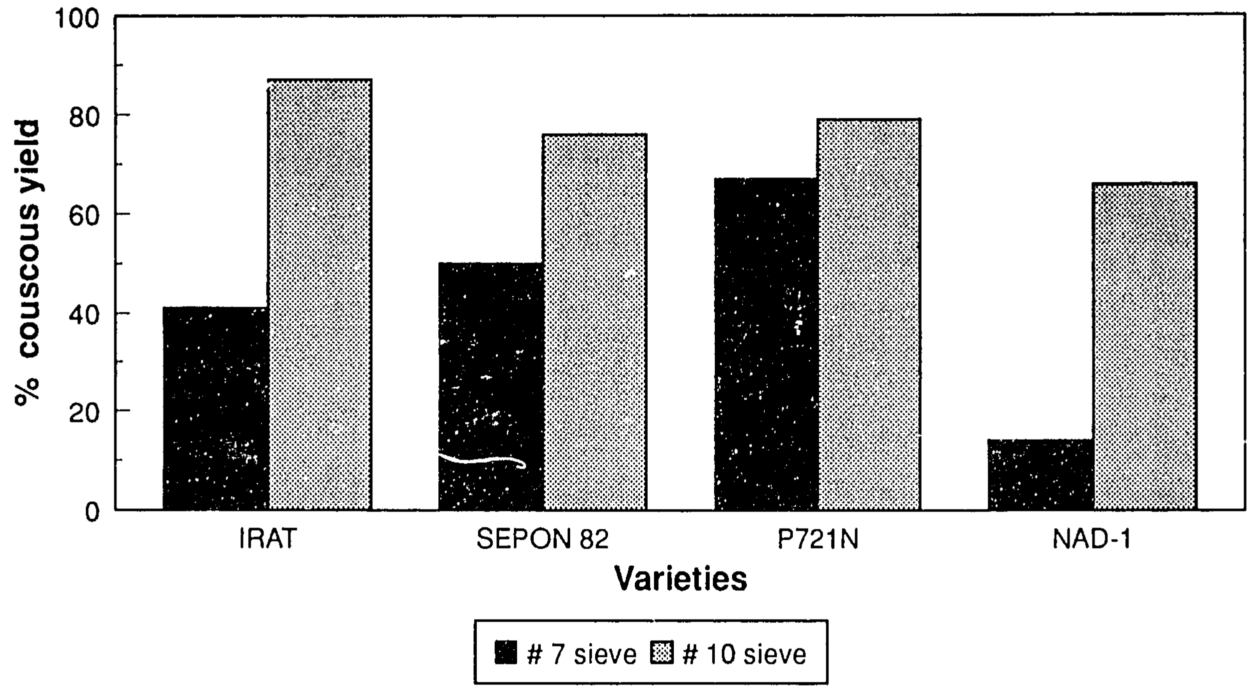

Figure 1. Couscous yield obtained using #7 and #10 sieves.

sorghum (SAFRA) was 66% digestible uncooked and 58% cooked. Digestibility of the highly digestible lines was higher than for maize protein and approximately the same as wheat protein digestibility. Using a three enzyme (trypsin, chymotrypsin, peptidase) pH-stat system rate of digestion, as indicated by titration of NaOH to maintain constant pH, was markedly higher for the highly digestible sorghum compared to normal (P 721N) (Figure 2). In less than 5 minutes the same number of peptide bonds were hydrolyzed in the highly digestible line as it took 60 minutes in the normal type. Scanning electron microscopy showed that the highly digestible sorghum had small, irregular shaped protein bodies compared to P 721N (not shown). They also had a pitted appearance. The highly digestible trait was shown to be consistent over two growing seasons and from plots at Purdue and Mexico.

We now know that the reason sorghum proteins are generally less digestible than other cereal proteins has to do with the highly disulfide-bound, relatively enzyme-resistant outer shell of its protein bodies. The major kafirin storage protein (α-kafirin), which is located inside the protein body, was found to be relatively easy to digest. Digestive enzymes must, then, first hydrolyze the outer γ-kafirin protein as well as a putative high molecular weight protein that we believe is bound at the protein body periphery. This latter protein was found to correlate inversely with *in vitro* digestibility of uncooked sorghum. Recently, this high molecular weight protein (approximately 100 kDa) was characterized by its N-terminal amino acid sequence and amino acid composition. A computer search of a data bank of known protein sequences is being done to match and identify this protein. Polyclonal antibodies have also been made in the rabbit against the high molecular weight protein in order to determine its location in the endosperm using immunocytochemical techniques and to develop an enzyme-linked immunosorbant assay (ELISA) to accurately quantitate this protein for a correlation study using a range of sorghum varieties with different digestibility. We believe this test may have potential as a screening method for the protein digestibility trait.

The highly digestible sorghum genotype mentioned above was shown, unlike normal sorghums, to have rapid enzymatic digestion of α-kafirin. A time course digestion was performed and the undigested proteins visualized by sodium dodecyl sulfate-polyacrylamide gel electrophoresis. Using the three enzyme system described above, α-kafirin was digested (at least one peptide bond hydrolyzed) within the first few minutes of incubation, while in normal sorghum a large quantity of α-kafirin remained even after 1 hour of digestion. It appears that α-kafirin, which makes up approximately 65% of the total protein in sorghum, is readily accessible, or exposed, to the digestive enzymes. This could have other implications beyond improving protein digestibility. α-Kafirin in these genotypes can also potentially interact with other proteins and constituents of the flour to improve functional properties, or food-making properties, of the sorghum. Flour functionality will be examined in normal and highly digestible genotypes in the 1994 crop.

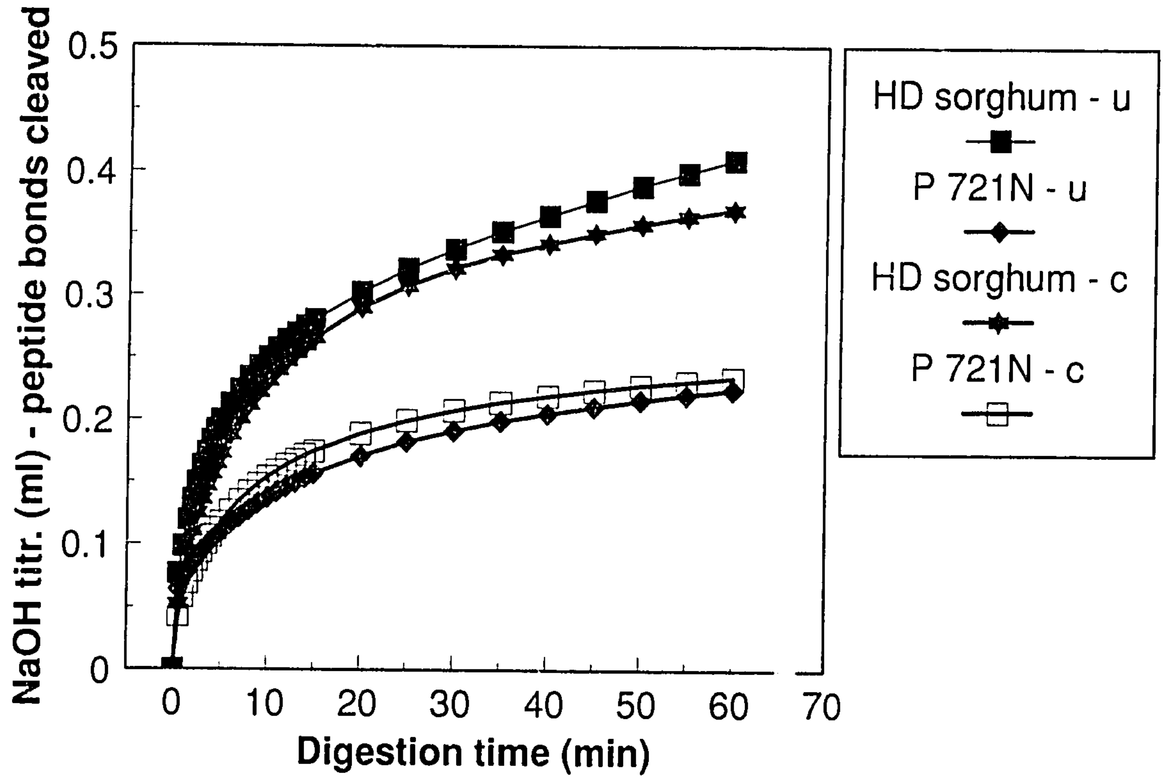

Figure 2. pH-Stat titration curve of highly digestible (HD) and normal sorghums.

Kafirin Synthesis and Crosslinking During Seed Development

α-, ß-, and γ-Kafirin contents were determined in developing sorghum seed using a rabbit-based ELISA developed in our laboratory to each of the kafirin proteins. The purpose of this study was to relate changes in synthesis and structure of the kafirins during development to observed changes in digestibility. It was also observed that formation of the vitreous endosperm occurred during later stages of development, and a study is now in progress to relate drydown, protein crosslinking, and endosperm vitreousness. Kernel hardness is an important grain trait relating to processability.

In mature sorghum α-kafirin made up approximately 67% of total kafirin, ß-kafirin 23%, and γ-kafirin 10%. α-Kafirin was found in 10 days after half bloom (DAHB) flour and content increased most notably between 20 and 30 DAHB. ß-Kafirin was first detected at 20 DAHB and reached maximum content by 40 DAHB. Similarly, γ-kafirin appeared at 20 DAHB and increased in content until 35 DAHB. Amount of kafirins calculated on a seed basis, rather than flour basis, showed synthesis was complete by 40 DAHB.

Up to 30 DAHB both uncooked and cooked protein digestibility was very high. Afterwards, digestibility decreased until maturity coinciding with seed drydown. Substantial disulfide crosslinking occurred in the γ-kafirin protein at 30 DAHB and at maturity nearly all of this protein was insoluble in a nonreducing solvent (one that does not cleave disulfide bonds). The increase in crosslinking was concomitant with a decrease in both uncooked and cooked digestibility. SDS-PAGE showed only one other small group of high molecular weight proteins (the principal protein mentioned above) that became insoluble due to disulfide crosslinking at late stages of development (after 30 DAHB). The majority of α- and ß-kafirin remained in a "non-crosslinked" or soluble form (in a nonreducing solvent) throughout development and seed maturity. This study further implicates γ-kafirin, as well as the high molecular weight proteins, as those proteins responsible for the resistance of sorghum protein bodies to digestion. It was not apparent from this study that any of the kafirins were preferentially synthesized at the time that coincided with the decrease in digestibility.

Kafirin and Non-Kafirin Contents in Sorghum

A new method for isolation of maize zein and non-zein proteins was modified and adapted for quantitation of sorghum kafirin and non-kafirin. Nearly all seed proteins were extracted in an alkali buffer (pH 10) containing 1% sodium dodecyl sulfate and 2% 2-mercaptoethanol. To the extract t-butanol was added to 60% total volume at which point the non-kafirin proteins precipitate and the kafirins remain in

Table 1. Comparison of kafirin contents using new and conventional quantitation methods, and non-kafirin contents of sorghum varieties.

Variety	Protein	Kafirin		Non-Kafirin
		New	Conventional	
	(g/100 g flour)	(g/100 g protein)		
Whole Grain				
P 721N	9.4	68.4	49.6	5.9
SRN 39	11.4	72.9	53.8	5.3
Sepon 82	10.5	68.3	49.0	7.8
SC283-14	10.3	68.1	54.7	14.6
P721Q	10.3	63.8	41.4	8.9
Endosperm				
P721N	8.5	80.1	66.0	6.1
SRN 39	10.4	77.1	59.6	5.9
Sepon 82	9.8	77.6	62.9	7.0
SC283-14	8.7	82.0	70.2	7.7
P721Q	9.0	72.4	52.3	10.3

solution. Kjeldahl nitrogen was analyzed on the two fractions. This separation was shown by SDS-PAGE to be devoid of cross-contaminants. In order to remove non-protein nitrogen from the kafirin fraction another extraction was made after the flour had been extracted with saline solution. Table 1 shows kafirin and non-kafirin contents using the new method compared to the conventional extraction method using aqueous alcohol (60% t-butanol) plus reducing agent (2-mercaptoethanol). True kafirin content, therefore, is substantially higher (12-22%) than values in the literature reported using the standard method.

Compared to maize prolamin (zein), sorghum had higher average prolamin (kafirin) content (approximately 10-14% higher) and lower non-prolamin content (11-19% lower). These new higher values for kafirin, and correspondingly lower values for non-kafirin, could help explain why sorghum grain behaves differently both in functional and nutritional aspects when compared to maize. Nutritional quality of grain protein is determined largely by the amount of non-kafirin (or non-zein) content since these proteins contain the lysine and tryptophan in the seed. Functional properties of the flour, which determine its versatility to make food products, also are influenced by the amount of non-prolamin proteins available to interact between themselves and other constituents of the flour. Since kafirins are encapsulated in protein bodies that remain intact during cooking they essentially are not functional proteins in terms of forming cohesive structures, gels, etc. Breeding for increased non-kafirin content may improve both of these grain properties.

Networking Activities

Research Investigator Exchange

Ms. Senayit Yetneberk (Head, Food Quality Laboratory, IAR, Addas Ababa, Ethiopia) spent six weeks in April-May 1994 in my laboratory training on chemical and physical techniques for sorghum quality evaluation. Funding was through a World Bank project at the IAR.

B.R. Hamaker visited INRAN, Niger October 16-20, 1993 to discuss ongoing projects with Moussa Oumarou (Head, Cereal Quality Laboratory) and to participate in the EEP Niger project evaluation. This was following a two week trip to Cameroon as part of a team to assess possibilities for a USAID project in food processing/marketing. International airfare was paid by SUSTAIN, a Washington-based NGO.

Attended and presented findings from the project at the Annual American Association of Cereal Chemists meeting in Miami, Florida; and the Annual Institute of Food Technologists meeting in Atlanta, Georgia.

Publications and Presentations

Journal Papers

Mohamed, A.A., B.R. Hamaker and A. Aboubacar. 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.

Hamaker, B.R., E.T. Mertz and J.D. Axtell. 1994. Effect of extrusion on sorghum kafirin solubility. Cereal Chem. In press.

Oria, M.P., B.R. Hamaker and J.M. Shull. 1994. *In vitro* protein digestibility of developing and mature sorghum grain in relation to α-, ß-, and γ-kafirin disulfide crosslinking. J. Cereal Sci. In press.

Abstracts of Presentations

Hamaker, B.R. and M.P. Oria. 1993. Potential relationship of a HMW protein to protein digestibility of sorghum. Cereal Foods World 38:624.

Oria, M.P., B.R. Hamaker and J.M. Shull. 1993. Resistance of sorghum α-, ß-, and γ-kafirins to pepsin digestion. Cereal Foods World 38:624.

Mohamed, A.A., B.R. Hamaker and A.W. Kirleis. 1994. Use of viscosity and soluble solids content of sorghum flour batter as indices of kisra quality. Institute of Food Technologists annual meeting, p. 109.

Oria, M.P. and B.R. Hamaker. 1994. Evidence for the role of a high-molecular-weight protein in lowering sorghum protein digestibility. Cereal Foods World, in press.

Weaver, C.A., B.R. Hamaker and C.P. Huang. 1994. Differences in rates of protein digestion due to kafirin-containing protein bodies. Cereal Foods World, in press.

Hamaker, B.R., J.M. Shull, and M.P. Oria. 1994. Digestibility of the major storage protein (α-kafirin) of *Sorghum bicolor* grain. Cereal Foods World, in press.

Utilization and Quality of Sorghum and Millet

Project TAM-126

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Summary

Sorghum varieties vary significantly in steam flaking properties, with waxy types producing consistently greater diameter, more durable, and excellent appearing flakes with improved *in vitro* digestibilities. The heterowaxy sorghums also had improved steam flaking properties, but were lower in quality than the waxy grains. The Texas Agricultural Experiment Station (TAES) has released two waxy female parents and are proposing the release of a tan plant, white waxy pollinator. Nonwaxy food-type sorghum hybrids produced flakes with excellent appearance. Significant differences in flake quality were not found among commercial red, cream and yellow hybrids. It is likely that differences exist but our techniques are not sensitive enough to detect them.

The cultivar significantly affected the rate of starch and endosperm modification during malting of sorghum. Waxy sorghum had greatest endosperm modification and most extensive loss of starch among intermediate texture sorghum cultivars, even though it had the lowest levels of amylase enzymes. Dorado produced malt with the highest level of α- and ß-amylases which confirms our previous studies.

Waxy sorghum has excellent properties for use in some food systems such as granolas, snacks and breakfast foods. The waxy endosperm property appears useful in sorghum malt and for grits used in production of lager beer because it breaks down more easily. However, waxy grain is not useful for tortillas, noodles, rice-like products and some porridges because it develops excessive stickyness.

Noodles can be made from 100% nonwaxy sorghum flour or endosperm fractions. They have dry-matter losses similar to rice noodles, but the cooking time and techniques must be carefully standardized.

Some commercial food-type hybrids that have white, tan plant grains have excellent processing properties and good yields. More of these hybrids were planted in 1994 by producers. Thus, it appears that several commercial seed companies have or will have food-type sorghum hybrids for sale to farmers very soon. This will lead to significant improvement in overall sorghum quality in the U.S.

Studies to determine the role of antifungal proteins in mold and weathering resistance of sorghum cultivars are underway. Sorghums have varying levels of antifungal proteins, but their effects on molds that cause deterioration in sorghum are unknown.

Changes in sorghum during malting, steam flaking and other processes continue to be documented with environmental and traditional scanning microscopy. The effect of various conditioning agents and enzymes on flake structure and digestibility of sorghum is economically significant.

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; and 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 significance 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, and processing properties. Various food and feed products were prepared to test the quality of the different grain samples. Some of these findings are summarized below.

Sorghum Malting Quality - 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 developing improved malting procedures and by selecting new sorghum cultivars with improved malting potential. We conducted studies to determine the effect of five different sorghum cultivars and germination times on the dry-matter losses, enzyme activities, extract levels, density changes and composition of malts. These cultivars represented the great diversity among sorghums.

Malts germinated for five days from 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 released for production in Honduras. The malt from Dorado, a white food sorghum grown in Central America, had the best overall enzyme levels. Malisor 84-7, a hard food sorghum developed in Mali, and the waxy sorghum malts had the greatest dry-matter losses and the lowest α- and ß-amylase activities. However, the changes in starch during malting was highest for the waxy malt. This suggests that the waxy endosperm is more rapidly hydrolyzed than the nonwaxy intermediate texture endosperm sorghums. The potential to develop waxy sorghums with improved malting properties appears to be promising because the endosperm would be rapidly modified which could decrease malting time and conversion time as well.

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. Dorado had the highest enzyme activities in this study and in two other studies we have conducted. It was released in El Salvador because of its excellent food properties, especially in tortillas. Thus it is possible to have sorghums with excellent food quality and desirable malting properties at the same time.

Sorghum Processing Quality for Food and Feed

Dry Milling Properties of Sorghum

Sorghum samples from several trials were analyzed and evaluated for milling characteristics. The new food-type sorghums consistently had equal or improved grain yields, improved milling yields, and the colors of the decorticated kernels were far superior to those of white sorghums with purple plant color (Table 1). These sorghum hybrids (Table 1) plus others were grown in drill strips in a farmer's field near St. Lawrence, Texas to demonstrate the potential of food-type sorghums. Three tan plant, white, food-type hybrids from two commercial hybrid seed companies were compared to commercial red, cream, and yellow hybrids. There was some weathering of the grains post maturity, so the white tan plant sorghums had a very significant improvement in appearance, which was also observed in the appearance of the raw milled kernels and cooked rice-like products. DeKalb hybrids (DK 77, DK Y388), Warner 902W, and ATx631 x RTx436 (TAES) had grain yields that ranked at the top of the test, which shows that the food-type hybrids are competitive with commercial feed sorghum hybrids. Warner 902W grain performed well in large commercial dry milling and brewing trials in Mexico in 1993. A field day to promote and evaluate food sorghum production and utilization has been planned by The Grain Sorghum Producers Association for September 1994 in the Lubbock, Texas area.

Steam Flaking of Sorghum

Research on steam flaking quality of sorghum sponsored in part by the Texas Sorghum Producers Board has shown that various sorghum hybrids respond differently to steam flaking. The feedlot industry is the major processor of sorghum in the world. Some feedlots pay a premium for white or yellow sorghum varieties because they flake more

Table 1. The quality of new commercial food sorghums compared to commercial hybrids[a]

Hybrid	Seed/ plant color	Appearance[a]	Grain yield (lb/ac)	1000 kernel weight (g)	Test weight (lb/bu)	Hardness[c] index	Density (g/cc)	Food quality rating[b]	Yield of decorticated grain (%)	Kernel color[d] (L)		
										Whole	Decorticated raw	cooked
Warner 632	Wh/P	4.5	2300	20.9	56	5.1	1.36	3	78.7	50.8	63.0	56.6
Warner 528	Wh/P	4.5	3575	22.6	58	4.8	1.35	4	79.0	54.6	62.3	57.8
Warner 902W	Wh/T	1.0	3750	22.1	57	4.1	1.37	2	81.3	54.4	63.9	61.2
DK 77	Wh/T	1.0	5350	23.3	58	4.2	1.37	1	80.7	54.6	65.2	65.8
DK Y388	Wh/T	1.5	4225	20.9	59	3.6	1.37	1	83.2	53.8	65.6	61.4
DK 39Y	Y/P	3.0	2450	21.7	55	4.9	1.35	5	84.0	45.2	62.9	58.7
DK 42Y	Y/P	3.5	3525	23.4	55	3.8	1.38	3	82.8	49.5	64.1	59.8
NK 714Y	Wh/P	4.0	2475	24.5	55	3.5	1.37	5	84.5	52.3	59.5	57.8
ATx631xRTx436	Wh/T	1.5	3685	26.7	53	4.0	1.37	2.5	83.3	54.0	64.0	61.8
ATx2752*RTx430	R/P	5.0	2980	27.3	54	4.8	1.37	5	77.6	33.5	55.8	49.6

[a] The sorghum hybrids were grown at St. Lawrence, Texas in drill strips in 1993. The means of three replicates are presented. Grain yield is a single observation.

[b] Evaluated on decorticated kernel.

[c] Hardness index was determined with a tangential abrasive decorticator device, softer grains have higher values. Values are the rate (% min) of weight loss during decortication.

[d] The Hunter color difference meter was used to measure lightness. High L values indicate lighter appearance. Cooked means the grits were cooked in water, blotted dry and color was measured.

Wh - white pericarp, P - purple plant color, Y - yellow endosperm, translucent pericarp, T - tan plant, R - red pericarp

Wh/T - food-type sorghums, Wh/P - cream sorghums, Y/P - yellow sorghums, R/P - red sorghums.

efficiently. The goal of the research conducted jointly by Texas Tech University and the Cereal Quality Lab is to evaluate differences in the steam flaking properties of sorghum hybrids. Several experiments were conducted at the Texas Tech University Burnett Feedlot Research Center near Lubbock, Texas to compare the performance of food-type, waxy, and heterowaxy sorghums with commercial red, cream and yellow sorghums. Sorghum hybrids were grown under irrigation near Halfway, Texas in a cooperative effort among plant breeders and others.

The Texas Tech experimental steam flaking unit was fitted with a sensitive power meter. All sorghums were processed in replicated trials using tempered and non-tempered grain. Reference grain samples were used to calibrate the equipment daily. 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 had slightly greater *in vitro* digestibilities than the other sorghum flakes. The results of our 1993-94 experiments confirm our conclusions made in 1992-93.

It is clear that the waxy and heterowaxy sorghums have improved flakes that would improve the performance of sorghum in livestock feeds. If the industry wants to improve sorghum processing properties, waxy sorghum will be a way to proceed. A new white, waxy male is being released from the TAES, and two female waxy sorghums have been released. The yields of waxy hybrids are not as high as those of nonwaxy hybrids; therefore, the most feasible way to utilize the waxy characteristic is to use heterowaxy hybrids which would have very competitive grain yields and agronomic characteristics. The grain sold by the farmer would have a mixture of waxy, nonwaxy and partially waxy kernels. We have found that heterowaxy grain processes better than comparable nonwaxy grains.

Tempering sorghum prior to steaming reduced energy consumption and produced flakes with significantly less breakage during handling. These observations confirm that tempering is absolutely necessary for proper evaluation of steam flaking properties of sorghum.

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 (Figure 1). The sulfurous acid has a marked effect on the pericarp of steamed grain, and significantly enhances flake quality. This shows that disruption of the proteins in sorghum has a major effect on steam flaking. These observations suggest that we may be able to find chemicals that significantly enhance the processing efficiency and digestibility of sorghum.

The steam flaking experiments conducted this past year clearly confirmed that sorghum hybrids have significant differences in their steam flaking properties. However, it is impossible to conduct sufficient experiments using the steam flaker because of time and sample size requirements. We have designed small-scale equipment for steaming and flaking 100 g samples of sorghum which can be used to determine the effect of various conditioning agents, chemi-

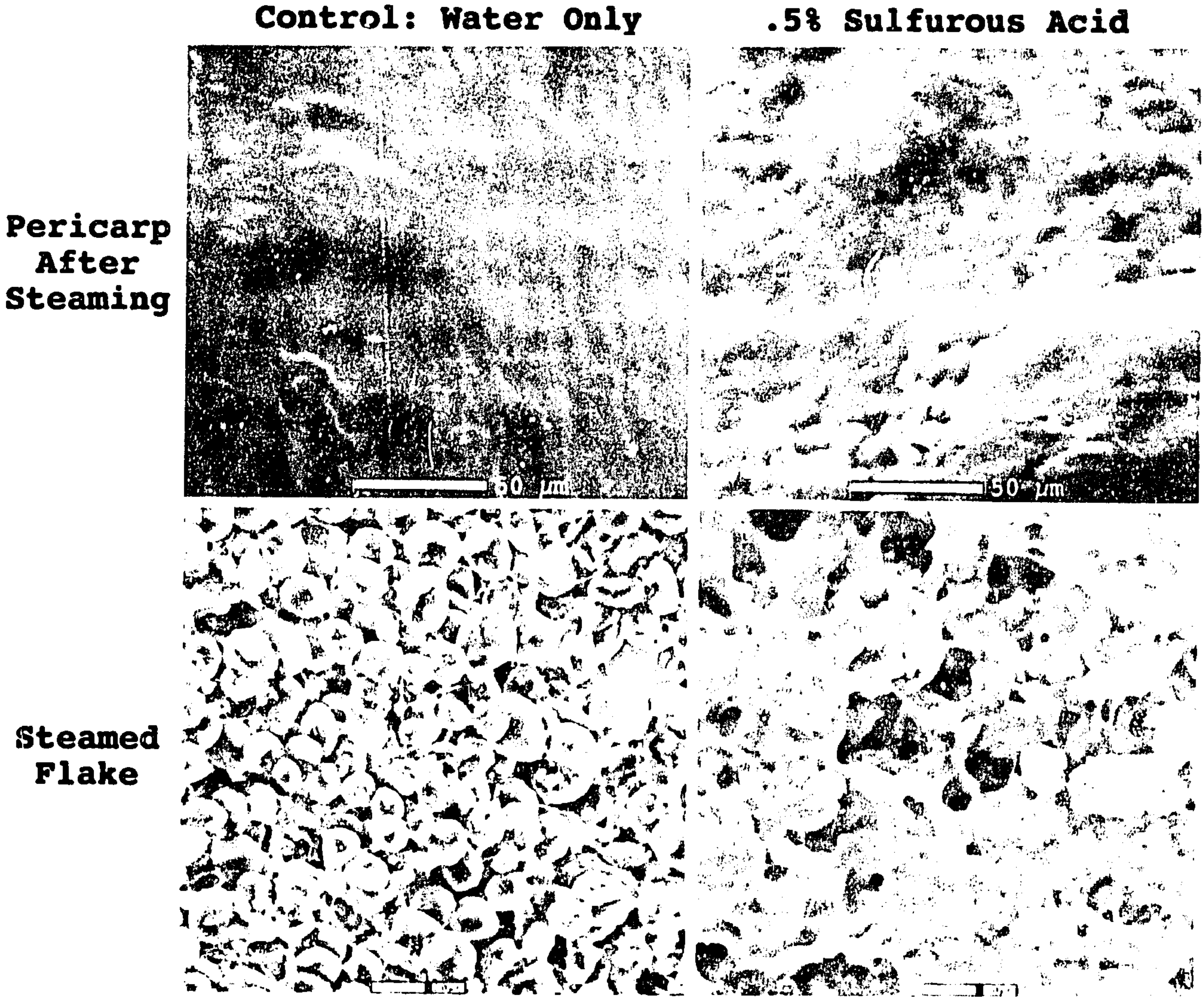

Figure 1. Environmental scanning electron micrographs of sorghum kernels treated with water and with water containing 0.5% sulfurous acid. The top photos show the structure of the flakes immediately after processing through the rollers.

cals, tempering and steaming times on moisture uptake, kernel structure and flake quality. Preliminary information suggests that this procedure can be used to study the critical factors affecting steam flaking and how they interact with different varieties.

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 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. These unusual 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 also has potential for commercial food products.

Noodles

Systems for the production of noodles from sorghum (100%) were 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 variety. In addition, sorghum with tan plant color and straw colored glumes were compared to those with purple plant color. The sorghums with an intermediate to hard endosperm texture and tan plant color had the highest milling yields, the lightest color flour and produced the best noodles. However, the soft sorghum produced unacceptable noodles. They were sticky and had poor color and high dry-matter losses during cooking. Sorghums with intermediate to hard endosperm texture produced non-sticky freshly extruded noodles with good handling properties. They produced relatively hard dried noodles which absorbed less water during cooking. They had dry-matter losses during cooking comparable to rice noodles and they were not sticky. 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 of Dorado, a white tan plant sorghum from Central America) had acceptable flavor and texture. The waxy sorghum flour produced sticky dough that could not be used for noodles. The P-721 sorghum produced noodles that were off-color because of the purple pigments. A taste panel composed of people who were used to consuming wheat noodles still liked the sorghum noodles, even though their texture was different from wheat noodles. Thus, sorghum could be used to produce desirable noodles at a relatively low cost; however the variety of sorghum is critically important.

JOWAR Crunch

Traditional alkaline-cooking was modified to produce a new snack prepared from special food-type sorghums called JOWAR. The JOWAR (Dorado) was boiled (96°C, for 30 and 60 minutes) or autoclaved (120°C for 30 and 60 minutes) 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, shelf-stable, and thus could be fried to produce JOWAR crunch.

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 prepared by autoclaving had similar yields and were more gelatinized when compared to those prepared by boiling. Pellets with low moisture expanded more and produced low-oil snacks. Pellets with higher moisture contents (≥ 8%) yielded acceptable products when fried at 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 minutes 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.

Grain Molds - Screening Antifungal Proteins in Sorghums

Preliminary Results

Sorghum grain molding is a common problem resulting in substantial losses in yield and quality. Several agronomic, physiological and biochemical characteristics of the grain have been identified that correlate positively with resistance to molding. A recent development is the identification of antifungal proteins in sorghum. Sorghum caryopses contain different kinds of fungal inhibiting proteins, such as chitinases, β-1,3 glucanases, ribosome inhibiting proteins and a new group of proteins called sormatin.

We have continued to evaluate the potential of different antifungal proteins on grain molds and weathering of sorghum. The presence and levels of sormatin and chitinase in sorghums with varying degrees of mold resistance at different stages of maturity were investigated. Samples were analyzed for differences in levels of these proteins among cultivars from anthesis to maturity and during germination.

Differences in Cultivars

More than 20 cultivars were screened for sormatin and chitinases. One major protein cross-reacted with sormatin (~22 kDa) and 2 major proteins cross-reacted with chitinase (~29 and 35 kDa). Differences were observed in the levels of sormatin and chitinase between sorghum cultivars. More significant differences were observed in the levels of chitinases than sormatin. Work is underway to correlate these observations with the extent of molding occurring in the field.

Changes During Maturity

Sorghums sampled at 12, 22 and 32 days after anthesis were screened for sormatin and chitinases. Sormatin concentration increased with maturity in most cultivars. Several proteins cross-reacted with chitinase. However, differences were noticeable in the 29 and 35 kDa bands. Changes in chitinases during maturity were more variable; the proteins increased with maturity in some cultivars, while the levels peaked 22 days after anthesis in other cultivars.

Changes During Germination

Significant differences in concentration were observed in sormatin and chitinase during germination. Sormatin concentration decreased following steeping and then increased over five days of germination. Small concentrations of sormatin were also observed in the shoots. The 29 kDa chitinase decreased during steeping and then increased between two to three days of germination. Small amounts of this protein were also observed in the shoots. The 35 kDa chitinase increased during five days of germination. Large amounts of 35 kDa chitinase were observed in shoots. Changes in levels of antifungal proteins during germination and the presence of these proteins in the shoots are hypothesized to play a protective role during seed germination.

Location and Leaching

Sormatin and chitinase were observed in both the decorticated grain and pericarp tissues. Amounts of these proteins in the pericarp and endosperm tissues varied between different cultivars.

Whole seeds were surface sterilized with alcohol, soaked in water for 24 hours and assayed for sormatin and chitinase. Sormatin and chitinase (29 and 35 kDa) in the seeds decreased following soaking. Sormatin (22 kDa) was not observed in the leachate; however, cross-reacting proteins at 29 and 35 kDa were observed. Chitinase (29 and 35 kDa) was observed in the leachate. Sormatin and chitinase were distributed throughout the sorghum caryopsis (endosperm and pericarp) and appear to have the ability to migrate within the structure of the caryopsis.

Although these proteins have *in-vitro* antifungal activities against a few species of fungi, their effect and role in sorghum grain molding is unknown. Work is underway to correlate these observations with the molding ability of sorghums in the field. Work is also underway to test the activity of these proteins against specific grain molding fungi and to correlate the presence of several of these antifungal proteins in caryopses to their resistance or susceptibility to molding.

Collaborative Sorghum Improvement Research

This project cooperates closely with other members of the sorghum program to incorporate the best quality characteristics into new cultivars. 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 nixtamalization. The alkaline cooking tests are especially sensitive and pick up off-colors easily.

From this research, Texas A&M has released several inbreds that produce white, tan-plant sorghum hybrids with excellent food and feed processing quality. For example, recent work in Mexico has confirmed that the new food sorghums had significantly higher yields of grits compared to 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 after maturation. However, these sorghums need more resistance to molds and weathering to be grown in the hot humid areas of the world.

Networking

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 has undergone significant changes in personnel and needs additional assistance to achieve its objectives. New personnel will need training. Plans to provide short-term assistance are developing. Increased emphasis on developing improved local sorghums with photosensitivity, and 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 traveled to Honduras to work with Dr. F. Gomez, Pan American School, Zamorano, on food quality of sorghum and maize samples from the breeding program. Samples were selected for further evaluation at Texas A&M University.

Dr. H.D. Almeida-Dominguez, Institute of Technology of Merida, 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 two weeks conducting analyses on sorghum malt in the Cereal Quality laboratory. Some chemicals and equipment have been sent to Merida.

Cooperation with the University of Sonora continues, with publication of papers resulting from our previous research.

L.W. Rooney has a cooperative project with Dr. S. Serna-Saldivar, Professor, Food Science, Instituto Tecnologico y de Estudios Superiores de Monterrey (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 is conducting brewing trials on grits from white food-type sorghums. Results are promising.

Dr. Sema-Saldivar and three ITESM M.S. students conducted sorghum and maize analyses for two weeks in the cereal quality lab.

North America

Several papers were presented at the annual American Association of Cereal Chemists conference in Miami, Florida 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.

Training

Five M.S. students completed their studies and returned to Mexico, Mozambique and Zimbabwe. Two U.S. students completed degrees and initiated careers in the food industry. Ms. Senayit Yetneberk, Food Scientist, from the Ethiopian Agricultural Research Institute, Nazaret spent seven weeks learning to conduct analysis on sorghum and maize. She processed the grains into tortillas, snacks, and ready-to-eat breakfast foods. She left with a good understanding of cereal technology and quality procedures that might be useful in Ethiopia. The use of maize and sorghum in Mexican foods was of special interest to her. She produced both maize and sorghum tortillas and chips.

L.W. Rooney currently serves as chairman of the Sorghum and Millet Working Group of the International Association for Cereal Science and Technology.

Publications and Presentations

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Almeida-Dominguez, H.D. and L.W. Rooney. 1993. Properties of diastatic sorghum malt. 1993 IFT Annual Meeting, Chicago, IL, July 10-14.

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Beta, Trust. December 1993. The malting properties of different sorghum cultivars. M.S. Thesis. Texas A&M University, College Station, Texas. 99 pp.

Cruz y Celis, Laura. December 1993. Ready-to-eat breakfast cereals from food-grade sorghums. M.S. Thesis. Texas A&M University, College Station, Texas. 97 pp.

Lekalake, Rosemary. August 1993. Factors affecting the cooking and extrusion properties of sorghum for noodle production. M.S. Thesis. Texas A&M University, College Station, Texas. 97 pp.

Abstracts

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Beta, T., L.W. Rooney and R.D. Waniska. 1993. Malting characteristics of sorghum varieties. AACC Meeting, Miami. October 3-7. Cereal Foods World 38(8):594.

Floyd, C.D., L.W. Rooney and R.D. Waniska. 1993. Modification of carbohydrates in sorghum during malting. AACC Meeting, Miami October 3-7, 1993. Cereal Foods World 38(8):594.

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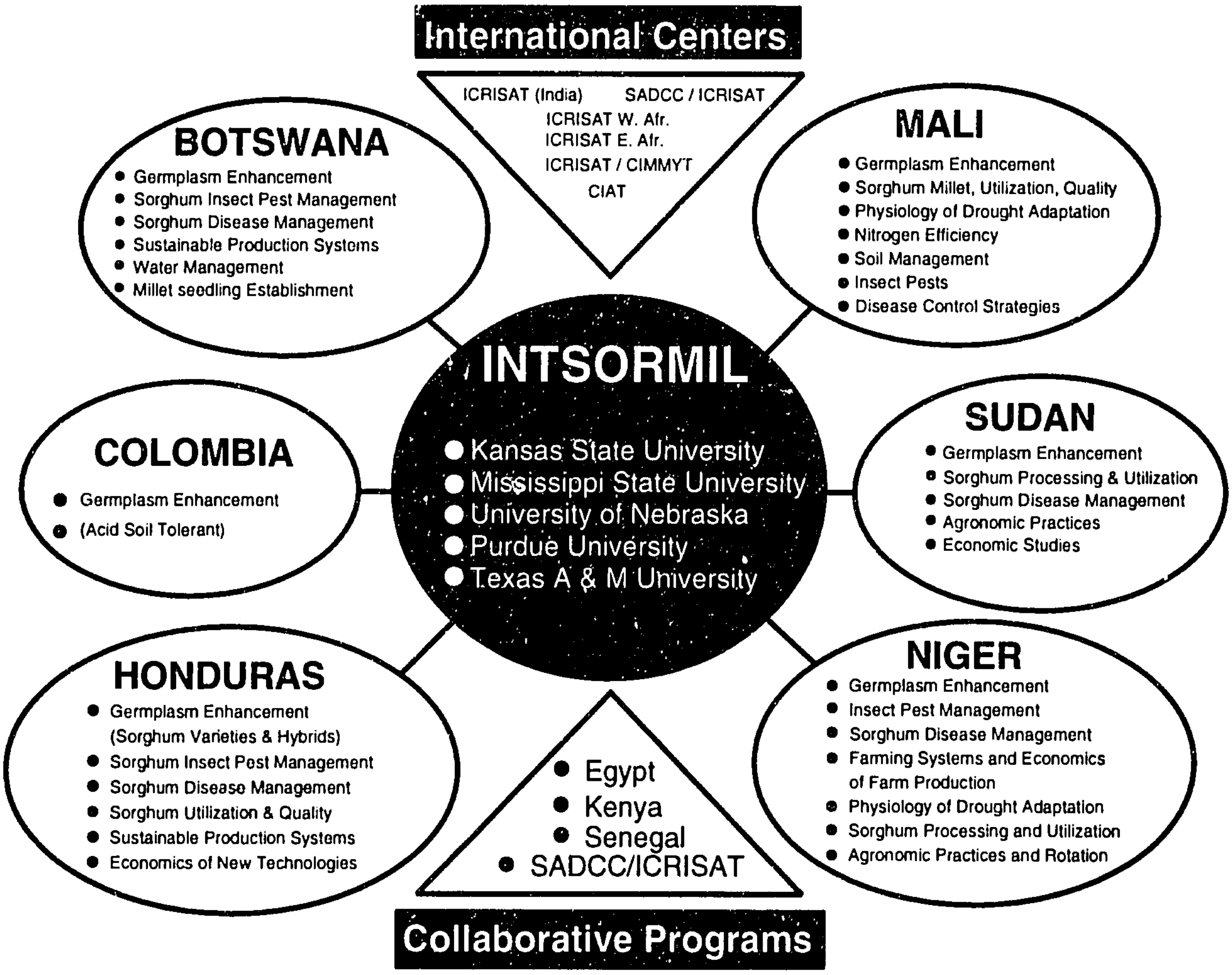
INTSORMIL Collaborative Sites



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Ali Zein, Agricultural Research Center, Giza, Egypt
Thanaa Fahmy Ibrahim, Agricultural Research Center, Giza, Egypt
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The Egypt/INTSORMIL program consists of research efforts within two groups in the Agricultural Research Center (ARC). The plant pathology research group in the MSSCFC Section of the Plant Pathology Institute and the sorghum research section of the Field Crops Research Institute of ARC.

Plant Pathology

Dr. Thanaa Fahmy Ibrahim, Dr. Tawfic Abdel-Moity and Mr. Abu-Serie Ismael participated in short-term training in the Plant Pathology Department of Kansas State University during the spring semester of 1994. Dr. Ibrahim focused on classical microbiology of bacterial pathogens of sorghum. Dr. Abdel-Moity studied parameters that are involved in the use of nontoxin-producing *Fusarium* species as biological controls in sorghum. Mr. Abu-Serie Ismael conducted experiments with SDS polyacrylamide gel and agarose gel electrophoresis of proteins and DNA to determine differences between Egyptian and U.S. isolates of *Pseudomonas andropogonis*. These data were to be incorporated into Mr. Ismael's Ph.D. thesis.

Work focused on the characterization of *Fusarium* populations from Egypt and comparing these populations with those from other locations. Egyptian *Fusarium* populations from sorghum appear to be dominated by members of the D mating population (*Fusarium proliferatum)* instead of the F mating population *(Fusarium proliferatum)* as is common in the United States and Tanzania. The reasons for this difference in population composition are unknown. Members of the D mating population are known to make gibberellic acid and may be responsible for the pokkah boeng disease symptoms that we have commonly observed on Egyptian sorghum. Some members of the D mating population are known to synthesize moniliformin and fumonisin mycotoxins, and, thus, may pose a hazard to humans and animals that consume sorghum grain and/or sorghum forage.

Sorghum Agronomy

Production experiments have dealt with the effects of different water and nitrogen levels and the water x nitrogen level interactions in order to optimize water use efficiency (WUE) and nutrient use efficiency (NUE). Water and N level effects at modest input levels are almost additive. Experimentation approach and set ups are now geared up and need several years operation in a range of the "New Lands" marginal areas to come up with the best guidelines to stretch Nile water supplies and minimize N imports. Drs. Bashir and Kamal have a good start on this. Nubaria needs to be developed along with irrigation equipment for other sites.

Sorghum breeding faces challenges to tailor germplasm to the expanding marginal land areas and boost production. A good percentage of the germplasm used there is like Giza 15 and some locals which fit their conditions quite well in the traditional sorghum areas. The germplasm base related to these is probably fairly narrow and breeders are involved in widening the base. One hopefully useful approach was started last year by applying pollen from Giza 15 and many locals to sterile heads in a Nebraska midseason stress resistant tan plant population to develop a new Egypt adapted randomly mating population. Such a population should provide an easy means to incorporate new germplasm sources into a breeder working pool to be used in conjunction with conventional breeding approaches.

Mr. Mohamed Hovny, from the Shandoweel station, spent two years in Nebraska and returned in August 1994 to resume stress related research duties. We appreciated having him with us for two years and are confident he will be an effective researcher. We look forward to interacting with him on stress problems, with emphasis on stress during grain fill, and large seed size which is preferred in the market in many developing countries.

Substantial equipment investments have been made in Egypt from in country funds and over $25,000 from Nebraska projects. Both people and equipment resources have been brought to a good production potential for sound continuation research.

Honduras and Central America

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Summary

The INTSORMIL Sorghum Project in, "Tropical Sorghum Conservation and Enhancement in Honduras and Central America," has operated in Honduras since October 1981. Its overall objective is to improve the quality of life of farm families in Honduras that produce sorghum. This is accomplish through *in-situ* conservation and enhancement of local landrace sorghum populations and the development and promotion of advanced technology intended to shift sorghum production from a tradition-led enterprise to a science-based industry. The transfer of new sorghum technology is accomplished primarily through on-farm demonstrations and publications of research results and educational materials.

In situ conservation of maicillo is continuing by deploying elite alleles bred in two enhanced maicillos. On-farm demonstration plots showed that by controlling the "longosta" insect complex and by applying k ha^{-1} of nitrogen at floral differentiation, yields can be doubled when growing the enhanced maicillos. It was also evident that to use the yield potential bred into these enhanced maicillos soil conservation structures would be needed. Both cultivars are ready for release in 1995.

Two broomcorn varieties IS11 and Acme, completed their on-farm evaluation cycles showing outstanding fiber yield and quality. A sustained quality fiber supply, in conjunction with economic information, seed availability and technical support, will directly impact the national economies of Honduras and Nicaragua, through an increase in broom manufacturing, job creation–especially for women, and export earnings. Both varieties have excellent resistance to pathotype 5 of *Peronosclerospora sorghi* (Weston and Uppal). These cultivars will be available shortly to farmers upon official release.

Final field evaluation of the hybrid ATx626 x R8503 was also completed and is ready for official release. An EAP student completed his thesis on "Nicking of ATx626 & R8503, and ATx623 & Tx2784," a thesis problem oriented to foster seed production over a range of different environmental and management conditions. This information is

critical to the CITESGRAN/Agronomy in order to sell seed of the parental lines to producers and recommend simultaneous planting and appropriate management practices to offset nicking differences.

Project Title

Tropical Sorghum Conservation and Enhancement in Honduras and Central America

Objectives, Production and Utilization Constraints

Objectives

- Determine acceptance of two broomcorn cultivars by the broom industry in Honduras and Nicaragua.
- Summarize information for the release of two broomcorn varieties, two enhanced maicillos and one grain sorghum hybrid.
- Conduct maicillo research including breeding nurseries, advanced yield tests and on-farm demonstration trials with new maicillo technologies in southern Honduras.
- Publish the results of grain sorghum performance trials.
- Conduct the sorghum downy mildew nurseries at Comayagua.

Constraints

Sorghum is grown on about 356,000 ha in Central America (UPSA, 1994). This region has undergone a net increase of some 19,000 ha in the time period of 1988-1992, with Guatemala adding 7,000 ha, El Salvador 29,000 ha, Honduras 34,000 ha and Costa Rica reducing production to practically nothing. The two largest producers of sorghum are El Salvador (150,000 ha) and Honduras (93,000 ha).

Conservation and Evaluation of Maicillo Diversity

'Maicillo Criollo' is the local name for tropical landrace sorghum populations found in semi-arid regions of Central America which range along the Pacific side of the isthmus from southeastern Guatemala through El Salvador and southern Honduras, south to Lake Nicaragua. Maicillo is the last remnant of tall, photoperiod sensitive sorghum landraces brought to the new world and for the most part is an unexplored gene pool that covers some 235,000 ha or 67% of the sorghum acreage in Central America. Although maicillo is of African descent, it possesses unique traits for adaptation to traditional maize intercropping systems and local food processing customs. These changes have come about through allopatric differentiation and artificial selection by small farmers in Central American. As the need to boost sorghum productivity increases in Central America, maicillo is slowly being replaced by higher yielding but uniform sorghum cultivars like 'Sureño.' This process not only threatens the extinction of many undiscovered useful genes, but increases the probability of an epidemic occurring.

Low Yield Potential

National sorghum yield in Honduras has increased from less than one metric ton per hectare to 1.1 metric ton per hectare in the last 5-year period. Not only is this a reflection of the adverse environment in which sorghum is grown, but it is also a result of the preponderant use of landrace sorghum populations which have low but stable yields. The inability of maicillo criollo to respond to management practices with increased grain yield is the primary constraint to sorghum production. Before new technologies like soil and water conservation interventions can improve soil fertility and become economically feasible, the genetic potential of traditional cultivars to respond with increased grain production must be enhanced. Increase in sorghum yield and area is primarily due to the utilization of commercial cultivars (hybrids and varieties), which are boosting sorghum production in Central America.

Traditional Farming Systems

Maicillo is an old world crop that has adapted to neotropical slash and burn agroecosystems. More than 90 percent of the sorghum planted in Honduras and El Salvador is late maturing landrace populations which are intercropped with early maturing maize. Although maize is the preferred staple, it is often intercropped with sorghum by subsistence farmers in hot, erratic rainfall areas as a hedge against drought. Maicillo's sensitivity to photoperiod and its ability to withstand shading are essential for its adaptation to traditional maize intercropping systems. In contrast, introduced cultivars require genetic modification before they can be used in these systems. Study of sorghum-maize intercropping systems is necessary to develop an understanding of how they work and what agronomic and genetic changes will increase their productivity.

Photoperiod Sensitivity

Maicillo Criollo has an acute sensitivity to photoperiod and day lengths of 12 hours or less are required for floral initiation. In Honduras, floral initiation occurs during the first fortnight of October regardless of spring planting date. Because of maicillo's short day requirement, it fails to flower before the first frost in the United States. Consequently, its improvement must be carried out within its adaptation domain in the Tropics (12-15 N lat.).

Insect Pests

An early season lepidopterous pest complex, called the langosta by Honduran farmers, is an important constraint to sorghum and maize production in the region. The fall armyworm, along with other lepidopterous larvae—*S. eridania, Metaponpneumata rogenhoferi,* and *Mocis latipes*—wreak havoc each spring by chaotically attacking seedling fields with little or no warning. Understanding the complex, its species diversity, density, time of occurrence, and origin, is necessary to develop an adequate control strategy.

Sorghum Downy Mildew

Sorghum Downy Mildew (SDM) is a recently introduced disease that is endemic in the region. Not only is maicillo susceptible to SDM, but the threat of this disease is compounded by the existence of the most virulent pathotype, P5, of *Peronosclerospora sorghi* reported in the Americas which was discovered at the 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. The introduction and deployment of resistant genes offer the best alternative for control.

Anthracnose

Anthracnose posses a major disease threat in Honduras and probably throughout Central America; therefore, a program to increase the level of resistance to sorghum is urgently needed. Deployment of a susceptible hybrid in the Olancho area, for example, can be devastating. Consequently, the anthracnose reaction of all commercial hybrids needs to be obtained, if for no other reason, than to avoid the growing of an otherwise excellent hybrid that may have a susceptible reaction to anthracnose. The maicillo sorghums have not been systematically evaluated for their reaction to *Colletotricum graminicola*, the pathogen causing anthracnose. This needs to be done, but it has a lower priority than the evaluation of commercial hybrids because the extent of anthracnose damage in traditional farming systems is much less. Concurrently, a program on the extent of pathogen variability, similar to what was done for the downy mildew pathogen, needs to be developed for Honduras. Aspects of this program should include the evaluation of isolates from other countries in Central America.

Leaf Blight

Even though leaf blight is not a wide spread disease, it has the potential to cause significant losses at higher altitudes. There have been some trends that indicate a slow but steady increase in leaf blight susceptibility, specifically in Tx623, Tx626 and some commercial hybrids.

Seed Availability of Broomcorn Cultivars

Broomcorn fiber is either imported from Mexico by two or three companies in Central America, or produced by small farmers using seed removed from the imported fiber. The result is an increase in the value of export and poor fiber quality produced by small farmers. A constant seed supply of appropriate broomcorn cultivars offers an alternative to foster the broom industry.

Networking

The Latin American Commission for Sorghum Research (CLAIS), initially supported by ICRISAT, has significantly reduced its coordination role in the area. Central American research and extension systems are being reorganized to include more participation of the private research and extension systems. New scientific and technical personnel are being hired that will benefit from CLAIS coordination and technical assistance. INTSORMIL remains the only source of technical collaboration with NARS in the region.

Research Approach and Project Output

The Honduran sorghum program is a small program consisting of a national coordinator, three Ingeniero Agronomos, and a secretary. In spite of its size, the program has been very productive. Much of its success stems from the continuity and stability provided by the union of its three composite institutions—INTSORMIL, MNR, and EAP—and extensive collaboration with other sorghum researchers. Beginning July 1, 1993, Dr. Gómez is in charge of the INTSORMIL project for the Honduras/Central America prime site, after Dr. Meckenstock, a long-term technical advisor was retired from the EAP. The daily collaboration between Dr. Gómez and Dr. Meckenstock for more than twelve years, has been instrumental in the success of the program. The program has established an elaborate network of collaborators in Honduras that includes both GOH and PVOs. At present, four sites are used to evaluate commercial hybrid performance and are also utilized to screen maicillo breeding materials for an array of biotic and abiotic stress factors. Numerous other collaborators and sites are used to validate new sorghum cultivars and other technologies on-farm. Multi-location testing is essential for developing cultivars with broad adaptation and resistance to multiple diseases. Commercial installations are used to determine the fiber quality of broomcorns.

Two technical thrusts that this Project initiated are conservation of local landrace sorghum populations and their enhancement. Both thrusts deal with maicillo or photoperiod sensitive sorghum and the success of one depends upon the other. Our approach to conservation is a passive, *in-situ* approach, whereas enhancement is an active, more aggressive approach.

Conservation

The success of all breeding programs depends on available genetic resources. When working with unique cropping systems, such as sorghum-maize intercropping, it is essential to have access to germplasm that is adapted to these peculiar conditions. Central America accommodates an array of such genetic resources that is cared for in a gene pool that spans some 235,000 ha. Our objective is to continue to conserve, even enhance, this genetic diversity *in-situ* where it will continue to evolve and serve man.

Replacement of maicillo by exotic photoperiod insensitive germplasm represents a threat to genetic diversity, and to the maize-maicillo intercropping system used by small farmers in the semi-arid regions of Central America. Our approach strives to conserve maicillo *in-situ* and is relevant to areas where landrace populations dominate traditional farming systems. Its success hinges on our ability to upgrade local landraces populations that are then returned to farmers' fields.

Our sorghum project has assumed the responsibility for conserving this sorghum gene pool. The goal of our conservation effort is to create a mosaic of maicillo, enhanced maicillo, and improved variety fields in which genes flow freely among these different kinds of sorghum. Ostensibly, an informal network of village level landrace custodians will care for this germplasm as they have cared for maicillo. The creation of enhanced maicillo cultivars and their subsequent deployment on-farm, not only is intended to increase genetic diversity *in-situ*, but to stave off maicillo's replacement by introduced cultivars.

A long term program was initiated in 1981 to genetically enhance and reduce genetic erosion in the maicillo germplasm, through a systematic deployment of enhanced maicillo cultivars as vectors of elite exotic alleles. Deploying these elite alleles for yield, quality and resistance to biotic stresses among maicillo populations are the first steps in conserving the adaptative gene pool of maicillo. Quantification of the degree of fixation of the exotic elite alleles deployed in previous years, will help us to determine threshold levels for the survival of elite maicillo alleles. First enhanced maicillos were first tested on farmers' fields in 1987.

In situ conservation of maicillo germplasm has contributed several useful traits to sorghum world gene banks. In addition, there is some indirect evidence that different alleles at the Ma_1 locus–responsible for the acute photosensitivity response are present in the maicillo populations. Although the value of these genes is still not known, they are genetic resources that would have been lost had we disregarded maicillo. These traits were found through a team effort forged by the INTSORMIL scientist network.

Enhancement

Our enhancement work is based on a set of short-, mid-, and long-term goals. Each time frame is concerned with a different kind of sorghum. Short-term goals deal with the introduction and release of elite cultivars, whereas mid-term goals deal with the development of enhanced maicillo varieties. Long-term goals concentrate on developing maicillo hybrids.

Introductions

Previous near-term goals have been met with the introduction and release of three food type cultivars: 'Tortillero', hybrid 'Catracho', 'Sureño' and a sorghum-sudangrass forage hybrid 'Ganadero' (ATx623*Tx2784). Our present short-term goals are to round out our sorghum portfolio with the release of a red seeded grain sorghum hybrid (ATx626*R8503), and two broomcorn varieties. This next generation of releases reflects a change in our attitude towards development which is shifting from self-sufficiency to self-reliance.

The final field evaluation of the hybrid ATx626 x R8503 was also completed for official release. Mr. Porfirio Lobo, an Ingeniero Agrónomo candidate completed his thesis on "Nicking of ATx626 & R8503, and ATx623 & Tx2784," a thesis problem oriented to foster seed production over a range of different environmental and management conditions. His results confirmed a perfect nicking of both parental lines (71 d). This information is critical to the CITESGRAN/Agronomy in order to sell seed of the parental lines to producers and recommend simultaneous planting and appropriate management practices to offset nicking differences.

Broomcorn

The USAID office in Honduras estimates that broomcorn industry can generate about one-million dollars. Two broomcorn cultivars were named ZAMES-1 y ZAMES-2 for release purposes. In addition to these two improved cultivars, information on management practices as well as economic information is being generated to increase production efficiency. This industry is capable of producing a significant number of jobs for women in rural areas, and generate export earnings.

Broomcorn research is conducted on-farm in Honduras and Nicaragua. Fiber produced at the experimental level is brought to the broomcorn factories–both, industrial and family enterprises. Fiber quality is classified and brooms are made to complete the evaluation. Consulting is done by regular visits to broomcorn fields. This relationship makes the sorghum project a leader in broomcorn research in Central América. EAP is producing foundation seed of both cultivars to supply individual producers.

During 1994, the Sorghum Project provided technical assistance to two broomcorn producers, one in Nicaragua and the other in Honduras. Ing. Adolfo Montiel, a Nicaraguan who runs a low technology commercial broom factory, that supplies the Nicaraguan market wanted to expand to other Central American Countries. Early that year, we planted on his farm demonstration plots several broomcorn cultivars. He selected one of our varieties and harvested all the seed he could and distributed it to 250 small farmers that together planted about 140 ha. Farmers planted around eight pounds of seed per hectare and produced 190,000 pounds of fiber, which was sold almost entirely to Ing. Montiel at a market price of $0.20 per pound ($38,000). This young entrepreneur is linking several NGOs operating in Nicaragua and funded by several European governments, including the Danish, Dutch and Finish governments. He has already started to export brooms to Panama at a higher price than prices obtained in Nicaragua. His own words to describe this collaboration is "Exito Total" (total success). In addition, he is already asking for seed to plant 700 ha for 1995 with new small farmers.

Early in 1994, a religious NGO "Polígono Industrial Copaneco" funded by the Belgium and Canadian governments, contacted us to inquire about the possibility of providing technical advice on the establishment of a broomcorn factory. We initially planted on-farm demonstration plots of the varieties we are releasing to show the management practices on how to maximize yield and quality. Meanwhile, they started lobbying for funds and finally obtained a grant of $250,000 for the broom factory and loofah production.

Fiber length of our two varieties is shorter than the required by the industry, but is long enough for the low technology broom enterprises. There is a need to develop a long fiber broomcorn, which will increase acceptability by the industry in general.

Enhanced Maicillo Varieties

Development of enhanced maicillo varieties or photoperiod sensitive sorghum dominates our mid-term goals. This activity is the crux of our conservation effort because it creates the plant vectors that will further the introgression of new genes into the maicillo population *in-situ*, while simultaneously improving crop yields.

Specific maicillo breeding objectives are: 1) reduce plant height that in effect, shifts the stem to panicle sink ratio in favor of producing more grain; 2) add tan plant color which reduces the amount of polyphenols in the pericarp and thereby improves grain quality for making tortillas; 3) increase resistance to foliar diseases like rust and Cercospora which enhances forage quality as well as grain yield; 4) incorporate resistance to sorghum downy mildew which is endemic in the region and threatens stable maicillo production; 5) select for longer panicles and better head exertion which augments yield through increased seed number; and 6) maintain several important maicillo characteristics such as maturity, white seed color (w/o testa), and shade tolerance. Other characteristics that have carried over from maicillo, but that we have not directly selected for, are resistance to anthracnose and an increased level of soluble carbohydrates (Brix) in the stem. Because photoperiod sensitivity is maintained in enhanced maicillo cultivars, this work can only be done in the region.

We use the pedigree breeding method to develop our materials because it allows us to concentrate on specific traits and because maicillo generally has good combining ability. As the enhanced maicillo lines progress through the system, F_2 and F_3 selections are made to stabilize desirable height, maturity, pericarp color, and plant color traits. Because we use three locations to screen this material, we also select for drought stress and shade tolerance at RAPACO, resistance to sorghum downy mildew at Comayagua, and resistance to foliar diseases at Choluteca and Olancho. As superior lines are identified in more advanced generations, F_5-F_7 are placed in our International Improved Maicillo Yield Trial (EIME). This is a multilocation yield test, referred to as EIME in Spanish, used to select materials for on-farm demonstration plots. The 1993 EIME consisted of 36 entries and was planted at four locations in Honduras Choluteca, Comayagua, RAPACO, and Zamorano (Table 1).

Since 1990, enhanced maicillo hybrids have represented about half of the entries in the EIME. Two general conclusions can be made about the performance of this test: 1) maicillo hybrids have consistently out yielded varieties, and 2) some progress has been made by including new enhanced maicillo lines which, in addition to have an outstanding grain quality, outyielded DMV197 in several environments. New entries in 1993 such us (Sureño*Caturra 68)-3-3-2-1 and [(SEPON77*Sta. Isabel) ICSV 151]-derivatives, showed promising characteristics to be tested on farms. The maicillo hybrid (entry 16) A[Tx631(81LL691*Porvenir)]-17-1m-4m-4m-3m-1m*[DMV180(SPV346(81LL691*Billy))]-49-3-1-2m yielded 7.2 t ha-1 at Zamorano, the highest yield observed.

The two enhanced maicillos that have been tested on farmers' fields since 1992 are ready for release. This accomplishment fulfills a midterm goal established at the beginning of the Project-the development of enhanced maicillo varieties. The cultivars Porvenir Mejorado (DMV-197) and Gigante Mejorado (DMV-179) has withstood farmers, housewives and extension personnel criticisms as well as environmental conditions during the course of evaluations.

On-Farm Research

On-farm Demonstration Plots

Our on-farm testing program is an integral part of *in-situ* conservation. Not only does this activity enable us to collect maicillo from farmers most likely to trade-in their old cultivars, it provides the mechanism whereby enhanced maicillo cultivars—the vectors for transferring exotic genes—are introduced into the maicillo population. Since maicillo is a living system, our approach to conservation stresses the deployment of an array of enhanced maicillo germplasm, by testing different cultivars on-farm each year, rather than formally releasing varieties which would eventually saturate the formal seed market and slow the introgression of new genes into the maicillo population.

Table 1. Grain yield of 36 maicillo cultivars in the EIME, over four locations in Honduras, 1993.

Entry DMV	Genealogy	Grain yield (kg ha^{-1})				
		Average	Zamorano	RAPACO	Choluteca	Comayagua
1	F1 A(Tx623*Pes.)-1-*(CS3541*Lib.)-6-1	4.1	6.3	3.1	2.6	4.6
2	F1 A [Tx631 (81LL691*por.)]-17-2m*(CS3541*Lib.)-6-1	3.8	5.2	2.3	2.1	5.5
3	F1 A (SEPON77*S.Isabel)-6*(CS3541*Lib.)-6-b	2.9	3.9	2.2	1.9	3.6
4	F1 A Var 1*(CS3541*Lib.)-6-b	3.0	4.7	1.4	1.9	3.8
5	F1 A Var1*(D71020*Billy)-48-2-3-1-b-1-b-b-b-b	3.7	5.0	2.3	2.4	5.2
6	F1 ATx631*(D71020*Billy)-48-2-3-1-b-1-b-b-b-b	3.5	4.2	3.6	1.9	4.4
7	F1 A (Red.*Coludo)-3-1-*(R5388*Lib.)-b-11-2R-1	4.0	5.1	3.8	3.1	4.0
8	F1 A (Tx623*Pes.)-1-2-1*(SC414*P.N.)-53-1-3-1-4	3.5	4.8	2.3	2.1	4.8
9	F1 A [Tx631(81LL691*Por.)]-17-*[(IS12511*SC108)Lib.5177]SBIII]-1	3.8	5.1	2.9	1.7	5.3
10	F1 ATx631*[(IS12511*SC108)Lib. 5177] SBIII]-1	3.4	5.3	1.4	2.0	5.0
11	F1 A[Tx2801(81LL691*Por.)]-69-1m*[(SC326*SC103) SBIII]-12-1-2	3.4	5.8	2.0	1.4	4.2
12	F1 ATx631*[(TAM428*SBIII)Billy]-7-1-1	3.2	3.8	1.9	2.5	4.7
13	F1 A Var 1*[SPV346 (81LL691*Billy)]-36	3.0	5.0	2.4	1.6	2.9
14	F1 ATx631*[SPV346 (81LL691*Billy)]-36	3.9	6.6	2.1	2.2	4.6
15	F1 A [Tx631(81LL691*Por)]-17*[DMV180(SPV346(81LL691*Billy))]-49	2.5	3.7	1.8	1.3	3.3
16	F1 A (TX623*Pes.)-1-2-1*{[SPV346(81LL691*Billy)](SC414*P.N.)}-25	4.0	7.2	2.7	1.6	4.4
17	179 (SPV346*Gigante Pavana)-1-1-2	3.0	3.7	1.9	1.5	4.9
18	221 (Sureño*Caturra 68)-3-3-2-1	2.1	2.5	2.2	1.0	2.6
19	210 (TAM428*MC100)-2-2	2.6	4.3	1.8	0.9	3.5
20	197 (TAM428*Porvenir)-29-1-1-b-b-1-b	2.9	3.9	1.5	1.1	5.0
21	137 (TAM428*Porvenir)-29-2-3-b-b	3.3	4.6	1.9	2.4	4.2
22	222 [(SEPON77*Sta.Isabel) ICSV 151]-5-7-2-4	2.8	4.7	1.0	1.1	4.5
23	223 [(SEPON77*Sta.Isabel) ICSV 151]-6-1-1-2	2.2	4.9	0.6	1.2	2.1
24	224 [(SEPON77*Sta.Isabel) ICSV 151]-6-2-1-1	1.3	1.3	1.0	0.6	2.1
25	225 [(Tx435 (MB9*Liberal)]-1-2-1-4	2.1	4.1	1.8	1.1	1.3
26	226 [(Tx435 (MB9*Liberal)-3-3-1-1	2.2	4.6	1.7	0.5	2.1
27	227 {[(SC326*SC103) Lib.] SC1207}-10-2-1-5	2.1	2.5	1.4	0.7	3.7
28	218 {[SPV346 (81LL691*Billy)]*(SC414*P.N.)}-4-1-1	2.3	3.5	1.8	1.2	2.9
29	213 {[SPV346 (81LL691*Billy)]*(SC414*P.N.)}-7-1-b	2.7	3.6	2.1	1.2	4.1
30	219 {[SPV346 (81LL691*Billy)]*(SC414*P.N.)}-25-3-4	2.4	3.1	2.3	1.2	2.9
31	228 {[SPV346 (81LL691*Billy)]*(SC414*P.N.)}-41-1-2-2	2.6	4.3	1.8	1.3	3.2
32	MC ES 727	2.3	3.6	1.6	0.8	3.2
33	MC Lerdo Ligero	2.4	3.5	1.8	1.6	2.6
34	MC Pelotón	2.6	4.0	2.6	1.3	2.6
35	MC Porvenir	2.1	4.0	1.8	0.5	2.0
36	MC San Bernardo III	2.6	4.1	2.4	1.1	2.9
	Average	2.9	4.3	2.0	1.5	3.7
	Maximum yield	1.3	1.3	0.6	0.5	1.3
	Minimum yield	4.0	7.2	3.8	3.1	5.3

Table 2. Average performance of two enhanced maicillo cultivars evaluated on 59 small farms in southern Honduras in the time period of 1989-1993.

Technological level	Yield Grain t ha^{-1}	Forage t ha^{-1}	Heads nº/ha	Plant Height m	Soluble Solids ºBrix	Anthesis Nº days
DMV179 (SPV-346*Gigante)	1.4	54.3	76,000	2.5	13	139
T1 = Maicillo Criollo	1.8	54.3	99,000	2.1	15	129
T2 = Improved Seed	2.0	61.4	123,000	2.2	16	131
T3 = T2 + "Langosta" Control	2.8	65.7	151,000	2.1	15	131
T4 = T3 + 60 kg ha^{-1} of Nitrogen						
DMV 197 (TAM-428*Porvenir)						
T1 - Maicillo Criollo	1.4	54.3	76,000	2.5	13	139
T2 = Improved Seed	1.9	61.4	99,000	2.0	15	121
T3 = T2 + "Langosta" Control	2.5	64.3	112,320	2.0	14	126
T4 = T3 +60 kg ha^{-1} of Nitrogen	3.0	65.7	123,263	2.0	16	121

Every year we conduct several on-farm demonstration plots to expose small farmers to enhanced maicillo cultivars planted with a gradient of new improved production technologies. New technologies are: enhanced maicillos, chemical protection to the "langosta" insect complex and 60 kg ha^{-1} of nitrogen applied at floral differentiation (last week of September). Table 2 presents the average performance of these two new cultivars.

Results obtained from 59 on-farm demonstration plots during 1992 and 1993, indicate that enhanced maicillos outyielded maicillo criollos at all technological levels. There is an average increase in grain yield of 0.45 t ha^{-1} by merely replacing the maicillo cultivar by either one of the enhanced maicillos. Increase in plant population as a result of controlling the "langosta" insect complex and expressed as the number of harvested heads, shows a significant rela-

Table 3. Yield performance and grain quality of DMV179 over a 4-year time period. Honduras.

	Gigante Mejorado				Best Maicillo			
Characteristic	1988	1989	1990	1992	1988	1989	1990	1992
Grain yield (t/ha)[†]	3.8	3.6	3.0	2.5	2.8	3.2	2.4	2.4
Pericarp thickness (1 = thin, 5 = thick)	2.5	4.0	2.0	1.0	4.0	4.3	3.2	1.5
Pericarp removal (1 = all, 5 = nothing)	1.5	3.0	3.5	2.5	2.5	3.2	2.7	2.5
Nixtamal color (1 = light, 5 = dark)	1.0	1.2	2.5		1.5	3.3	2.8	
Hardness (% decortication 4 min in TADD)	17.5	11.4	22.3	27.3	35.4	25.7	28.6	25.5
Grain density (g/cc)	1.39	1.38	1.39	1.4	1.35	1.36	1.37	1.4
1000-kernel weight (g)	26.8	26.0	24.2	20.4	24.6	20.6	23.0	25.7
Protein (% dw)		11.7	8.7	8.5		9.8	8.9	11.1
Endosperm texture (1 = hard, 5 = soft)	2.5	2.0	3.2	2.5	3.1	3.5	3.2	2.5

[†] Average grain yield in EIME over three locations.
Grain quality analyzed on grain samples from Choluteca at the Cereal Quality Laboratory, Texas A&M University.

Table 4. Grain yield of two enhanced maicillos under three different production systems: Experimental plots (4 m^2), on-farm demonstration plots (144 m^2) and commercial fields, as compared with maicillo criollo grain yields.

Cultivars	Experimental plots[†] qq/mz	On-farm[‡] qq/mz	Commercial fields [§] qq/mz
Gigante Mejorado	46.2	28	32
Porvenir Mejorado	49 2	26.1	40
Maicillo	38.5	13.8	18

[†] EIME, average yield 1988, 1989, 1990, 1991 y 1992
[‡] Nuevas Tecnologías de Sorgo: Instructivo 1993.

tionship with grain and forage yield. Finally, the application of 60 kg ha^{-1} of N, clearly demonstrates the efficiency in N assimilation of improved maicillos over the criollos. Maicillo grain yield is easily doubled by planting the enhanced maicillos with "langosta" control and 60 kg of N ha^{-1}.

Enhanced maicillos also show a reduction in height of 0.5 m with respect to maicillo criollos. Forage quality is substantially increased by 3-4° Brix, that makes the stover more nutritious and palatable to cattle. Maturity has been kept at one week earlier than maicillos criollos. This earliness is adequate for escaping late dry periods, and minimizing grain molds.

Francis Flores and José Maria, farmers from Tierra Blanca, Namasigüe, Choluteca that have participated in the on-farm demonstration plots, indicate that these maicillos offer them several advantages. Their short statures facilitate harvest, reduce lodging, rodent damage and avoid grain losses by stepping on heads of lodged plants when harvesting. Other farmers from the el "Gramal Tierra Hueca," Choluteca, that also run a cattle farm, expressed that "Porvenir Mejorado" and "Gigante Mejorado" are sweeter and juicier than maicillos criollos, and the forage is preferred by cattle. Some farmers complained about the difficulty in threshing DMV197.

Tests conducted at the Texas A&M Cereal Quality Laboratory have conclude that the enhanced maicillo Gigante Mejorado (DMV-179), with pedigree (SPV346*Gigante de Pavana), presents an outstanding grain quality for tortilla production. Tortilla quality has been monitored since 1988. Table 3 presents yield data and grain quality characteristics for DMV179 over a four year time period, as compared with a sample of maicillo criollos.

Even though Porvenir Mejorado (DMV198) has a red plant color and it does not have the same grain quality as Gigante Mejorado (DMV179), it shows better yield potential and good agronomic characteristics (Table 4). In commercial fields, in Santa Fé and Namasigüe, Choluteca grain yields of 40 y 32 qq/mz were obtained by farmers with Porvenir Mejorado and Gigante Mejorado respectively in 1993. Both cultivars have an excellent level of resistance to gray leaf spot pathogen (*Cercospora sorghi*), a disease that reduces foliar area significantly in the maicillo criollos (Gómez and Meckenstock, 1993); and are 10 times more resistant to the downy mildew pathogen, than the best maicillos criollos-Pelotón, Porvenir and San Bernardo (Meckenstock, 1986).

Fifty-five on-farm demonstration plots were sent out in 1993 with yield data returned from thirty-eight plots. Performance data will also be used to determine potential impact and effectiveness of different soil and water interventions.

Agronomy

To move the sorghum yield plateau on hillside farms in southern Honduras, it is necessary to first increase the genetic potential and defensive capabilities of maicillos. It is also necessary to stabilize the farm with soil and water conservation techniques (Gómez, 1990). Studies conducted by Thompson (1991), in Namasigüe, Choluteca, demonstrate that the use of soil conservation structures built by "Proyecto L.U.P.E" and other NGOs, minimize soil losses, increase organic matter accumulation and improve water

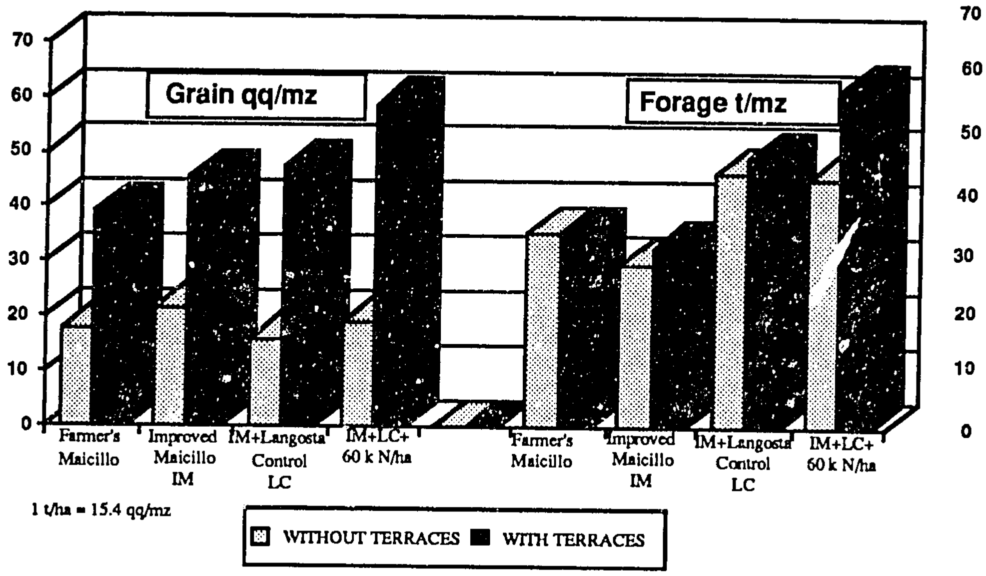

Figure 1. Terraces built by L.U.P.E with improved maicillos (DMV179) maximize grain and forage yield at farmer hillside farm of Doña Agustina, Los Espabeles, 1992.

holding capacity, resulting in a significant increment in biomass production of 35 percent (8,687 versus 5,563 kg ha^{-1}). Results of on-farm demonstration plots planted in 1993 to compare the yield advantage of using soil conservation structures indicated a substantial gain in grain and forage yield. Figure 1 depicts the need for adoption of soil conservation structures on hillside farms to provide a better growing environment for sorghum to increase productivity. Without soil structures yield potential will never be expressed, regardless of the amount of agricultural inputs used.

Special Projects

Dr. Gómez has been successful in establishing three special projects that augment the effectiveness and stability of the program. These are the commercial hybrid performance test, which is sponsored by private seed companies, the control of sorghum downy mildew and maicillos nurseries, which are sponsored by the European Economic Community (EEC). These projects are administered by the EAP and managed by Dr. Gómez and are exemplary of the kinds of sustainability we are trying to build into the program.

Commercial Hybrid Testing

Central American Governments have privatized the seed industry. The national sorghum program assists this endeavor by conducting a commercial hybrid performance test for private seed companies. This testing program began in 1989 and is the only public listing of commercial cultivars published showing performance, and distributors for any crop in Honduras. This is another example how the sorghum project continues to lead by example. In 1993 and 1994, testing took place in four States: Choluteca, Comayagua, Francisco Morazán, Olancho and El Paraíso. Since initiating the performance test, we estimate from seed import records, that hybrid sorghum acreage has increased by 35 percent or 15,000 hectares. Favorable prices coupled with performance information, obviously has led farmers to choose sorghum over other crops. Average grain yield in those areas where commercial hybrids are grown reaches 2.5 t ha^{-1}.

The commercial hybrid performance test has helped foster the fledgling Honduran sorghum industry in several ways. First, it allows the commercial seed companies to up-grade their hybrids. Thus, farmers have access to better adapted hybrids with higher yield potential. For example, Dekalb introduced three new hybrids, including a white tan hybrid, Northrup King has reduced the number of hybrids it now markets in Honduras from three to one after some of their hybrids gave a poor showing in 1990. Cristiani Burkard and Pioneer hybrids, which did well in Jamastrán in 1990-93, are now the preferred hybrids in that area. Second, new companies desiring entry into the Honduran market can use the test to attract dealers. Third, the performance test reduces the risks farmers perceive when accepting new technologies. This is especially true when farmers attend field days and see the hybrids for themselves. Fourth, farmers often adopt some of the management practices we use to achieve higher yields; e.g., treating seed with insecticide, adjusting plant densities, and using higher fertilizer rates. Fifth, the MNR uses the results to grant seed import permits and sixth, credit institutions are beginning to look at our reports and consider the possibility of making loans to sorghum producers. Presently, the three largest sorghum seed companies in Honduras, Cristiani Burkard, DeKalb, and Pioneer subscribe to our service.

Control of Sorghum Downy Mildew

A minigrant from the EEC was awarded for the third year to conduct the International Sorghum Downy Mildew Nursery (SDM). The objective of this special project was to use differential lines to monitor SDM hot spots in Honduras for changes in virulence and to screen breeding material for P5 resistance.

Although the International Sorghum Downy Mildew Nursery was first established at the Las Playitas experiment station, we relocated it in 1991 to the adjacent Center for Agriculture Development (CEDA), after monitoring for virulence indicated that P5 existed there as well. The nursery was managed by Dr. Napoleon Reyes-Discua, Director of CEDA. The advantage of screening for downy mildew in Comayagua is that lines resistant to P5 hold resistance elsewhere in the Americas. Some commercial companies that must meet downy mildew resistance requirements in other countries in Latin America are now opting to screen their materials in Comayagua.

Sureño Update

Sureño (PI 561472 and NSSL 259979.51) has found widespread acceptance throughout the sorghum growing regions in Honduras. It is the first sorghum cultivar released by the MNR that has found its way into informal seed markets. Consequently, it not only has sustained its survival, but continues to increase its acreage share with nominal institutional help. Seed production continues to be a problem. Only three registered seed growers produced *Sureño* in 1993-1994. Two-thirds of the production did not meet the certification requirements due to poor germination caused by weathering from grain molds. To obtain good quality seed, Sureño must be planted in places were its maturation occurs in dry environments.

Pearl Millet Update

Prof. David Andrews provided a set of millet cultivars and populations for evaluation their yield potential under Honduran conditions. Table 5 presents grain yield of the cultivars evaluated in 1994. Grain yields in hybrids were very impressive. The best hybrid 378-1M*NPM-3(93M70-16 ISO) yielded 4,514 kg ha^{-1}. In general, Pearl Millet seems to have a high yield potential under Zamorano conditions. Tiller ability in millets seems important to compensate for low plant densities. In all cases, these cultivars showed a high leaf disease resistance (LDR=1.1).

Table 5. Pearl Millet yields at Zamorano in 1994.

Cultivar	Yield (kg ha^{-1})
378-1A * 086R (90M ISO)	3,451
68A * 89-0083R (92M ISO)	4,131
68A * NPM-1	3,386
378-1M * NPM-3(93M70-16 ISO)	4,514
NPM-3	1,524
NCD-2	3,187
Average yield	3,365

We are planning to do more testing to study the feasibility for a millet hybrid release for the very dry areas of Honduras.

Networking Activities

Institutional Arrangements

MNR-EAP Memorandum of Agreement (MOA)

In 1991, the MNR signed an MOA with the EAP which places the responsibility of sorghum research with the school. This MOA was elevated to the status of Acuerdo (no. 3524-91) when it was approved by the Honduran President Dec. 9, 1991. This restructuring of the NAR sorghum component is consistent with USAID/H and GOH objectives on privatization and serves as a model for privatizing other agricultural services in the ministry. INTSORMIL's long-term relationship with the MNR has enabled Honduras to develop a long-term comprehensive sorghum research program that is beginning to gain support from the sorghum industry in Honduras and other international donors.

PL480 Support

The GOH and USAID/H provide local currency support for the sorghum project through the Title I PL480 program. The present PL480 funding level dropped to 269,000-lempiras which is equivalent to 30.000-dollars. Local currency covered most of in-country costs, including counterpart and support staff salaries. A USAID mission initiative to have the GOH match PL480 funds programmed for all CRSPs with national funds was enforced in 1994; however, the Honduran Government did not match the agreed amount. This is in lieu of the fact that U.S. assistance to Honduras will be cut back drastically in the next five years until, finally, all aid is stopped in 2000.

Additional funding

Special projects are being developed to create new funding sources. To date, these projects have focused on commercial hybrid testing and the International Sorghum Downy Mildew Nursery in Comayagua. The national sorghum program won two strengthening grants (15,000 dollars) from the EEC this year for the control of sorghum downy mildew in Honduras and support maicillo breeding activities.

EEC/PRIAG

In 1994, Dr. Gómez was appointed as Vice-president of the National Council of PRIAG (i.e., the Regional Program to Strengthen Agronomic Research on Basic Grains in Central America) which is sponsored by the European Economic Community and administered by IICA. As a senior scientist, he is providing valuable counsel to PRIAG in establishing their research grant program. A portion of his responsibilities includes evaluation of research proposals submitted by eligible sorghum workers in the region. This position adds an important new facet in networking.

PCCMCA

Dr. Gómez, Guillermo Cerritos, Alberto Morán and Hector Sierra attended the 40th annual meeting of the PCCMCA. Mar. 23-27, 1994. San José, Costa Rica. Dr. Gómez acts as the liaison officer between ASA and PCCMCA.

Scientist Exchange

Dr. Gómez traveled to Kansas City MO in June and November, 1994 to participate as a member of the INTSORMIL Technical Committee, where he represents the Latin American Region.

Dr. Gómez traveled to Seattle WA in November to attend the ASA meetings, where he looked for possibilities to open an ASA Chapter at Zamorano.

CRSP Review Team

In July, 1994, a CRSP Review Team visited Honduras. The Sorghum Project was in charge of coordinating their itinerary. The team traveled to southern Honduras where they visited INTSORMIL, TROPSOILS and POND DYNAMICS activities. They also visited MNR, USAID/H office, and the Ministry of the Environment. This was an excellent opportunity to overview the impact of CRSP activities in Honduras

Germplasm Exchange

Dr. Fred Miller, Texas A&M University, sent 4 female and 53 male lines for hybrid seed production in Comayagua.

Seed (400 g) of two improved maicillos was distributed among 62 farmers in southern Honduras.

Seed of six enhanced maicillos and maicillo criollo was sent to Dr. Page Morgan from Texas A&M to initiate study in photosensitivity control.

Genetic seed of ATx623 (1 kg) and BTx623 (5 kg) were donated to the seed production unit at the EAP.

Five broomcorn varieties (450 g each) was sent to Adolfo Montiel for adaptation studies in Nicaragua. All were resistant to pathotype 5 of *P. sorghi.*

Basic seed of Tx2784 (2 kg lbs.) was donated to the seed production unit at the EAP. This is the sudangrass male parent of Ganadero.

Basic seed of A-BTx626 and RTx8505 (2 kg lbs.) was donated to the seed production unit at the EAP. These are the parental lines of Zam-rojo.

Publications and Presentations

Publications

Gómez, F., D.H. Meckenstock, H. Sierra, and A. Morán. 1993. *In situ* Conservation and enhancement of Maicillo. (In Spanish). p. 123-129. Agronomy Department Annual Report, vol. 6, Escuela Agrícola Panamericana, El Zamorano, Honduras.

Cerritos, G., and F. Gómez. 1993. Sorghums for the Industry of Biodegradable Brooms (In Spanish). p. 130-133. Agronomy Department Annual Report, vol. 6, Escuela Agrícola Panamericana, El Zamorano, Honduras.

Gómez, F., D.H. Meckenstock and G. Cerritos. 1993. 1992 Grain sorghum performance tests (In Spanish). Tech. Rep. EAP/SRN/INTSORMIL-3. Escuela Agrícola Panamericana, El Zamorano, Honduras.

Gómez, F. , D.H. Meckenstock and G. Cerritos. 1994. 1993 Grain sorghum performance tests (In Spanish). Tech. Rep. EAP/SRN/INTSORMIL-3. Escuela Agrícola Panamericana, El Zamorano, Honduras.

Lobo, P. 1994. Nicking of "Ganadero" and "ZAM-Rojo" parental lines (In Spanish). Ing. Agro. Thesis. Panamerican Agricultural School. El Zamorano, Honduras.

Meckenstock, D.H. 1993. Tropical sorghum conservation and enhancement in Honduras and Central America.p. 205-215. INTSORMIL Annual Report 1993. (USAID/DAN-1254-G-00-0021-00). Sorghum/Millet Collaborative Research Support Program, Univ. of Nebraska, Lincoln, NE.

Presentations

Gómez, F. Conservation and enhancement of maicillo. PCCMCA, 23-27 Mar. 1994. San José, Costa Rica.

Cerritos, G. Biodegradable Brooms made of Sorghum. Poster. PCCMCA, 23-27 Mar. 1994. San José, Costa Rica.

Gómez, F. The Honduras National Sorghum Project:an Overview. 1994. Secretaria de Recursos Naturales.

Mali

D.T. Rosenow
Texas A&M University

Coordinators

Dr. D.T. Rosenow, Sorghum Breeder, Country Coordinator, Texas A&M University, Lubbock, TX
Dr. Aboubacar Touré, Sorghum Breeder, Host Country Coordinator, SRA/Sotuba, DRA/IER, Bamako, Mali

Collaborative Program

The program in Mali is a coordinated effort between INTSORMIL and IER. It is multi-disciplinary and multi-institutional in scope and includes all aspects of sorghum and millet improvement, production, and utilization. Each Malian scientist develops research plans cooperatively with an INTSORMIL counterpart in concert with the overall IER Mali research plan. Major INTSORMIL collaborators travel to Mali annually during the critical period of the crop year to consult, review progress, and plan future collaborative activities with their Malian counterparts. Occasionally, IER scientists travel to the U.S. for annual review and planning. These plans are reviewed by the country coordinators, consolidated, and then presented to the IER for their annual research planning process for approval or modification. This insures that the research fits into the annual overall IER plan. The USAID sponsored bilateral IER/Texas A&M/SPARC project assists IER in research project development, execution, and research financial management for the entire IER program including other donor funding and agencies.

Memorandum of Agreement

A Memorandum of Agreement formally establishing INTSORMIL collaboration with IER that allows transfer of funds was signed in Mali on October 10, 1984. The annual Amendment to the MOA, which consists of the 1993-94 work plan and budget, was developed jointly by the country coordinators in March-April, 1993, and approved by IER and INTSORMIL in May, 1993.

Financial Input

The USAID Mission provides significant financial support to the total IER research program, of which sorghum and millet are a part, through the SPARC Project. IER and SPARC make decisions on which specific project or locations are funded by SPARC, depending on needs and where INTSORMIL country funds are allocated. Eventually, plans are made for all external funding, including the INTSORMIL funds transferred to Mali, to be managed through the SPARC/IER financial system. Approximately 60% of the yearly Mali Country Budget is transferred directly to Mali from the INTSORMIL Management Entity. The remainder is retained by the Management Entity and used for major equipment purchases, supplies, IER scientist travel, IER scientist short term training, or special needs as they arise Also, some individual U.S. INTSORMIL investigator transfer pass-through funds to Malian counterparts or pur chase equipment/supplies directly from their project funds

Collaborating Institutions

Institute of Rural Economy (IER), Bamako, Mali
Texas A&M University
University of Nebraska - Lincoln
Purdue University
Kansas State University
SPARC (USAID/TAMU) Project
USAID/Bamako
ICRISAT/WASIP/Mali
TropSoils CRSP

Research Disciplines and Collaborators

Germplasm Enhancement - Sorghum

Aboubacar Toure, IER; D.T. Rosenow, G.C. Peterson F.R. Miller, INTSORMIL.

Germplasm Enhancement - Millet

Karim Traore, IER; W.D. Stegmeier, INTSORMIL.

Crop Protection Systems - Entomology

Yacouba Doumbia, IER; G.L. Teetes, INTSORMIL; N Diarisso, TAMU student (IER).

Crop Protection Systems - Pathology

Marian Diarra (Sorghum), Mamadou N' Diaye (Millet) IER; R.A. Frederiksen, INTSORMIL; M. Diourte - KSU student (IER).

Crop Protection Systems - Striga/Weed Science

Bourema Dembele, IER; G. Ejeta, INTSORMIL.

Crop Production Systems - Agronomy/ Physiology/Soils

Sidi B. Coulibaly, Samba Traore, Abdoul Toure, Minamba Bagayoko, Zoumana Kouyate (TropSoils), IER; S.C. Mason, J.W. Maranville, A.B. Onken, INTSORMIL; M. Doumbia, TAMU student, (IER) (TropSoils), A. Traore, UNL student (IER).

Utilization and Quality

Mariam Haidara, Ibrahim Goita (Deceased), IER; L.W. Rooney, INTSORMIL.

Economics

Ousmane Coulibaly, IER (Purdue student); J.H. Sanders, INTSORMIL.

Sorghum/Millet Constraints Researched

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 needs of 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.

Head bugs and associated grain 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.

Grain prices which cycle between high and low yield-level years are a deterrent to adoption of improved technology, thus milling properties become critical for 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.

Efforts are concentrated to strengthen research on breeding, crop physiology, soil and water relationships, entomology, pathology, *Striga*, food processing, and food 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

Work to develop *Striga* resistant sorghums and photoperiod sensitive late maturing sorghums to escape head bugs and molds was expanded the last two years. InterCRSP activities with TropSoils were initiated for breeding and selection of sorghums for tolerance to soil toxicities and to study the nature of the problem. New tan-plant Guinea-type breeding progeny offer an opportunity to study the feasibility of new food and industrial products which could enhance demand and stabilize prices.

Research Progress

Germplasm Enhancement

Pearl Millet Breeding

The millet breeding program in Mali is making good progress in addressing needed improvements regarding disease and insect resistance, adaptation, and agronomic characteristics that affect productivity. Landraces from different ecological zones have been evaluated at different locations. These materials were collected at Nioro, Bema, Mopti (northeast), and Sikasso (south). Ten high performing ecotypes were selected. They are being improved via the mass selection method. The same entries are being used in a crossing block for their grain quality (kernel size and color).

Many experimental varieties have been evaluated in the CIVAREX, "Cinzana Varieties Experimentales". Several performed well and will be suitable for intercropping with legumes such as cowpea and peanut, and root crops like cassava and sweet potatoes. Several composites were evaluated in isolated plots for dwarfness, head compactness, and downy mildew resistance. Roguing and recombination gave good results.

Several lines derived from nine Malian varieties were screened at Hays, Kansas. Three good lines were retained in Mali. Also crosses were made between Kansas elite lines and materials from Mali. Fifty-two F1 and forty eight F2 were evaluated. They had an acceptable level of downy mildew resistance. Backcrosses will be made with most of these lines. They had suitable height for intercropping. More than sixty entries were evaluated through ICRISAT and ROCAFREMI (Millet Improvement Network in Central and West Africa) collaborative programs. Two or three years evaluation will allow selection of some entries for on-farm evaluation.

Sorghum Breeding

Crossing and Breeding Nurseries

In the 1993 rainy season, 48 parents were planted at Sotuba with 115 new crosses made. These F1's were planted at Sotuba during the 93-94 off-season to produce F2's. The best tan-plant Guinea F6 derivatives were selected to be backcrossed to CSM 388, Bimbiri, Soumale and Tiemarifing, in order to enhance the guinea traits to develop very true tan-plant guinea lines.

F2, F3, and F4 progeny were grown at Sotuba, Samanko, Bema, Cinzana, and Longorola with 350 F2 selections, and 255 F3 selections made. Eighty-one F4 families were selected for advance in the off season to the Preliminary Trial in 1991.

Excellent progress was made in the objective to develop white-seeded, tan-plant guinea cultivars. F6 progenies from crosses involving Bimbiri Soumale and CSM388 looked very promising. Especially outstanding were the derivatives of the cross, Bimbiri Soumale *87CZ-Zera Zera. They appear to have excellent yield potential. They have good guinea plant, grain, glume, and panicle characteristics, and some have juicy stems. Most Bimbiri Soumale derivatives were F6's in the preliminary trials, while the best CSM388 derivatives were in the F4 stage. They will move to the Advanced Trials and Preliminary Trials in 1994.

The progenies from late maturing improved maicillo varieties from the INTSORMIL program in Honduras were not acceptable for grain quality, but had proper maturity for southern Mali. They were recrossed to local and improved types in an attempt to improve the head bug and grain mold resistance.

Advanced Varieties

Three different Preliminary Yield Trials and three Advanced Yield Trials (to fit rainfall belts) were planted and evaluated at Bema, Cinzana Massantola, Katibougou, Sotuba, Samanko, and Soukoula. From the Advanced Trials, eight were selected for on-farm testing. From the Preliminary Trials, entries were selected to be promoted to the Advanced Trial next year.

In southern Mali, seven cultivars selected from the CMDT southern Mali collection of late, photosensitive sorghums were evaluated at Longorola, Soukoula, and Tierouala. After two years of evaluation, three were selected for on-farm testing and for crosses, Kalagua Seguetana, Foulatieba, and Kalofolo.

Plant Protection

Entomology

Research activities for 1993 were focused essentially on the bio-ecology of head bug (*Eurystylus marginatus*) and the identification of new resistance sources. The fluctuation of larva and adult populations was studied. The population of head bugs was higher in 1993 than in 1992.

In preliminary screening in the field nursery at Sotuba, 49 new advanced generation lines were evaluated under natural infestation conditions. In another three year experiment screening for resistance, we evaluated 50 advanced breeding lines. In the first experiment the entries showing good head bug resistance were 89-CZ-CS-F5-73 AF, ACSV 401, 88-BE-F4-257-3, 87-SB-F4-275-2 and 87-SB-LO-F4-155 with a visual rating between 1.0 and 1.7. Results in the second experiment showed that the INTSORMIL lines from Texas 90-CZ-CS-TX-2, 90-CZ-CS-TX-12, 90-CZ-CS-TX-6, 90-CZ-CS-TX-1, PR2566 and PR2562 were resistant to head bug under severe natural infestation. All are derivatives of Malisor 84-7. In another advanced screening trial, IS21468 was confirmed as having resistance equal to that of Malisor 84-7.

Diazinon again looked promising in controlling head bugs in 1993. With lines treated with diazinon, the head bug incidence under natural infestation was very low compared to the check. Also, 200 grain-weight was higher for treated heads (4.21g) than for the control under natural infestation (3.20g).

Pathology

Forty lines from INTSORMIL in the GWT (Grain Weathering Test) were screened for grain mold resistance at Sotuba under natural conditions. Six lines, SC170-6-17, SC279-14E, R6078, 87BH8606-6, Town, and BE7149, showed resistance and will be used for further testing.

Apron Plus® and Oftanol - T were very effective in controlling converted kernel smut on Tiemarifing with a disease incidence of 1% and 5% respectively. Vitavax was less efficient with a disease incidence from 30% to 50%.

The 70 entry ADIN (All Disease and Insect Nursery) was evaluated under natural infestation for anthracnose and sooty stripe at Sotuba with several lines showing useful levels of resistance.

Striga

Cultivars from Malian Collection (Seguetana), selected lines from Dr. G. Ejeta, Purdue University and from the national breeding program were used in the *Striga* evaluation field trials in 1993. Among the cultivars collected in southern Mali, the best six, CMDT 30, CMDT 39, CMDT45, CMDT48, CMDT76, and CMDT115, showed less *Striga* incidence than the check Tiemarifing.

At Samanko and Katibougou, selected F5 breeding lines (Malisor 84-7*SRN39) from Purdue were as resistant as the resistant check, Tiemarifing, in preliminary screening trials. Six advanced generation lines (SRN39*Zerazera) developed and selected at Purdue for resistance to *Striga asiatic* were tested on-farm in the Katiabougou area. All showed high levels of resistance to *S. hermonthica* and 92PR-203 also showed excellent agronomic traits.

At Cinzana, a reportedly resistant local guinea landrace variety, Seguctana Cinzana, showed excellent resistance in a field screening nursery. This line will be studied in the Purdue Lab.

Crop Production/Agronomy Physiology Soils

Seedling Screening for Drought and Heat Tolerance

Selected early and intermediate maturity advanced including breeding lines were tested for high heat and drought tolerance in the 92-93 off-season in charcoal pits at Cinzana. In the early trial 87-LO-F4-92 (Malisor 84-1), 88-CZ-F4-173-3, 89-CZ-CS-F5-126AF and Bagoba were tolerant. Malisor 92-1 had the highest plant survival at the 3rd, 7th, and 15th day after planting. In the intermediate maturity trial, 90-CZ-CS-104 and 90-CZ-CS-F5-65 showed good seedling survival.

Peanut-Sorghum Rotation

In 1993, previous peanut crop effect was very important to sorghum grain yield. There was a 74% increase due to previous peanut cropping alone at zero N level, and 114% and 102% yield increase when 40kg and 80kg of N were applied to previous peanut plots. Other results have indicated that the rotation effect is not due only to legume N effect.

Sorghum-Peanut Intercropping

The land equivalent ratio (LER) is used as a land use efficiency indicator. The efficiency of sorghum peanut intercropping in 1993 was estimated at 1.48. The yield of sorghum grain in intercrop was 48% of sole sorghum and that of intercropped peanut was 100% of the yield of sole peanut crop. Rotations with sorghum-peanut intercrop, compared to sole sorghum, showed a 36% yield increase of sorghum grain in the rotation compared to sole sorghum.

Cowpea - Pearl Millet Rotation

Previous cowpea had a significant effect on pearl millet grain yield. At the zero N level there was a 56% yield increase. This increase was more than the effect of 20kg N/ha (15% increase) and equivalent to that of 40kg N/ha (56% yield increase). Combined nitrogen and previous cowpea was even greater with yield increases of 67%.

Pearl Millet - Cowpea Intercropping

The land equivalent ratio (LER) of millet-cowpea intercrop indicated a 55% yield increase in total production. Partial LER of pearl millet grain yield over nitrogen levels was 100% for zero and 85% and 73% for 20 and 40 kg N/ha. The rotation effect of millet-cowpea intercrop on succeeding sole millet was a positive 14% without N application.

Long Term Residue Management Study

A residue management study on sorghum and millet monoculture and rotation of cereal-legume was initiated in 1990 with three residue treatments: removed; leaving residue on soil surface; and incorporated. There was no effect on grain or stover the first three years, but in 1993 grain yield differences occurred for the first time. For both crops, incorporated and removed were superior to leaving residue on the surface. The consistent lower yields where residue was maintained on the surface could be due partially to an observed reduction in stand. The crop residue treatments showed no effect on peanut and cowpea yields.

Biomass-Harvest Index Study

Different planting dates and different fertilizer levels had no significant effect upon total biomass or harvest index of 15 local Malian varieties. Similar results were obtained on a similar study of five advanced Malian breeding lines.

Sorghum Photosensitivity Adaptation Study

Three Guinea types and three non-sensitive improved cultivars were planted every 15 days from May to the end of July. The days to flower changed for the Guineas until the last two dates, while the non-sensitive lines showed little effect upon days to flower. The Guineas flowered earlier with the later planting dates.

Sandy Soil Toxicity on Sorghum Study

This InterCRSP activity among IER, INTSORMIL, and TropSoils involved evaluation of sorghum genotypes for tolerance in field plots at Cinzana. In 1992, F2 population involving Bagoba, Babadia Fara, and Gadiaba consistently showed tolerance. In 1993, 46 cultivars were evaluated in the same plot, and under very severe conditions, the northern Mali durra cultivar, Cadiaba (Cinzana) consistently showed genetic resistance to this soil problem. Analyses of soil next to individual plants by TropSoils was done to attempt to determine the cause of the extreme spatial variability.

Grain Quality Studies

Breeding Line Evaluation

The advanced medium maturity trial and early trial grain samples were evaluated in the Cereal Technology Lab for kernel characteristics, physical properties, decortication yield, and tô properties. The early materials generally had a slightly lower decortication yield. In general, all gave good tô color and quality. The preliminary trials from Cinzana and Bema were also analyzed. Data are used by breeders in making decisions to discard or keep test entries.

Couscous Preparation Survey

A study was conducted in Bamako to determine parameters important in couscous preparation, using 117 women from 14 different ethnic groups. The sorghum variety was consistently an important consideration in couscous quality. Large white seed which decorticates easily, with high flour yield, produces good couscous. Other factors important to couscous quality are flour textile, grain mold, making fashion, water quality, type of steamer, steaming time, and mucilage type.

Seed Germination

The seed laboratory germinated 537 samples of sorghum from the entomology program to study the effects of head bug and grain mold/weathering. Only 43% of the samples gave excellent germination. There were large differences among genotypes.

Economics

Ousmane Coulibaly, a Malian Ph.D. student at Purdue, initiated his thesis fieldwork in Mali on a study of technologies to increase water availability and soil fertility in the Sudanian and Sudano-Guinean zones of Mali. He also assisted IER scientists in their evaluation of the economic effect of a fungicide application for downy mildew control on pearl millet.

Mutual Benefits

All research results reported should be beneficial to Mali, as well as to surrounding countries where similar production constraints occur. Information on sources of improved food quality and food type sorghums should be useful in improving overall quality of U.S. sorghum grain. Several Malian breeding lines show excellent grain yield potential, leaf disease resistance, and excellent grain quality in Puerto Rico and South Texas.

Institution Building

INTSORMIL provided research equipment for the breeding program (bags, tags, bird repelling reflecting tape, etc.) and for the lab at Cinzana. Also, computers were provided for Sotuba and Cinzana, a copier for Sotuba, and two soil moisture meters for agronomy/physiology research. Support from the INTSORMIL budget, some individual PI budgets, and the USAID Mission was critical to the execution of the Mali sorghum and millet research programs.

Several Malian students at INTSORMIL institutions should make important contributions upon their return to Mali. Mr. M. Doumbia and A. Sow in soils (TropSoils) at TAMU, Mr. O. Coulibaly in agricultural economics at Purdue, Mr. A. Traore in agronomy at Nebraska, Mr. M. Dioute in pathology at KSU, and Mr. N. Fiarisso in entomology at TAMU should all return to Mali fairly soon and strengthen the IER research program. The soil research component in IER should be significantly improved with the return of Doumbia and Sow. Plans are underway with the assistance of SPARC, for a Post-Doc in L.W. Rooney's lab to work for one year in the Cereal Technology Lab at Sotuba to strengthen the lab until the time when trained Malians return. The death of M. Goita, the retirement of Mde. Haidara and the departure of others have hampered the Food Quality Laboratory.

The contribution of INTSORMIL trained Dr. Moussa Traore (Ph.D.-Nebraska), former physiologist and Mali Country Coordinator, now the permanent advisor to Minister of Agriculture, has been huge in the reorganization and current operation of IER. The contribution of Dr. Oumar Niangado, Director General of IER, has also been significant. He is a former INTSORMIL collaborator and millet breeder, and has been instrumental from the beginning in INTSORMILs working in Mali. Dr. Aboubacor Touré, Ph.D. from TAMU in breeding, is currently a sorghum breeder, Head of the Mali national sorghum program, and INTSORMIL Country Coordinator.

INTSORMIL travelers to Mali during the year included: Drs. D.T. Rosenow and G.C. Peterson, sorghum breeders; L.W. Rooney, food scientist: G.L. Teetes, entomologist; R.A. Frederiksen, pathologist; A.B. Onken, soil fertility, from Texas A&M University; Drs. J.D. Maranville and S.C. Mason, agronomists from Nebraska; Prof. W.D. Stegmeier, millet breeder from Kansas State; Drs. G. Ejeta, sorghum breeder; L. Butler, biochemist/*Striga*; and J.H. Sanders, economist, from Purdue; and Dr. John Yohe, INTSORMIL Program Director. Mr. Ousmane Coulibaly, Malian Ph.D. student in economics at Purdue traveled to Mali to initiate his thesis research. Mr. Aboubacar Touré, sorghum breeding technician from Sotuba spent six weeks in sorghum breeding training under D.T. Rosenow at Lubbock, Texas. Dr. Aboubacar Touré traveled to the U.S. twice, once to participate in the Workshop on Soil Stress, August 1993, and once to develop work plans with PIs in June, 1994. Dr. Toure also traveled to Niger in October, 1993 to attend the INTSORMIL African Country Coordinators Meeting in Niamey. Samba Traore represented IER's millet research program at the R'ʾCAFREMI meeting in Niamey.

Networking

The research accomplishments in Mali are immediately and directly transferable to most countries in West Africa. Work on sorghum and millet food technology applies to Africa and many areas of the world. Head bug and drought are common to West Africa. Grain mold is a world-wide problem. Exchange of elite germplasm with useful traits is an excellent means of networking among breeders.

Effort is made to utilize existing networks to extend technology to the region in both sorghum and millet. There has been a long history of collaboration with ICRISAT in

Mali, and ICRISAT continues to be useful in networking in the areas of entomology, pathology, and breeding.

Within Mali, there is a pre-extension organization to do on-farm trials, and then the extension personnel do more detailed evaluation and demonstration of new technologies on-farm. Minamba Bagayoko coordinates extension on-farm trials in the Mopti region. Probably more use should be made of some of the NGOs and PVOs working in Mali.

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.
- Short term training has been provided in the U.S. for Malian PIs 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.

Infrastructure

- Designed and equipped food technology laboratory at Sotuba.
- Built and equipped physiology laboratory at Cinzana.
- Provided computers/word processors for researchers and laboratories.
- Short-term technical assistance on soil fertility/agronomy, entomology, pathology, physiology, food technology, and breeding.
- 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 that drought response of cultivars 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.
- 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 significant areas.
- Genetic tolerance to soil toxicity problems has been demonstrated, and tolerant varieties identified (Bagoba, Babadia Fara, and Gadiaba). Gadiaba Cinzana has the highest level of resistance.
- 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.
- Late, photosensitive sorghums from Honduras have provided appropriate maturity for southern Mali sorghum.
- White-seeded, tan-plant guinea-type breeding lines have been developed from the direct cross (guinea*zerazera). They possess excellent guinea traits and yield potential.

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 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 are 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.
- 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 sorghum with tan-plant and straw color glumes is required to produce high-quality, value-added products.

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 grain molds combine to cause devastating loss in grain yield and quality of lost introduced types.
- Heads bugs cause more damage than pathogens, but pathogens are more severe as bug damage increases.
- Inheritance of head bug resistance is quantitative and primary recessive.
- Some other non-guinea type sources of head bug resistance have been identified in addition to Malisor 84-7.
- 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.
- Anthracnose resistant sources have been introduced, evaluated, and used.
- Sooty stripe resistant lines have been identified.
- *Striga* resistance using lab screening in the U.S. works under field conditions in Mali.
- An easy, efficient method of screening for head bug resistance using bagged vs. non-bagged heads has been developed and can be used to evaluate a large number of entries with little effort.
- A screening technique has been developed using performed plastic bags to screen for grain mold separately from head bugs.

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 increase grain yield by 18 to 56% which is equivalent to the application of 20 to 40 kg/ha of nitrogen fertilizer application.

- Sorghum-peanut intercropping increased land use efficiency (LER) by 4, 13, and 41% over sole crops at zero, 40, and 90 kg/ha N, while millet-cowpea intercrop increased the LER by 29-33% at all N levels.

- 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

John D. Axtell and Ouendeba Botorou
Purdue University and INRAN/Niger

Coordinators

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Collaborative Program

This is an interdisciplinary, multi-institutional collaborative research program which involves INRAN and U.S./INTSORMIL institutions.

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 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/W. Due to USAID budgetary constraints, this PID was not funded.

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 in Wad Medani, Sudan, IN.E.R.A. in Burkina Faso, and the Purdue/Niger Applied Agricultural Research (NAAR) project.

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

Drought, insect pests, long smut and *Striga* are the major constraints in Niger. Extremely high soil temperature leads to difficult problems in crop establishment. 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

Examples of research progress findings - 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 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 the 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 xP3Kolo 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.

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 16 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 U.S. 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.

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 Maradi

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 at Purdue.

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. at Purdue with Dr. Hamaker.

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.

Mr. Abdoulaye Tahirou is currently at Purdue working on his M.S. degree with Dr. Jess Lowenberg-Deboer

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 West African countries.

Research Accomplishments

Socioeconomics - Abdoulaye Tahirou, Mohamadou Abdoulaye and J. Lowenberg-Deboer

During the 1993 agricultural season, the socioeconomics component of the INRAN/INTSORMIL collaborative research program has continued the investigation of sorghum by-products. The general objective of the study is to determine how by-products affect farmer decisions. This second year of data collection is intended to give a dynamic view of the system.

Data were collected in Dagarka and Kaku, the same two villages in the area of Birni N'Konni that were surveyed in 1992. The same 23 farmers were interviewed. Sorghum by-products were found to be an important part of the agricultural system in the area of Birni N'Konni. They are important in animal nutrition, and farmers get a certain cash revenue from them.

The average value of the sorghum stover at harvest (October) was 7752 fcfa per hectare. If the farmers can store their sorghum stover production until March, the average value is almost doubled to 14535 fcfa per hectare. Sorghum stover and stalks are commonly used for forage and energy. They are also used for fences and making beds. All the farmers in the sample report the use of sorghum stover as forage, about 80% for energy, 10% for fences and 25% (all at Kaku) for bed construction. Sorghum bran is used mainly for animal nutrition or sold.

Less than 30% of farmers interviewed in both villages responded that they could leave part or all the sorghum stover they produced on the field to help control wind erosion and/or maintain soil fertility. Farmers know that this can help control erosion, but the use of the stover short term benefits are important in this subsistence farming system.

Although many aspects are taken into account for the choice a sorghum variety, the first criteria tends to be the overall grain yield. Other aspects farmers look at when choosing a variety include: the color (especially the flour), the hardness of the grain (bran is more easily removed without damaging the grain from hard grains), the color of the stover and its quantity after the harvest.

It is essential that future economic evaluation of technologies in this area take into account the value of sorghum stover. Sorghum production in this area is mainly carried out through an intercropping system with millet and cowpea. Agronomic evaluation on-station or on-farm can help identify varieties suitable for intercropping.

Data collected in this survey are being used to develop a representative farm model for this area which includes both crop and livestock activities. The interaction between these two activities among Nigerien farmers is becoming more important especially now with the devaluation of its currency making imported inputs more expensive.

Entomology - Hame Kadi-Kadi, Ousmane Youm and Frank Gilstrap

In 1993, discussions were held with Mamadou Ouattara, Ouendeba Botorou and Hame Kadi-Kadi (INRAN), Ousmane Youm (ICRISAT), I. Bayoun and F. Gilstrap to develop collaborative plans to assess the sources of mortality for the millet head miner (MHM) in Sadore and Maradi. These plans called for Mr. Kadi-Kadi to come to ICRISAT-ISC in September-October, 1993, and receive short-term training from Mr. Bayoun and Dr. Youm on methods and techniques needed for 1994 research. However, Mr. Kadi-Kadi was unable to participate in the training. The work reported below was conducted entirely on and near the facilities of the ISC.

The millet head miner (MHM), *Heliocheilus albipunctella* (de Joannis), commonly causes significant crop losses of pearl millet, *Pennisetum glaucum* L., a primary food crop in Sahelian West Africa. MHM is an excellent candidate for demonstrating a control strategy that emphasizes effective natural enemies. It occupies a predictable habitat in an ecosystem with relatively consistent annual habitats, has one generation per year, attacks several host plants including wild millet, and across West Africa supports a relatively large guild of natural enemies. Our objective in this research is to evaluate natural enemies of *H. albipunctella*, and the results will serve to appraise tactics and develop a biological control strategy for *H. albipunctella*.

The following research is needed before biological control can be used as part of an integrated management strategy that deals effectively with MHM. During 1993-1996, we will conduct collaborative exclusion studies on MHM developmental stages in Sadore and Maradi, these data will be used to construct life tables for MHM. Our 1993 research provides baseline methods and initial results for planning 1994 experimentation. The 1993 experimentation consisted of cage exclusion studies and population monitoring at Sadore.

Exclusion experiments are essentially a series of paired plots in which natural enemies are excluded from one-half, and are allowed access to the other one-half (Control or Check). Survival is measured in all plots, and the differences between treatments are a direct measure of the natural enemies' controlling impact. Treatments can be modified in many ways to collect different kinds of pest mortality information. In 1993, we used caged exclusions that consisted of placing a physical barrier (i.e., panicle cage) over panicles in the plots. Openings were made in one-half of these cages to permit natural enemy ingress and egress. Different types of cage treatments were set up to evaluate enemies occurring on different MHM stages (i.e., eggs, early and late instars) separately. Treatments included (1) cages closed throughout panicle development, which excluded all natural enemies; (2) cages opened only during the egg stage, and then closed until the end of the season; (3) cages opened only during early MHM instars, and then closed until the end of the season; (4) cages opened only during development of late MHM instars; and (5) cages opened throughout panicle development. At the end of the season, millet heads were cut and MHM were counted.

Our results showed attacks by natural enemies have a very significant impact on mortality of MHM, and most of this mortality occurs during the late larval stages. Cages opened throughout panicle development had the same total number of surviving MHM individuals as closed cages. A significant finding from this first year of data is that we encountered relatively few species of enemies attacking

MHM. Two predators and two parasites were the most commonly recovered natural enemies.

The most common predator was Orius sp., a small anthocorid predator that attacks MHM eggs and early instars. The second most common was an ant that attacked full-grown larvae after they dropped to the soil to pupate.

The two commonly encountered parasites were both parasitic Hymenoptera. The most common parasite was an encyrtid, *Copidosoma* sp., an egg-prepupal parasite that attacks the MHM eggs and emerges as an adult from the MHM prepupa. This parasite is polyembryonic, i.e., one parasite egg produces offspring. An average of 394 (maximum = 802) adult parasites emerged from each parasitized MHM. The second most common parasite was a braconid, *Bracon hebetor*. *Bracon* is a gregarious ectoparasite that attacks late larval stages of MHM. Parasitism by *B. hebetor* occurs mostly late in the season, and can reach 80-90% of the total MHM population. Female *B. hebetor* attack late MHM instars, permanently paralyzing them. Some attacks result in the parasite ovipositing eggs externally on the MHM host. Studies in 1993 encountered many larvae killed by *B. hebetor* but without parasite eggs. Thus, *Bracon hebetor* functions ecologically both as a predator and as a parasite. *Bracon hebetor* has a short generation time and is polyphagous.

In 1994, we will continue these experiments, and conduct additional experiments as needed for an age-specific life table for MHM. These experiments will take a natural cohort of MHM and follow it through to the end of the season and then to the next season. We will then construct survival budgets for MHM, and characterize the portion of MHM population removed by natural enemies. Our research approach will consist of host exposure techniques, caged exclosures and natural population monitoring.

Cereal Quality - Moussa Oumarou,
Adam Aboubacar and Bruce Hamaker

The Cereal Quality Laboratory (LQC) at INRAN has conducted several surveys to determine the different methods of couscous preparation used in Niger. Two different locations were selected for the surveys. In one location (Maine-Soroa), three types of locally grown cereals (sorghum, millet and durum wheat) were used to produce couscous using the preparation method of that location. All three cereals were processed the same way and produced acceptable couscous. In the other location (Tera) couscous was produced using three millet varieties (C.I.V.T., SOUNA 3, and H.K.B. Tif) grown in 1992 at the Kollo station. Table 1 shows the physical and milling properties of the grains.

Four different processing methods were used to produce couscous and a macaroni type product. Two of the procedures, one for couscous and the other for macaroni were different from the other two only in the fermentation step. A sensory panel was used to evaluate the different products and their quality was found to be improved by fermentation. All processing steps were recorded in order to determine the best method(s) that could be used for a commercial production of couscous.

The LQC has also conducted a study on composite flour breads. Breads were made in collaboration with a local bakery at Niamey, using blend of 10, 20, 30, and 40% sorghum and millet flour with wheat flour. The results showed that incorporation of millet or sorghum flour up to 20% gave acceptable bread. At higher concentrations, the bread was heavier and tended to break easily. It was also found that increasing the proof time increased loaf volume. A sensory evaluation study indicated that consumers preferred the incorporation of millet flour over sorghum. Demonstrations of bread from composite flour were made to processors and government officials at a workshop organized by INRAN in Niamey.

Sorghum Breeding - Moussa Adamou,
Issoufou Kapran, Gebisa Ejeta and John Axtell

During the summer of 1993, several trials were conducted at the main INRAN stations at Maradi and Kollo, while *Striga* resistance testing was conducted at the Konni station. In addition, demonstration plots were conducted by a large number of farmers, especially around Maradi and Konni. In all cases, the results were very satisfactory, with new elite material being observed on-station and farmer interest in the demonstration plots on the rise. It was therefore decided to keep the breeding project at least at the same level of activity for 1994. For this crop season, most of the genetic material was provided by the Purder University/INTSORMIL program, and some was also provided by Nebraska.

The germplasm from Purdue covers many aspects of sorghum improvement, including early generation material for pedigree selection, elite lines for adaptation/observation in Niger, hybrid yield trials to evaluate the performance of new R and B lines, on-station testing of new *Striga* resistant lines and a *Striga* resistance population, and aspects of

Table 1. Physical and milling properties of three millet samples.

Cultivar	Percent vitreousness	1000 kernel weight	Decortication yield	Broken kernels %
C.I.V.T.	50	9.0	56.6	6.0
Souna 3	50	6.5	54.3	21.2
HKB Tif	20	9.0	64.8	6.0

hybrid seed production and on-farm testing. Following a conversation with I. Kapran, Prof. David Andrews provided some new lines and hybrids for comparison with other INRAN/INTSORMIL germplasm. Conduct of these trials and nurseries was discussed in early June 1994 at Niamey, Kollo and Maradi between I. Kapran and Dr. Moussa Adamou, Issoufou Kollo for the *Striga* tests, and the two sorghum technicians M. Abdou and N. Kondo. Except for Kapran, on study leave at Purdue, these individuals are primarily responsible for the field work in Niger. Actual planting was started toward the end of June, and to date the rainfall figure has been exceptionally high in almost all of Niger. In fact, flooding has occurred on the heavier soils of the two main INRAN stations at Kollo and Maradi, as well as on some of the on-farm plots. Still, preliminary observations suggest that at least on the drier soils, nurseries will provide interesting data. Experimental hybrid seed production continues at several locations to provide more seed for future demonstration plots, as well as mastering the best nicking scheme between the parents of NAD-1 hybrid. Field days are once again scheduled for early October to provide more farmers the opportunity to visit other demonstration plots and research plots in nearby INRAN stations.

Plant Pathology - Issoufou Kollo
and Richard Frederiksen

Cooperation with ICRISAT was continued through the joint International Anthracnose Virulence Nursery. The enhanced collaboration stems from the recognition of the importance of this disease in the more humid sorghum growing regions of the developing world. Anthracnose collaboration permits the better evaluation of the durability of host resistance and a better estimate of the variation in pathogenicity among isolates of the pathogen worldwide. Participating regions include West Africa, Mali and Niger; East Africa, Sudan; Southern Africa, Zambia and Zimbabwe; and Brazil. Our work has demonstrated that there is tremendous variation among isolates from locations and between locations. Sorghum downy mildew has become less and less of a problem because of global cooperation in the development of host resistance, characterization of isolates and through the use of highly effective fungicide seed dressings. RFLP and RAPD markers linked to head smut, downy mildew, and acremonium wilt resistance have been placed within specific linkage groups on the sorghum genome. In 1991, a new product with a mixture of pesticides was developed that has the potential of inexpensively controlling downy mildew of pearl millet. Preliminary data are remarkably impressive. Work on the product Apron Plus® is being conducted in Niger and was proposed in Sudan. In Niger, 180 on-farm tests have shown an average yield increase for pearl millet of 18% with the application of Apron Plus®.

South America (Colombia/CIAT)

Lynn M. Gourley and Guillermo Muñoz
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Institutions Involved

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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 (IDIAP)
Fondo Nacional de Investigaciones Agropecuarias (FONAIAP), Venezuela
Private sector, including national and multinational seed enterprises

Collaborative Program

Introduction

This is a terminal report for the INTSORMIL Colombian Prime Site. This Prime Site was terminated and INTSORMIL activities merged with the Honduran Prime Site on June 30, 1994 by INTSORMIL, primarily because of USAID travel restrictions to Colombia. This report will summarize the Colombian Prime Site's activities and productivity since its inception.

Program Implementation

This collaborative research project operated in Colombia under four formal and several informal agreements which facilitated 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, 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.

Through a 1988 INTSORMIL buy-in, research was initiated in the acid savannas of Arauca by means of 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 nonprofit organizations such as 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 FEDEARROZ.

The INTSORMIL collaborative research project, MSU-111, was managed by the Office of International Programs, Mississippi State University.

Interdisciplinary Research

This Prime Site was originally established to conduct breeding research on problems relating to acid soil production constraints of sorghum and pearl millet. The research was initiated in 1982 by Dr. Lynn M. Gourley, MSU-104 PI. Plant breeders at all INTSORMIL institutions have had germplasm evaluated at this site through germplasm exchange. Specific long-range research goals in Colombia had included breeding for acid soil tolerance (MSU-104), pearl millet (UNL-118 and KSU-101), drought tolerance (TAM-122), pathology (TAM-124), and grain quality

(TAM-126 and PRF-103B) investigations. Some entomology input was provided by MSU-105.

The MSU-111 project (also terminated on June 30, 1994) operated from CIAT, near Palmira in the Cauca Valley, where multinational seed companies have most of their experiment stations. Through CIAT infrastructure, the project had established linkages with most public and private research programs, and NARS of other Latin American countries.

The major center for seed increase and distribution was at CIAT, Palmira. In contrast, breeding activities took place at different sites in the Colombian Eastern Plains (Llanos Orientales), where soils with different levels of Al saturation are found in both well-drained and poorly drained savannas. The project used 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 collaborated in agronomic and breeding research, according to established objectives.

Because of the diversity of collaborating institutions, the project conducted more than just acid soil tolerance breeding research. For example, FENALCE developed lines for semi-arid areas (TAM-122) and lines resistant to grain molds. ICA developed drought-tolerant lines, adapted to acid soils and resistant to grain molds (TAM-124). The universities conducted research in agronomy and physiology (UNL-114), and entomology (TAM-125 and MSU-105). The El Alcaraván Foundation developed germplasm adapted to acid savannas and slightly acid soils (vegas). The Foundation was also interested in grain quality and utilization (TAM-126 and PRF-103B). Most of these research activities were conducted by scientists from ICA or the private sector, supported by undergraduate students working on 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. In-kind funds for the project were also obtained from contributions of collaborating research institutions, and directly from the private sector. Funds from these sources often amounted to more than those received directly from INTSORMIL. Colombia has an USAID representative only, thus no Mission funds were available.

Operational funds for the MSU-111 project were transferred from MSU to CIAT and were accounted for as an externally funded project. CIAT also managed the El Alcaraván account for INTSORMIL. Although the amount of real money provided by other collaborating institutions was small, the strong cooperation among them resulted in their absorbing most of the fixed costs, thus reducing INTSORMIL's share of the overall costs considerably.

The El Alcaraván Foundation supplied almost U.S. $600,000 operational funds and another $600,000 in-kind support, during 1988-1994 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 provided 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 represented over a 4:1 leveraging of INTSORMIL's financial support.

Collaboration with Other Organizations

International Centers

The selection of the International Center, CIAT, as the operational headquarters for the Colombian Prime Site research was ideal. The student training program and CIAT's outreach programs throughout Latin America kept INTSORMIL's sorghum and millet research very visible. Collaboration with ICRISAT Center and ICRISAT's outreach programs in Mexico (CIMMYT) and SADC in Zimbabwe contributed to the success of this project. At the time the INTSORMIL program in Colombia was terminated, CIAT, ICRISAT and INTSORMIL were attempting to get funding from the Latin American Bank for a joint acid soil research project.

Since 1982, CIAT and ICRISAT have supported International Workshops in Colombia concerning sorghum and millet research. In 1984, CIAT provided facilities and other support for the Workshop "Evaluating Sorghum for Tolerance to Al-Toxic Tropical Soils in Latin America" and in 1991 for the Workshop "Sorghum for the Future." CIAT has supported the project in several other ways: administratively, CIAT staff time, 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 breeders' 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 many 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 soil regions.

Most Latin American countries are privatizing and opening their economies to outside trade. 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.Sc.) 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 working relationship was established with CIAT, facilitating research 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 met annually to establish work plans.

Since 1988, relations among the institutions involved in Colombian sorghum research became complex, requiring careful coordination of research activities. Specific short- and long-term goals were developed jointly with INTSORMIL Projects MSU-111 and MSU-104, ICA, El Alcaraván, FENALCE, and the Colombian universities. Formal planning meetings were held annually to discuss specific experiments, organizational funding, and individual responsibilities. Results were published annually, and distributed among those involved.

Sorghum/Millet Constraints Researched

Constraints

The main overall constraint to sorghum production in Latin America is the high cost of production. Most sorghum has been grown on high value land, making production of this crop a nonprofitable enterprise. One method of reducing production costs was incorporating marginal lands into the production system. This low-value land has production constraints including the poor distribution of water, soil acidity, and high Al saturation, presence of pests and diseases, periods of excessive rainfall with high relative humidity, and other related agronomic problems. Thus, sorghum production in these areas required the development of varieties or hybrids adapted to the specific ecological problems prevalent in each region.

In spite of the constraints encountered in these marginal areas, the amount of land available is such that the acid, well-watered savannas of Latin America constitute the main potential region for sorghum production. Acid, infertile soil savannas account for more than 10% of the land area in Latin America and the Caribbean. Some 76 million hectares of well-watered savannas are currently available for more intensive cultivation in the future in Colombia alone. Farmers throughout the region require low-input technology and research information to avoid resource degradation problems; thus work to develop sustainable agricultural systems becomes a mandate.

Research Methods

Standard research methods were used for all the breeding related activities in Colombia. Early generation breeding material was received each year from MSU-104 and was evaluated in each of the levels of Al saturation established. This germplasm was screened in several locations by all the participating institutions. A full set of germplasm was sent to ICA and the El Alcaravan Foundation and was screened for acid and nonacid soils. The pedigree system of plant breeding was the main breeding method used.

Sorghum breeding lines, and sorghum and pearl millet yield trials were grown on acid soil field plots in which purchased inputs have been added in low quantities. This resulted in the severe stunting or killing of Al-susceptible genotypes. This stress-breeding technique was being employed by INTSORMIL and ICA breeders and has proven effective in selecting acid soil tolerant genotypes.

Evaluation of INTSORMIL breeding lines and hybrids for tolerance to drought was conducted in collaboration with ICA Experiment Stations at Motilonia and Nataima.

Research Progress

Research progress was excellent until the Colombian Prime Site was discontinued. Due to travel restrictions, this country program was the smallest within INTSORMIL in terms of number of PIs involved. Since MSU-111 and MSU-104 were both breeding projects, INTSORMIL's involvement was primarily breeding while ICA's role was more in other disciplines and included some extension activities.

ICA and the El Alcaravan Foundation, with INTSORMIL'S support, released two acid soil tolerant sorghum cultivars in 1993 which are adapted to growing conditions in Arauca in the Colombian Eastern Plains. The cultivars have been named Icaravan 1 (IS 3071) and Icaravan 2 (IS 8577). Icaravan 1 is exceptionally hardy and has produced more than 3 t ha^{-1} grain under low fertilization levels and when the Al-saturation level is 60% or less. It also tolerates partial flooding after flowering - an essential characteristic in poorly drained savannas. Icaravan 2 is very tolerant to Al toxicity and has good agronomic characteristics when grown under Arauca's soil and climatic conditions.

FEDEARROZ and ICA announced the release of a hybrid for the dry Caribbean region of Colombia, which uses an A-line from the INTSORMIL MSU-104 project and an R-line from Texas A & M University. Hybrids using one or both parental lines developed in Colombia are currently being evaluated in many countries with acid and/or infertile soils. Since 1990, experimental sorghum hybrids using lines developed in Colombia have been evaluated in east Africa. The bird resistant germplasm being developed by the INTSORMIL Colombian program is similar to that used throughout many areas in Colombia and in western Kenya and throughout Uganda is used for food. Several of these hybrid combinations are in the final stages of evaluation before being released to farmers.

Mutual Research Benefits

National and multinational seed companies in Latin America will use the technology generated from this collaborative project to produce acid-soil tolerant varieties and hybrids. The release of Al-tolerant inbred lines would have also expanded the agricultural industrial market in the U.S. FEDEARROZ and ICA have released a hybrid for the dry Caribbean region of Colombia, which uses INTSORMIL inbreds. In 1994 the Kenya Seed Company, a partially government owned organization, entered two sorghum hybrids in the Kenya National Performance Trials. These hybrids are made by using an A-line from Texas A & M University and two acid soil tolerant R-lines from MSU-104 germplasm developed in Colombia. Also, a world collection sorghum line identified as being superior in Colombian trials is currently being used in a commercial hybrid in the U.S. and in southern Africa.

Institutional Building

Research Support

The research and extension organizations in Colombia have been strengthened by the INTSORMIL program at this Prime Site. The PIs of MSU-111 and MSU-104 have helped to organize and coordinate the sorghum improvement program into a comprehensive coordinated effort. 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 other supplies. INTSORMIL has also provided assistance in statistical analysis. Periodically, it provided scientific information on innovations in sorghum research, and financed scientists who worked directly with INTSORMIL to visit CIAT to use its excellent library and to learn the most up-to-date research techniques. INTSORMIL also financed ICA's sorghum scientists to attend occasional meetings on scientific advances and problems in sorghum production within Colombia and in other countries. Annual meetings were held on specific themes of importance to the country and/or Latin America. These meetings brought together outstanding scientists, keeping them up to date on the latest research advances in sorghum.

When the INTSORMIL MSU-111 project was terminated, all of the equipment, supplies, and sorghum and millet germplasm in the project was donated to ICA. Because of the close association formed with the Colombian sorghum and millet scientists, it is understood that some contact between INTSORMIL and the Colombian program will be maintained in the future.

Research Investigator Exchanges

Many sorghum and millet researchers and administrators from national and international institutions and private seed companies have visited the acid soil field screening nurseries at CIAT-Quilichao, ICA-La Libertad, and El Alcaravan and ICA-Arauca. The many visitors at CIAT get an opportunity to see the INTSORMIL sorghum and millet breeding nurseries at CIAT-Palmira. This project has also been instrumental in providing support for Colombian and other Latin American scientists to attend meetings and workshops outside of Colombia.

Human Resource Development

At the time the Colombian program was terminated, 17 Colombian students had conducted their thesis research using sorghum and millet and received their B.Sc. degrees from National Universities with INTSORMIL's assistance. An additional five students were collaborating with INTSORMIL and will complete their B.Sc. degrees with the assistance of CIAT senior staff. Postgraduates from Colombia, or those who conducted research in Colombia, include four M.S. and seven Ph.D. students, which were granted their degrees from INTSORMIL Universities. The number of Colombian graduate students currently in INTSORMIL universities and conducting research on sorghum and millets is unknown.

Networking

This Prime Site was informally linked with many countries in South and Central America and in Africa in which CIAT conducts research. Over the years, cooperative research linkages were established with the national research programs of ICA-Colombia, EMBRAPA-Brazil, CENIAP-FONAIAP-Venezuela, INIPA-Peru, and IDIAP-Panama. These countries are in the major acid soil areas and are conducting research to solve soil acidity problems. This collaborative linkage network unified INTSORMIL researchers and host country scientists to solve a common problem in the region through exchange of germplasm, research result dissemination, technical consultation, training, and workshops.

The INTSORMIL Colombian Program, headquartered at CIAT, promoted and established a Latin American network.

International Workshops held in Colombia were developed and coordinated by INTSORMIL PIs in 1984, 1991, 1992, and 1993. Involving both public and private sectors at national and international levels, the network emphasized the introduction, exchange, storage, increase, and distribution of germplasm. The network planned to 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.

Research Accomplishments

The ICA-INTSORMIL collaborative research has resulted in the release of four Al-tolerant varieties. The first two varieties released in 1991, Sorghica Real 60 (MN 4508) and Sorghica Real 40 (156-P5-Serere 1), have consistently produced high grain yields on acid soils in both cropping seasons during the year. ICA and the El Alcaravan Foundation, with INTSORMIL support, released the second two acid soil tolerant sorghum cultivars in 1993, Icaravan 1 (IS 3071) and Icaravan 2 (IS 8577), which are adapted to growing conditions in Arauca in the Colombian Eastern Plains. To date, six commercial seed companies have requested 100 t of foundation seed to be increased and sold to local farmers.

A SEPON line developed by ICRISAT and taken through U.S. quarantine by MSU-104 has been released as a high yielding sorghum variety in Niger. In collaboration with INTSORMIL breeders at Purdue University, the line was selected from the MSU-104 winter nursery grown at CIAT and sent to Niger for evaluation and eventual release.

Hybrids using one or both parental lines developed in Colombia are currently being evaluated in many countries with acid and/or infertile soils. At least three commercial sorghum hybrids, using a line developed or identified by the INTSORMIL PIs working in Colombia, are being grown in Colombia, the U.S., and in southern Africa. Since 1990, experimental sorghum hybrids using lines developed in Colombian have been evaluated in east Africa. In western Kenya and throughout Uganda, the bird resistant germplasm used throughout many areas in Colombia is used for food. Several of these hybrid combinations are in the final stages of evaluation before being released to farmers.

Since the Colombian Prime Site was established, approximately 28 theses and dissertations of research conducted on sorghum and millet have been published by students from Colombia or other nationalities completing their research in Colombia. In addition, two books, 11 chapters in books, the proceedings of six International Workshops, and 46 other publications on sorghum and millet relevant to the activities of the Colombian PIs, or their collaborators, have been published. Approximately 22 invitational papers and 40 other presentations, mostly concerning the acid soil research, have been made by the Colombian PIs, or their collaborators, at professional meetings.

In summary, the land area with infertile soil is growing throughout the world due to nutrients not being replaced after they are removed in the harvested grain and stover. INTSORMIL PIs at the Colombian Prime Site have been very successful in developing a theory about the possibility of finding genetic diversity for tolerance to low pH soils and incorporating this tolerance into sorghum cultivars which are now in the hands of farmers trying to support their families on these marginal lands.

The credit for the success of the INTSORMIL Colombian Prime Site should go to the INTSORMIL Board of Directors and committees which supported this project through funding for 11-1/2 years, the National Program ICA, the International Center CIAT, and to the PIs who lived and conducted the research throughout Colombia. The project was initiated by Dr. Lynn M. Gourley who served as PI from November 1982 until December 1984 and again from March 1987 until June 1988. Dr. Catalino I. Flores was PI from January 1985 until February 1987 and Dr. Guillermo Munoz from July 1988 until the Colombian Prime Site was terminated at the end of June 1994.

Southern Africa
(Botswana, Zimbabwe, Namibia, Zambia)

M.D. Clegg
University of Nebraska

Coordinators

Dr. Max Clegg, Department of Agronomy, University of Nebraska, Lincoln, NE 68583
C. Manthe, Entomologist, Botswana
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D. Malepa, Plant Pathologist, Botswana
P. Disipi, Plant Pathologist, Botswana
E. Mtisi, Plant Pathologist, Zimbabwe
K. Leuschner, Entomologist, ICRISAT/Motopos, Zimbabwe
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B. Nath Verma, Sorghum Breeder, Zambia
G. Kaula, Plant Pathologist, Zambia
M. Chisi, Sorghum Breeder, Zambia
W. Lechner, Chief Ag Officer, Namibia
S. Iipinge, Millet Breeder, Namibia
S. Niitembu, Agronomist, Namibia
J. Matanyaire, Extension, ICRISAT/Namibia
D. Andrews, Millet and Sorghum Breeder, University of Nebraska
G. Odvody, Plant Pathologist, Texas A&M University

Collaborative Program

The INTSORMIL collaborative research program in southern Africa is in transition from using an expatriate scientist to coordinate activities in Botswana to direct INTSORMIL U.S. Principal Investigators collaboration with host country scientists in several southern Africa countries. This transition has been slow because of budgetary constraints and logistical/communication difficulties.

Organization

After termination of the ATIP project which included financial support for the expatriate scientist, the new mode of operation for Botswana and southern Africa was for U.S. and host country scientists to form joint partnerships and prepare research proposals to access INTSORMIL funds allocated for this region. Unfortunately, these funds were eliminated because of INTSORMIL funding constraints, thus, collaborative research during 1993-94 was direct scientist to scientist collaboration with funding coming from U.S. INTSORMIL Principal Investigators budgets. These results are presented in the individual project reports.

Financial Inputs

Due to USAID budget reductions, only $10,000 was allocated for 1993-94 and was used for U.S. and host country scientists' travel.

Collaboration with Other Organizations

Collaborative activities are continuing with the ICRISAT Southern Africa Center located in Bulawayo, Zimbabwe. A regional sorghum/millet research network has been developed in the SADC countries with support from SMIP (Sorghum/Millet Improvement Program). Host country scientists are becoming more active in this network.

Sorghum/Millet Constraints Researched

Production Constraints

Sorghum and pearl millet are important crops in the SADC countries, with both grain and stover being widely used. The grain is used mainly for human food, but some grain and the stover are used as livestock feed. During the 1980s, farmers yields have averaged less than 500 kg ha^{-1}. These low yields partially reflect crop failures when no grain was harvested. It also reflects the low natural level of soil fertility, and the limited use of fertilizers and/or crop rotation. To reach the critical yield level of 1.5 to 2.0 Mg ha^{-1}, a crop uptake of 45 to 60 kg ha^{-1} N, and 16 to 20 kg ha^{-1} P is required regardless of the cultivar or production practices used.

The low, irregular, and low-efficiency rainfall patterns of the region combined with sandveld and hardveld soils with low water retention and poor weed control also contribute to the low yields of sorghum and millet. In some instances, broadly soil texture fractions (i.e. coarse sand, fine sand, silt, clay) and unstable surface soil properties result in a high bulk density (compaction) when dry, and surface sealing with crust formation. This slows the infiltration rate of rain and limits crop root penetration.

Water conservation and redistribution technologies, soil fertility improvement, residue incorporation, and weed control are urgently needed to improve soil structure and water conservation for crop establishment, and production of higher grain and stover yields.

Research Methodology

Individual INTSORMIL principal investigators are conducting research on agronomy, entomology, food science, plant breeding and plant pathology. This research is reported in the principal investigator's individual reports.

Research Progress

Botswana

The are two large, distinctly different clientele for sorghum production in Botswana. One is the small family farmer who uses sorghum primarily for food and brewing, and the other is the large farmer who has the resources to utilize hybrid sorghum seed, fertilizer, and large equipment for sorghum production. The latter is generally located in the Pandamatenga region.

Several sorghum hybrids, and sorghum and pearl millet varieties are scheduled to be released soon. They all will be cultivars with good food quality characteristics, and are presently being rated for insect and disease resistance/tolerance by INTSORMIL and host country plant pathologists.

The 1993-94 cropping season was characterized by farmers having problems with poor stand establishment and severe drought. Farmers who had prepared their land early and planted at the proper time had average crops. Many farmers plowed and planted too late resulting in very poor stands. Research with seed dressings (fungicides plus insecticides) resulted in improved sorghum stands. Early plowing (first rain) combined with continued weed control until a December planting rain, resulted in increased sorghum yields.

Zimbabwe

The sorghum program has developed three early maturing seed parents from UNL-115 which initially was grown in Sebele. Selections from Botswana Serere 6A had also performed well in Namibia.

Male sterility in finger millet has been developed and is easily recognized. Seed set on unbagged male sterile heads shows 5-10% crossing which will occur with fertile plants in adjacent rows. This is sufficient for random mating and convenient for 'marking' sterile plants. Higher levels of seed can be obtained by deliberate pollination.

Screening of sorghum breeding materials found that lines having SC326-6 and SC120 in their background generally had better resistance to leaf blight than local and other improved cultivars.

Namibia

The national research focus is on breeding and agronomy of pearl millet. The national breeding program is comprehensive in its objectives, and David Andrews provides technical support to host country scientists. Agronomy and fertility experiments are in progress using cattle manure (kraaling overnight) and/or different levels of N and P fertilizers.

Zambia

Various plant disease problems were observed at Mansa, Mt. Makulu, and Golden Valley. At Mansa, anthracnose studies are being emphasized. At Mt. Makulu, viral necrosis ranged from 30-60% among the cultivars present. Severity of incidence ranged from minimal to 50% necrosis of leaves. At Golden Valley, sooty stripe destroyed 60% of the leaf tissue on susceptible cultivars. Research is being conducted on the use of seed treatment for control of sorghum downy mildew (SDM).

Mutual Research Benefits

Food types of sorghum and pearl millet have been developed for the U.S. using germplasm from southern Africa. Plant breeding techniques and soil fertility practices developed in the U.S. are being utilized for improving agricultural production in southern Africa. Emphasis on sustainable agriculture research will lead to improvements in crop production management strategies for both the U.S. and southern Africa.

Value added benefits for sorghum grain will be obtained from studies on use of sorghum flour in products such as noodles, and improved malting characteristics of grain. Progress is also being made to include sorghum flour and malting characteristics in breeding and selection programs.

Institution Building

The 10-year SADC/ICRISAT/INTSORMIL training program was completed in Sept 1993. Nine southern Africa countries were involved with 81 students trained. Former students have returned home and became productive scientists within their national programs. Some former students have moved into administrative positions, and others into the private sector. Inaccessibility to current literature, new technology, and maintaining contact with scientists in their professional disciplines are constraints which affects the research productivity and morale of scientists in host countries. It has been proposed that short term developmental leaves (5 months or less) to U.S. universities, or possibly other public/private facilities, be available on a competitive basis. This would enhance scientist research capabilities.

Several INTSORMIL Principal Investigators continue to maintain collaborative research programs with national scientists in southern Africa. They include Prof. David Andrews in Plant Breeding; Dr. Max Clegg in Agronomy; and Dr. Gary Odvody in Plant Pathology.

Networking

Participation of the host country and INTSORMIL scientists in the SADC/ICRISAT Sorghum and Pearl Millet Research Network is increasing.

Electronic mail linkage between national research institutions and universities (both host country and U.S.) is almost a reality. A sorghum/pearl millet bulletin board on Internet would be an excellent vehicle for networking among southern Africa scientists.

INTSORMIL Principal Investigators, David Andrews and Gary Odvody, made trips to the southern Africa region to work with collaborating scientists. Chris Manthe participated in the USAID/CRSP review in Nairobi, Kenya.

Research Accomplishments

The southern Africa INTSORMIL site is in transition from an expatriate scientist located in Botswana to a collaborative mode between host country and INTSORMIL scientists. Thus, several research projects are being initiated, and past accomplishments are contained in the 1993 Annual Report. Individual Principal Investigator accomplishments are reported in project reports found elsewhere in this Annual Report.

Sudan

Gebisa Ejeta
Purdue University

Program Coordinators

Gebisa Ejeta, Country Coordinator, Department of Agronomy, Purdue University, West Lafayette, IN 47907
El Hilu Omer, Agricultural Research Corporation, 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 Dr. Badir Salim, 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 his 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 basically nonexistent, 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, 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 and Abdel Moneim Taha, ARC; 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 have been adequate and appropriate. Technical support has always been good. Laboratory facilities are modest and supplies have always been short. 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

Sorghum Breeding

Osman El Obeid Ibrahim

During the 1993 crop-season, the sorghum breeding program at Gezira Research Station (GRS) ARC, continued to concentrate on hybrids and varietal development and evaluation. Major emphases were placed on hybrids and varieties with multi-location testing. The varietal breeding nurseries included new crosses, establishment of F_1 plants, advancement of segregating generations and evaluation of converted lines, drought tolerant parental lines and backcross progenies as part of ARC/ INTSORMIL Collaborative breeding research. Varietal trials at GRS included evaluation of advanced (36 entries) and preliminary (176 entries) trials for yield potential and/or drought tolerance.

The hybrid breeding nurseries included evaluation of new parental lines and synthesis and evaluation of new experimental hybrids. The hybrid trials included advanced (72 entries) and preliminary (144 entries) tests. The ARC/ INTSORMIL collaborative joint trial for 1993 crop-season, contained 126 sorghum hybrids and their parental lines, and was conducted under irrigation and rainfed situations at GRS.

As a result of several years of on-station varietal and hybrids development and evaluation, several promising experimental varieties and hybrids were identified and advanced to on-farm and standard levels of multi-location trials during the 1993 crop-season. The on-farm test contained one hybrid and two open pollinated varieties. The standard test included 11 varieties and 15 hybrids. Multi-location testing was extended to cover eight irrigated and four rainfed locations. Two open pollinated varieties and one hybrid, showed good and stable yields, namely 89/OSFS 2431 under irrigation and high rainfall zones, P-967083 under Jebel Marra conditions, and 89/OSH 5283 under irrigation. These cultivars will be considered for submission to the National Variety Release Committee, hopefully, during 1994/95.

As a result of intensive breeding work in the last ten years, several promising elite varieties and hybrids have been accumulated in the program. However, testing of these materials has been restricted to limited numbers of locations and agroecological zones in the country. There is a pressing need for intensifying the testing program to cover more locations and agro-ecological zones, especially in traditionally sorghum-growing rainfed areas, where the bulk of the crop is produced. Another factor slowing or discouraging the release of new products, especially hybrids, is the lack of a viable seed industry. Farmers, especially in irrigated production areas, have come to highly appreciate the concept and value of pure and or improved seeds, which should encourage the development of seed industry in the country.

Striga Research

A.G.T. Babiker, S.M. Eltyeab
and M.T. El Mana

On-farm and on-station trials were undertaken on irrigated and rain grown sorghums. The objective of the on-station trials was to develop control measures which are effective during the early subterranean stages of the parasite growth. The objective of the on-farm trials was to demonstrate to farmers and extension workers the technical feasibility of some of our previous findings.

Sorghum trials were planted in an artificially *Striga*-infected plot. Improved lines obtained from Purdue University, as well as local popular high yielding varieties were used. Urea (190 kg/ha) was applied at planting. Chlorsulfuron (2.4g/ha) was applied 4 weeks after planting as a soil directed spray. *Striga* count was made 75 days after planting. Lines tested were PR 227, PR 239, PR 269 and PR 293. Dabar (*Striga* susceptible) and SRN 39 (*Striga* resistant) were included as controls. *Striga* population density varied between 7 and 39 plants/m^2. PR 269, PR 239 and SRN 39 sustained the lowest emergence (7-14 plants/m^2) while Dabar had the highest emergence (39 plants/m^2). Urea reduced infestation by 52 to 86%. Infestation on PR 269, PR 239 and SRN 39 was the most reduced, while that on Dabar was the least affected. Chlorsulfuron reduced *Striga* infestation by 68 to 94%. The herbicide suppressed *Striga* infestation about equally on all varieties, except on PR 293. *Striga* reduced crop stand. Dabar was the most affected, while SRN 39 was the least. Urea mitigated the adverse effects of *Striga* on sorghum in all varieties, except on Dabar and on PR 293. Chlorsulfuron, on the other hand, resulted in a substantial increase in crop stand, irrespective of the variety used. The parasite delayed heading in all varieties. Urea and chlorsulfuron, invariably, increased the number of heads. Among all varieties, Dabar and PR 293 were the least responsive to the herbicide and fertilizer. SRN 39, PR 227 and PR 269 showed about equal response to both herbicide and fertilizer. *Striga* reduced straw yield of all varieties. Untreated SRN 39 and PR 269 had the highest straw yield, while Dabar and PR 293 displayed the lowest yield. Urea and chlorsulfuron mitigated the adverse effects of *Striga* on straw yield. Dabar and PR 293 displayed a low response to urea, while PR 269 was highly responsive. Across varieties, chlorsulfuron was more effective than urea.

The local varieties Gadam EL Hamam, AjabSedo, Iriana, Korakolo; Safra, SRN 39 and Tetron were also tested in a separate experiment. Compared to the *Striga* resistant variety (SRN 39), the local varieties supported two to three fold greater *Striga* emergence. *Striga* emergence was reduced by both urea and chlorsulfron. The suppressive effects of urea on *Striga* emergence was negligible on Ajabsedo, moderate on Iriana, Korakolo and Gadam EL Hamam and was good to excellent on Safra, Tetron and SRN 39. Chlorsulfuron was more effective against the parasite than urea. *Striga* emergence was moderate on AjabSedo and Iriana, low on Gadam EL Hamam, Korakolo and Safra and was negligible on Tetron and SRN 39. The stand of all varieties, except SRN 39, was reduced by the parasite. The highest reduction was displayed by AjabSedo, while moderate losses were exhibited by Iriana, Korakolo, and Safra. Urea, substantially, improved the stands of Korakolo, Iriana and AjabSedo. However, its effect on Safra was negligible. The herbicide improved stands of most varieties with more pronounced effects on Gadam EL Hamam, AjabSedo and Safra. Sorghum heading was considerably curtailed by the parasite as only 25 - 69% of plants produced heads. SRN 39 was the least affected. Urea and Chlorsulfuron improved heading in all varieties. Safra and Korakolo displayed the lowest and highest response to urea, respectively. Chlorsulfuron was more effective than urea. Among varieties, Gadam EL Hamam, AjabSedo, Iriana, Korakolo and Safra displayed the highest response. The parasite reduced straw yield of all varieties. Urea increased straw yield by 70 to 140%. Gadam EL Hamam, SRN 39 and Tetron were the most responsive. Chlorsulfuron increased straw yield by 80 to 560%. Chlorsulfuron-treated Tetron and SRN 39 gave the highest yield.

In yet another test, the hybrid Hageen Dura-1 (HD-1), Gadam EL Hamam, Dabar, AbuSabeen, Tozi Umbenein, SRN 39 and Mogud were evaluated. Emergence of *Striga* varied between 10 and 21 plants/m^2. The highest emergence was supported by AbuSabeen, Tozi Umbenein and Gadam EL Hamam. SRN 39, on the other hand, supported the lowest emergence. Urea reduced *Striga* infestation on all varieties except HD-1. *Striga* suppression varied from moderate (52%) on AbuSabeen to excellent (95%) on SRN 39. Chlorsulfuron effectively reduced *Striga* emergence on all varieties. Complete suppression of the parasite was achieved on SRN 39. *Striga* reduced crop stand. The observed losses were negligible on SRN 39 and Tozi Umbenein, but were severe on HD-1 and Abu Sabeen. Urea and Chlorsulfuron improved stand on all varieties except HD-1. *Striga* reduced heading in all varieties. Losses due to the parasite were heavy (78-79%) for HD-1 and Abu Sabeen and were negligible for Tozi Umbenein and SRN 39. Urea and chlorsulfuron increased heading in all varieties. Heading in HD-1 and Abu Sabeen was increased by two to four fold. The parasite reduced straw yield of all varieties except SRN 39 and Tozi Umbenein. HD-1, Abu Sabeen and Dabar displayed the highest losses. Urea and chlorsulfuron mitigated the adverse effects of *Striga* on straw yield, particularly that of the susceptible varieties. Straw yield of Abu Sabeen was increased by two to four fold.

An on-farm trial, in collaboration with the extension service, was undertaken at El Rawashda, a village north of Gadaref town. Sorghum (CV. Korakolo) was planted in early August, with rows 80 cm apart and spacing within the row 10 cm apart. The crop was later thinned to single plants per hill. Sorghum treated or untreated with urea at planting, was sprayed with a tank mix of chlorsulfuron (2.4g/ha) and dicamba (300 g/ha) or left untreated. The herbicides were applied as soil directed sprays, four weeks after planting. Sorghum planted late August was included as a control to reflect the farmers practice of late planting in *Striga* infested areas.

Sorghum sown early August was heavily infested by *Striga* (73 plants/m^2). Late August sown crop sustained a lesser infestation (25 plants/m^2). The tank mix of chlorsulfuron and dicamba, when not preceded by urea, effected 83% control. Urea treatments made prior to herbicide application increased herbicidal efficacy (95% control).

Untreated early sown sorghum gave low yield (0.39t/ha). Late planting of sorghum effected a higher yield (0.6t/ha). The tank mix of chlorsulfuron and dicamba, irrespective of the preceding urea treatment, increased sorghum yield to about 0.8 t/ha.

Sorghum-Millet Pathology

El Hilu Omer

Screening of Sudan germplasm for resistance to long smut was continued this season. Five hundred entries were planted as single lines and at boot stage were inoculated in the standard method reported before. Twenty cultivars were fairly resistant. These will be subjected to further confirmation tests during the 1994 season. None of the 21 cultivars introduced from Egypt and Syria proved tolerant to long smut.

New Seed Dressings Against Covered and Loose Smut

Vitavax, Celest, Divident, Captan and Apron®/Vitavax were tested against covered and loose smuts. Vitavax, Captan and Apron®/Vitavax at 200-300 cc/g/100kg gave excellent disease control, but were not dissimilar to the standard Fernasan D.

The two products, Tecto TM and Monceren Combi, were effective against covered and loose smuts and Apron Mix was effective against Pythium improved stand and gave higher yields than the untreated control, but were not significantly better than the standard.

Disease survey in six districts of Kordofan State indicated that downy mildew (*Selerospora graminicola*) on pearl millet is the most serious disease. Infection ranged from 16-80%. It was more prevalent in high rainfall areas, getting less in drier areas. Ergot (*Clavicepsfusilformis*) and smut *(Tolyposporium penicillariae)* are second to downy mildew in importance. Grow-out of farmers varieties, in Gezira Research Station, indicated that the seed plays a primary role in disease spread.

Sorghum Entomology

Four seed treatments were compared for assessing damage incurred to sorghum by insect pests before emergence and throughout the seedling stage. The most serious pests considered were mole crickets, termites, cutworms, soil weevils and to a lesser extent, white grubs. The seed dressings tested were Promet at 0.3, 0.4 and 0.5 ml/10 kg; Gaucho at 150, 100 and 80 g/100 kg and Lindane (standard) at 150 g/100 kg. An untreated control was added for comparison. The trial was carried out at Sim-Sim and Rahad Research Station. Row spacing was 60 cm. and 10 cm. between plant holes and 3 seeds/hole were used in replicated trial.

Higher rates of Pomet, Lindane and all rates of Gaucho gave good crop established and were significantly better than the untreated control but were not dissimilar to the standard. However, insect infestation was remarkably higher in rainfed areas compared to irrigated Rahad. In Rahad, delayed sowing gave higher infestation compared to optimum sowing date. Early sowing under irrigation, irrespect of the treatment, gave higher grain yield; 4517 kg/ha for July sowing as compared to 3048 kg/ha for August sowing.

Among chemicals tested for control of American bollworm, Damazine Thiodan 35 ULV at 2.38 l/ha was the best chemical for control of the pest and gave a significant higher yield than the unsprayed control. None of the 14 tested varieties and promising cultivars showed tolerance to stem borers but, HD-1 gave the lowest infestation.

Institution Building

The INTSORMIL/Sudan program has continued to provide direct allocation of funds to the Agricultural Research Corporation.

As a result of U.S. Government travel restrictions to Sudan, U.S. PIs did not travel to Sudan this last year. Collaborators continue to interact and exchange information through correspondence, however. The only major travel undertaken was made by Dr. Osman Obeid, sorghum breeder at the Gezira Research Station, Wad Medani, who traveled to the U.S. in August, 1993. Dr. Obeid came to attend the international workshop on "Adaptation of Plants to Soil Stresses," organized and held by INTSORMIL at the University of Nebraska, Lincoln. Dr. Obeid also traveled to Purdue University to work with Dr. Gebisa Ejeta on sorghum breeding related research.

Attempts to have a team of Sudanese sorghum and millet research collaborators travel to Nairobi, Kenya to meet and visit with the USAID/CRSP Review Team in June 1993 were unsuccessful because of visa restrictions by the Government of Kenya.

Networking

The Agricultural Research Corporation of Sudan, INTSORMIL's sole collaborator in Sudan, has an effective network for dissemination of research results to clientele groups. The many agricultural production schemes in Sudan are managed by well-trained agriculturists who interact with ARC scientists in both organized and informal forums.

Annual agricultural meetings are held where current research results are presented and emerging constraints are discussed. Both agricultural research and extension scientists from the Ministry of Agriculture attend these annual meetings. Sudanese scientists are also active participants in regional and international workshops where contemporary agricultural issues are discussed. Many Sudanese scientists hold leadership positions in regional networking activities. For instance, Dr. A.G.T. Babiker has been the leader of the Pan African *Striga* Control Network and attended meetings in Zimbabwe and Kenya in 1993.

Research Accomplishments

An itemized list of major accomplishments that resulted from INTSORMIL/Sudan collaborative efforts since the inception of the program in 1980 has been given in Year 14 report.

Significant research results of immediate benefit, that have resulted from Year 15 efforts include:

Identification of a superior experimental hybrid and two open pollinated varieties to be considered for national release, possibly in 1995.

Identification of improved high yielding *Striga* resistant varieties with significant yield superiority over the currently adopted variety, SRN-39.

Effective demonstration of the importance of nitrogen fertilizer and herbicides on *Striga* infertilization, particularly when used with a *Striga* resistant cultivar.

The superior performance of chemical products used as seed dressing for control of covered and loose smut of sorghum.

Varietal differences in response to chemical treatment of seed dressing for bollworm control has been shown.

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, 96 students from 33 different countries were enrolled in an INTSORMIL advanced degree program. Approximately 78% 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.

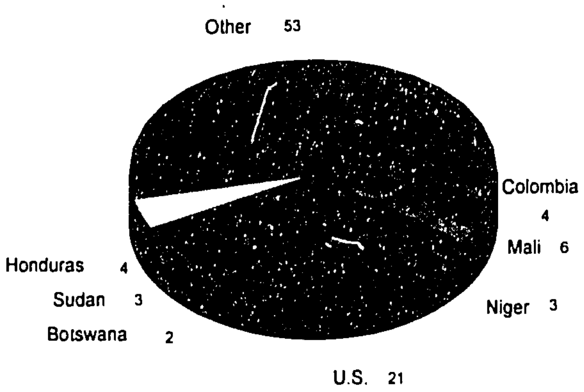
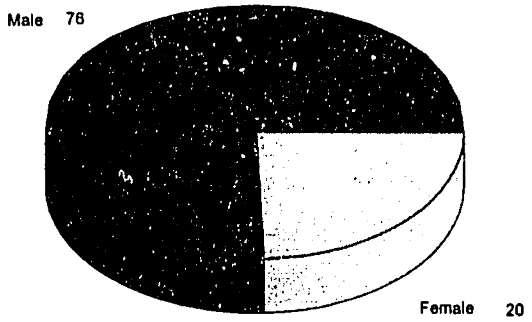
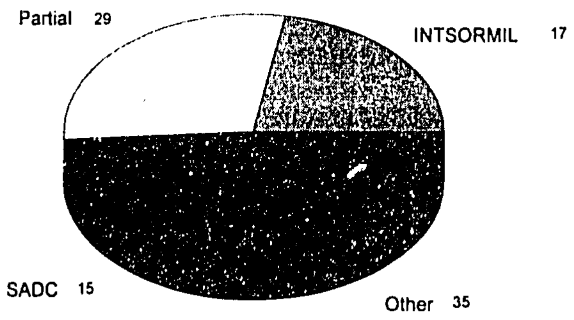


Figure 2. Training analysis - gender breakdown.



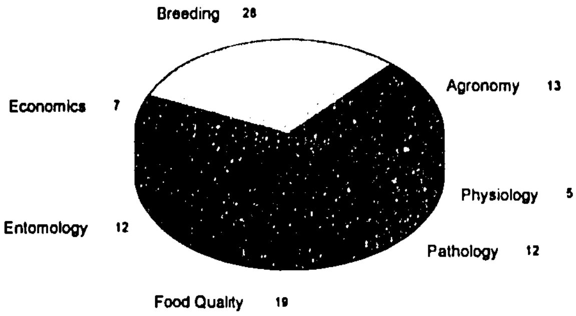
INTSORMIL also places a high priority on training women which is reflected in Figure 2. In 1994, 20% of all INTSORMIL graduate participants were female. Seventeen of the total 96 students received full INTSORMIL scholarships. An additional 29 students received partial INTSORMIL funding and the remaining 50 students were funded from other sources as shown in Figure 3.

Figure 3. Training analysis - source of funding.



All 96 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 increased slightly in 1993-94 as compared to 1992 and 1993. However, the number of INTSORMIL funded students has decreased gradually over the years.

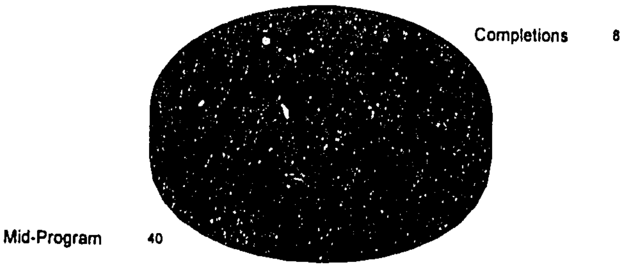
In addition to graduate degree programs, short term training programs have been designed and implemented on a case by case basis to suit the needs of host country scientists. Several Host Country scientists were provided the opportunity to upgrade their skills in this fashion during 1994.

INTSORMIL cooperated with ICRISAT on a ten year special training program for countries of the Southern African Development Community (SADC) which terminated in December, 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 Agricultural 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 40 for 1993-94 (Figure 5). SADC funds ended in December of 1993 and most students returned home prior to that date. Students remaining have acquired funding through other sources to complete their degrees.

Figure 5. SADC Training analysis - annual status.



The SADC/ICRISAT Southern African training program held a high profile in INTSORMIL training activities. Of 40 students matriculating in the U.S., Canada and Brazil, 15 are studying under INTSORMIL scientists while the remainder are with subject matter specialists not covered by INTSORMIL scientists. There were 8 degree completions in 1993.

The following tables are a compilation of all INTSORMIL training activities for the period July 1, 1993 through June 30, 1994.

Year 15 INTSORMIL Training Participants

Name	Country	Univ.	Discipline	Advisor	Degree	Gender	Funding*
Gono, Lawrence	Zimbabwe	KSU	Agronomy	Vanderlip	PHD	M	S
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	PHD	M	I
Maliro, Charles	Malawi	UNL	Agronomy	Clegg	PHD	M	S
Ennin, Stella	Ghana	UNL	Agronomy	Clegg	PHD	F	O
Uden, Loren	U.S.	UNL	Agronomy	Clegg	MSC	M	O
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
Ortega, Augustin Limon	Mexico	UNL	Agronomy	Mason	MSC	M	P
Stockton, Roger	U.S.	UNL	Agronomy	Mason	PHD	M	O
Kamau, Clement K.	Kenya	MSU	Breeding	Gourley	MSC	M	O
Ndulu, Lexingtons	Kenya	MSU	Breeding	Gourley	MSC	M	I
Odouri, Chrispus	Kenya	MSU	Breeding	Gourley	MSC	M	O
Okora, Julius O.	Kenya	MSU	Breeding	Gourley	MSC	M	O
Ouma, Josephine	Kenya	MSU	Breeding	Gourley	PHD	F	O
Kapran, Issoufou	Niger	PRF	Breeding	Axtell	PHD	M	O
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	P
Ibrahim, Yahia	Sudan	PRF	Breeding	Ejeta	MSC	M	I
Tuinstra, Mitchell	U.S.	PRF	Breeding	Ejeta	PHD	M	O
Weerasuriya, Yohan	Sri Lanka	PRF	Breeding	Ejeta	PHD	M	P
Gouveia, Sergio Jeremias	Mozambique	TAM	Breeding	Miller	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
Beder, Samy M.	Egypt	TAM	Breeding	Rosenow	VS[1]	M	O
Gebeyehu, Geremew	Ethiopia	TAM	Breeding	Rosenow	VS[1]	M	O
Toure, Aboubacar	Mali	TAM	Breeding	Rosenow	VS[1]	M	I
McCosker, Tony	Australia	TAM	Breeding	Rosenow/Peterson	VS[1]	M	O
Doumbia, Mamadou	Mali	TAM	Breeding	Peterson	PHD	M	O
Katsar, Catherine Susan	U.S.	TAM	Breeding	Peterson/Teetes	PHD	F	O
Jeutong, Fabien	Cameroon	UNL	Breeding	Andrews	PHD	M	O
Abdoulaye, Tahirou	Niger	PRF	Economics	Sanders	MSC	M	I
Ahmed, Mohamed	Sudan	PRF	Economics	Sanders	PHD	M	I
Chiche, Yeshi	Ethiopia	PRF	Economics	Sanders	VS[1]	F	O
Coulibaly, Ousmane	Mali	PRF	Economics	Sanders	PHD	M	O
Garcia, Joao Carlos	Brazil	PRF	Economics	Sanders	VS[1]	M	O
Lawrence, Pareena Gupta	U.S.	PRF	Economics	Sanders	PHD	F	I
Nichola, Tennassie	Ethiopia	PRF	Economics	Sanders	PHD	M	I
Calderon, Pedro	Honduras	MSU	Entomology	Pitre	MSC	M	I
Ching'oma, Godfrey	Malawi	MSU	Entomology	Pitre	MSC	M	S
Portillo, Hector	Honduras	MSU	Entomology	Pitre	PHD	M	I
Bayoum, Imad	Lebanon	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
Rojas, E.	Costa Rica	TAM	Entomology	Gilstrap	MSC	M	P
Roque, Javier	Mexico	TAM	Entomology	Gilstrap	PHD	M	P
Diarisso Yaro, Niamoye	Mali	TAM	Entomology	Teetes	PHD	F	O
Magallenes, Ricardo	Mexico	TAM	Entomology	Teetes	PHD	M	P
Mott, Dale Allen	U.S.	TAM	Entomology	Teetes	MSC	M	O
Paliani, Anderson	Malawi	TAM	Entomology	Teetes	MSC	M	S
Alkire, Mark	U.S.	PRF	Food Quality/Util	Butler	MSC	M	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

Name	Country	Univ.	Discipline	Advisor	Degree	Gender	Funding*
Aboubacar, Adam	Niger	PRF	Food Quality/Util	Hamaker	MSC	M	I
Buckner, Becky	U.S.	PRF	Food Quality/Util	Hamaker	PHD	F	O
Oria, Maria P.	Spain	PRF	Food Quality/Util	Hamaker	PHD	F	I
Weaver, Charlotte	U.S.	PRF	Food Quality/Util	Hamaker	MSC	F	O
Acosta, Harold	Colombia	TAM	Food Quality/Util	Rooney	PHD	M	P
Anderson, Brian	U.S.	TAM	Food Quality/Util	Rooney	MSC	M	P
Asante, Sam	Ghana	TAM	Food Quality/Util	Rooney	PHD	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
Lekalake, Rosemary	Botswana	TAM	Food Quality/Util	Rooney	MSC	F	S
Seetharaman, Koushik	India	TAM	Food Quality/Util	Rooney	PHD	M	P
Suhendro, Elly	Indonesia	TAM	Food Quality/Util	Rooney	MSC	F	P
Wright, Lee	U.S.	TAM	Food Quality/Util	Rooney	MSC	M	P
Diourte, Mamourou	Mali	KSU	Pathology	Claflin	PHD	M	O
Lu, Ming	China	KSU	Pathology	Claflin		M	O
Muriithi, Linus M.	Kenya	KSU	Pathology	Claflin	PHD	M	O
Narvaez, Dario	Colombia	KSU	Pathology	Claflin	MSC	M	O
Nzioki, Henry S.	Kenya	KSU	Pathology	Claflin	MSC	M	O
Anderson, Cindy	U.S.	KSU	Pathology	Leslie	M.S.	F	P
Huss, Martin	U.S.	KSU	Pathology	Leslie	PD[2]	M	P
Xu, Jin-Rong	China	KSU	Pathology	Leslie	PHD	M	O
Oh, Boung-Jun	Korea	TAM	Pathology	Frederiksen	PHD	M	O
Osorio, Jairo	Colombia	TAM	Pathology	Frederiksen	PHD	M	O
Mansuetus, Anaclet	Tanzania	TAM	Pathology	Frederiksen/Odvody	PHD	M	S
Rosewich, Ute L.	Germany	TAM	Pathology	Frederiksen	PHD	F	I
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	P
Nyakatawa, Ermson	Zimbabwe	UNL	Physiology	Eastin	MSC	M	S
Petersen, Chris	U.S.	UNL	Physiology	Eastin	MSC	M	O

* 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 15 SADC/ICRISAT Training Participants

Name	Country	University	Discipline	Advisor	Degree	Gender
Alfredo, Manuel	Angola	Vicosa	Pathology	Ferreira da Silva	MSC	M
Domingos, M'panzo	Angola	Vicosa	Agronomy	Nogueira Fontes	MSC	M
Lele, Etani	Botswana	KSU	Agronomy	Vanderlip	MSC	M
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	Durnford	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
Kaganda, Suleiman	Tanzania	UNL	Forages	Anderson/Moser	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
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
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, Mississississippi 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
through FY 94

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
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**

University/ Project No.	Buy-In	Year	Life of Buy-In	Annual Amount	Total
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
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
					$ 476,503
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

University/ Project No.	Buy-In	Year	Life of Buy-In	Annual Amount	Total
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
					$ 385,125
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
	FAO/IAR Ethiopia Training	1994	1 year	20,000	20,000
					$ 7,171,182
Total Buy-Ins					**$ 16,790,994**

INTSORMIL
Sponsored and Co-Sponsored Workshops
1979 - 1994

	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
41.	Workshop on Adaptation of Plants to Soil Stresses	Lincoln, NE	8/93
42.	Application of Genetics and Biotechnology to the Characterization of Fungal Pathogens of Sorghum and Millet	Bellagio, Italy	11/93

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 Anthracnose 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	Maicillo 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