INTSORMIL

Annual Report 1995

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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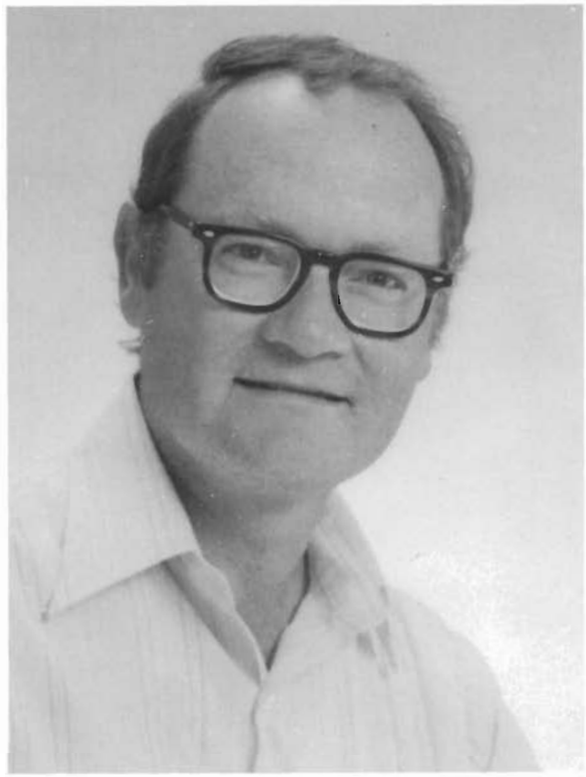
Dr. C. Y. Sullivan
(1931-1995)



The 1995 INTSORMIL Annual Report
is dedicated to the memory of Dr. Charles Sullivan
in remembrance of his contribution to INTSORMIL
and sorghum/millet research.

Cover Photographs
(top to bottom)

1. Dr. Charles Sullivan and Mr. Siriba Dione (Mali sorghum physiologist) discussing thesis research on sorghum. (Photo courtesy of Dr. Jerry Maranville.)

2. Example of drying of pearl millet heads in the field after harvest in Niger. (Photo courtesy of Dr. John Yohe.)

3. Grain storage huts in pearl millet field in Niger. (Photo courtesy of Dr. John Yohe.)

4. Niger farm wives processing millet grain with wooden mortar and pestle after removing from storage. (Photo courtesy of Dr. John Yohe.)

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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 (BIFAD), 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 (BIFAD), Participating Land-Grant Universities, Host Country Research Agencies and Private Donors

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Kansas State University
Mississippi State University
University of Nebraska
Purdue University
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Introduction and Program Overview

The Collaborative Research Support Program (CRSP) concept was created by the U.S. Agency for International Development (USAID) and the Board for International Food and Agriculture Development (BIFAD), under the auspices of Title XII of the Foreign Assistance Act, as a long term mechanism for mobilizing the Land Grant Universities in the international food and agricultural research mandate of the U.S. Government. The CRSPs are communities of U.S. Universities working with USAID and USAID Missions, other U.S. Federal Agencies, developing country National Agricultural Research Systems (NARS), International Agricultural Research Centers (IARCs), private agencies, industry, and private voluntary organizations (PVOs). The Sorghum and Millet Collaborative Research Support Program (CRSP) is one of eight CRSPs currently in operation.

The Sorghum and Millet Collaborative Research Support Program (i.e., INTSORMIL CRSP) conducts collaborative research using partnerships between U.S. University scientists and scientists of the National Agricultural Research Systems (i.e., NARS). INTSORMIL is programmatically organized for efficient and effective operation and has captured most of the sorghum and millet research expertise in the United States. ***The INTSORMIL mission is to use collaborative research as a mechanism to develop human and institutional research capabilities to overcome constraints to sorghum and millet production and utilization for the mutual benefit of U.S. and LDC agriculture.*** Collaborating NARS and U.S. scientists jointly plan and execute research that mutually benefits developing countries and the United States. Prime sites will be maintained in the agroecological zones of western, southern, and eastern Africa, and in Central America. These sites support the general goals of building NARS institutional capabilities, creating human and technological capital for solving sorghum and millet constraints with sustainable global impact, promoting economic growth, enhancing food security, and encouraging entrepreneurial activities. 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.

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. The development of food sorghums and sorghums with improved feeding properties such as increased digestion and reduced tannin contents has contributed to sorghum becoming a major feed grain in the U.S. and Mexico and in other countries in South America. The new food sorghums produce grain that can be used for special ethnic and dietary products as well as for foods. Special white sorghums in Mali have the potential for allowing farmers wives to process sorghum into high value food products for sale in village and urban markets which can compete with wheat and rice products. The usual types of sorghums cannot make effective food products that can compete with wheat and rice products. These developments have occurred because of the significant interaction that INTSORMIL scientists have from production through processing and marketing.

Although significant advances have been made in improvement and production of sorghum and millet in the regions INTSORMIL services, population continues to exceed production capacity. There remains an urgent need to continue the momentum of our successes in crop improvement as well as our efforts in strengthening the NARS.

INTSORMIL has maintained a flexible approach to accomplishing its mission. In preparation for the 1996-2001 grant extension proposal, INTSORMIL has implemented several critical recommendations made by the External Evaluation Panel and an Internal/External Committee, with input from the INTSORMIL Technical Committee (TC) and Ecogeographic Zone Council (EZC).

The success of the INTSORMIL program can be attributed to the following strategies which guide the program in its research and linkages with technology transfer entities.

- **Developing institutional and human capital**: INTSORMIL will promote educational outcomes in collaborating host countries. The outcomes include institutional strengthening , development of collaborative research networks, promoting and linking to technology transfer and dissemination infrastructure development, and enhancing national, regional, and global communication linkages. ***A major innovative aspect of the INTSORMIL focus is to maintain continuing relationships with collaborating host country scientists upon return to their research posts in their countries. They become members of research teams of INTSORMIL and NARS scientists who conduct research on applications of existing technology and development of new technology. This integrated relationship prepares them for leadership roles in regional networks in which they collaborate.***

- **Conserving biodiversity and natural resources**: Research outcomes of the collaborative research teams include development and release of enhanced germplasm; development and improvement of sustainable production systems; development of sustainable technologies to conserve biodiversity and natural resources and to enhance society's quality of life, and enlarge the range of agricultural and environmental choices. Thus, INTSORMIL promotes conserving millet and sorghum germplasm, conserving natural control of sorghum and millet arthropod pests and diseases, developing resource-efficient cropping systems, developing integrated pest management programs, developing cultivars with improved nutrient and water use efficiencies, and evaluating impacts of sorghum/millet technologies on natural resources and biodiversity.

- **Developing research systems**: Collaboration in prime sites have been strengthened by using U.S. and NARS multi- disciplinary research teams focused on common objectives and unified plans. INTSORMIL scientists provide global leadership in biotechnology research on sorghum and millets. The output from these disciplinary areas of research are linked to immediate results. Biotechnology and other tools of science integrated with traditional science will contribute to alleviating production and utilization constraints in sorghum and pearl millet within the medium term of 5-10 years. New technologies are then extended to farmers' fields in developing countries and the United States through further collaborative efforts. In addition, INTSORMIL plays a part in initiating consideration of economic policy and processing constraints to regaining the competitiveness of sorghum and millet as a basic food staple.

- **Supporting information networking**: INTSORMIL research emphasizes working with existing sorghum and millet networks to promote effective technology transfer from prime sites to local and regional institutions. Technology transfer is strengthened by continued links with regional networks, International Agricultural Research Centers, and similar local and regional institutions. Emphasis is placed on strong linkages with extension services, agricultural production schemes, private and public seed programs, agricultural products supply businesses, and nonprofit voluntary organizations, such as NGOs and PVOs, for efficient transfer of INTSORMIL generated technologies. Each linkage is vital to development, transfer, and adoption of new production and utilization technologies.

- **Promoting demand driven processes**: Development of economic analysis for prioritization of research and farm-level industry evaluation and development of sustainable food technology, processing and marketing systems, are all driven by the need for stable markets for the LDC farmer. INTSORMIL seeks alternate food uses and new processing technologies to save labor and time required in preparation of sorghum millet for food. Research products transferred to the farm will seek to spur rural economic growth and provide direct economic benefits to consumers. INTSORMIL assesses consumption shifts and socioeconomic policies for reducing effects of price collapses, and addresses methods for reducing processing for sorghum and millet. Research outcomes seek to reduce effects of price collapse in high yield years, and to create new income opportunities. INTSORMIL socioeconomic projects measure impact and diffusion and evaluate constraints to rapid distribution and adoption of introduced new technologies.

The INTSORMIL program addresses the continuing need for agricultural production technology development for the developing world, especially the semiarid tropics. There is international recognition by the world donor community that the developing country agricultural research systems must assume ownership of their development problems and move toward achieving resolution of them. The program is a proven model that empowers the NARS to develop the capacity to assume the ownership of their development strategies, while at the same time resulting in significant benefits back to the U.S. agricultural sector and presents a win win situation for international agricultural development.

Administration and Management

The University of Nebraska (UNL) is the Management Entity (ME) for the Sorghum/Millet CRSP and is the primary grantee of USAID. UNL subgrants are made to the participating U.S. Universities for the research projects between individual U.S. scientists and their host country counterparts. Country project funds, managed by the ME and U.S. participating institutions, flow to the country program in support of the research activities at the host country level. The Board of Directors (BOD) of the CRSP serves as the top management/policy body for the CRSP. The Technical Committee (TC), 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, and TC during the past year.

- The INTSORMIL Ten Year Strategic Plan was completed.

- The Draft of the INTSORMIL Five Year Grant Extension Proposal was completed.

- The USAID Management Review Team completed its five year review of the administrative aspects of the program in December, 1994. The team visited the program sites at Nebraska, Kansas State University, Texas A&M University, Mississippi State University, and Purdue University. The review teams' Five Year Report was released in March, 1995.

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

  * INTSORMIL Newsletter, INTSORMIL Publication No. 95-1.

  * INTSORMIL Annual Report 1994, INTSORMIL Publication No. 95-2 .

  * INTSORMIL Annual Report 1994, Executive Summary, INTSORMIL Publication No. 95-3.

  * Leslie, J.F. and R.A. Frederiksen. (eds.) 1995. Disease Analysis through Genetics and Biotechnology: interdisciplinary bridges to improved sorghum and millet crops. Iowa State University Press. 359 pp.

- The INTSORMIL Board of Directors authorized the merging of the Technical Committee and the Ecogeographic Zone Committee into one committee of eight members.

- The INTSORMIL Board of Directors approved the 1995-96 annual budget with a 6.74% increase in funds, which included $100,000 from the Niger Mission to be used in support of Inter-CRSP NRM research activities.

- The Board of Directors approved the temporary appointment of a UNL faculty member at one quarter time to fill the position of Associate Director.

- INTSORMIL/Purdue entered into an agreement with the PVO, World Vision, to provide one ton each of eight different improved *Striga* tolerant sorghum varieties (a total of 8 tons of improved seed).

- Plans were initiated to hold the "INTERNATIONAL Conference on Genetic Improvement of Sorghum and Pearl Millet", in Lubbock, TX, September 23-27, 1996.

- The CRSP Council entered into discussions regarding an Inter-CRSP agreement with the USAID/Africa Bureau for implementation of an Inter-CRSP Natural Resource Management regional project for West Africa. The IPM CRSP was designated the lead CRSP for development of this effort.

- Due to funding constraints, INTSORMIL closed its program presence in Colombia. Collaborative activities in Colombia continue on an informal basis.

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 production and utilization of 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 1994-95, there were 75 students from 22 different countries enrolled in an INTSORMIL advanced degree program and advised by an INTSORMIL principal investigator. This was a decrease of 22% from the previous year. Approximately 73% 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 24% of all INTSORMIL graduate students were women.

The number of students receiving 100% funding by INTSORMIL in 1994-95 totaled 21. An additional 20 students received partial funding from INTSORMIL. The remaining 34 students were funded from other sources but are working on INTSORMIL projects. 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 due to 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 1994-95.

Networking

The Sorghum/Millet CRSP Global Plan for Collaborative Research includes workshops and other networking activities such as research newsletters, publications, the exchange of scientists, and the exchange of germplasm. The INTSORMIL Global Plan is designed for research coordination and networking within ecogeographic zones and as relevant between zones. The Global Plan:

- Promotes networking with IARCs, NGO/PVOs, private industry and government extension programs to coordinate research and technology transfer efforts.

- Participation in regional research networks to promote professional activities of NARS scientists, to facilitate regional research activities (such as multi-location testing of breeding materials), promote germplasm and information exchange, and facilitate impact evaluation of new technologies.

- Develops with regional research networks, short-term and degree training plans for sorghum and pearl millet scientists.

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 currently cooperates with the ICRISAT programs in East, Southern, and West Africa, and the ROCAFREMI (Réseau Ouest et Centre Africain de Recherche sur le Mil, Niger) of West/Central Africa. Sudanese collaborators have provided leadership to the Pan African *Striga* Control Network. 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.

Benefits to Host Countries

Realized Benefits of Program

INTSORMIL can document a wide range of benefits to host countries, U.S. agriculture, and the broader scientific community. Many of these benefits have reached fruition with improved programs, economic benefits to producers and consumers, and maintenance or improvement of the environment. Others are at intermediate stages ("in the pipeline") that do not allow quantitative measurement of the benefits at present, but do merit identification of potential benefits in the future. The collaborative nature of INTSORMIL programs has built positive long-term relationships between scientists, citizens and governments of host countries and the United States. This has enhanced university educational programs and promoted understanding of different cultures enriching the lives of those involved, and hopefully making a small contribution to world peace, in addition to sustainably improving sorghum and pearl millet production in developing countries and in the United States.

International

Scientific by Technical Thrust

Germplasm Enhancement and Conservation

Germplasm exchange, movement of seeds in both directions between the U.S. and host countries, has involved populations, cultivars, and breeding lines carrying resistances to insects, diseases, *Striga,* drought, and soil acidity, as well as elite materials with high yield potential which can be used as cultivars per se or used as parents in breeding programs. Specific germplasm releases (including breeding lines) for host country use include the following.

- Improved yield (for all host countries)

- Improved drought tolerance (Africa and drier areas of Latin America)

- Acid soil tolerance

- *Striga* resistance (West and Eastern Africa)

- Midge and Greenbug resistance (Latin America)

- Downy mildew resistance (Latin America and Botswana)

- Anthracnose resistance (Latin America and Mali)

- Charcoal rot and lodging resistance (Africa and drier areas of Latin America)

- Head smut and virus resistance (Latin America)

- Foliar disease resistance (for all host countries)

- Improved grain quality characteristics for food and industrial uses (for all host countries)

The hybrid sorghum success story in Sudan traces to ICRISAT/INTSORMIL/ARC collaboration in which they developed, produced seed, and popularized the first hybrid sorghum, Hageen Dura-1 (Tx623 x K1567), for this country. The female line Tx623 was used due to its wide adaptation, high yield potential and drought resistance. It currently is produced on about 12% of the sorghum area in the Sudan Gezira Irrigation Scheme, the largest in the world under one management. The Hageen Dura-1 success story provides an example of the potential economic gains possible through plant breeding research, followed by seed production/marketing activities. Impact studies show that the internal rates of return to this research without further extension of the production area in Hageen Dura-1 were 23% for low fertilizer levels, and 31% for high fertilizer use levels. With the present rate of diffusion, the investment on this research would pay approximately $1 million of annual benefits. The line Tx622 (a sister line to AT623 in Hageen Dura) has been introduced to China, and is used in hybrids planted on tens of thousands of hectares.

In Honduras, three food-type high yielding sorghum maicillo cultivars have been tested and released. These are Tortillero (CS3541 Sel.), Catracho (Tx623 x Tortillero), and Sureño [(SC423 x CS3541)E35-1]-2-2. Sureño, in particular, has widespread acceptance by Honduran farmers because of its superior grain quality, high yield potential, disease resistance, and dual purpose use for both forage and grain. It is the first sorghum cultivar released by the MNR that has found its way into informal seed markets in Honduras. INTSORMIL's socioeconomic research has also shown that in Honduras the internal rate of return to the development of two new sorghum cultivars, Sureño and Catracho, which are in diffusion, is estimated at 32% or, on annuity basis, $0.7 million annually for the next 30 years. These new sorghum cultivars have economically benefitted small farmers dependent on small-acreage hillside farms, the poorest farmer segment in Honduras.

The INTSORMIL/Honduras sorghum project has been cooperating with the "Poligono Industrial Copaneco", a religious NGO funded by the Belgium and Canadian governments. The sorghum project has been providing technical advice on agronomic management and marketing of broom corn fibers. The NGO project is producing broom corn fiber and selling it to "Broom and Mops", a broom export factory located at San Pedro Sula in Honduras. INTSORMIL/Honduras has developed a new long fiber variety of "broom corn" sorghum which will compete more successfully with imported fibers from Mexico. Seed increase of this new variety will be made in 1995. Cost benefit analyses indicate this to be a profitable business for small producers to participate in.

Honduras plays a unique role in conservation of local landrace sorghum germplasm (maicillo or photoperiod sensitive sorghum). Central America is the only location in the world where sorghum has evolved to fit the cropping systems of the steepland hillsides. The INTSORMIL/Honduras sorghum project has assumed the responsibility for conserving this sorghum gene pool. The goal of the 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 new drought tolerant sorghum hybrid designated NAD-1 (NAD-1 = Tx623 x MR732) has proven to be highly productive and well adapted in Niger. The grain quality is acceptable for local food preparations and the yields reported from 100 on-farm demonstration plots in 1992 were approximately twice the yields of local varieties. Overall, the average yield of NAD-1 between 1986 and 1994 is 2758 kg/ha on-station, ten times the average yield of the farmer in Niger (273 kg/ha). In 1993 the farm level plots showed the average farmer yield for the Konni and Jirataoua region was 2365 kg/ha for NAD-1. In 1994, NAD-1 yielded an estimated 1725 kg/ha (Say), 3500 kg/ha (Jirataoua), 3800 kg/ha (Cerasa), and 4600 kg/ha (Konni) for an overall farmer yield of more than 3000 kg/ha. Farmer interest has been very high since this is the first sorghum hybrid that has actually reached farmer fields, and both the head size and grain yield have been impressive. It is important now to develop a seed industry (either private or parastatal) in Niger that is able to produce and distribute quality hybrid sorghum seed so producers can benefit from this research output.

In Colombia, the ICA-INTSORMIL collaborative research has resulted in the release of four aluminum 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. The second two varieties released by ICA and the El Alcaravan Foundation, with INTSORMIL support, 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 3t/ha grain under low fertilization levels when the Al-saturation 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 climate conditions. FEDEARROZ and ICA have announced the release of a sorghum hybrid for the dry Caribbean region of Colombia which uses an A-line from the INTSORMIL project and an R-line from INTSORMIL Texas A&M University.

A *Striga* resistant variety, SRN-39, has been identified as promising and released for production in Sudan. In one area alone about 1200 ha of SRN-39 was grown in 1992. SRN-39 and other possible sources of resistance to *Striga* are being used in breeding programs in Sudan, Mali, Niger and other countries to improve adaptation, yield potential and agronomic characteristics. They are being tested in integrated control programs with various cultural practices, fertilizer management, and different mechanical and chemical control strategies. Recently eight tons, one ton each of eight high yielding *Striga* resistant food grain sorghums were released by Purdue University to the PVO, World Vision, for use in nine countries in Africa.

Excellent progress has been made in Mali to develop white-seeded, tan-plant guinea cultivars. F_6 progenies from crosses involving Bimbiri Soumale and CSM388 look very promising. Especially outstanding are the derivatives of the cross, Bimbiri Soumale x 87CZ-Zerazera, that have excellent yield potential. They have good guinea plant, grain, glume, and panicle characteristics, and some have juicy stems. Six new non-guineense advanced generation breeding lines were selected for seed increase to be placed in selected 1995 on farm trials. This material includes lines from the Bimbiri Soumale x 87CZ-Zerazera crosses which should be useful for enhanced quality, value added, commercial food products.

Sustainable Production Systems

In agronomy and soil/crop management, a major INTSORMIL impact has been understanding the soil/cropping system/genotype interactions. Research in Mali has shown that small nitrogen (N) additions are beneficial and necessary to sustain sorghum grain yields. In 1994, the increase in pearl millet yield due to N application was 31% and 66% with 20N and 40N, respectively, in monoculture and 64% and 66% for 20N and 40N, respectively, in millet-cowpea rotation. Crop rotation (millet-cowpea) alone without N increased millet grain yield by 74%. The increase was 35%, 34%, and 56% the past three years. The legume effect appears worth 30 to 40 kg N/ha. This information has been compiled and is being used by extension personnel in their recommendations to farmers.

INTSORMIL research results have demonstrated 18 to 203% yield enhancement of pearl millet and grain sorghum yields in Africa by use of crop rotation with legumes, and a 20 to 50 kg/ha N equivalent contribution to cereals following legumes. In Mali and Niger, intercropping has shown land use efficiency increases of 14 to 48% over sole crops, and also to enhance yields of succeeding crops when intercrop legume yields are high. Obviously legume production, no matter the system, is important to producing optimal sorghum and pearl millet yields when N fertilizer is limiting, especially for improved cultivars.

In Botswana, the benefits of single element fertilizer have been determined and demonstrated to farmers. Water harvesting technology has been evaluated and appropriate recommendations have been extended to farmers. Management practices on water runoff show if additional water could be diverted to a site, better yields resulted. Increased water availability must be coupled with the proper plant population, fertilizer level and pest control to produce high yields. In the event that excess water occurs, the system must be designed to release water without erosion. The National Tillage Trials showed early tillage frequently improved soil water storage. This coupled with 15 kg P ha^{-1} fertilizer increased yield. Due to low sorghum yield potentials, addition of phosphorus (P) was not economical where soil P was greater than 5 mg kg^{-1}. Nitrogen did not increase yields unless rainfall was uniformly distributed during the season, while manure/crop residue additions were effective in increasing water intake and grain yield.

Research in Mali and Botswana has shown that grain yields do not always increase with applied fertilizer N when conditions are extremely dry. However, in the higher rainfall regimes, yield increases are consistently obtained with N application. In Mali, the local varieties such as Tiemarifing have produced higher N use efficiencies than the improved types such as Malisor 84-7. There is a need for P in sandier soils, and this often is the mineral element most limiting in Mali and Niger sorghum and pearl millet production.

Residue management studies in Niger have shown 300 to 500% pearl millet yield increases during the first year to leaving or applying 1 to 3 ton/ha pearl millet residues to the soil surface. In contrast in Mali, residue treatments of; removed, leaving residue on soil surface, and incorporated, had no effect on grain or stover yield the first three years. After three years for both crops, yields on plots with residues incorporated, or 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 had no effect on peanut and cowpea yields.

Stand establishment of sorghum and pearl millet, especially improved cultivars, is common due to heat and water stress, crusting, and due to the small seed size. Pearl millet research indicated that screening for large seed, or producing large seeds by partial head removal, improves stand establishment and often grain yield.

Stand establishment research on sorghum indicates that kernel density is associated with seedling vigor and emergence, and the germination/emergence temperature response varies greatly among genotypes. Emergence potential in crusted soils is associated with large coleoptile diameters, and is a highly heritable trait with additive gene effects.

Sustainable Plant Protection Systems

In crop protection, a wide range of sources of resistance for insects, diseases, and *Striga* have been identified and crossed with locally adapted germplasm. This process has been improved immensely by INTSORMIL collaborators developing effective resistance screening methods for sorghum head bug, sorghum long smut, grain mold, leaf diseases and *Striga*.

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

The INTSORMIL PIs at Purdue University have studied each stage of the *Striga* life cycle separately. They are characterizing the host-parasite interaction at each stage, particularly the chemical signals exchanged. For each stage, simple ways to detect ineffective interactions are sought such as an agar gel assay for germination stimulant production. These screening methods are being used to identify crop genotypes bearing the resistance-conferring traits, and to map the traits on the sorghum genome.

The sorghum line SRN-39 has been identified as resistant to *Striga* due to low production of the chemical signal required for *Striga* germination. This trait is inherited as a single recessive gene. Other sources of resistance or tolerance to *Striga* have been identified such as CMDT 30, CMDT 39, CMDT 45, CMDT 48, CMDT 76 and CMDT 115 in Mali. The Malian landrace Seguctana Cinzana has also shown excellent resistance. Selected F_5 breeding lines (Malisor 84-7*SRN39) from Purdue and IER, Mali were as resistant as the resistant check, Tiemarifing, in screening trials. Six advanced generation lines (SRN39*Zerazera) developed and selected at Purdue for resistance to *Striga asiatic* have been tested in Mali and showed high levels of resistance to *S. hermonthica.* The line 92PR-203 also showed excellent agronomic traits.

Integrated *Striga* studies have been conducted in Sudan. The herbicide, chlorsulfuron, reduced *Striga* infestation by 68 to 94% and improved sorghum crop stand. Urea application reduced the adverse effect of *Striga* on sorghum plants, and late planting reduced infestation. Fertilizer studies in Niger showed that potassium application had no effect on *Striga* infestation, and phosphorus application had variable effect.

The collaborative research on African sorghum head bugs in West Africa, especially in Niger and Mali has quantified damage (yield and quality loss); identified resistant genotypes, including practical methodology to screen for resistance; and described bug species composition, biology, and population dynamics. Research activities have studied the bio-ecology of head bug (*Eurystylus marginatus*) and the identification of new resistance sources to be used in integrated pest management programs. The larva and adult populations vary naturally across years. The insecticide Diazinon effectively controls head bugs resulting in increased grain weight. This provides a chemical rescue alternative if other integrated control strategies fail to control head bugs.

Screening in Mali identified good head bug resistance for the lines 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, and for the Texas lines 90-CZ-CS-TX-2, 90-CZ-CS-TX-12, 90-CZ-CS-TX-6, 90-CZ-CS-TX-1, PR2566 and PR2562. All of these lines are derivatives of Malisor 84-7. Another screening trial, confirmed the line IS21468 as having resistance equal to that of Malisor 84-7.

Research activities in 1994 focused on evaluation of new breeding lines and the identification of new sources of resistance to the head bug (*Eurystylus marginatus*). The breeding lines 89-CZ-CS-F5-137 and 87-SB-LO-F4-155, along with the line ICSV401, compared favorably to Malisor 84-7 in head bug/grain mold ratings. In the advance trial 90-CZ-CS-Tx-2, 90-CZ-CS-Tx-1, and PR2562 had a good visual score.

Sorghum lines resistant to sugarcane aphid have been identified in Botswana and Zimbabwe, and the mechanism of resistance assessed.

Biology and control of sorghum long smut have been studied by collaborators in Sudan and Niger. Evaluation of acremonium wilt, head smut and anthracnose is part of this research effort. Cooperative research between Ciba Geigy and national programs have shown the seed treatment Apron® Plus to control downy mildew of pearl millet. The sorghum lines, SC170-6-17, SC279-14E, R6078, 87BH8606-6, Town, and BE7149, have resistance to grain mold, anthracnose and sooty stripe in Mali. These lines are being used for further testing and in the sorghum breeding program.

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

Pearl millet head miner *(Heliocheilus albipunctella)* is a serious insect pest of West Africa, and has been found to be an excellent candidate for biological control since it has a predictable habitat, consistent annual habits, produces one generation per year, and has several natural enemies. Two major predators and two commonly encountered parasites have been identified, and are being studied. It is reasonable to expect an adequate knowledge base about this insect pest to develop a regional biological control research program in 1996, with NARS entomologists participating in the ROCAFREMI network.

Several cultivars with SC326-6 in their genetic background have demonstrated good general adaptation to the Southern Africa region and possess excellent leaf blight and anthracnose disease resistance. These lines are being utilized as parental lines in breeding programs. An advanced improved pearl millet line selected from the Serere 6A population is being tested for its potential as a new variety.

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

Crop Utilization and Marketing

Food quality laboratories have been established and equipped in Mali and Niger. Both are conducting sorghum and pearl millet food technology research to develop or improve food products, and assist breeding programs. These laboratories developed a Sorghum Quality Laboratory Manual which has been widely distributed in West Africa.

The use of sorghum in composite flour (up to 50%) for wheat bread making has been investigated and its commercial viability and acceptability in Sudan and Niger. Niger research showed that incorporation of pearl 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 pearl millet flour over sorghum. Demonstrations of bread from composite flour have been made to processors and government officials in Niger.

The newly released cultivars in Sudan such as HD-1, Ingaz, and SRN-39 have been evaluated for their *kisra* quality properties and have been found suitable.

Processing sorghum in certain ways have been found to increase protein and energy digestibility. A traditional fermented product, Sudanese *nasha*, and high temperature, low moisture extruded gruel made from decorticated sorghum, were found to be highly digestible in children for both protein and energy. New processed foods from sorghum in Sudan were evaluated for nutritional quality and research was conducted that will improve quality and help efforts to commercialize *kisra*, the staple Sudanese fermented flat bread.

Research found that high amounts of kafirin decrease the gelatinization potential of the starch granules thereby making a thinner porridge. Porridge texture was found to be the most important attribute when different sorghum cultivars were evaluated using sensory panels in Niger. Laboratory tests for porridge quality were identified that best correlate to consumers in Niger. Grain hardness tests, which are important indicators of end-use quality, were evaluated and suitable methods that are rapid and simple are being used.

Simple methods to evaluate milling and porridge quality of sorghum have been developed and used to assist breeders in developing new cultivars. For example in Mali, Malisor 84-7 was developed specifically for improved thick porridge quality. Its tan plant color and hard endosperm provides excellent quality grain which has been found to have resistance to head bugs. Critically important quality factors like pericarp removal, grain deterioration by head bugs and molds, the effect of plant color and different cultivars on porridge quality were discovered and introduced as selection criteria into the sorghum improvement program.

The Cereal Quality Laboratory (LQC) at INRAN has conducted several surveys to determine the effect of crop selection and pearl millet varieties on couscous preparation used in Niger. Sorghum, pearl millet, and durum wheat all produced acceptable couscous in this study. Work continues with INRAN/Niger scientists on sorghum and millet-based couscous. Pilot scale couscous processing equipment has been purchased for the INRAN food processing laboratory. This unit will be used for testing and demonstration to local entrepreneurs, women's groups, etc. The commercial sorghum and millet based couscous will be tested in the market place.

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.

MILEG, a prepared weaning food from dehulled pearl millet and cowpea flours (3:1 blend), is being produced and sold by a small food company in Bamako, Mali. The product prototype was developed cooperatively by the Institute of Rural Economy food technology laboratory, with assistance from INTSORMIL/Texas A&M University food scientists.

A new sorghum product called SORI was developed in Mali. The basic process is similar to rice parboiling. Partially cooked, steeped sorghum was dried and decorticated to produce endosperm pieces that can be cooked like rice. When cooked, the decorticated kernels remain intact, retaining their individual integrity. The process is fairly simple, and does not require sophisticated equipment. The SORI process looks promising. Studies continue and this line of research has been initiated in Mali.

Parboiling research trials showed the importance of grain with tan plant color to produce improved highly acceptable food products. This has led to current breeding objectives to produce an improved local photosensitive sorghum with tan plant color specifically for use in value added processing.

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

Benefits to the U.S.

Germplasm Enhancement and Conservation

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

Germplasm resistant to sorghum midge, developed through INTSORMIL support, has served as the foundation for many similar breeding programs throughout the world. Three A/B- line pairs which have been developed as sorghum midge resistant hybrid seed parents. These are the first released sorghum midge resistant A/B pairs with the traits needed to produce commercially acceptable resistant hybrids.

Materials from the INTSORMIL/USDA/Texas A&M University Sorghum Conversion Program and selected breeding cultivars from other projects are evaluated regularly for resistance to internationally important diseases and insects in a cooperative/collaborative program throughout the sorghum growing world. INTSORMIL PIs have cooperated in the release of 360 converted exotic sorghum lines. The releases were made in three groups: 240 lines in 1986, 110 in 1992, and 50 fully converted exotic lines and 253 partially converted bulks were released in 1994/95. These are all available to the U.S. Seed Industry. Recently, over 1300 sorghums from the Sudan germplasm collection (3000 accessions) were evaluated at Lubbock, TX for photoperiod sensitivity, and non-sensitive entries crossed to standard A (male sterile) lines to evaluate for B/R fertility restorer reaction. Other items of the Sudan collection were evaluated in Puerto Rico, Kansas, and Indiana for photoperiod sensitivity. New introductions from Mali (24), Southern Africa Region (9), China (6), Kenya (2), Burkina Faso (1), and Niger (1) were grown and evaluated in Puerto Rico. Five were selected as potential candidates for entry into the conversion program.

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

Food quality sorghums have demonstrated 10-13% yield advantage over feed grain sorghums, while providing superior grain useful for both human food raw material or livestock/poultry feed.

One major dominant gene and one major recessive gene were found to control the ability to stay green under drought conditions. A consistent relationship has been shown between high nonstructural carbohydrates in the stem and charcoal rot resistance, as well as resistance to most types of lodging: (1) charcoal, moisture stress type, (2) weak neck, and (3) post-freeze stalk lodging. Foliar disease resistance has not only increased yield potential, but also feed value of forage sorghums. The stay green characteristic improves the feeding value of sorghum stover significantly. INTSORMIL Project, TAM-121, has developed and released 68 inbred parental stocks for use domestically and internationally since the INTSORMIL program was initiated. A few lines were identified with the dominant type of stay green when used in hybrid combinations. Most these stay green lines also transmit lodging resistance to hybrids.

Several sources of the brown-midrib gene which results in lower lignin content have been identified. Both A and R lines have been released, and potentially can be used in sudangrass and dual purpose (silage) hybrids for livestock feed and bio-gas production.

In January 1995, INTSORMIL/Purdue University reported a breakthrough in sorghum digestibility research. Irregularly shaped protein bodies discovered in sorghum kernels under the electron microscope may signal improved human nutrition in some developing countries and higher quality livestock/poultry feed worldwide. In 25 experimental genetic lines of sorghum, two have been identified with significantly faster protein digestion. These two genetic lines of more highly digestible sorghum fall right between maize and wheat in digestibility. That makes sorghum potentially competitive with other cereal grains as a source of dietary protein for humans and livestock/poultry. Poultry feeding tests have been initiated to verify the findings.

Tropical germplasm with drought tolerance, such as Segaolane from Botswana, have been identified and are used in private seed company breeding programs. Research has shown drought tolerant characteristics of relative water content, osmotic potential and heat tolerance.

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

Lines having tolerance to the acid-soil complex have been made available to private seed companies, but have limited use in the U.S. due to the limited acid soil sorghum producing area. This research has identified genotypes with ability to survive and produce grain at very low phosphorus levels. This may lead to development of lines/hybrids with high phosphorus use efficiency able to produce high yields with low soil phosphorus levels.

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

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

Several superior pearl millet seed parents have been obtained from the male-sterilization backcross program at Kansas. F_1 hybrids appear to have similar grain yield potentials when compared to sorghum hybrids of similar maturity. In the U.S., research continued on producing segregating populations for selection in West Africa, providing data on production of protogyny hybrids for use in low-resource agriculture and developing hybrid parent lines in the A_4 cytoplasmic male sterility system which has several major advantages over the A_1 system, and may also be useful for improving agriculture in developing countries.

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. Yield tests in 1994 confirmed that A4 combinations can give yields equivalent to A1 hybrids.

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

Sustainable Production Systems

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

Sorghum-soybean crop rotation has been shown to consistently enhance sorghum grain yields by 19 to 64% the year following soybeans, and by 20% the second year following soybeans. Approximately 50 kg/ha N equivalent is contributed by soybeans to the following cereal crop, and increased soil NO_3 -N in the soil profile has been documented. Rotation with soybeans improve the protein content of sorghum grain and stover. Research has also documented rotation effects on root distribution, water extraction, and microbial biomass, and vesicular-arbuscular mycorrhizal colonization of sorghum plants. Extension agents, crop consultants, and private industry agronomists use the information to promote crop rotational systems.

Stand establishment is often a serious limitation in pearl millet and sorghum. In both crops, dense kernels result in more rapid and higher percent emergence, and additionally, large kernel size is important in pearl millet. Breeding and crop production programs are actively investigating means to improve these characteristics in seed production fields.

Soil crusting also often limits stand establishment. Research on sorghum has found this trait to be highly heritable due to additive effects, and to be associated with large coleoptile diameters. Studies are being conducted to better understand the physiological basis of genotype differences for emergence in crusted soils.

Weeds are very competitive with sorghum. Research has shown that for each kg of weeds, there was a loss of 1.2 kg of grain. Under the poorest management, no weed control, yields are reduced about 80%. Water use efficiency was increased greatly with weed control. This shows that farmers could double grain yield with excellent weed control.

Studies to develop an agronomic production practices package for dwarf pearl millet as a new alternate crop for the U.S. have been initiated. Narrow row spacing, nitrogen application, and good weed control were identified as important practices, although pearl millet appeared to be more competitive with weeds than grain sorghum.

Sustainable Plant Protection Systems

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

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

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

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

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

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

Research at Texas A&M University has employed a holistic approach to identify, evaluate, and deploy sorghum midge, greenbug, and yellow sugarcane aphid resistant sorghums as a component of IPM, and develop and validate sorghum plant and sorghum midge dynamics computer models.

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

Sorghum landraces from Central America have been identified with antibiosis resistance to fall armyworm, which can be used with sorghum breeding programs in the U.S. It has also been shown that corn can be used as a trap crop for fall armyworm, and that planting higher populations reduce plant damage.

Biological and ecological relationships and insecticide susceptibility for fall armyworm for Florida, Mississippi, Honduras, and Jamaica have been determined. This provides a basis for understanding infestations and developing control strategies for this migrating insect pest of economic importance in the U.S.

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

Dr. Richard Frederiksen (TAM-124) has selected 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.

Crop Utilization and Marketing

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

Sorghum digestibility in humans was shown by nutritionists to be low compared to other cereal grains, and from this project we now have a clear concept of why the storage proteins, or kafirins, are difficult to digest. Presently, a high molecular weight non-kafirin endosperm protein that inversely correlates to reduced digestibility is being evaluated as a possible means of increasing digestibility through breeding or genetic manipulation. INTSORMIL PIs have identified a sorghum line in the World Collection (IS 2319) which has a significantly reduced cross-linked kafirin fraction and shows very good digestibility results in rat feeding trials, whether cooked or uncooked. They believe this cross-linked kafirin is responsible for many of the digestibility problems in sorghum and are giving this activity a very high priority.

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 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.

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

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

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

New prototype food products including noodles, ready-to-eat breakfast foods, weaning foods, granolas, instant porridges, baked products and others have been developed from 100% sorghum and millet for potential utilization in several countries. Products have been made with sophisticated techniques like extrusion and micronizing and also with simple, low-technology methods appropriate to targeted countries. The major constraint limiting their application is the lack of a consistent supply of good quality sorghum and pearl millet grains at a competitive price.

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

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

The adverse effects of molds and weathering on sorghum quality significantly limit the use of sorghum for foods in many areas. Major progress to understand the factors affecting grain deterioration has been made. Work continues to secure mold resistant sorghum cultivars. New information on the role of antimicrobial proteins is being developed.

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

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 five 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, (4) information and research networking, and (5) demand driven processes.

Sustainable Plant Protection Systems

Agroecology and Biotechnology of Stalk Rot Pathogens of Sorghum and Millet

Project KSU-108 and KSU-108B
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Dr. John A. Kinsey, Fungal Genetics Stock Center, Department of Microbiology, University of Kansas Medical Center, Kansas City, KS
Dr. Paula J. Bramel-Cox, Department of Agronomy, Kansas State University, Manhattan, KS
Drs. D. J. Jardine and R. W. Bowden, Department of Plant Pathology, Kansas State University, Manhattan, KS
Prof. D. J. Andrews, Department of Agronomy, University of Nebraska, Lincoln, NE
Dr. M. B. Dickman, Department of Plant Pathology, University of Nebraska, Lincoln, NE
Dr. Paul E. Nelson, Department of Plant Pathology, The Pennsylvania State University, University Park, PA
Dr. Richard A. Frederiksen, Department of Plant Pathology and Microbiology, Texas A & M University, College Station, TX
Dr. Gary Odvody, Texas A&M Research and Extension Center, Corpus Christi, TX
Dr. Darrell Rosenow, Texas Agricultural Experiment Station, Lubbock, TX

Summary

The research funded by this project includes both disease screening of breeding materials and the identification of parameters influencing pathogen population dynamics in agroecosystems. Screening of the ADIN nursery from Texas A & M for resistance to bacterial stripe was continued this year. Resistant accessions included SC 326-6, SC 414-12E, BTX 378, B 35-6, and TX 2862; susceptible entries included TX 2767, TX 430, TAM 428, BTX 623, R 9117, and 90B2662.

Fungal diseases examined this year were pokkah boeng and sooty stripe. Laboratory conditions were developed to increase the amount of conidia produced by *Ramulispora sorghi* (causal agent of sooty stripe) for the purpose of increasing inoculum; these conditions consist of a pH between 4.5 and 5.5, a temperature of 24°C, with potato dextrose agar as the medium. Most pokkah boeng isolates have been classified in the D mating population of *Gibberella fujikuroi* (anamorph *Fusarium proliferatum*), indicating that previous identifications of the causal agent of this disease were incorrect, at least in sorghum. The genetic map, described preliminarily during the previous year, has been finalized and is the first comprehensive map available for any *Fusarium* species. The RFLP markers are now available for characterization of field populations of these fungi.

Objectives, Production, and Utilization Constraints

Objectives

Determine the causal agent of pokkah boeng disease of millet and sorghum. Ascertain the epidemiological parameters of the causal agent. Evaluate sorghum and pearl millet germplasm for genetic variability to the causal agent.

Develop characters for assessing genetic variability in *Fusarium* populations.

Develop an effective screening protocol for sooty stripe (*Ramulispora sorghi*) under greenhouse and field conditions. Measure conidial production and fungal growth on various media and under different temperature and pH conditions. Determine the optimum temperature and relative humidity for maximum disease incidence and severity.

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.

Provide pure cultures of fungi, plant pathogenic bacteria and antisera from our collection to LDC scientists to expedite diagnoses of fungal and bacterial diseases of pearl millet and sorghum.

Constraints

Fusarium spp. associated with sorghum and millet do obvious damage as stalk rot, grain mold and pokkah boeng and less obvious damage through the contamination of grain with mycotoxins detrimental to humans and domestic animals. Identification of causal strains and their economic importance requires assignment to the correct species and an assessment of the genetic variability within the population

Pokkah boeng is a disease of maize, sorghum, and sugar cane that is nominally attributed to *Fusarium subglutinans*. Diseased plants are characterized as having an "onion-leaf" or "rat-tailed" appearance. In essence, the whorl of the plant fails to unfold due to either plant or fungal exudates which bind together the leaves. Plants with lesser damage often exhibit leaves with a scorched appearance. Other symptoms include a "knife-cut" or where the lesion appears to be cut on a transverse plane. Leaves of infected plants are often rippled and have a leathery texture. Heavy losses may occur since the inflorescences often fail to emerge.

Sooty stripe of grain sorghum is caused by *Ramulispora sorghi* and occurs wherever sorghum is grown under warm, humid conditions. Yield losses have not been quantified in the U.S., however, in Mali, yield losses up to 46% were reported. The pathogen survives as sclerotia in leaf residue on or below the soil surface; sclerotia sporodochia can be important survival structures if infected leaves remain intact on the soil surface. The infection process and optimum conditions for disease development and dissemination are poorly understood.

Growth of *R. sorghi* in culture is very slow and often sporadic, and several weeks are commonly required for even minimal production of conidia. The difficulty in growing sufficient inoculum has hindered attempts to screen sorghum germplasm for tolerance to sooty stripe. Physiological growth parameters that might be limiting the growth of this fungus on artificial medium will be systematically evaluated.

Pseudomonas andropogonis (E. F. Smith, Stapp) is the causal agent of bacterial leaf stripe of grain sorghum. The disease is very common and can cause losses in sorghum grown under warm, humid conditions. In the U. S., bacterial leaf stripe is one of the three major bacterial diseases of sorghum. Symptoms of bacterial leaf stripe occur mostly on leaves and occasionally on stalks and inflorescences of susceptible cultivars. Colonization of stalks result in vascular bundles changing in color from white to brown or tan. Yield losses have not been ascertained.

P. andropogonis is particularly important in the export trade as numerous countries require a phytosanitary certificate that states that the seed or feed grain is free of the pathogen. The survival of the pathogen on or within infested seed remains speculative. The effect of different levels of genetic variability among sorghum germplasm and among plant tissues in the ability of the pathogen to survive between growing seasons have not been determined.

Research Approach and Project Output

Research Methods

Suspected pokkah boeng tissue was disinfested of microbial contaminants by immersing the samples in 95% ethanol for 10 seconds and then in 10% bleach for four minutes. Samples were washed three times in sterile distilled water. Small pieces of tissue were placed on Nash-Snyder (selective for *Fusarium* spp.) medium and incubated at 28 C for one week. Isolates are being identified to biological species and isolates within a biological species assigned to a vegetative compatibility group.

Differences between different biological species (mating populations) of *Gibberella fujikuroi* were confirmed by examining electrophoretic karyotypes constructed following CHEF gel electrophoresis.

A genetic map composed primarily of RFLP markers was constructed in mating population A of *G. fujikuroi* (*Fusarium moniliforme*). These markers can be used to study variability in field populations of this fungus in a population context.

Single spores of *R. sorghi* were obtained from sclerotia on infected leaves of grain sorghum plants. Thirty-four different media were evaluated. Three-day-old conidial colonies were transferred to the center of the petri dish. The plates were sealed with parafilm and incubated at 28°C in the dark. Every two days, a small section of the colony was placed in a drop of water on a slide and then examined with the microscope. The following scale was used: 1 - no conidia; 2 - limited number of conidia; 3 - moderate number of conidia, individual spores can be readily distinguished; 4 - numerous conidia, individual spores are difficult to distinguish; and 5 -abundant conidia, individual spores can not be identified. Each experiment was repeated twice with five replications for each medium.

Sorghum leaf extract media (SLE) was prepared by boiling 25-30 g of dried sorghum leaves in 1 L of water for 20 min. The liquid was filtered through three layers of cheesecloth and 20 g agar was added and then autoclaved.

Dandelion extract agar was prepared by boiling 100 g of fresh or 25 g dried dandelion (*Taraxacum officinale*) plants in 500 ml of water for 15 min. The liquid was filtered through three layers of cheesecloth. The volume was adjusted to 1 L; 20 g agar was added and then autoclaved.

The effect of temperature on conidial production was tested by spreading 0.5 ml of a conidial suspension (1 X 10^6/ml) on the following media; SLE, dandelion extract, Bilai, PDA (200 g potatoes, 20 g dextrose, 20 g agar and 1 L water), and water agar. Plates were sealed with parafilm and incubated at 16, 20, 24, 28, and 32°C. Ten days after plating, 20 mls water with 0.1% Tween 20 was added to the petri dishes and conidia were dislodged with a glass rod. Conidia in the resulting suspensions were counted in a hemacytometer.

The effect of pH on conidial production was measured on PDA in which the pH was adjusted to 3.5, 4.5, 5.5, 6.5, 7.5 and 8.5. Plates were inoculated as described above, and then sealed with parafilm and incubated at 20, 24, 28 and 32°C. Ten days after plating, the conidia were dislodged with a glass rod and counted with a hemacytometer as described above.

To determine genetic variability and overwinter survival of *P. andropogonis*, ADIN seeds (courtesy D. T. Rosenow, Texas A & M University, Lubbock) were planted on 2 June, 1993 and 17 May, 1994. Plant spacing was 76 cm between and 11 cm within the rows. Three replications were planted. Each replicate consisted of 10 plants per row per entry in a randomized, balanced, incomplete block design. In 1994, 19 of the 1993 entries were replaced with new accessions. Fertilizer was applied pre-plant with ammonium nitrate (34:0:0) at 94.2 kg/ha. Weeds were controlled by applying ramrod/atrazine pre-emergence at 12.6 L/ha followed by two hand weedings.

P. andropogonis inoculum was prepared by growing cells in liquid NBY broth and a streptomycin resistant strain in NBY amended with 100 µg/ml streptomycin sulfate (Sigma, St. Louis, MO) in an incubator shaker at 26°C for 48 hr. The suspension was centrifuged at 2,000 rev min^{-1} for 20 min; supernatant was decanted and the bacteria resuspended in 100 mM phosphate buffer (pH 7.2) (PB). A colorimeter (Klett-Summerson, NY) was used to adjust the cell suspension to a concentration of approximately 10^8 colony forming units per ml. Only one batch of inoculum was prepared to avoid variation in concentration.

The plants were inoculated at the 7-8 leaf stage of growth on 7 July, 1993 and 31 June, 1994. Inoculations were made with an Idico filler-plug gun (Forestry Suppliers, Inc. Jackson, MS) equipped with a 14-gauge needle and calibrated to deliver 1.0 ml inoculum per plant. The needle was inserted into the uppermost fully developed leaf collar. An average of five plants per row per entry were inoculated and the remaining plants served as controls.

Bacterial stripe symptoms were visually estimated before inoculation, and 2-3 weeks after inoculation on a 0-5 scale: 0 for no lesions and 5 for a nearly totally blighted leaf. Ratings of 0 -1.4 were considered resistant, ratings of 1.4 - 2.4 were considered intermediate, and ratings of 2.5 - 5.0 were considered susceptible. Disease ratings were based on an average of five inoculated plants per entry with three replications. Disease progression to the top two leaves was estimated at flowering and also at soft grain stages. The severity data estimates were averages of all inoculated plants in the row per entry.

Research Findings

Pokkah boeng studies are primarily based on a set of 350 *Fusarium* isolates collected from sorghum in different portions of Egypt by our Egyptian collaborators. These samples represent a broad cross-section of the Egyptian sorghum growing areas. The majority of these isolates are not *Fusarium subglutinans*, but are instead *Fusarium proliferatum*. We think it likely that previous workers have misidentified this organism because of the very similar morphological appearance of these two species. To date our data are based on our analysis of mating tests. Isozyme analyses to confirm these results are in progress. VCG analyses of these isolates have begun, and the pattern is not yet definitive. There are a relatively large number of VCGs (at least 30) that are represented by multiple isolates. Some of these isolates were recovered from different geographic locations, so the hypothesis that there are dominant strain types within the country remains, but has not been proven. Since some *F. proliferatum* strains are known to be capable of producing the fumonisin mycotoxins, the possibility of fumonisin contamination of sorghum in Egypt needs to be more closely examined.

Variation in *Fusarium* was examined using electrophoretic karyotypes and by identifying RFLP probes on a genetic map that can be used to measure genetic disequilibrium within field populations of *Fusarium* from sorghum and millet.

Using pulsed field (CHEF) gel electrophoresis we resolved karyotypes of the six biological species (mating populations A-F) of *Gibberella fujikuroi* (anamorphs *F. moniliforme*, *F. subglutinans* and *F. proliferatum*). Thirty-four strains were examined in electrophoresis runs that required up to two weeks to complete, and gross karyotypes suggest a haploid number of 12 chromosomes in all of the biological species. All of the strains have two chromosome bands that are as large or larger than the largest chromosome of *Schizosaccharomyces pombe* (5.7 Mega base pairs - Mb), and one of these bands is larger than the largest chromosome of *Neurospora crassa* (10 Mb). All strains from the same biological species have a similar karyotype, regardless of geographic or host origin, but each biological species had a distinct karyotype (Figure 1). Comparison of karyotype profiles following Southern analysis using homologous and heterologous nuclear gene probes and single-copy RFLP probes revealed some differences in hybridization between, but not within, biological species. Estimated genome sizes are 45-50 Mb for mating populations A, B, D and F, and 50-55 Mb for mating populations C and E. The smallest of the 12 chromosomes varies the most between biological species and was present in all field isolates, but it can be lost following meiosis (3% of all meioses). Sequences on this chromosome could be particularly valuable in distinguishing these fungi through rapid PCR-based diagnostic protocols. The karyotype analysis supports the distinctions previously described that were based on studies of mating alone.

We constructed a recombination-based map of *Gibberella fujikuroi* mating population A (*Fusarium moniliforme*), using strains that are widely used for genetic studies of this fungus. The map (Figure 2) is based on the segregation of 142 RFLP markers, two auxotrophic genes (*arg1* and *nic1*), mating type (A^+/A^-), female sterility (*ste1*), spore-killer (*Sk*), and a gene that governs the production of the mycotoxin fumonisin B_1. Twelve genetic linkage groups were identified and correlated with the chromosomes described above via Southern blots between appropriate markers and the CHEF gels. This map is the first comprehensive map for any member of the genus *Fusarium*. It provides opportunities to compare closely related strains and species for the identification of genes and regions that are important in mycotoxin production, host preference, and speciation. The relatively low level of repetitive DNA and the relatively small average kb/centiMorgans ratio (32), means that map-based cloning of targeted loci should be able to proceed without great difficulty. The 142 single copy RFLPs used in the map are all candidates to use in evaluation of population diversity since they represent sequences that are known to be polymorphic and have known genetic relationships to each other.

Media supporting high conidial production by *Ramulispora sorghi* (Table 1) included PDA (fresh), sorghum leaf extract agar and dandelion extract agar. Optimum temperature for conidial production occurred at 20 and 24°C. Optimum pH for conidial production (Table 2) was between 4.5

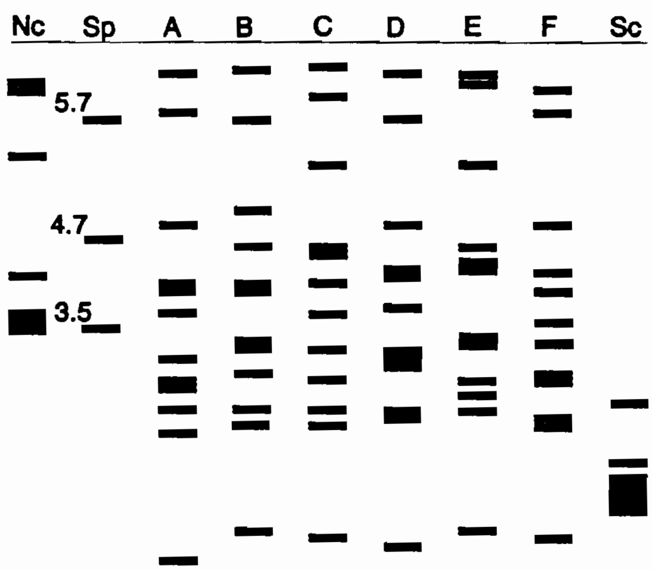

Figure 1. Computer-generated cartoon of electrophoretic karyotypes of representatives of the six mating populations of *Gibberella fujikuroi* (*Fusarium* section *Liseola*). (Doublet bands on agarose gels were drawn with double density. Strains used were (from left to right) *Neurospora crassa*; *Schizosaccharomyces pombe*; *G. fujikuroi* strains A-00102, B-00278, C-01996, D-00502, E-00990, and F-04091; and *Saccharomyces cerevisiae*.)

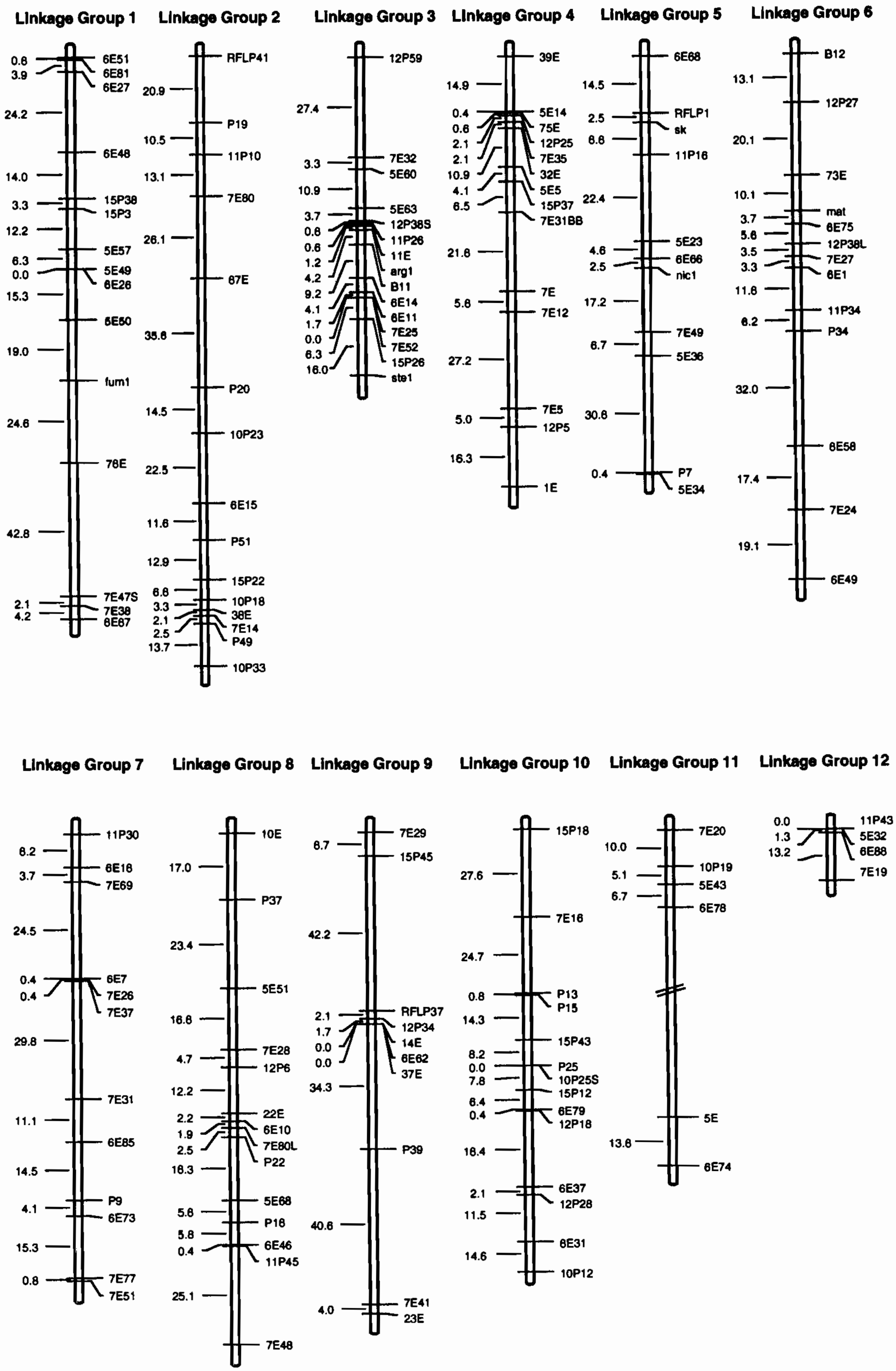

Figure 2. Genetic map of *Gibberella fujikuroi* mating population A (*Fusarium moniliforme*). (Linkage groups are numbered according to molecular size of the corresponding band on a CHEF gel (Figure 1). The largest chromosome is chromosome 1. All markers represent RFLP polymorphisms except; *arg1* - arginine auxotrophy, *fum1* - fumonisin biosynthesis, *matA* - mating type, *nic1* - nicotinic acid auxotrophy, *Sk* - spore killer *ste1* - female sterility, and *B11* and *B12* - RAPD markers.)

Table 1. Effect of temperature and media on conidial production by Ramulispora sorghi after incubation for ten days.

	Temperature (°C)				
Medium	16	20	24	28	32
PDA	49.0[a]	103.1	114.7	0.58	0.1
Sorghum leaf extract agar	62.3	110.1	99.9	77.8	25.5
Dandelion extract agar	38.1	82.0	95.3	92.7	60.3
Bilai medium	11.0	13.8	21.4	17.0	9.8
Water Agar	1.1	1.9	1.6	1.8	1.3

[a]Number of conidia x 10^4

Table 2. Effect of temperature and pH on conidial production by *Ramulispora sorghi* after incubation for ten days.

	Temperature (°C)			
pH	20	24	28	32
3.5	38.0[a]	66.3	0.07	0.01
4.5	107.6	117.2	0.58	0.10
5.5	100.2	78.0	0.10	0.10
6.5	137.6	56.5	1.03	0.09
7.5	101.5	31.8	0.38	0.19
8.5	105.7	32.5	0.17	0.01

[a]Number of conidia x 10^4

and 5.5 at 24°C. When incubated at 20°C, the optimum pH ranged from 4.5 - 8.5.

ADIN and *Pseudomonas*. Disease severity ratings for bacterial leaf stripe were recorded two weeks after inoculation on a 0-5 scale. For 1993 and 1994, disease severity ratings were significantly different (P<.01) among accessions and groups of resistant, intermediate, and susceptible germplasm. Significant differences (P<.05) were also observed between years. Resistant accessions included SC 326-6, SC 414-12E, BTX 378, B35-6, and TX 2862. Susceptible entries included TX 2767, TX 430, TAM 428, BTx 623, R 9117, and 90B2662.

Of the ADIN germplasm entries tested in 1993; 35 were considered resistant, 14 intermediate, and 1 susceptible (Table 3) with an average disease rating of 1.2. In 1994, 19 were considered resistant, 14 intermediate, and 17 susceptible (Table 3) with an average disease rating of 1.9. In 1993, only the accession R 9117 had a rating above 3.0. No accession was immune to *P. andropogonis*.

Plant ratings taken after flowering indicated that susceptible cultivars sustained significantly more disease than intermediate ones. The resistant accessions showed only traces of bacterial leaf stripe under field conditions.

Networking Activities

Editorial and Committee Service

Dr. Leslie served on the Editorial Board of *Applied and Environmental Microbiology*.

Dr. Leslie served as an Associate Editor and on the Editorial Board of *Mycologia*.

Dr. Leslie served as a member of the International Society for Plant Pathology's *Fusarium* Committee.

Research Investigator Exchange

Seminar Presentations

Dr. Leslie made the following invited presentations as departmental seminars, and as a workshop participant:

Research Division, Northrup-King, Stanton, Minnesota -1/94.

Myco Pharmaceuticals, Cambridge, Massachusetts - 2/94.

School of Biological Sciences, Universiti Sains Malaysia, Penang, Malaysia - 6/94.

American Institute of Food Technologists' Annual Meeting, Atlanta, Georgia - 6/94.

Symposium on "Fungal Collection for Drug Discovery", Cambridge, Massachusetts -6/94.

Fifth International Mycology Congress, Vancouver, British Columbia, Canada - 8/94.

Consortium for Plant Biotechnology Research Annual Meeting, Chicago, Illinois - 11/94.

Long-term Laboratory Visitors

Dr. Claflin's Laboratory - Ms. Wang Mei, Jilin Academy of Sciences, Gongzuling, PRC, July 1, 1994 - June 30, 1995

Table 3. Visual field ratings of the grain sorghum All Disease and Insect Nursery to *Pseudomonas andropogonis.*

Accession	1993[a]	1994[a]	Reaction type[b]
SC 326-6	0.8*	1.0	R
SC 414-12E	1.3	1.3	R
SC 630-11E	2.3	2.8	S
Tx 2783	0.0	2.1	I
QL 3 (India)	0.0	2.2	I
BTx 378	0.0	1.3	R
88 B 943	0.0	2.0	I
90 CCEON 343	0.0	0.5	R
TX 7078	0.3	2.4	I
91 CC 515	0.5	0.9	R
92 BD 1016	0.5	0.6	R
R 9188	0.5	1.0	R
BTx 635	0.5	2.3	I
R 9110	0.5	2.3	I
BTx 631	0.5	1.8	I
90 EON 328	0.5	0.8	R
87 EOM 366	0.5	0.8	R
87 BH 8606-6	0.5	1.2	R
88 B 928	0.5	1.9	I
90 CW 8147	0.5	1.7	I
BTx 2755	0.7	2.2	I
85 DG 4300-5	0.7	1.3	R
Tx 2767	0.8	2.7	S
Tx 430	0.8	2.8	S
91 B 2978	0.8	2.3	I
SRN 39	1.0	2.8	S
Sureño	1.0	2.9	S
91 BE 7414	1.0	1.3	R
87 EON 109	1.2	2.9	S
RTx 436	1.2	2.5	S
B 35-6	1.2	1.0	R
Tx 2862	1.3	1.0	R
TAM 428	1.3	3.2	S
Malisor 84-7	1.3	2.4	I
91 BD 1319	1.3	1.2	R
90 B 2662	1.3	3.3	S
BTx 623	1.5	3.3	S
BTx Arg I	1.5	2.5	S
80 C 2241	1.5	2.6	S
B 1	1.7	1.8	I
88 B 924	1.8	2.0	I
82 BDM 499	1.8	2.8	S
B 8503	1.8	2.9	S
R 8903	2.0	2.8	S
92 CW 5447	2.0	1.2	I
86 EOM 361	2.0	1.2	I
89 CC 443	2.0	1.3	I
88 B 1016	2.2	2.9	S
MB 108 B	2.2	1.3	I
R 9117	3.3	4.1	S
LSD (P<0.05)	**0.9353[c]**	**0.9002[c]**	
	0.099[d]	**0.0708[d]**	

[a]Disease serverity score means (0-5 scale)
[b]R Resistant accessions (0.0-1.4); I=Itermediate (1.5-2.4); S=Susceptible (2.5-5.0).
[c]LSD individual entries.
[d]LSD for groups.

and Mr. Xiude Xu, Sorghum Research Institute, Liaoning Academy of Sciences, Shenyang, PRC, November 1, 1994 -present.

Dr. Leslie's Laboratory:- Keith K. Klein, Sabbatical visitor 9/94-8/95 (Sponsored by USDA National Research Initiative competitive grant). Present position: Associate Professor, Department of Biology, Mankato State University, Mankato, Minnesota.

Assistance Provided

Bacterial cultures and scientific reprints were furnished to Mr. Tarekegn Geleta, Dire Dawa, Ethiopia for assistance in his M.S. program. from Dr. Claflin's laboratory.

Dr. Leslie's laboratory provided standard *Fusarium* cultures to:

Dr. C. J. Kedera, KARI, Kitale, Kenya.

Dr. Paul E. Nelson, *Fusarium* Research Center, The Pennsylvania State University, University Park, Pennsylvania.

Fungal Genetics Stock Center, University of Kansas Medical Center, Kansas City, Kansas.

Dr. Themis J. Michailides, Kearney Agricultural Center, University of California, Parlier, California.

Dr. Clegg Waldron, Dow-Elanco, Indianapolis, Indiana

Dr. Walter A. J. de Milliano, S&G Seeds, B.V., Enkhuizen, the Netherlands

Dr. Charles Bacon, USDA Russell Research Center, Athens, Georgia.

Dr. W.F.O. Marasas, PROMEC, South African Medical Research Council, Tygerberg, South Africa.

Dr. Marian Beremand, Department of Plant Pathology and Microbiology, Texas A & M University, College Station, Texas.

Dr. Elhamy El-Assiuty, Plant Pathology Research Institute, Agricultural Research Center, Giza, Egypt.

Dr. Gary Yuen, Department of Plant Pathology, University of Nebraska, Lincoln, Nebraska.

Dr. Claude P. Seletrinnikoff, University of Colorado Health Sciences Center, Denver, Colorado.

Dr. Adriana Tomas, Pioneer Hi-Bred International, Johnston, Iowa

Drs. Ronald D. Plattner, Anne E. Desjardins, and Kerry O'Donnell, USDA National Center for Agricultural Utilization Research, Peoria, Illinois

Publications and Presentations

Abstracts

Desjardins, A. E., R. D. Plattner and J. F. Leslie.1994. Segregation of fumonisin production in progenies of crosses between strains of *Gibberella fujikuroi* (*Fusarium moniliforme*) mating population A from various host plants and geographic areas. Proceedings of the Fifth International Mycological Congress (Vancouver, Canada): in press.

Kedera, C. J., J. F. Leslie, and L. E. Claflin. 1994. *Fusarium moniliforme* in maize, an endophyte? Proceedings of the Fifth International Mycological Congress (Vancouver, Canada): in press.

Leslie, J. F. Distinguishing mating populations of *Gibberella fujikuroi*. Proceedings of the Fifth International Mycological Congress (Vancouver, Canada): in press.

Leslie, J. F. A genetic perspective on populations of *Fusarium moniliforme* (*Gibberella fujikuroi* mating populations A and F). Proceedings of the Fifth International Mycological Congress (Vancouver, Canada): in press.

Journal Articles

Kedera, C. J., J. F. Leslie, and L. E. Claflin. 1994. Genetic diversity of *Fusarium* section *Liseola* (*Gibberella fujikuroi*) in individual maize plants. Phytopathology 84:603-607.

Books, Book chapters and Proceedings

Leslie, J. F. 1994. Moderator's report -Ecology and genetics of the Chestnut Blight fungus. Proceedings of the International Chestnut Conference (Morgantown, West Virginia, 10-14 July 1992), 171-172.

Dissertations and Theses

Anderson, C. 1994. Restriction Mapping of the Internal Transcribed Spacer of the Ribosomal DNA of *Fusarium* section *Liseola*. M.S. thesis. Kansas State University, Manhattan, KS.

Kedera, C. J. 1994. Tracking and identification of genetic diversity within populations of *Fusarium* section *Liseola* from maize. Ph.D. Dissertation. Kansas State University, Manhattan, KS.

Low Input Ecologically Defined Management Strategies for Insect Pests on Sorghum

Project MSU-105
Henry N. Pitre
Mississippi State University

Principal Investigator

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Collaborating Scientists

Dr. Francisco Gomez, Plant Breeder, Agronomy Department, Panamerican School of Agriculture (EAP), Apartado Postal 93, Tegucigalpa, Honduras.
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Dr. Billy Wiseman, Entomologist, USDA, Insect Biology and Population Management Research Laboratory, Tifton, Georgia.

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 the sorghum and corn crops. 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 the armyworm species has identified the role of these insects in this complex. This information has contributed to the successful conduct of entomological research designed 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 role 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 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.

The entomological investigations in MSU-105 have provided the basis for development of insect pest control strategies for sorghum and corn production in Honduras and surrounding regions in Central America with similar insect pest constraints. The expansion of the project into El Salvador, Guatemala and/or Nicaragua will expand the scope of MSU-105 activities in this ecogeographic region.

Objectives, Production and Utilization Constraints

Objectives

Conclude the studies on aspects of biology and behavior 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 seedlings and older plants on subsistence farms in Honduras.

Determine influence of specific weed management practices on insect pests in the "langosta" complex and natural enemy populations on production farms.

Determine the influence of specific planting dates on the "langosta" pests and natural enemy populations on production farms.

Determine the efficacy and residual impact of insecticide spray(s) on the lepidopterous larvae in the "langosta" complex on production farms.

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 in MSU-105 with the armyworm species (*Spodoptera frugiperda, S. latifascia*, and *M. rogenhoferi*) in different crop production areas in Honduras. Insect pest biology, ecology and seasonal populations dynamics studies elucidated the role of these three insect species in intercropped sorghum and corn. Noncrop 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 previously identified the importance of two of the lepidopterous caterpillar species in the "langosta" complex, studies in 1994-95 emphasized the third species, *M. rogenhoferi*. The relationship of this little researched species with noncrop vegetation and crop plants in sorghum-corn production environments was emphasized. Studies were concluded on the influence of host plants on larval developmental time and adult survivorship. The pest population levels and dynamics of infestations on the crops during the growing season for this species, and others in the lepidopterous complex, assists in developing total insect pest management strategies for the "langosta" in intercropped sorghum and corn in specific regions of Honduras. Aspects of this research is transferable to other areas in Central America.

The international significance of the *Spodoptera* species, as well as *M. rogenhoferi*, particularly in relation to migration and pest control and insecticide 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 United States (this is particularly significant for the fall armyworm, a serious pest throughout the Americas).

Alternative insect pest management practices (limiting insecticide use) which are practical for use by the subsistence farmer have been evaluated in MSU-105. Investigations have been further designed to elucidate specific aspects of langosta pest management tactics previously identified as practical for control of the species in this lepidopterous complex that limit crop production. The sorghum breeding program with EAP 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

Research Methods and Research Findings

Honduras

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

M. rogenhoferi, like *S. 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 revealed that this species infests non-crop vegetation of several types beginning immediately after the onset of the rainy season. Observations indicated that *M. rogenhoferi* appeared to have only one or possibly two generations in southern Honduras. Thus, studies with this species were initiated in 1993-94 and continued in 1995 to determine:

1. The univoltine or multivoltine behavior of the species,

2. Host oviposition preference for and larval development on broadleaf plants compared with sorghum, corn and other grass plants, and

3. 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. The occurrence of larvae of various age structure was recorded from late April to late July. 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 were used to depict insect occurrence in time and with host plant growth stage. Our observations suggest that sorghum and corn may be sink habitats for *M. rogenhoferi* and that certain non-crop vegetation types are preferred over sorghum and corn.

M. rogenhoferi larvae were collected on non-crop plants that emerged following the initiation of the rains and prior to crop planting in May or June; this further supported 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 regions 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.

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 were initiated in the laboratory with *M. rogenhoferi* using the most common noncrop plants (*Amaranthus hybrydus* and *Cassia occidentalis*) from the study habitats in southern Honduras, as well as sorghum and corn. Insects fed these host plants were measured daily to determine the influence of the host plants on larval development and adult survivorship. Data included larval and pupal weights, larval developmental time, and larval survival.

M. rogenhoferi fed broad leaf plants survived better than those fed sorghum, but there were no differences in larval survival on *A. hybridus* and *C. occidentalis* on sorghum or corn. *M. rogenhoferi* development was delayed about 1 to 1.5 days when fed sorghum or corn compared with those fed *A. hybridus* or *C. occidentalis*. Larvae and pupae weights were significantly greater for larvae fed *A. hybridus* and *C. occidentalis* compared to weights of larvae fed sorghum or corn. Survival of pupae and adults were higher for larvae fed the non-crop plants, supporting the observations by H. Portillo (MSU-105) that sorghum and corn may be sink habitats for *M. rogenhoferi*.

Female *M. rogenhoferi* moths lived longer when larvae were fed *C. occidentalis* than when fed the other test plants; however, no significant differences were found when longevity of adults and larvae were compared on *A. hybridus* and corn. Larvae fed sorghum did not develop to adults as the plants developed. *A. hybridus* and *C. occidentalis* appear to be very suitable host plants for *M. rogenhoferi* to initiate population establishment during the early part of the growing season. However, it appeared that *M. rogenhoferi* completed a single generation on the crop and non-crop plants and then pupated in the soil in diapause.

The preliminary studies that suggested diapause in *M. rogenhoferi* during the dry season and suggested that soil moisture was closely associated with termination of this biological process (MSU-105) were given further evaluation. This relationship was investigated in the laboratory exposing pupae (from field collected larvae) to various moisture levels at times after pupation. Larvae were reared on the specific host plants (sorghum, corn, or three non-crop plants) previously identified as important hosts for *M. rogenhoferi*. Pupae in the soil were exposed to five soil moisture levels (0%, 10%, 20%, 30% soil saturation) and continuous moisture (10% moisture over time) at monthly intervals. These studies provide a better understanding of environmental influences (e.g., host plant and soil moisture) on 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 in the development of insect control tactics for individual species in the complex.

To investigate diapause in *M. rogenhoferi*, larvae were reared on sorghum, corn, watermelon, *A. hybridus* and *C. occidentalis*, allowed to pupate in soil and then exposed to five different soil moisture levels (0%, 10%, 20%, 30% soil saturation) and continuous moisture (10% maintained over time) at monthly intervals after pupation (August to May). Time in diapause and soil moisture appeared to be closely related to termination of this resting stage. Soil moisture levels of 20 and 30% stimulated greater adult emergence during the months of April and May when compared to 0 and 10% soil moisture. Not all *M. rogenhoferi* entered the diapause stage at the same time, and the different test diets did not appear to have any influence on termination of diapause. This biological information is useful in understanding the role of crop and non-crop plants, as well as survival potential of the species in the "langosta" complex. This is the type of biological information necessary for design of successful insect pest management methods for the complex of defoliators that is the principal pest constraint to sorghum and corn in many areas of Central America.

Weed Management — Influence on the "Langosta" Lepidopterous Pest Complex and Beneficial Agents.

Weeds have been shown to have an influence on the biology and behavior of the "langosta" species. However, specific and detailed weed management practices have not been evaluated (in comparisons) on subsistence, production farms. In 1995, weed management treatments were tested in on-farm comparisons to determine the best program to include in on-farm validation and demonstration studies (to be initiated in 1996). Treatments included different levels of weed control during the growing season. Information was obtained on weed species identification, establishment, buildup, and diversity, as well as weed association with insect pest diversity and density, and weed association with predator-parasitoid diversity and density. Yield data and economic information (cost of on-farm labor, cost of external inputs, and economic investment and return) will be obtained for each treatment. This study will be completed after harvest in January, 1996.

Planting Date — Influence on the "Langosta" Lepidopterous Pest Complex and Beneficial Agents.

Farmers traditionally plant sorghum and corn as soon as possible after the first rains, typically in late April or early May. Planting time can have an impact on the level of insect pest infestation and crop damage. This is particularly apparent when insect pest infestations are closely associated with environmental factors that influence extreme population establishment and buildup. This appears to be the situation with the "langosta."

As with the weed management investigation, different planting dates were tested in on-farm experiments in southern Honduras to determine the optimum planting dates to be included in validation and demonstration studies (to be initiated in 1996). Treatments included a traditional planting date and four subsequent plantings at short intervals thereafter. Data was collected as indicated in the weed management investigations (above). This study will be completed after harvest in January, 1996.

Insecticide Evaluations — Influence on the "Langosta" Lepidopterous Pest Complex and Beneficial Agents.

Chemical insecticides, when available to the subsistence farmers, are used to suppress the "langosta" complex on sorghum and corn. This approach is often less than acceptable for a variety of reasons, including selection of ineffective materials, poor application methods and improper timing of application. The insecticide evaluations conducted in 1995 were performed to evaluate selected insecticides applied at appropriate times. The different application schedules were evaluated for insect infestation on the crops, material efficacy, reinfestation, impact on predators and parasitoids, and yield and economic returns.

Of the chemicals tested, Lannate provided the highest level of control of the "langosta" species, followed by Lorsban, Curacron and Tamaron. The chemicals reduced parasitism by 30% and foliar damage was less when insecticide was applied to the early larval stages. Best results were obtained following an intensive sampling program to determine egg infestation level and/or early larval stages. Tamaron has a low price and can be considered for use depending upon infestation level and age structure of the population, whereas Lannate would be more effective when treatment is required for a variable population of larvae.

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 three of the "langosta" species; these investigations have provided the information for design of integrated insect pest management programs for designated areas. The use of cultural control methods (e.g., planting dates and 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.

Networking Activities

Germplasm and Research Information Exchanges

Supplies and equipment required by graduate students in performance of research activities in the laboratory and field in Honduras were supplied (as in previous years) by MSU-105. Some financial support (cash) is provided annually to the students for research expenses while in Honduras.

Publications and Presentations

Journal Articles

Portillo, H.E., H.N. Pitre, D. H. Meckenstock and K. L. Andrews. _______. Performance of a lepidopterous pest complex (the langosta in Honduras) on sorghum, maize and non-crop vegetation. Environ. Entomol. (Accepted).

Castro, M. T., H. N. Pitre, and D. H. Meckenstock. ______. Fall armyworm (*Spodoptera frugiperda*) (J.E. Smith) (Lepidoptera: Noctuidae) development on Honduran landrace sorghums as a function of plant age. Trop. Agric. (Submitted).

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Portillo, H. E., H. N. Pitre, D. H. Meckenstock, and K. L. Andrews. ______. Performance of a lepidopterous pest complex (the langosta in Honduras) on sorghum, maizes and non-crop vegetation. Environ. Entomol. (Submitted).

Portillo, H. E., H. N. Pitre, D. H. Meckenstock, and K. L. Andrews. _____. Oviposition preference of *Spodoptera latifascia* (Lepidoptera: Noctuidae) for sorghum, maize and non-crop vegetation. Fla. Entomol. (Submitted).

Portillo, H. E., H. N. Pitre, D. H. Meckenstock, F. Gomez and J. Lopez. ____. Validation of new agronomic and plant protection technologies in intercropped sorghum and maize in southern Honduras. Trop. Agric. (Submitted).

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

Projects PRF-104B and PRF-104C
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Dr. Abdel Gebbar Babiker, Weed Control Program, Agricultural Research Corporation, Gezira Station, Wad Medani, Sudan

Summary

This project applies the techniques of biochemistry in an interdisciplinary manner, with LDC and other INTSORMIL collaborators, to losses to birds, grain mold, and *Striga*, major constraints on sorghum production, and to low nutritional quality due to sorghum's defense chemicals, a major constraint on sorghum utilization.

Perhaps our most noteworthy activity in recent months is, in collaboration with Dr. Ann Hagerman, characterization of a new form of sorghum tannin, pro-3-deoxyanthocynidin. This new material has been found so far only in leaves of red sorghums infected with leaf diseases. It may play a role in disease resistance. Tan plant sorghums do not make it. It binds globular proteins strongly, similarly to the conventional tannin (pro-3-hydroxyanthocyanidins) from sorghum seeds, but the protein-rich proteins bound so strongly by conventional sorghum tannin are not bound at all by this newly discovered material. Thus, it provides important information about the nature and selectivity of protein binding by various types of 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 an integrated interdisciplinary research program coordinated closely with that of Dr. Ejeta. Our general approach is on sorghum improvement by enhancement of its resistance to pests, but we also contribute new basic knowledge about sorghum and its pests and nutritional constraints. 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. 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 particulary appropriate for African subsistence farmers with limited access to inputs.

Project Output

Methods development - Our only contribution to new methodology in the past year has been a method for purifying the new pro-3-deoxyanthocyanidin material, and a method for quantitating it. We are still seeking to develop a simple and reliable bioassay for the "toxin" produced by *Striga*, and a reliable chemical assay for dhurrin.

Mold and leaf disease resistance in sorghum - We have re-examined and reconfirmed our original observation of the correlation of sorghum grain mold resistance with seed content of flavan-4-ols and with tannins. The only exception is a rare type of mold resistant white seeded sorghums which have no tannins or flavan-4-ols. Resistance in this type of sorghum grain appears to be due to the presence of protective proteins rather than 3-deoxyanthocyanidin pigments.

In infected leaves of red and purple plant type sorghums we found a previously unreported phenolic material which on treatment with acid at 100 degrees converts to a mixture of the 3-deoxyanthocyanidins, apigenidin and luteolinidin. We have now purified and characterized this new pro-3-deoxyanthocyanidin and found that it indeed does bind tannins and therefore warrants being called a "tannin." However, its protein binding specificity is quite different from the conventional pro-3-hydroxyanthocyanidin tannin previously characterized from sorghum seed. This material binds conventional globular proteins similarly to seed tannin, but does not bind proline-rich proteins at all, in strong contrast to seed tannin. This finding strongly suggests that the crucial component of conventional sorghum tannins that causes such strong binding to proline-rich proteins is its 3-hydroxy group, and that this group is unimportant in binding to conventional globular proteins.

Tannin-free bird resistant sorghums - Two bird-resistant sorghums which are tannin-free and have excellent nutritional value have been found in our laboratory to contain the cyanogenic glucoside, dhurrin. We have also found dhurrin in some of their progeny. We have now found, with the help of Dr. Nahrstedt who provided several thousand dollars worth (at market price) of pure dhurrin for our feeding trials with Japanese quail, that pure dhurrin is definitely repellant to birds. This was the last link in the identification of the bird repellant factor of these bird resistant but tannin-free sorghums as dhurrin. We have shown that the glucosidase enzymes which hydrolyze dhurrin and release cyanide are present in sorghum grain, and that merely moistening the flour results in release of the cyanide to be driven off in cooking, so that it does not pose a nutritional threat. Sorghums containing this bird-resistant factor can readily be used as poultry feed by feeding it as a moist mash. 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.

Tissue culture - We lost our veteran tissue culturist, Ms. Cai, to the Biotechnology Division of Pioneer Hi-Bred International last fall, and have not continued that work in our laboratory. Our second major journal report on somaclonal variation in sorghum in *in vitro* culture has been published in Theoretical and Applied Genetics. Our major review chapter on the same subject is in press.

Striga - Reconsideration of the life cycle of *Striga* and the necessity of its coordination with that of its host has led us to the recognition of the tight integration of the *Striga* life cycle with growth and development of the host by means of a series of chemical signals exchanged between the two. We have played an important role in the identification of the first signal, germination stimulant, and have provided evidence for later signals exchanged in both directions between *Striga* and its host by means of vascular connections, rather than through the soil medium as for germination stimulant and haustorial initiator.

Continuing to build on our previous observations that *Striga* germination stimulant increases the *Striga* seed's capacity to produce the important plant hormone,ethylene, we showed, with Dr. T. Housley and Nivia Medina, undergraduate summer student from Puerto Rico, that the resulting ethylene can also affect the host roots. Nivia's preliminary results indicate that roots of both tan and red plant type sorghums respond to exogenous ethylene by a massive overproduction of the flavone, apigenin, and that smaller increases in the 3-deoxyanthocyanidin pigments are also triggered this way. Most intriguing was the observation that of the few genotypes tested, those resistant to *Striga* responded to ethylene much more strongly than did the susceptible genotype control.

In our laboratory, Dolly Bell-Lelong has extracted and isolated from *Striga* several unique phenolic glycosides, with complex sugar structures, as candidates for the *Striga* "toxin."

Networking Activities

Workshops

L.G. Butler, Workshop on Parasitic Weeds: Biology and Resistance, May 30th-June 2nd, 1995, IACR-Long Ashton Research Station (Burwells/Bristol), UK.

Cooperating scientists

Dr. Ann Hagerman, Department of Chemistry, Miami University, Oxford, Ohio 45056.

Dr. Adolf Nahrstedt, Institut fur Pharmazeutische Biologie und Phytochemie, Westfalische Wilhelms-Universitat, Munster, Germany.

Drs. Athene Lane and John Bailey, IACR-Long Ashton Research Station, University of Bristol, Bristol, UK.

Dr. Sam Mukuru, ICRISAT Sorghum Breeder, SAFGRAD, Nairobi, Kenya.

Dr. Robert Schaffert, EMBRAPA, Sete Lagoas, MG, Brazil.

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

Dr. L. M'Ragwa, Ben Kanyengi and Gordon Abayo, Kenya Agriculture Research Institute, Nairobi, Kenya.

Drs. Axtell and Housley (Agronomy), Bennetzen (Biology), Rogler (Animal Science), Hamaker (Food Science), Nicholson (Botany & Plant Pathology), all at Purdue University.

Research Investigator Exchange

Abdellah Mohammed, Dr. Babiker's assistant at ARC, Sudan, is currently studying for his M.S. under Dr. T. Housley of Agronomy, and is using our *Striga* containment facility for the research.

Research Information and Material Exchange

Many copies of our (with Drs. Ejeta and Babiker) Research Bulletin on *Striga* and reprints of our journal articles and book chapters were distributed worldwide. Polyphenol analyses and *Striga* germination analyses, as well as samples of sorghum, millet, tannin, sorgoleone and other materials were provided for several of the collaborators listed and for many others not listed, including analyses for Northrup King and Rocco, Inc, with the results of the latter communicated forcefully to the headquarters of the National Grain Sorghum Producers Association. Laboratory supplies were provided for Dr. A. G. Babiker, ARC, Sudan.

Publications and Presentations.

Abstracts

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Cai, T., G. Ejeta and L. G. Butler. 1994. Effect of Genotype, Explant Source, and Medium Composition on Callusing, Embryogenesis and Regeneration in Sorghum, Am. Soc. Agronomy Annual Meeting, Seattle, WA.

Menkir, A., A. Melake Berhan, L. G. Butler, H. Warren, and G. Ejeta. 1994. Grain Mold Resistance in Sorghum, Am. Soc. Agronomy Annual Meeting, Seattle, WA.

Weerasuriya, Y., A. Melake Berhan, G. Ejeta, L. Butler and J. Bennetzen. 1994. A Molecular Marker-Based Linkage Map of Sorghum, Am Soc. Agronomy Annual Meeting, Seattle, WA.

Journal Articles

Cai, T., G. Ejeta and L. G. Butler. 1994. Development and Maturation of Sorghum Seeds on Detached Panicles Grown *In Vitro*. Plant Cell Reports, 14, 116-119.

Cai, T., G. Ejeta and L. G. Butler. 1995. Screening for Grain Polyphenol Variants from High Tannin Sorghum Somaclones. Theoretical and Applied Genetics 90, 211-220.

Reda, F., L. G. Butler, G. Ejeta and J. K. Ransome. 1994. Screening of Maize Genotypes for Low *Striga asiatica* Stimulant Production Using the "Agar Gel Technique."African Crop Science J. 2, 173-177.

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Siame, B. A., G. Ejeta, and L. G. Butler. 1994 Phenolic Composition of Tan and Red Isogenic Sorghum Genotypes and their Reaction to Leaf Diseases. Acta Horticulturae 381, 675-678.

Books, Book Chapters and Proceedings

Book Chapters

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Cai, T. and L. G. Butler. 1995. Somaclonal Variation in Sorghum. for Y. P. S. Bajaj (Ed.). Somaclonal Variation in Crop Improvement II. Springer-Verlag, Berlin, (in press).

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Babiker, A.G.T., I.A. Ali, G. Ejeta, L. Butler and W.R. Woodson. 1995. *Striga asiatica* Germination Requires Stimulation of 1-aminocyclopropane-1-carboxylic acid (ACC) Synthesis and Oxidation. Workshop on Parasitic Plants: Biology and Resistance. May 30-June 2, 1995. Bristol, UK.

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Disease Control Strategies for Sustainable Agricultural Systems

Project TAM-124

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Summary

Emphasis has been placed on the mapping of host resistance in sorghum for use in marker-assisted selection. Populations of recombinant inbreds for mapping resistance genes to anthracnose, downy mildew, head smut, leaf blight, and grain mold are being evaluated. Marker-assisted selection will permit both the breeding of resistance to pathogens not present and the building of more durable resistance. Characterization of pathogen populations using neutral genetic markers demonstrated the clonal nature of isolates of *Colletotrichum graminicola* from sorghum. *C. graminicola* isolates from johnsongrass are unrelated to isolates from commercial sorghums. Interestingly, johnsongrass isolates from Texas are genetically similar to maicillo sorghum isolates from Honduras. Our collaboration with ICRISAT permits us to obtain and maintain isolates of *C. graminicola* from various hot spots around the globe. Improved methods for evaluating reaction to head smut and identifying the pathogen mating type in culture will hasten research on both detection of resistance and dynamics of the pathogen population analysis.

Research Objectives

Honduras

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

Continue 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/ICRISAT

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

Initiate preparation for 1998 or 1999 Sorghum/Millet Crop Protection Conference.

Mali

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

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 by both conventional and biotechnical methods.

Improve disease screening methods.

Study biology of disease epidemiology of sorghum pathogens as needed.

Organize, maintain, and distribute the international sorghum disease and pathogen identification nurseries in collaboration with ICRISAT, and with TAM-122 and TAM-128.

Detect, identify and catalogue *Colletotrichum graminicola* and *Sporisorium reilianum* isolates 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 collaboration on the incorporation of the resistance(s) into useful cultivars. Most of this work is done cooperatively with plant breeders, biotechnologists, geneticists, and entomologists in the Texas programs, but also occasionally with breeders in other states, nations (NARS), or with an International Crop Research Center, specifically ICRISAT.

Collaborative Research in Niger

Downy Mildew of Pearl Millet

Apron® Plus controlled downy mildew of pearl millet. Studies by Mr. I. Kollo at Tara and Kollo, Niger demonstrated a direct relationship between treatment rate and yield (Figure 1). Not surprisingly, increasing rates of treatment with Apron® Plus also results in the decrease in severity of downy mildew.

Striga of Pearl Millet

Mr. Kollo studied the ability of the herbicide Dicamba to control *Striga* of pearl millet. When applied at 0.2 kg/ha, it significantly reduced the number of *Striga* from 162 (control) to 52. The interaction between Dicamba and nitrogen on emergence of *Striga* was poorly related. The high coefficient of variability (Cv = 25.3%) may account for the poor fit.

Collaborative Research in Sudan

The Sudan program addresses major pathological problems affecting sorghum and pearl millet production in the country. Particular emphasis in sorghum is on smut diseases; covered, loose, and long smut. On millet, downy mildew is considered by far to be the major pathological constraint.

Covered, Loose, and Long Smut of Sorghum

Research results achieved this season indicated that Vitavax, Vitavax + Apron® Plus,and Captan give the best control of both covered and loose smut. Out of the five hundred Sudan collection lines tested the previous season for long smut resistance, 50 entries were selected on the basis of low to little infection. Artificial inoculation this season rated 37 as susceptible, 9 as less susceptible, and 4 with no infection. The same group is now being retested.

Downy Mildew of Pearl Millet

Downy mildew of pearl millet is prevalent in farmers' fields in Kordafan (11 to >80%), depending on rainfall. The higher the rainfall, the higher the incidence. All farmer varieties in the country are susceptible to the disease. Preliminary results indicated that metalaxyl at the rate of 2-8 g.a.i./kg seed gives control up to 40 days. The higher rates of the chemical were however toxic to the plant and caused reduced germination. Screening of a selected number of cultivars introduced from ICRISAT indicated that ICMV88908, ICTP8203, and ICMV221 are the most resistant entries. The test is being repeated in 1995 at different locations together with other entries from ICRISAT.

Domestic Research

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 completed in 1994. One hundred ninety-seven hybrids were evaluated for resistance to anthracnose, sorghum downy mildew, maize dwarf mosaic virus, grain mold, head smut, and stalk rots. These have been distributed to growers and county agents directly, but will also be incorporated into a computer-sized program on integrated sorghum 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 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 are evaluated 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. D. Rosenow (TAM-122), maintain sets of anthracnose, sorghum downy mildew, and head smut resistant converted lines. These specific nurseries represent valuable sources of disease resistance traits for breeding programs.

Recombinant inbred populations are being developed and maintained for the mapping of selected host resistance genes to anthracnose, head smut, leaf blight, grain mold, and downy mildew (Table 1). Dr. Jeff Dahlberg and Dr. Clint Magill have assisted in the development of these populations. Several are required because different genes are known affecting reaction to any one of several pathogens. We are continuing to develop near-isogenic lines of Tx430 and TAM428, each possessing downy mildew resistance from four different sources.

Sorghum Head Smut

Presently, sorghum resistance to *Sporisorium reilianum*, the causal organism of head smut, is evaluated in field trials following natural infection or artificial injection with inoculum. These trials can be expensive in terms of time and money and are restricted to the growing season. Natural infection requires repeated trials to obtain reliable data since environmental effects may result in disease escape, whereas

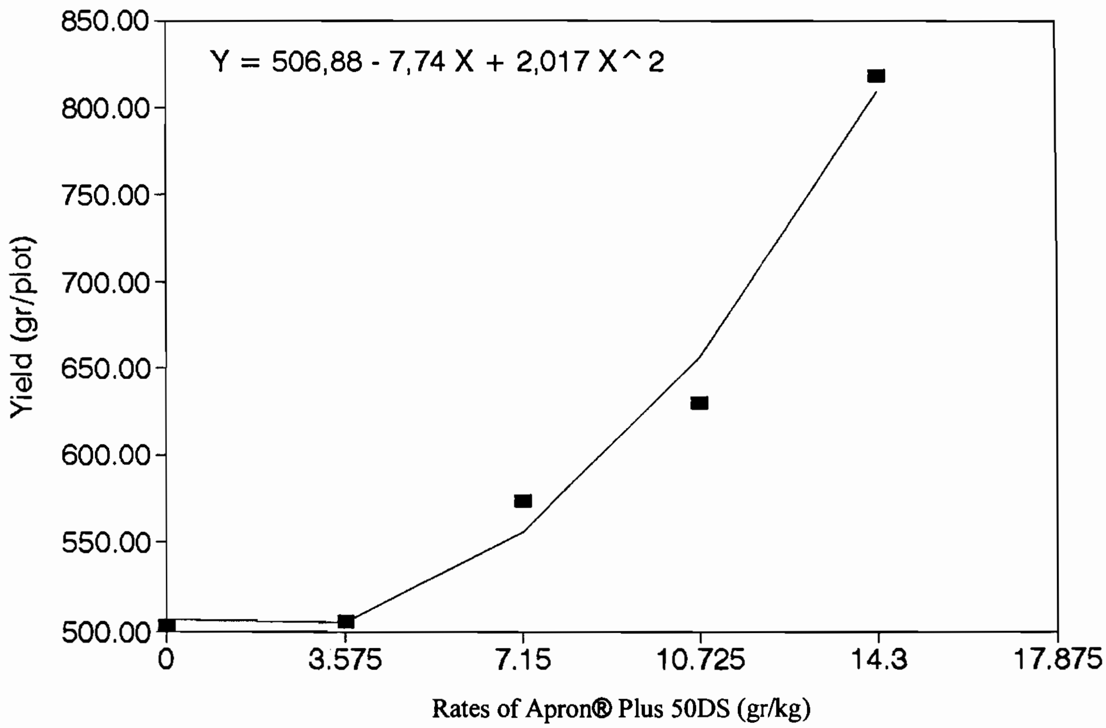

Figure 1. Relation between Apron® Plus and yield pearl millet (Locality of Tara)

Table 1. A list of recombinant inbred populations for mapping disease resistance genes.

Lines	Generation planted	Number of lines	Diseases to be scored*
Major lines			
BTx623 X SC326-6	F_5 & F_6	117	A, LB
BTx623 X SC748	F_5 & F_6	83	A, HS, DM, GM
BTx623 X IS12539C	F_5	75	A
BTx623 X IS8112C	F_5	71	A
BTx623 X IS2862C	F_5	55	A
BTx623 X SC414-12E	F_6	164	A, HS, DM
Sureño X SC120-12	F_4	131	GM
BTx635 X RTx7078	F_5	101	HS
ATx635 X SC170-6-17	F_6	79	HS
BTx635 X CS3541	F_5	78	HS
Other lines			
ATx635 X BTx399	F_6	16	HS
ATx635 X BTx414	F_6	48	HS
ATx635 X SC241-14E	F_6	32	HS
ATx635 X SA281	F_6	17	HS
ATx635 X FC6601	F_6	26	HS

* A=Anthracnose; LB=Leaf Blight; HS=Head Smut; DM=Downy Mildew; GM=Grain Mold.

inoculation with sporidia is labor-intensive and may bypass resistance factors (non-meristematic) that provide satisfactory levels of resistance under field conditions. Mr. Jairo Osorio is working on a research program to address some of these concerns. His objectives are: (1) to develop an infection assay that does not bypass non-meristematic resistance mechanisms and yet is highly efficient in reducing escape from infection, and (2) to identify molecular markers linked to this non-meristematic resistance in sorghum.

Mr. Osorio has developed a greenhouse-screening procedure for head smut that essentially duplicates natural infection (Table 2).

Table 2. Head smut infection in two susceptible lines of sorghum inoculated with teliospores of *S. reilanum*, Taylor isolate.

Line	# of Plants	# Infected	% Infected
RTx7078-Inoculated	135	123	91.1
RTx7078-Control	25	0	0.0
SC241-12E-Inoculated	109	43	39.5
SC241-12E-Control	25	0	0.0

Two types of host resistance mechanisms to *S. reilianum* have been described in sorghum; a meristematic factor for which RAPD markers were identified by Oh et al. (1994) in linkage group A and a non-meristematic factor which is thought to be fixed in early generations and effective against all races of the pathogen. Identifying molecular markers tightly linked to the locus controlling non-meristematic resistance would be a significant step towards the use of marker-assisted selection and development of cultivars with more durable resistance to head smut. F_3 progeny from the cross CS3541 x RTx7078 were grouped into two phenotypic classes, R (0% smut) and S (4-32% smut), based on head smut evaluation to natural infection at Corpus Christi. Using a bulk segregant approach and AP-PCR, a series of arbitrary 10-mer primers (a total of 520) were used to identify polymorphisms between both bulks. Those primers showing polymorphic loci between R and S pools were then examined on the parental DNAs (CS3541 and RTx7078), the individual F_3s constituting the bulks, and additional F_3s for which phenotypic data were not conclusive (very low infection levels or 0% head smut on poor stands). Out of the 520 primers tested on bulked DNAs, 30 identified polymorphic loci among these pools, and 5 distinguished R and S individual F_3s. One of these primers (OPH04) which positively identifies susceptible individuals was used to predict the field reaction to head smut in 70 F_3s from a cross between a resistant line (BTx635) and a susceptible parent (RTx7078). In addition, a group of 200 F_3s from the cross between BTx635 (R) and B1 (S) is being scored for smut reaction at two locations and following needle inoculation at one location. Field data from these segregating populations will be used as the phenotypic marker for mapping purposes. We expect to locate the R locus and determine the distance of the marker(s) based on the size of this population.

Ms. Cynthia Owens has been working with head smut from sorghum and corn. A double-strength complete charcoal medium (DCM), developed by Day and Agnostakis (1971) and modified by R. Holliday (1974) for the identification of sexually compatible isolates of *Ustilago maydis*, was evaluated for its efficacy in identifying compatible isolates of *S. reilianum* from sorghum and from corn. Individual sporidial cultures of sorghum head smut and corn head smut were grown in potato dextrose broth for 2-3 days at room temperature. All isolates were crossed pair-wise on DCM. After two days, white, convoluted colonies with "fuzzy" mycelial growth were identified as positive reactions (sexually compatible cross) and flat, yeast-like colonies were scored as negative reactions (individual isolates or an incompatible cross). Two isolates, CHS 2.1 and CHS 3.1, displayed a positive reaction in all spots, indicating that these isolates were not derived from single sporidial colonies. All plate mating reactions were verified in the greenhouse by injecting these crosses to a susceptible corn variety. F1 hybrid smut teliospores from a cross between a CHS isolate and SHS isolate were produced. Future studies on host-specificity and mating-type distribution will be greatly enhanced with the use of this plate mating technique, which has proven to be reliable and inexpensive in the detection of compatible *S. reilianum* sporidial isolates.

Sorghum Downy Mildew

Sorghum materials continued to be screened in the greenhouse for resistance to sorghum downy mildew using our greenhouse inoculation technique. Developed in the mid-1980's by J. Craig, this technique was demonstrated to researchers in Nigeria by Mr. Delroy Collins in 1992. We also evaluated sorghum for reaction to downy mildew in field nurseries at three locations in Texas (College Station, Corpus Christi, and Edroy).

Sorghum Anthracnose/Sorghum Leaf Blight

Progress has been made by Dr. K. Boora in obtaining markers more closely linked with resistance to anthracnose in sorghum, caused by *Colletotrichum graminicola* and sorghum leaf blight, caused by *Exserohilum turcicum*. A total of 300 random primers (10-mers) were surveyed for polymorphism with genomic DNA of BTx623 and SC326-6. Two hundred seventy-four random primers showed amplification. One hundred sixty-six random primers out of these 274 produced polymorphism among the parents for RAPDs and amplified 1270 discreet RAPD fragments. Using bulk segregant analysis, primer OPD12 amplified a band fragment of approximately 250 bp that appears to be closely linked to the resistant allele for leaf blight. Primers OPD12 and OPC12 amplified fragments linked to the susceptible allele. We have cloned the RAPD products and they will be sequenced to use as RFLP probes. We have also surveyed these random primers on the anthracnose bulks. Two primers OPF7 and OPI4 amplified bands that appear to be closely linked to the recessive resistance allele, and primer OPK16 amplifies a fragment that is less closely linked to the dominant susceptible allele for anthracnose. We are currently attempting to clone and sequence the unique RAPD products to use as RFLP probes, to generate longer primers to serve as sequence tagged sites.

Ms. Ute Rosewich has continued work on the population biology of *Colletotrichum graminicola*. Seven RFLP probes hybridizing to low copy DNA fragments have been used to study genetic diversity within and between populations of *C. graminicola* to determine at what spatial level genetic diversity is distributed within this organism, and to determine the extent of gene flow between populations. Sampling from populations of different ecological contexts was done to determine whether there is more genetic variation in more complex environments, e.g. disease nurseries vs. commercial fields, and how this compares to the genetic variation found in populations from a wild host, johnsongrass (*Sorghum halepense*), a common perennial weed. There have been speculations that johnsongrass might be a reservoir for *C. graminicola* and serve as an overwintering host. Therefore, sampling from johnsongrass was also done to determine whether an exchange of isolates occurs between the two host species (johnsongrass and sorghum). Another study was directed toward determining whether any genetic changes in populations of *C. graminicola* from sorghum can be detected over time.

Representatives of populations of *C. graminicola* were collected from several locations in the United States and elsewhere. Sorghum samples were obtained from the Sorghum Anthracnose Nursery in Griffin, Georgia over three years, ca. 100 isolates in 1991 and 1992 and ca. 200 isolates in 1993 (population abbreviation: G91-G93). In Honduras, sorghum samples were collected from three conventional sorghum hybrid fields in Honduras with ca. 100 isolates per sampling site (HNCT, HNEP, HNLI) and also from landrace sorghums ("maicillos") grown by subsistence farmers. A total of 61 isolates from maicillos were collected from three different fields within the general area of Choluteca (HNCH). One hundred sorghum isolates were also examined from the disease nursery at Mansa, Zambia, generally regarded as a "hot spot" for *C. graminicola* (ZAMA). In La Ward, Texas, 100 infected sorghum stalks were collected from a 5000 m2 area of a commercial sorghum field (LWS) and a total of 80 johnsongrass isolates were collected from 20 m transects at two sites directly bordering sorghum fields, one next to the LWS site (LWII) and the other ca. three miles away (LWI). About 150 johnsongrass samples were obtained from an infested area near La Grange, Texas, ca. 100 miles from La Ward (LG). No sorghum fields were in the neighborhood of this site. Samples of sorghum isolates were also obtained from several locations in South Texas in addition to the LWS site (BVS, CCS, EBS, ECS, SECS, and HCS).

The DNA from all isolates of the *C. graminicola* populations collected was hybridized to the seven RFLP probes. Different restriction size variants detected by each probe have been treated as alleles at a single RFLP locus. Each allele was assigned a number according to its frequency in the sample, whereby allele frequencies of the population from Georgia served as a base. Information from all loci was combined to form multilocus haplotypes, which is the summary of the alleles present at each locus for each isolate. The summary of all multilocus haplotypes identified for each of the locations together with the frequencies in the sample is shown in Table 3.

In general, all populations demonstrated a low amount of variability, which is surprising based on the high amount of pathogenic variability observed for this fungal species.

Table 3. Multilocus haplotypes from populations of *Colletotrichum graminicola* as determined by seven RFLP probes.

	Alleles							
Population (n)	pSCg1	pSCg3	pSCg10	pSCg17	pSCg23	pSCg28	pSCg31	Frequency
G-91 (n=105)	1	1	1	1	1	1	1	0.85
	2	2	2	1	2	2	1	0.08
	2	3	2	1	1	2	1	0.04
	2	2	2	1	3	2	1	0.02
	3	2	2	1	3	2	1	0.01
	2	2	2	2	4	2	1	0.01
G-92 (n=98)	1	1	1	1	1	1	1	0.79
	2	2	2	1	2	2	1	0.10
	2	3	2	1	1	2	1	0.05
	2	3	2	1	1	1	1	0.03
	2	3	2	1	2	2	1	0.01
	2	4	2	1	1	2	1	0.01
	2	2	2	2	4	2	1	0.01
G-93 (n=209)	1	1	1	1	1	1	1	0.79
	2	3	2	1	1	2	1	0.08
	2	2	2	1	2	2	1	0.06
	1	3	1	1	1	1	1	0.02
	2	2	2	1	3	2	1	0.01
	2	2	2	1	1	2	1	0.01
	3	2	2	1	3	2	1	0.01
	1	2	2	1	3	2	1	0.005
	3	2	2	3	4	2	1	0.005
	2	5	2	1	1	2	2	0.005
	1	2	3	2	4	2	2	0.005
HNCT (n=108)	1	1	1	1	1	1	1	0.87
	1	1	1	1	1	2	1	0.04
	1	1	1	1	2	1	1	0.01
	1	2	1	1	1	1	1	0.01
	1	1	1	5	1	1	1	0.01
	1	1	2	5	1	1	2	0.01
	1	1	3	1	1	2	1	0.01
	1	1	1	6	1	2	1	0.01
	1	1	3	6	1	2	1	0.01
	1	2	3	5	1	2	2	0.01
	3	2	1	5	1	1	2	0.01
HNEP (n=85)	1	1	1	1	1	1	1	0.88
	1	1	1	1	4	2	1	0.06
	3	1	1	1	1	1	1	0.01
	3	1	1	1	3	1	1	0.01
	3	7	1	1	1	2	1	0.01
	3	1	1	5	1	2	1	0.01
	3	2	3	5	1	2	2	0.01
HNLI (n=94)	1	1	1	1	1	1	1	0.87
	1	1	3	5	1	2	1	0.03
	1	1	1	5	4	2	2	0.03
	3	1	1	5	1	1	1	0.02
	1	1	1	1	1	1	2	0.01
	1	1	1	1	1	2	1	0.01
	1	1	3	1	1	1	1	0.01
	1	1	1	5	1	1	2	0.01
ZAMA (n=97)	1	7	2	1	1	2	2	0.38
	1	1	1	1	1	1	1	0.23
	2	7	2	1	1	2	1	0.18
	1	6	1	6	1	2	2	0.11
	2	7	2	1	1	2	2	0.03
	1	6	2	6	1	2	2	0.02
	2	8	2	1	1	2	1	0.02
	3	6	2	6	1	2	2	0.01
	2	6	2	1	1	2	2	0.01
	1	7	2	1	1	2	1	0.01

Table 3. - Continued.

	Alleles							
Population (n)	pSCg1	pSCg3	pSCg10	pSCg17	pSCg23	pSCg28	pSCg31	Frequency
LWS (n=97)	2	6	2	1	3	2	2	0.99
	2	6	2	4	3	2	2	0.01
BVS (n=29)	2	6	2	1	3	2	2	0.79
	2	2	2	1	3	2	1	0.17
	3	2	2	1	10	2	1	0.03
CCS (n=21)	2	6	2	1	3	2	2	1.00
EBS (n=4)	2	6	2	1	3	2	2	0.75
	2	7	2	1	3	2	2	0.25
ECS (n=12)	2	6	2	1	3	2	2	1.00
SECS (n=4)	2	6	2	1	3	2	2	1.00
HCS (n=3)	2	6	2	1	3	2	2	1.00
LG (n=148)	4	9	3	6	9	3	3	0.53
	4	9	5	6	7	3	4	0.37
	4	9	4	6	9	3	4	0.07
	4	9	6	6	9	3	3	0.01
	4	9	4	6	9	3	3	0.01
	5	9	6	6	2	4	5	0.01
LWI (n=30)	4	9	4	6	9	3	4	0.57
	5	11	6	7	2	4	6	0.17
	6	10	6	7	2	4	5	0.10
	5	10	6	7	2	4	5	0.03
	5	10	6	6	2	4	5	0.03
	4	9	5	6	9	3	4	0.03
	4	9	4	6	2	3	4	0.03
	7	9	4	6	9	3	4	0.03
LWII (n=50)	4	9	4	6	9	3	4	0.28
	6	10	6	7	2	4	5	0.28
	5	10	6	6	2	6	7	0.12
	5	10	6	6	2	4	7	0.08
	5	10	6	6	2	4	5	0.06
	5	10	6	6	2	5	7	0.04
	4	9	3	6	9	3	4	0.02
	5	9	4	6	9	3	4	0.02
	5	11	6	7	2	4	6	0.02
	5	10	6	6	2	5	5	0.02
	5	9	6	6	2	5	5	0.02
	4	9	6	6	2	5	5	0.02
	4	9	6	6	2	5	7	0.02
HNCH (n=61)	4	9	4	6	8	3	1	0.43
	4	9	4	6	7	3	1	0.39
	4	9	3	6	8	3	1	0.05
	4	9	4	6	2	3	1	0.05
	4	9	3	6	7	3	1	0.03
	4	9	4	6	9	3	1	0.03
	4	9	4	6	10	3	1	0.02

However, more variation could be found in the more complex environments (disease nurseries of Georgia and Zambia) than in the homogenous environments of farmers' fields (sites in Texas and Honduras). The johnsongrass populations showed a level of variation comparable with that of the disease nurseries. Very little change in population composition can be detected over years for populations G91, G92, and G93. Genotypes persist over seasons at least for this location and frequencies for the multilocus haplotypes do not change, significantly. The higher number of multilocus haplotypes for G93 can be explained by the doubling of the sample size for that year. The sorghum isolates (LWS) and the johnsongrass isolates (LW I, LWII, and LG) were obviously different. Whereas LWI, LWII, and LG populations share many of the alleles at all loci, they share no allele with the LWS isolates. This strongly suggests that the initial inoculum for the sorghum does not originate from the johnsongrass population and that the two populations are genetically isolated. Remarkably, the isolates collected from the maicillos (HNCH) share many alleles with the isolates gathered from johnsongrass even though they were collected from different countries, indicating some mechanism of gene flow. In several locations (G91, G92, G93, HNLI, HNEP, HNCT, and ZAMA), the same multilocus haplotype can be found (1111111), indicating that gene flow does occur for the sorghum isolates as well. Similarly, in all locations sampled in South Texas (LWS, BVS, CCS,EBS, ECS, SECS, and HCS), one genotype was predominant (2621322). Neither isolates from johnsongrass nor from sorghum indicate that there is sexual recombination. All isolates can be defined as members of clonal lineages.

Sorghum Grain Mold

Dr. Sunitha Kumari is mapping fungal inhibiting proteins in grain sorghum. The objective of her investigation is to develop probes mapping for specific antifungal protein genes and to use these probes for identifying cultivars more resistant to grain mold. One hundred forty F3 plants from the parental cultivars, Sureno (resistant) and SC120 (susceptible), were used. *Fusarium moniliforme*, isolated from molded grain and maintained on potato dextrose agar, was used for the inoculation of the sorghum inflorescence and seedlings for RNA studies. Surface sterilized sorghum grain was plated on moist blotting paper and the incidence of grain mold fungi (*Fusarium* Spp., *Curvularia lunata, Alternaria alternata,* and *Dreschlera* Spp.) calculated. Each of the 140 lines were brought to the same moisture content and the hardness was determined using a texture analyzer. The crushing strength of Sureno grain was 14 kg/cm2 compared to a crushing strength of 8 kg/cm2 for SC120 grain. There was less grain mold infection in the hard grain than in the softer grain.

Several methods were used to develop the probes needed for RFLP analysis. Three hundred sixty oligonucleotide primers (10-mers) were used in amplification reactions to generate RAPDs. Oligonucleotide primers that were specific for antifungal proteins [ribosomal inactivating proteins (RIP), the 22 kDa and 18 kDa proteins, and the chitinase gene] were synthesized and used in polymerase chain reaction (PCR) to generate PCR clones. The cDNA expression library was obtained from Dr. Ray Bressan's lab at Purdue University. Antisera to the three antifungal proteins from sorghum (30, 26, and 18 kDa proteins) were used for screening as was the anti-zeamatin antibody from maize. Positive cDNA clones were obtained after primary, secondary, and tertiary screenings. A fourth screening step was included to eliminate false positives. The clones which were obtained using the anti-zeamatin antibody were cross checked using the zeamatin clone and it was found that eight of the 13 clones cross react. These clones will be sequenced for further work. With 18 kDa antibody, 8 positive antifungal clones were obtained, 4 with 26 kDa antibody, and 10 with 30 kDa antibody.

The number of DNA fragments amplified by RAPD primers ranged from 1-6 with some primers showing no amplification. Of the total RAPD primers tested, more than 60% showed polymorphism between the parents. Those with stronger polymorphic bands were selected. Ten were found that amplified segregating bands in the mapping population. The polymorphic fragments obtained from these primers are being used in the mapping studies. A single fragment of approximately 1 kb was obtained with the RIP primers, whereas fragments of 800 bp and 1 kb were obtained using the primers to 22 kDa and 18 kDa proteins, respectively. The primers for the chitinase gene resulted in the amplification of two DNA fragments of 1 kb and 0.8 kb. The number of bands observed with sorghum probes ranged from 1-4 between the resistant and susceptible lines.

RNA was extracted from developing grain and young seedlings. Sorghum lines resistant and susceptible to grain mold were planted in the field and the developing grain sprayed with a *Fusarium moniliforme* conidial suspension. Grain were then collected at 1, 4, 8, and 24 hour intervals. Heads inoculated with distilled water served as controls. The RNA blots were probed with the zeamatin clone. It was found that there was no cross reactivity in the leaf RNA, but there was binding with respect to seed RNA.

Networking Activities

Conferences attended or organized

R. Frederiksen served as the organizer of the Sorghum Improvement Conference of North America summer workshop at College Station, TX, July 20-22, 1994. The current status of sorghum biotechnology was reviewed by representatives of most of the active laboratories in the U.S. participating in the three day conference. Eighteen technical presentations, field and lab tours, and a review of the data management system were included.

Dr. Frederiksen organized, in collaboration with International Service of Acquisition of Agri-Biotech Applications (ISAAA), a biosafety workshop on Environmental Impact and Biosafety Issues of Genetically Engineered Sorghum. Contributors to this study included the Swedish Agency for Research Cooperation with Developing Countries (SARC) and the United State Department of Agriculture, Animal and Plant Health Inspection Service (USDA-APHIS). Approximately 80 individuals from 16 different countries participated. The technical papers and findings of the conference will be published as a special edition of the African Crop Science Journal (ACSJ). Frederiksen remains active on the ACSJ Editorial Advisory Board.

R. Frederiksen participated in the Biennial meetings of the African Crop Science Society (ACSS) at Blantyre, Malawi. During the conference, he was presented an award in "Recognition of Distinguished Contribution to Collaborative Research with African Institutions and Manpower Development for Africa". The next meetings of the ACSS will be in 1997 in South Africa.

Research Investigator Exchanges

Dr. S. D. Singh, Senior Plant Pathologist, ICRISAT, spent 6 months working on various aspects of host plant resistance, 1994-1995.

Dr. Yang Liguo, Sorghum Research Institute, Shenyang, China, spent 9 months working on mapping of host resistance traits and preparation of sorghum tissue cultures for transformation in Dr. Roberta Smith's laboratory.

R. Frederiksen presented 4 technical seminars on disease management and disease control at the Sorghum Research Institute, Liaoning Academy of Agricultural Sciences, Shenyang, Liaoning, China in August 1994.

Dr. El-Hilu Omer arrived from the ARC, Wad Medani, Sudan for a 2 month visit.

Other Cooperating Scientists

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Insect Pest Management Strategies for Sustainable Agricultural Systems

Project TAM-125
George L. Teetes
Texas A&M University

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Summary

Dr. Yacouba Doumbia was supported by project TAM-125 to travel from July 18 to 28, 1994 to Texas A&M University to review and plan collaborative research efforts in Mali with the Principal Investigator. He also reviewed the dissertation research of Md. Niamoye Y. Diarisso, a Department of Entomology IER/Malian graduate student under the direction of the Principal Investigator. Md. Diarisso's research involves an assessment of the causes of resistance in sorghum to the sorghum midge. During Dr. Doumbia's visit, plans were made for Mr. Kondjiri Conare, IER Entomology Technician, to come to Texas during the summer of 1995 to receive short-term training on methodology used in insect resistance-to-plants research.

Collaborative research in Mali in 1994 continued to concentrate on strategies to manage panicle-feeding bugs in improved sorghum cultivars. The collaborative team research has successfully developed simple methods to assess damage/resistance to sorghum panicle-feeding bugs, and quantified effects of bugs on sorghum grain quantity and quality. In addition, a research proposal on on-farm entomological research was prepared by the PI, Collaborating Scientist, and Md. Diarisso for funding through SPARC.

Research in Texas with the collaborating sorghum breeder was extremely successful in 1994. Sorghum midge-resistant A-lines were evaluated as lines and in hybrid combination, and have outstanding levels of sorghum midge resistance and much improved agronomic qualities. Parent line releases are planned for 1996.

Significant progress was made to develop biotype E and I greenbug resistant germplasm lines. Several thousand selections will be screened for seedling resistance during 1995-1996.

Objectives, Production and Utilization Constraints

Objectives

Mali sorghum panicle-feeding bug research. The objectives of the collaborative research project with Dr. Y. O. Doumbia in Mali are to develop screening techniques that easily and effectively assess the effect of panicle-feeding bugs on sorghum kernel yield and quality; relate interaction of panicle-feeding bugs to sorghum glume, kernel and grain texture characteristics; cooperate with sorghum breeders to develop sorghums resistant to bugs; assess the relationship of panicle-feeding bugs and their damage to pathogen infection and to grain/food quality; and conduct on-farm surveys of panicle-feeding bug abundance and damage assessment to local and improved sorghum varieties.

Technology development and graduate student research. Objectives of research conducted in Texas are to establish and maintain sorghum insect resistance nurseries at College Station, Beeville, Corpus Christi and Lubbock to screen for new sources of resistance to sorghum midge, greenbug, and yellow sugarcane aphid; evaluate improved resistant parental lines and hybrids; conduct research to support deployment of resistant sorghums into integrated pest management systems; and determine means to enhance the effectiveness and durability of resistance genes against biotype development. Other objectives include: 1) direct the research program of a Malian graduate student assessing the causes of resistance in sorghum to sorghum midge; 2) complete the direction of graduate study of a Mexican student who determined generational survival of sorghum midge; 3) direct the M.S. research program of a U.S. student assessing the factors affecting termination of diapause and overwintering survival of sorghum midge; 4) direct the research program of a U.S. Ph.D. student using RFLP technology to assess the genetics of greenbug resistance in sorghum; and 5) direct the research program of a U.S. Ph.D. student using RFLP/RAPD technology to assess the genetic variability of the greenbug and its biotypes.

Constraints

Panicle-feeding bugs are a major constraint to 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 consistency from year to year is obligatory. 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 a subsistence mode. Sorghums 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, ecological disruption, 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 sorghum production 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 progresses and farmers understand how to properly use and what yields to expect from insect-resistant cultivars.

Research Approach and Project Output

Mali sorghum panicle-feeding bug research. Because of commitments related to the PI being President of the Entomological Society of America during 1994, a trip to Mali to review collaborative research with Dr. Y. Doumbia was not possible. However, this project supported Dr. Doumbia to visit the sorghum entomology research program at Texas A&M University during 1994. During that visit, research on panicle-feeding bugs in Mali was reviewed, and summaries of that review are presented in this annual report. A detailed presentation of data is in the 1993 INTSORMIL Annual Report. Dr. Doumbia is currently Director of the Sotuba Research Station, and as such has multiple responsibilities that affect the magnitude of research he can conduct. We discussed the possibility of expanded collaboration when Md. Niamoye Y. Diarisso completes her Ph.D. degree at Texas A&M University and returns to Mali. Also, there is a recognized need for more research to be conducted on farmers' fields. This effort must be expanded in the future.

Research related to the annual objectives for research in Mali was conducted at the IER/Sotuba research station. This research included experiments on screening sorghums for resistance to panicle-feeding bugs, testing of methods that could be used by sorghum breeders to assess the resistance/susceptibility of their breeding material, and assessments of panicle-feeding bug damage and pathogen infection on sorghum grain quality and quantity.

Results supported past findings that there are sorghums with resistance to panicle-feeding bugs. Lines derived from MaliSor 84-7 and local Guinea sorghums provide the best level of resistance. Among lines derived from MaliSor 84-7, several had bug damage ratings similar to that of MaliSor 84-7. For example, three MaliSor 84-7-derived lines had mean bug damage ratings of 1.73, 1.87, and 1.92 compared to MaliSor 84-7 which had a bug damage rating of 1.42. Most susceptible check lines in these experiments had bug damage ratings of 3.0 or greater.

Using plastic pollinating bags to protect some of the panicles in a row from natural bug infestation and allowing unprotected panicles to be naturally bug infested provided a simple and excellent means for sorghum breeders to compare the effects of bugs on unprotected and protected panicles, and thus assess the level of resistance/susceptibility. In most experiments, the use of insecticides, cages, or plastic pollinating bags to protect panicles from bug infestation provided about the same level of protection. In one experiment, insecticide applications provided the best level of protection, but over several experiments, plastic pollinating bags provided as good or better protection than insecticide applications or cages, and were must easier and less time consuming to use.

The effects on panicle-feeding bugs and pathogens, especially during wet periods, often totally destroy the usefulness of grain for food. Seed germination is significantly reduced by bug feeding and pathogen infection. Much effort has been made to assess the amount of damage caused by bugs, and the amount caused by pathogens. Data have clearly shown that bugs cause more damage to grain quantity and quality than do pathogens. However, the combined effects are enormous. By applying a fungicide to naturally bug-infested panicles, kernel damage was reduced by 7%, while protecting panicles from bugs and not pathogens reduced damage by 45%. Kernel weight from panicles protected from pathogen infection was 3.62, but was 4.22 when protected from bugs.

Technology Development and Graduate Student Research. Following are summaries of the results of technology development efforts that support international research collaboration, especially with regard to evaluating sorghum midge- and aphid-resistant sorghums; and research projects of graduate students associated with INTSORMIL. The technology development component of TAM-125 is in collaboration with TAM-123, the project of Dr. G. C. Peterson, Sorghum Breeder at the Texas A&M Agricultural Experiment Station at Lubbock. During 1994, emphasis was placed on the evaluation of sorghum midge-, greenbug-, and yellow sugarcane aphid-resistant sorghums.

Technology Development

Field experiments to evaluate sorghum lines and hybrids resistant to sorghum midge were conducted at Corpus Christi and College Station, Texas during 1994. In 73-entry tests to evaluate sorghum midge- resistant sorghum lines at the two locations, damage ratings and yields of all experimental resistant lines were significantly superior to susceptible check lines, were statistically better than resistant check lines, and 50% of the experimental entries were selected for additional evaluation. Included in this group were five B-lines currently in the sterilization program and many new potential R-lines with agronomic traits superior to existing sorghum midge-resistant lines. Several of the new experimental R-lines exhibited superior foliar traits in diverse plant types, and some are tan plant/white pericarp genotypes.

Mean grain yield of experimental sorghum midge-resistant hybrids grown under high sorghum midge abundance at Corpus Christi ranged from 53-2885 kg/ha. Mean hybrid grain yield under moderate sorghum midge abundance at College Station ranged from 587-6277 kg/ha. At Corpus Christi, grain yield of resistant hybrids was significantly better than that of susceptible or of resistant by susceptible hybrids. Grain yield of resistant by susceptible hybrids did not differ significantly from that of susceptible hybrids. At College Station, grain yield of resistant hybrids was usually higher than that of susceptible hybrids, with most resistant hybrids superior to susceptible hybrids.

Several A-lines are in the final stages of selection and testing for release. At Corpus Christi, grain yields of hybrids with new resistant A-lines were significantly better than those of susceptible and resistant check hybrids. At College Station, yield of hybrids with superior A-lines also was significantly better than yields of susceptible and resistant check hybrids. A92NF3(MB110), A91NF6(MB104), A92NF9(MB104), and A93NF6(MB110), A-lines selected for release, produced resistant hybrids with grain yields of 5107-5920 kg/ha at College Station, 156-2134 kg/ha at Corpus Christi, and means of 3621-3976 kg/ha over locations (Table 1). The hybrids made by using superior resistant A-lines were significantly less damaged than the hybrids of resistant check A-lines, ATx2755 and ATx2801. Release of these new A-lines will represent a significant improvement in elite sorghum midge-resistant A-lines available for use by the commercial seed industry.

Testing of advanced B-line selections resistant to biotype E greenbug continued in 1994. Lines identified for release, with their experimental designations, are GR107-90M17, GR108-90M23, GR134A-90M50, and GR127-90M41. Each line produces hybrids with excellent grain yield. GR127-90M41 is a tan plant, white pericarp line with excellent resistance to foliar diseases. These lines provide commercial seed companies the opportunity to produce food-type sorghum hybrids that have greenbug resistance, tan plant color, and white pericarp.

Table 1. Mean grain yield and damage by sorghum midges of sorghum hybrids classified by reaction to sorghum midge at Corpus Christi (C.C.) and College Station (C.S.), Texas, 1994.

	Yield (kg/ha)			Damage rating [1]		
Sorghum hybrid classification	Mean	C.C.	C.S.	Mean	C.C.	C.S.
Hybrid from newly developed A line	3815.8	1795.3	5836.0	3.2	4.4	2.1
Hybrid from released A line	3206.5	1063.1	5349.8	4.7	6.5	2.9
Resistant check	3496.8	1577.0	5416.5	4.3	5.8	2.8
Resistant x susceptible check	2326.5	207.0	4446.0	6.7	9.0	4.4
Susceptible check	1784.3	193.6	3375.1	7.2	8.9	5.5

[1] Damage caused by sorghum midges was rated 1=0-10, 2=11-20, to 9=81-100% "blasted" sorghum kernels.

Development of new germplasm lines resistant to both greenbug biotypes E and I received increased emphasis in 1994. Two excellent sources of resistance have been identified for biotype I resistance, PI550607 and PI550610. To diversify the germplasm base of greenbug-resistant germplasm, PI550607 is used exclusively in R-lines and PI550610 primarily in B-lines. Approximately 90 different backcross populations were developed to place the greenbug resistance genes in elite agronomic backgrounds. Several populations have three or four crosses to temperate germplasm, and selections for agronomic types were made in the 1995 winter nursery in Puerto Rico. Selections will be screened for resistance to both greenbug biotypes and preliminary determination made of suitability for release. The primary goal of early generation release would be to allow the seed industry to select for their specific purpose from a population of material.

Discovery, confirmation, and initial utilization of genes for resistance to yellow sugarcane aphid have been achieved. Progeny derived from PI457709 have been developed that possess acceptable resistance in a combine-height, early maturing sorghum genotype. These lines are currently being evaluated for agronomic type. Progeny in the F_3 generation will be grown in 1995 to combine resistance to yellow sugarcane aphid with resistance to greenbug because yellow sugarcane aphid resistance sources are very susceptible to greenbug. Progeny in the F_3 generation derived from PI453951 will be grown during 1995. Primary effort with this resistance source is to move the resistance gene into B-line material while the PI457709 resistance gene is used in R-line material. Selection in 1995 will be for combine-height, early maturing genotypes with acceptable agronomic traits.

Graduate Student Research

Important progress was make in 1994 toward better understanding the causes of sorghum resistance to sorghum midge and the inheritance of greenbug resistance. This fundamental knowledge is useful to improving the effectiveness and durability of resistance.

The mechanism of resistance to sorghum midge has been identified to be primarily a female non-preference for oviposition. However, the causes of resistance to sorghum midge have not been understood. Based on data collected during 1993 and 1994, sorghum midge resistance was shown to be associated with the time of spikelet flowering during the day. Summarized results from 1993 and 1994 are provided here.

Most spikelets of sorghum midge-resistant sorghum flowered before daylight, before most ovipositing sorghum midges were in the field at 0700-1100 hours. By flowering early, resistant sorghum avoided much sorghum midge oviposition and damage. Susceptible sorghum, however, flowered at the time sorghum midges were ovipositing. Glumes of spikelets of resistant ATx2755, RTx2767, and ATx2755*RTx2767 sorghums were open from 0115-1030 hours. Most spikelets (36.8, 36.6, and 38.9% per tagged rachis branch) of ATx2755, RTx2767, and ATx2755*RTx2767 were flowering at 0600, 0700, and 0500, respectively, approximately four hours before most ovipositing sorghum midges were in the field. After flowering, glumes of resistant spikelets overlapped and enclosed the floral parts or cut the anthers off. Spikelets of susceptible ATx2752 and RTx430 sorghums were open from approximately 0100-1200 and 0600-1100 hours, respectively. Each spikelet of ATx2752 remained open for many hours, and some spikelets did not close until after 1430. Styles of ATx2752 were long. Spikelets of susceptible ATx2752*RTx430 were open from 0230-1100 hours. Most spikelets (64.6%) of ATx2752 and RTx430 (56.3%) were flowering at 0800, when sorghum midges were ovipositing. Most spikelets (48.3%) of ATx2752*RTx430 were open at 0700. Stigmas of RTx430 were large. Sorghum midge damage to the resistant sorghum lines and hybrid ranged from 18.1-23.8%. Damage to the susceptible lines and hybrid was 2.5 times greater (range of 49.5-58.5%).

Preliminary data indicate that spikelet morphology to a small extent and glume closure to a greater extent also are associated with resistance to sorghum midge. Sorghum midge-resistant sorghums have glumes that close quickly and more tightly than do susceptible sorghums. Data on these characteristics are to be collected in 1995.

RFLP analysis is being used to determine the genetic map location of genes conferring resistance in sorghum to greenbug biotypes C, E, and I. Five populations have been produced for the purpose of mapping this resistance. F_2 populations have been screened to identify genotypes segregating for resistance to at least one greenbug biotype. The progeny of these segregating populations are currently being evaluated to determine the relationship of genotypic polymorphisms to phenotypic performance. At present, it appears that resistance to greenbug biotype E is probably simply inherited, while resistance to biotypes C and I may be somewhat more complex. Locations of greenbug resistance genes will be based on DNA markers selected from a complete RFLP map of the sorghum genome developed by Dr. Andrew H. Paterson at Texas A&M University. Interactions among different greenbug resistance gene(s), allelism, and /or homology will be addressed as well. Additionally, comparative genome mapping will be used to determine the chromosomal locations in wheat, barley, rye, and oats which correspond to greenbug resistance gene(s) locations in sorghum. Knowledge of the relationship among biotype resistance within sorghum and among its other grass hosts will greatly enhance gene deployment strategies. Plant breeders would then be able to manipulate and disperse unique resistance gene combinations in ways that reduce selection pressure toward biotype formation. DNA markers closely linked to greenbug resistance would also allow plant breeders to use marker-assisted selection as a tool to aid in identification and manipulation of resistance gene(s).

The time overwintered sorghum midges emerge in the spring, and the abundance of sorghum midges that initiate the first spring generation, dictate the seasonal abundance and subsequent severity of damage the insect pest causes later in the growing season to sorghum. Prediction models of sorghum midge overwintering emergence would be more accurate if effects of moisture and information on rate of survival of overwintering sorghum midges in relation to crop residue destruction treatments were incorporated into the models.

Studies on the effects of moisture on the termination of diapause and subsequent spring emergence of overwintered sorghum midge consisted of three field treatments, each having 16 sample units; pyramid traps uncovered to allow rain to reach the soil; pyramid traps under plastic-covered shelters to exclude precipitation, but water added later during the experiment; and pyramid traps covered with plastic and kept dry. Efforts to keep the soil dry under the two treatments covered with plastic shelters failed when rainfall totals exceeded 1.27 cm. Therefore, no emergence data were collected from dry treatments, because all were moist after rainfall events. However, ≈9-12 days following a rainfall event of 1.27 cm, more sorghum midges than expected emerged.

At the end of the 1994 season, samples were taken from sorghum in the field to estimate the number of sorghum midges that had entered diapause. Number of sorghum midges in diapause was calculated by using a squeeze device to detect larvae in spikelets. The number of diapausing sorghum midge larvae per m^2 of soil was estimated to be 1324.

The field was prepared in three treatments to test for differences in levels of survival of overwintering sorghum midge. The three treatments were shredded only; normal (shredded and disked); and shredded, disked, and deep plowed. The following spring, traps were used to monitor sorghum midge emergence from the three treatments. Percent overwintering survival was more than twice as high for the normal, 0.0087%, than for the shredded, disked and deep-plowed treatment, 0.0039%. Percent survival of sorghum midge in the shredded only treatment, 0.0056%, was intermediate to the others.

Networking Activities

Research Investigator Exchanges

Dr. Yacouba Doumbia visited Dr. George Teetes in July 1994 to discuss and plan collaborative research on panicle-feeding bugs in sorghum in Mali. Also, he reviewed the dissertation research of Md. Niamoye Y. Diarisso and its implication to future collaboration in Mali. Plans were also made for Dr. Doumbia's entomology technician to come to Texas in July 1995 to receive short-term training in methodology to assess sorghum resistance to insects, especially with regard to sorghum midge. Ten other LDC scientists visited the sorghum entomology research program at Texas A&M University. In addition, Dr. Lee House, former ICRISAT Sorghum Breeder conferred with the Principal Investigator during July on the contents of a chapter on sorghum entomology in a manual on sorghum breeding.

The PI continues to serve on the TAMU Advisory Board for the Mali SPARC project, and participated in several activities with five IER/Malian officials during their visit to Texas A&M University in May. The PI also continues to serve as a member of the Board of Directors of the Consortium for International Crop Protection (CICP).

From funding sources other than INTSORMIL, the PI is contributing to the development of a Comprehensive Sorghum Crop Management Manual.

Germplasm and Research Information Exchange

Seeds were requested by five LDC scientists, and these requests were forwarded to Dr. Gary C. Peterson, the sorghum breeder collaborating with the Principal Investigator. Publication reprints or copies related to sorghum entomology were sent to 54 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, Principal Cereals Entomologist, ICRISAT, Patancheru P.O., Andhra Pradesh 502 324, India and Dr. Klaus Leuschner, Entomologist, SADC/ICRISAT Southern Africa Sorghum/Millet Improvement Program, P.O. Box 776, Bulawayo, Zimbabwe. Dr. Nwanze visited the sorghum entomology research program at Texas A&M University in May 1994. Discussions were on collaborative research and other networking opportunities. Dr. Klaus Leuschner will do a six-month sabbatical with the PI in 1996.

Publications and Presentations

Abstracts

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Diarisso, N. Y., B. B. Pendleton, and G. Teetes. 1995. Sorghum spikelet morphology and flowering time as causes of resistance to sorghum midge. 19th Biennial Grain Sorghum Research and Utilization Conference, Lubbock, Texas.

Paliani, A. L., G. L. Teetes, G. C. Peterson, R. M. Anderson, and B. B. Pendleton. 1995. Sorghum resistance to yellow sugarcane aphid. 19th Biennial Grain Sorghum Research and Utilization Conference, Lubbock, Texas.

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Biological Control Tactics for Sustainable Production of Sorghum and Millet

Project TAM-125B
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Summary

Collaborative work in Niger was continued in 1994. Data to date on millet head miner suggest that natural enemies are a significant source of mortality in MHM populations, but have their greatest impact on later MHM instars. Work will continue in 1995. Research on sorghum midge in johnsongrass, begun in 1993, showed that midge parasite production/gram of sample was greatest in the early and cooler parts of the year. Also, parasite numbers were consistently greater from johnsongrass near sorghum plantings than from johnsongrass distantly separated from sorghum. Yellow sugarcane aphids were collected from species of native and introduced grasses, and switchgrass *Panicum virgatum* was not a source of economic aphid infestations in the area of study.

Objectives, Production and Utilization Constraints

Objectives

Collaborative objectives are to (1) assess natural enemies for biological control of stalk borers and the millet head miner; (2) implement effective biological controls; (3) provide graduate level training on processes and strategies for biological controls in sorghum and millet, and (4) assess biological control as a component of pest management for sorghum and millet pests in local crop protection practices.

Constraints

Insect pests of sorghum/millet addressed by this project are key pests and constraints to production in the U.S. and West Africa. Detailed ecological understanding of pests and their natural enemies is essential to a sustainable annual crop management strategy, especially during times of year when pests occupy noncrop portions of an agroecosystem. Collaborative research in Niger addresses biological control of stalk borers and the millet head miner, and in the U.S. addresses biological control of midges, aphids and spider mites. U.S. research especially provides training for graduate students, evolving theory and concepts to implement biological controls in West Africa, evolving concepts and definitions for functional agroecosystems, developing methods for measuring impacts of natural enemies, and validating results of biological controls when implemented.

Research Approach and Project Output

Millet Head Miner Research in Niger. Millet head miner (MHM), *Heliocheilus albipunctella* (de Joannis), commonly causes significant crop losses of pearl millet, *Pennisetum glaucum* L., in Sahelian West Africa. Infestations reportedly approach 95% with a collective grain loss of about 60%. Available management options are mainly cultural (e.g., late planting and deep plowing) and generally impractical. MHM is a good candidate for a control strategy that emphasizes effective natural enemies. It occupies an ecosystem of consistent annual habitats, has one generation per year, and supports a large guild of natural enemies. A strategy that uses natural enemies for biological control requires that the enemies are assessed for their role in MHM mortality. However, information is limited on MHM within generation mortality, i.e., effectiveness of natural enemies. This information is essential before advocating natural enemies as a crop protection option in the low input and fragile farming systems of the Sahel.

Research Methods

In 1993, we began assessing total MHM mortality, especially that caused by natural enemies. Specific objectives are to (1) establish an MHM biology, (2) develop a cage exclusion method for estimating MHM mortality from natural enemies, and (3) develop reliable sampling methods for MHM and its natural enemies. We are conducting two types of experiments to assess MHM mortality, caged panicle natural enemy exclusion experiments and life table experiments.

Research was conducted at the ICRISAT Sahelian Center (ISC) at Sadore, Niger. We report here experiments that (1) estimate numbers of MHM pupae in the soil at the end of the dry season, (2) estimate pupal male:female sex ratios; (3) estimate fecundity and mating frequency; (4) assess activity and impact of MHM natural enemies; and (5) assess populations of MHM developmental stages.

Pupae were sampled from plots located in a farmer's field at Dogalkeina, ca. 7 km from ISC. Samples were collected during July through October in 1993, and during July in 1994. Twice weekly, four 1 m^2 by 30 cm holes were excavated near a Gao tree, *Faidherbia albida* (Del.); two were 1 m from the trunk and two were 25 m from the trunk. The excavated soil was sieved through a mesh screen (36 cells per cm^2). The mesh passed soil through, but not MHM pupae or prepupal mummies parasitized by *Copidosoma* sp. MHM stages were collected and recorded by gender, and then all were held in the laboratory for moth and parasite emergence.

Moth fecundity and mating experiments were conducted in the laboratory at ISC. MHM females were collected from light traps at ISC and returned to the laboratory for dissection. As female moths were dissected, we counted ovarian eggs and spermatophores in spermathecae (i.e., male sperm packages).

Sampling for life table analysis and construction began in ISC fields in July 1993, and continued through October 1994. This work addressed the relative importance of all of MHM mortality. Standard sampling units were used, MHM developmental stages were extracted from destructive samples of panicles, and all MHM developmental stages were maintained in the laboratory until they became adults or produced a parasite.

Panicles of caged natural enemy exclusion experiments were all artificially infested with MHM. The 1993 INTSORMIL Annual Report describes special methods used for 1993. These experiments were conducted in ISC fields during August-October of 1993 and 1994, and were established to generally compare survival of MHM in the presence and absence of natural enemies.

Single-panicle cages were constructed using a wire frame covered with screening (21 X 21 cells per cm^2). Cages were placed over panicles at the boot stage of development, and this prevented natural infestations of MHM on caged panicles. A cone painted with nondrying glue was attached at the bottom inside of each cage to capture dispersing prepupal larvae. Beginning in mid-August, cones were inspected daily for trapped prepupae, and were replaced weekly. Some cages were designated as "open," and these were managed to allow natural enemies access to MHM developmental stages inside. On cages designated as open, screening was raised ca. 20 cm to provide an entrance for natural enemies. Open cages were opened daily at 6 a.m. and closed again at 6 p.m. Closing cages during night hours prevented oviposition by natural populations of MHM. Larvae falling from open cages were trapped in plastic trays painted with non-drying glue and placed under millet panicles.

In 1994 experiments, we transferred 25 first-instar MHM larvae into each of 32 cages. Eight of these cages remained closed during the whole season, eight were opened after panicles infestation and remained open until appearance of the first mine, eight were opened after appearance of the first mines and remained opened thereafter, and eight remained open throughout the season.

Research Findings

Data showed that MHM is highly fecund, as females contained a mean 845 (SE=26.7) eggs. Each female has two ovaries and four ovarioles. Ovarioles contain an average 105 (SE=3.49) eggs, and lateral and median oviducts contain a mean 5.66 (SE=0.96) eggs. The actual numbers of eggs each female oviposits in the field is not yet determined. Dissections of 18 females showed two carrying no spermatophores, 13 carrying one spermatophore, and 3 carrying two spermatophores. Most MHM females apparently mate only once (1.06 ± 0.052; mean±S.D.) times.

Soil samples of pupae showed different sex ratios for MHM than samples from light trap catches. The sex ratio of soil-collected pupae was 1.00:0.95 male:female versus 1.00:3.75 for adults collected from light traps. These results suggest that females are more strongly attracted to light than males. Thus, gender data obtained from light trap catches should be interpreted with caution. Though all collected pupae and prepupal mummies were held until emergence, parasites did not emerge from pupae. However, a maximum 802 *Copidosoma* sp. (mean=394, SE=33.0) parasite adults emerged from the collected MHM prepupal mummies.

Previous reports observed that adults of *Bracon hebetor*, a larval parasite, are common near Gao trees. These reports also note that millet plants growing near the tree are less infested by MHM, and that many of these MHM are parasitized by *B. hebetor*. We took samples of MHM pupae and prepupae near a Gao tree, and our sampling showed no significant differences between MHM populations at 1 m from the tree versus those at 25 m distant.

Data from cage exclusion experiments generally show no significant differences among treatments in total numbers of surviving MHM larvae (Fig. 1-4). However, numbers of surviving larvae differed markedly between closed and open cages. This difference was most apparent by comparing MHM in cages closed the entire season with those opened the entire season. Also, numbers of larvae surviving in cages opened only during the egg stage (Fig. 1) did not differ from those open the entire season. Thus, the MHM egg stage

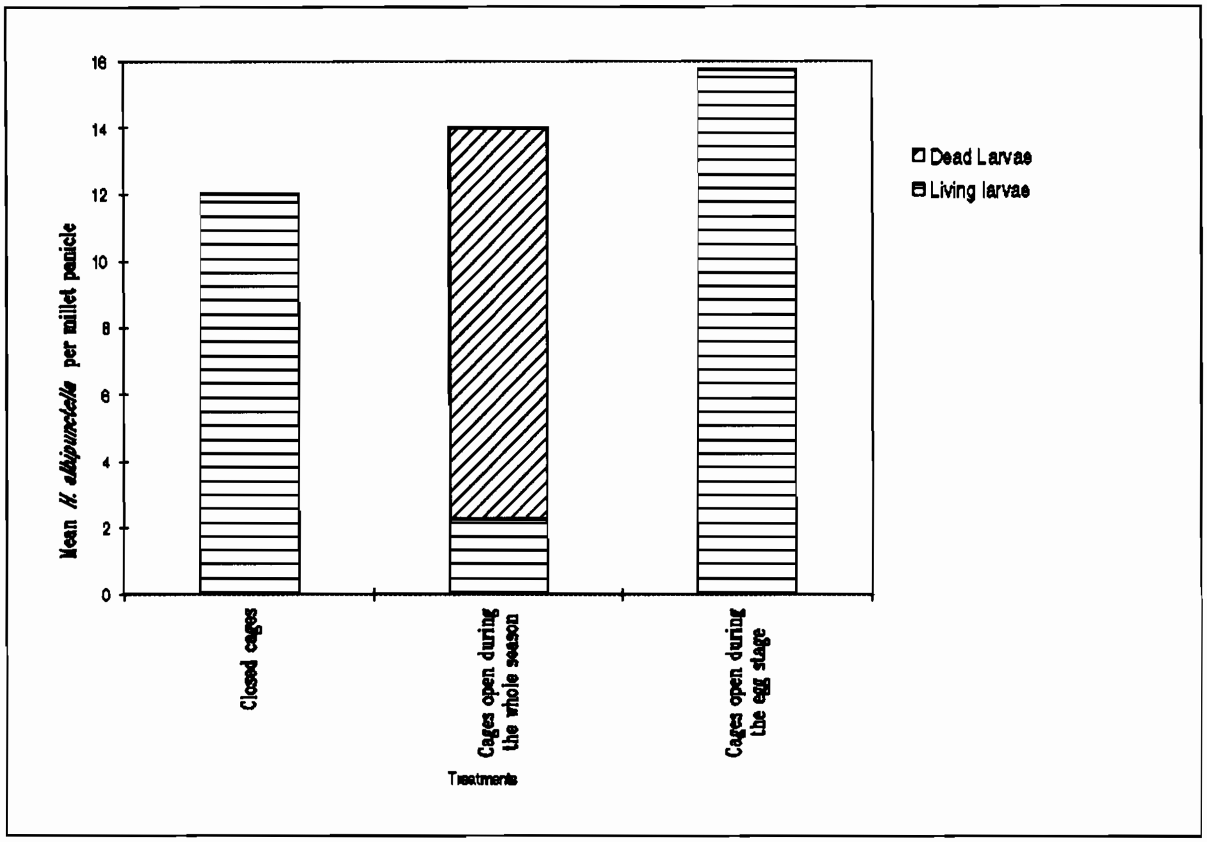


Figure 1

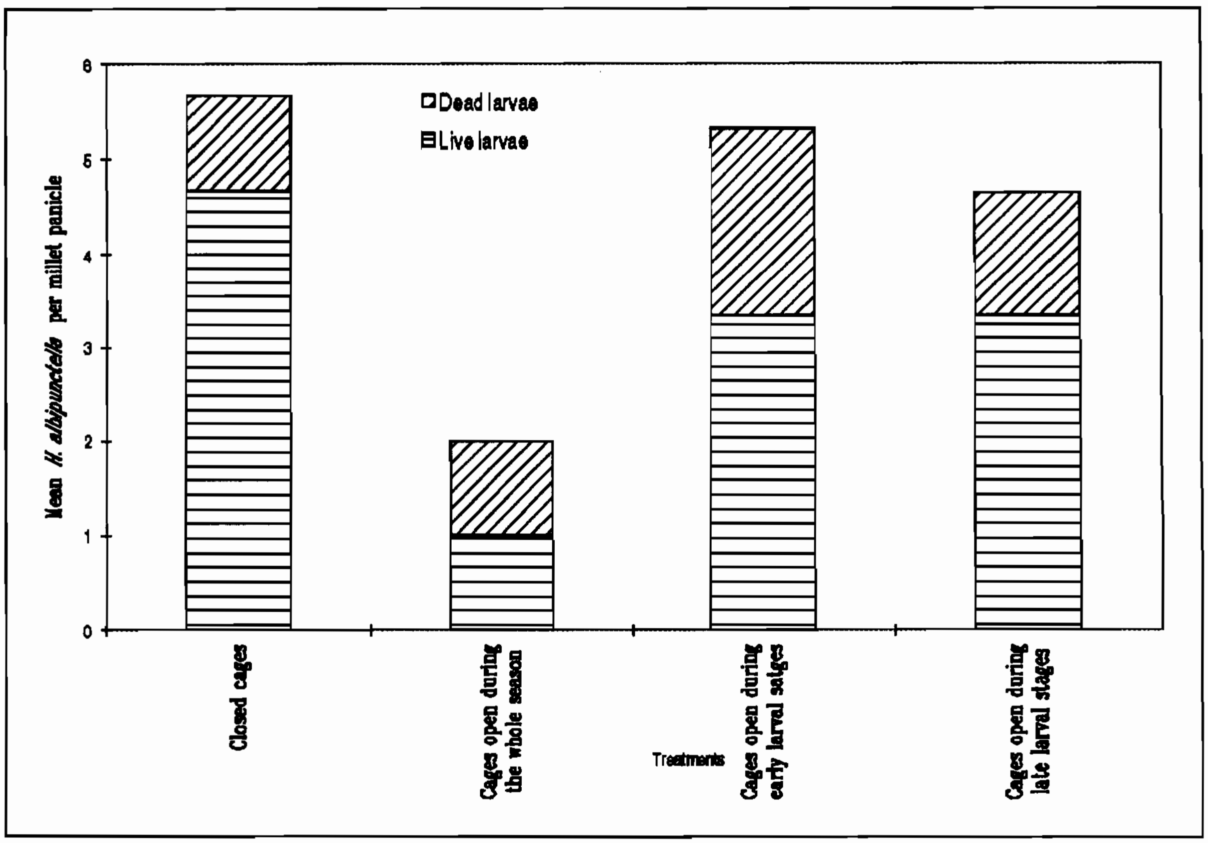


Figure 2

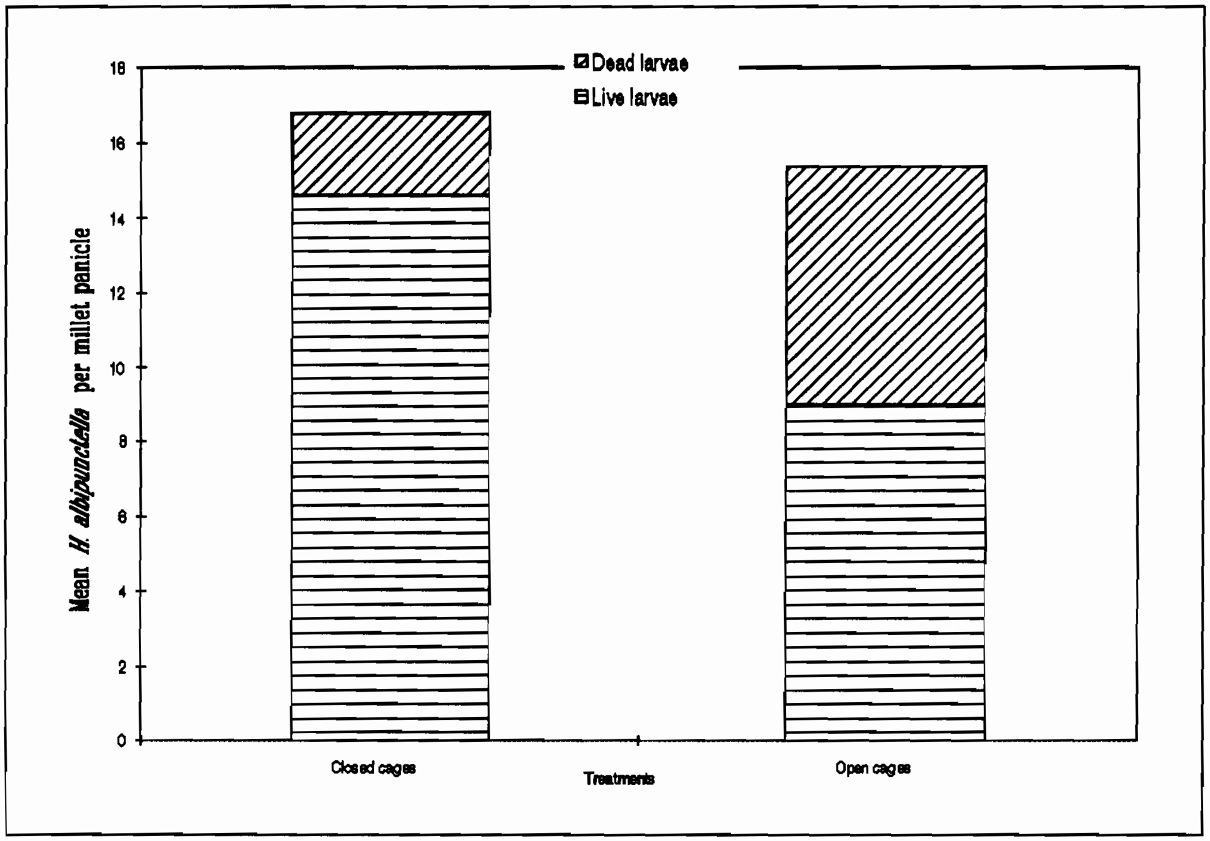


Figure 3

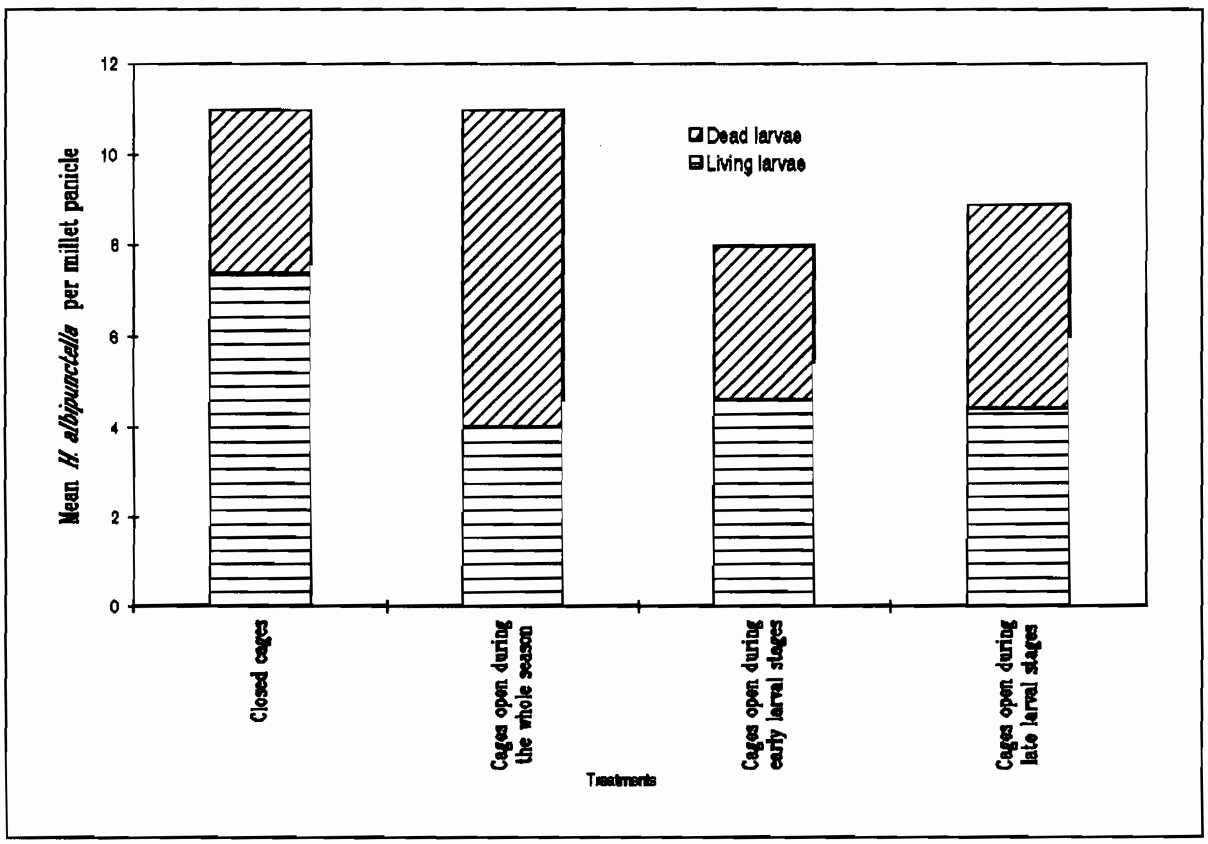


Figure 4

apparently does not support significant numbers of natural enemies and most egg mortality is replaceable by subsequent mortality. MHM mortality in cages that were opened when early or late larval stages were present did not differ significantly from mortality in cages closed during the entire season (Fig. 1 and 4); however, cages open only when late larval stages were present contained fewer total larvae than those opened only during early larval stages (Fig. 1). These results suggest a significant collective impact for all natural enemies attacking all MHM stages.

Analyses for age-specific life tables are incomplete, but intermediate results suggest some general conclusions on roles of MHM natural enemies. Species of MHM natural enemies collected in our experiments were less diverse than reports in the literature. Our results included two predators and two parasites. The two predators were an *Orius* sp. that attacks MHM eggs and early instars, and a predatory ant that attacks full-grown larvae on the panicle and when they drop to the soil to pupate. The two parasites included a braconid, *Bracon hebetor* Say, and an encyrtid, *Copidosoma* sp.

Bracon hebetor was responsible for most of the mortality in MHM larvae. *Bracon* is a gregarious ectoparasite that permanently paralyses its host. Many collected MHM larvae were paralyzed, but did not produce adult parasites. Most of these larvae showed symptoms typical of larvae stung by *Bracon.* Because *B. hebetor* females reportedly subsist on body fluids of hosts they attack, this parasite acts both as a predator and as a parasite. *Copidosoma* sp. is the second parasite species we collected. As noted above, as many as 802 adult parasites emerged from a single MHM mummy. Though many *Copidosoma* develop in a single MHM larva, this parasite attacks the MHM egg stage and completes development only when the MHM larva is full-grown. Considerable damage can occur while MHM larvae develop. Also, *Copidosoma* one generation per year, whereas *B. hebetor* has several generations per year. Thus, *Copidosoma* cannot respond quickly (i.e., a population numerical response) to significant changes in MHM larval populations. Though we observed some egg parasitism, we do not have an identification of the causal parasite. Egg parasitism was ca. 22% early in the season, and increased to 68% later in the season when MHM eggs were scarce.

In summary, our data to date suggest that natural enemies are a significant source of mortality in MHM populations but have their greatest impact on later MHM instars. Additional research on MHM enemies is needed before developing a management strategy that uses biological control.

Biological control of sorghum midge. Sorghum midge (*Contarinia sorghicola*) is a key pest of grain sorghum in Texas. The midge also attacks other hosts in Texas including Sudangrass (*S. sudanense*), Columbusgrass (*S. almum*) and johnsongrass (*S. halepense*). Despite the relevance of noncrop hosts to midge populations on grain sorghum, few reports assess midge populations that occupy these noncrops. Since 1993, we have (1) assessed the continuous population dynamics of sorghum midge and its parasites in johnsongrass, (2) assessed midge parasitism in johnsongrass refugia near and distant to grain sorghum, and (3) developed methods to measure generation to generation impacts of natural enemies on midge populations.

We conducted our 1993-1994 research in (1) a johnsongrass refuge next to grain sorghum (i.e., Brazos Bottom site), and (2) of johnsongrass pasture maintained as a forage crop near Sudangrass but isolated from grain sorghum (i.e., Leonard Road or pasture site). Johnsongrass panicles were sampled weekly from first appearance until the first killing frost. Sample panicles were selected at random. The first 100 panicles encountered were classified into four phenological stages: 1 = PREBLOOM, 2 = BLOOM, 3 = SOFT DOUGH, and 4 = HARD DOUGH. Panicles in soft dough were excised, returned to the laboratory, and panicle branches excised and weighed. Branches and seeds were placed in a paper bag which was secured shut and then stored for midge and parasite emergence.

Considering total midges per gram of sample, the population of midges was consistently greater at the pasture site, whereas total parasite production was greater at the Brazos Bottom site (Table 1). More midges and parasites were collected in 1993 than in 1994. Comparing parasite species by site and year, there is an apparent inverse relationship between numbers of *Eupelmus popa* and *Aprostocetus diplosidis*. This relationship suggests competition between these parasite species.

Though johnsongrass panicles in the bloom were available throughout sampling, midge and midge parasite production was greater in the early and cooler part of the season. Some midge production recurred in the fall after temperatures subsided (Fig. 5 and 6). Rainfall amounts and patterns varied significantly between years, and may have affected the dynamics of midge and parasite populations. Sample by sample paired analyses will compare midge and parasite production per site, year, temperature and rainfall.

Yellow sugarcane aphid (YSA), *Sipha flava*, can cause considerable damage or death to young grain sorghum, and outbreaks are usually localized and sporadic. Little is known about the seasonal life history of YSA in central Texas. Since 1993, we have been assessing various crop and noncrop hosts as sources for these sporadic outbreaks of YSA, and evaluating sites for eventual colonizing of YSA natural enemies.

In addition to grain sorghum and corn, our results in 1993-94 identified 21 species of native and introduced grasses that host YSA during parts of the year (Table 2). Relative suitability of these hosts seems to depend on at least four factors. First, grasses used by YSA include species of many genera. However, it seems that if one species within a genus is a host for YSA, other related species within the same genus also are hosts. Second, the physiological condition of the grass plant affects rates of YSA reproduction.

Table 1. Production of sorghum midge and parasites by site and year (LR=Leonard Road site; BB= Brazos bottom site; EP= *Eupelmus popa*; TV= *Tetrastichus blastophagi*; Ad= *Aprostocetus diplosidis*; TB= *Tetrastichus venustus*).

Data types: Total/gram % in Row % in Column % of Total		Midge per gram	Parasites per gram				Totals
			EP	TV	Ad	TB	
LR	1993	3.809	.501	.172	1.219	.526	2.418
		- -	.207	.071	.504	.217	- -
		.456	.255	.496	.873	.648	- -
		- -	.111	.038	.270	.116	.535
	1994	2.453	.334	.066	.033	.178	. 611
		- -	.547	.108	.054	.291	- -
		.293	.170	.190	.024	.219	- -
		- -	.074	.015	.007	.039	.135
BB	1993	1.385	1.066	.038	.049	.064	1.217
		- -	.876	.031	.040	.052	- -
		.166	.544	.109	.035	.079	- -
		- -	.236	.008	.011	.014	.269
	1994	.715	.060	.071	.095	.044	.270
		- -	.222	.263	.352	.163	- -
		.085	.030	.205	.068	.054	- -
		- -	.013	.016	.021	.010	.060
Totals		8.362	1.961	.347	1.396	.812	4.516
		- -	- -	- -	- -	- -	- -
		1.000	- -	- -	- -	- -	- -
		- -	.434	.077	.309	.180	- -

Table 2. Native and introduced host plants of Yellow Sugarcane Aphid.

Common name	Scientific name
Bermudagrass	*Cynodon dactylon*
Big bluestem	*Andropogon gerardii*
Birdwood	*Pennisetum* sp.
Buffelgrass	*Pennisetum ciliare*
Canada wildrye	*Elymus canadensis*
Dallisgrass	*Paspalum dilatatum*
Eastern gamagrass	*Tripsacum dactyloides*
Florida paspalum	*Paspalum floridanum*
Johnsongrass	*Sorghum halepense*
King Ranch bluestem	*Bothriochloa ischaemum*
Kleingrass	*Panicum coloratum*
Little bluestem	*Schyzachyrium scoparium*
Perennial ryegrass	*Lolium perenne*
Purpletop	*Tridens flavus*
Red sprangletop	*Leptochloa filiformis*
Silver bluestem	*Bothriochloa saccharoides*
Southern crabgrass	*Digitaria ciliaris*
Switchgrass	*Panicum virgatum*
Vaseygrass	*Paspalum urvillei*
White tridens	*Tridens albescens*
Yellow Indiangrass	*Sorghastrum nutans*

YSA reproduction is much higher on young, actively growing grass plants than on older, more mature plants. Third, the microhabitat environment of the grass can be important. The effects of environmental extremes and their direct or indirect effects on the host plant are not known. Our survey work suggests that high temperatures, low humidity, and a low soil moisture reduce YSA growth and reproduction. Last, the largest and most reproductive aphid colonies always occurred on the widest grass blades, and grasses with wide blades were usually the most heavily infested despite time of year.

Though switchgrass (particularly young regrowth) is a host of YSA, it is not the most important. Neither is it the source of economic infestations in the nearby grain sorghum. Earliest grasses infested in 1994 were perennial ryegrass (*Lolium perenne*), vaseygrass (*Paspalum urvillei*), bermudagrass (*Cynodon dactylon*) and King Ranch bluestem (*Bothriochloa ischaemum*). Because YSA does not seriously affect grain sorghum yields after the 5-leaf stage, key questions are (1) which early-season grasses are important to YSA population increases, and (2) why does YSA leave these grasses to infest seedling grain sorghum? Having identified many YSA hosts, we plan additional research on movement of YSA from noncultivated grasses to grain sorghum.

Parasitism of YSA was totally absent, but localized aphid populations were decimated in early 1993 and 1994 by populations of the coccinellid beetle, *Coccinella septumpunctata*. The coccinellids seemingly caused significant

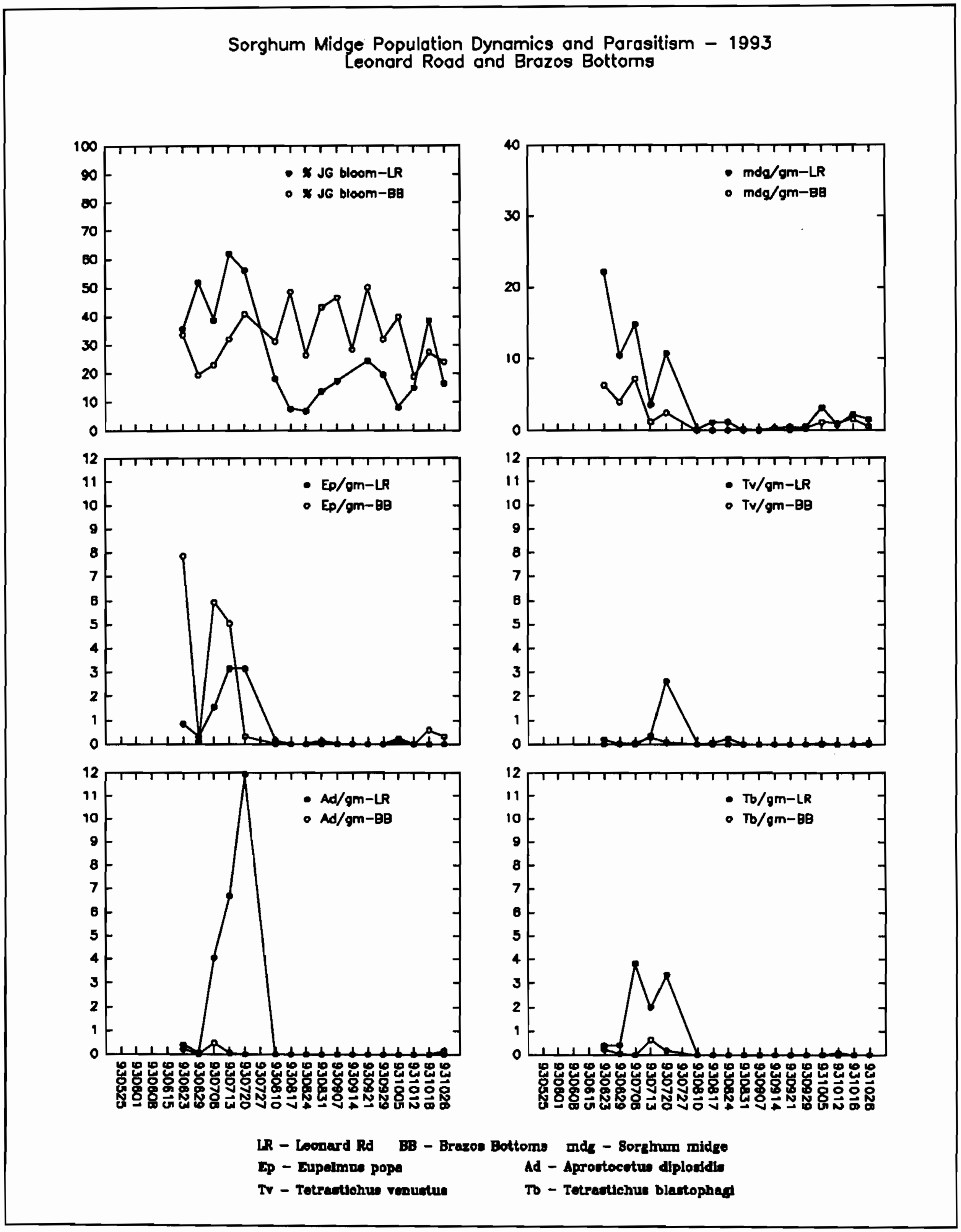
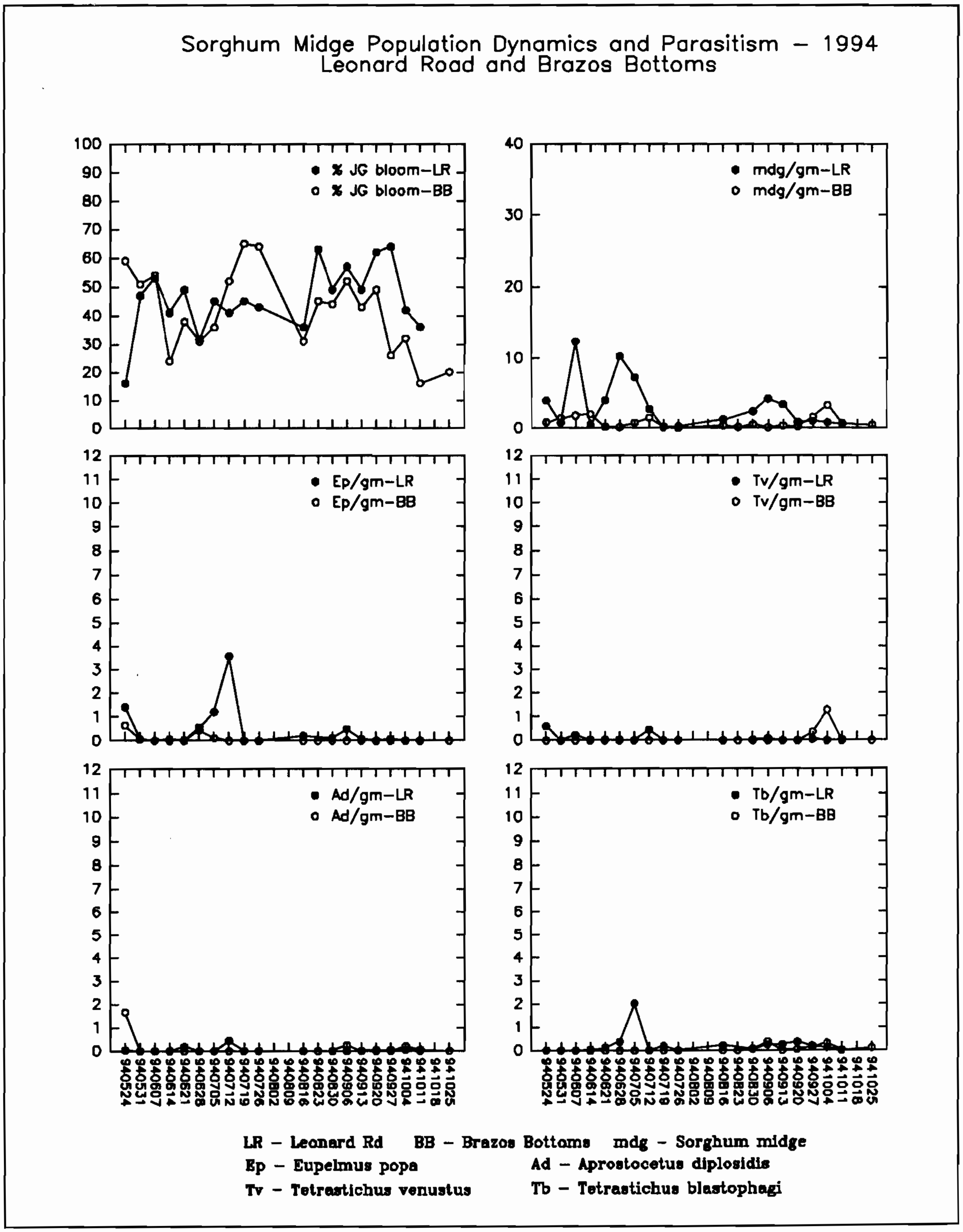

Sorghum Midge Population Dynamics and Parasitism – 1993
Leonard Road and Brazos Bottoms
% JG bloom–LR
% JG bloom–BB
mdg/gm–LR
mdg/gm–BB
Ep/gm–LR
Ep/gm–BB
Tv/gm–LR
Tv/gm–BB
Ad/gm–LR
Ad/gm–BB
Tb/gm–LR
Tb/gm–BB
930525 930601 930608 930615 930623 930629 930706 930713 930720 930727 930810 930817 930824 930831 930907 930914 930921 930929 931005 931012 931018 931026
LR – Leonard Rd BB – Brazos Bottoms mdg – Sorghum midge
Ep – Eupelmus popa Ad – Aprostocetus diplosidis
Tv – Tetrastichus venustus Tb – Tetrastichus blastophagi

Figure 5



Sorghum Midge Population Dynamics and Parasitism – 1994
Leonard Road and Brazos Bottoms
% JG bloom-LR
% JG bloom-BB
mdg/gm-LR
mdg/gm-BB
Ep/gm-LR
Ep/gm-BB
Tv/gm-LR
Tv/gm-BB
Ad/gm-LR
Ad/gm-BB
Tb/gm-LR
Tb/gm-BB
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940809
940816
940823
940830
940906
940913
940920
940927
941004
941011
941018
941025
LR – Leonard Rd BB – Brazos Bottoms mdg – Sorghum midge
Ep – Eupelmus popa Ad – Aprostocetus diplosidis
Tv – Tetrastichus venustus Tb – Tetrastichus blastophagi

Figure 6

suppression of YSA populations early in the year. We also observed evidence of predation by green lacewings.

Networking Activities

Fifteen LDC scientists visited the biological control program at Texas A&M University. Frank Gilstrap and Mr. Imad Bayoun traveled to Niger in late March-early April to participate in, and provide support for, the ROCAFREMI Annual Reunion of Projects. While there, Gilstrap and Bayoun presented a workshop on biological control to participants, and worked with participants during their research planning exercises. Gilstrap also met several times with Hamé Kadi Kadi (IRAN-Niger), Ouendeba Botorou (INRAN & INTSORMIL Host Country Coordinator), and Ousmane Youm (ICRISAT-SC) regarding progress on research toward biological control of the millet head miner. The results of this collaborative research is reported in another section of this report and is further described in the Niger country report. A primary goal of the meeting between Gilstrap, Bayoun, Kadi Kadi, Botorou and Youm was to prepare for the 1995 research season and to work toward a manuscript on research conducted to date. A portion of the TAM-125B budget was sent to Niger to help fund the work of Mr. Kadi Kadi. Out of the ROCAFREMI association, Gilstrap recruited two new students, a Ph.D. candidate from IER (Mali) and an M.S. candidate from INRAN (Niger). Both will begin their studies in January 1996, and both will conduct research on millet head miner in collaboration with O. Youm at ICRISAT-SC.

Publications and Presentations

Publication

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

Project TAM-128
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Summary

Despite an overall reduction in incidence of leaf blight (*Exserohilum turcicum*) at the Henderson station in Zimbabwe in 1995 compared to 1994, disease progressed from 5 to 20% and 13 to 43% on the most susceptible cultivars between 90 and 114 days (24 days) after planting. Under dry conditions in northern Zimbabwe and drought conditions in much of Zambia, there was a consistent incidence of sooty stripe (*Ramulispora sorghi*) across this region which indicated the necessity of host resistance to sooty stripe in some years. Virus symptoms of mosaic and leaf necrosis were observed again in 1995 on sorghum at Pandamatenga, Botswana and Mt. Makulu, Zambia but initial observations of virus symptoms were made on sorghum cultivars at Sebele, Botswana and Matopos, Zimbabwe. Incidence was low at all locations, even on cultivars of known high susceptibility; however, identity of the virus and identification of virus-susceptible cultivars needs to be pursued and deployment of varieties and hybrids highly susceptibility to virus should be avoided. Modifying aflatoxin-assay techniques eliminated problems with false-positive aflatoxin readings and determined that some sorghums can naturally, but erratically, develop low levels of aflatoxin (15-34 ppb) in South Texas. Extensive grain mold/weathering and grain sprouting in mature sorghum in South Texas nurseries in 1995 demonstrated that resistance to mold/weathering and sprouting was independent. A bacterial disease of pearl millet was observed at Matopos, Zimbabwe in 1995 and collaboration with national scientists was initiated to identify the pathogen and its potential impact.

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

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

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

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

Research Approach and Project Output

Foliar Diseases (Anthracnose, Leaf Blight, Sooty Stripe)

In 1994-95, three sorghum nurseries were planted at two locations in Zambia and two locations in Zimbabwe to evaluate response to anthracnose and leaf blight, respectively. Two of these nurseries, called Anthracnose Resistant Germplasm Nurseries (ARGN-1, 39 entries and ARGN-2, 40 entries), consisted primarily of entries that had maintained 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. The third nursery, ITAT (International Tropical Adaptation Trials) has several entries from ARGN-1 and ARGN-2 in specific hybrid combinations which enable an initial evaluation of the lines contribution to disease resistance and agronomic performance in hybrids at these demanding locations. Anthracnose developed only at the Mansa station where its development was late and erratic as it was in 1993-94.

At the Henderson Station in Zimbabwe in 1994-95, there was a reduced incidence of leaf blight (caused by *Exserohilum turcicum*) but an increased incidence of sooty stripe (caused by *Ramulispora sorghi*) compared to the previous season. Disease observation or incidence was evaluated at approximately 50, 90, and 114 days after planting. Susceptibility to either disease was more easily determined than was resistance. Cultivars of ARGN-1 and ARGN-2 with a 15% or greater incidence of either leaf blight or sooty stripe at 114 days after planting are shown in Table 1. At 90 days after planting at Henderson, the progression of leaf blight was already evident on the most susceptible cultivars. Entries having 25-43 % and 15-20% incidence of leaf blight at 114 days (Table 1) had 13% and 5-10% incidence, respectively, at 90 days after planting. Late season progression of sooty stripe at Henderson may have been even more rapid than leaf blight because the disease was only rated as present or absent rather than by percent incidence at 90 days after planting.

Table 1. Sorghum entries of the ARGN-1 and ARGN-2 susceptible (≥15%) to leaf blight or sooty stripe at the Henderson station in 1995.[a]

Genotype or Designation	Leaf blight Avg.	Sooty stripe Avg
(EBA7XTx434)-C7-C1...-L1	43	0
ATx638*R8602	30	4
R8602	25	8
R8924	20	8
S-245	18	13
B8610	15	13
BTx638 (B8618)	15	10
92BD1016/(R5647*(SC414*SC326-6	12	18
R8509	10	33
TAM428	8	23
ATX638*RTx436((A8618*R8505)	5	23
90CCEON362/(R1183*(SC120*TX7000))	5	15
(((SC120*Tx7000)*Tx7000)-10...-1*VG 116) -CF2...C2	4	19
(M35-1*CS3541)-1...-B3	4	15
RTx436(R8505)	3	30
(ADN55*B8204)-F2-B1-.....CBK	3	23
(Tx2817*EBA-1)-CF2...-B1	3	18
B8611	3	15
R8903/(80C2241*Tx433)-deriv-C1	1	33
91CC362/R8505*(R5646*SC326-6)	1	30
R8511	1	28
92BD1916/(PL2120*86EO361)-BD8	1	20
91CC371/R8505*(R5646*SC326-6)	1	20
86EON362/R5646*SC326-6	1	20
B8907	1	15
92BD1908/(PL2120*86EO361)-BD8	1	15
R6956/SC103*SC326-6	0	43
TX430	0	30
((SC120*Tx7000*Tx7000)-10...-T1-CBK	0	28
(((SC120*Tx7000)*Tx7000)...1*R6956)... C1	0	28
84C7730	0	25
87L3570/86EON362sel	0	23
((80C2241*Tx433)-1-C2-C1*84C7730)-F1-C3	0	23
(80C2241*R4224)-CF2...-B1	0	18
ATx631*RTx436(R8505)	0	15
87BH8341/86EON361sel	0	15
(SC103-12E*EBA1)-F1-C21-C3	0	15

[a] Average incidence (Avg, percent leaf area destroyed) of leaf blight (causal agent *Exserohilum turcicum*) or sooty stripe (causal agent *Ramulispora sorghi*) from two reps at 114 days after planting at the Henderson station in 1994-1995. Only entries with an incidence of 15% or greater of either disease is shown. Cumulative number of entries for both tests was 79. Evaluations were done on April 7, 1995 by Odvody, Mtisi, and Benza.

Insects, drought, and stand establishment problems interfered with definitive sooty stripe evaluation at the Panmure station in Zimbabwe and the Golden Valley Station in Zambia despite good to high incidence of the disease. The dry conditions in northern Zimbabwe and the drought in Zambia were associated with a greater, more regional occurrence of sooty stripe which was also uncharacteristically high in incidence at the Mansa Station in Zambia where anthracnose is most common. The need for some resistance to sooty stripe was evident in the reaction of several U.S.

lines that were completely killed by the disease before maturity at the Golden Valley Station where they were being evaluated for adaptation by sorghum breeder Dr. Medson Chisi.

Virus

Reaction of sorghum entries from the International Sorghum Virus Nursery (ISVN) planted at the Pandamatenga Station in Botswana had only a few plants with viral symptoms and tan or red leaf necrosis. Similar reactions occurred in this nursery at the Mt. Makulu station in Zambia. The variable incidence of virus in sorghum at these two sites probably indicate a strong dependence on the relative abundance of an aphid vector, probably yellow sugarcane aphid. Virus symptoms were observed in two other areas during March 1995 where they are not normally observed. Virus mosaic symptoms and red leaf necrosis were evident on a few plants of the sorghum variety Mahube (SDS2583) in pre-release testing at the Sebele station and on a virus-susceptible cultivar at the Matopos Station in Zimbabwe.

The overall impact of virus may not be important except where highly susceptible cultivars are introduced and widely disseminated. Identification of the major virus or viruses can help to reduce the introduction of vulnerable cultivars and assist in natural and inoculated field screening nurseries. To assist in identification of the virus or viruses, antisera are being provided to scientists in Botswana for their investigations and permits for importation of live virus are also being provided to interested scientists at strategic locations in Botswana, Zambia, and Zimbabwe where virus is recurrent. Dr. Stan Jensen (USDA, University of Nebraska) will use the live virus to conduct in depth analysis and characterization of the viruses to determine their relationship to each other and other reported similar viruses.

Drought Resistance and Charcoal Stalk Rot

Entries selected from the Drought Line Test (DLT) and Preliminary Drought Line Test (PDLT) in testing at the two Matopos locations in 1993-94 were evaluated in a SADC drought response nursery in 1994-95. The DLT was again evaluated in 1994-95 at these same two locations to observe stability of drought response in this region. Results again indicated that pre-flowering drought response was more important than post-flowering response and sorghums with the latter sometimes had significant head and floret blasting problems under severe early season drought stress. The DLT was also planted at the Pandamatenga station in Botswana but it was planted late and not exposed to high stress conditions. Selections of the most desirable cultivars were made at this station by Agricultural Research Station scientists from Botswana.

Grain Mold and Preharvest Aflatoxin in Grain Sorghum

Grain sorghums of the Genetics of Pericarp Nursery, representing various pericarp traits, were evaluated for vulnerability to naturally occurring preharvest aflatoxin in South Texas over two years. A widely-used, commercial immunoclonal antibody system (Aflatest 10, VICAM, Somerville, MA, U.S.) often gave false-positive results with sorghum grain from this nursery due to problems with colloidal suspensions and/or dissolved pigments in final filtrates. Adding NaCl before initial extraction prevented development of the colloidal suspension. The addition of 5 g of salt per each 50 g extraction sample is a common component for maize aflatoxin measurements to facilitate filtration, but it was generally regarded as optional for sorghum. Final filtrates of many sorghums free of colloidal suspensions and passed through the immunoclonal antibody columns continued to give false-positive readings if they were highly pigmented. Substituting 25% methanol for water in the final column wash alleviated nearly all of these problems. The combination of problems obscured detection of actual aflatoxin content in some sorghum samples by inflating them well above the 16-34 ppb determined by HPLC methods and similar readings determined by our revised Aflatest 10 method. Sorghum seed heavily stained by insect damage and other causes, or seed contaminated with dark-colored glumes, also contributed to problems with false-positive aflatoxin readings in our testing. Prior to our studies with this diverse group of sorghums we had infrequently experienced false-positive aflatoxin readings even with bronze (hetero-yellow endosperm) and yellow endosperm hybrids. However, we now have evidence that some cultivars naturally, but erratically, develop low levels of aflatoxin contamination. The contribution of pericarp traits and other kernel factors to aflatoxin contamination will be pursued in future studies.

The Grain Weathering Test (GWT), containing some of the best sources of grain mold and grain weathering resistance, is routinely evaluated at several sites in Texas including two or more in the South Texas area (Beeville, Corpus Christi). Though often a drought prone area, the high humidity environments and periodic rainfall, especially after crop maturity, provide an environment conducive to screening for resistance to grain mold/weathering. In 1995, grain weathering became severe a few weeks after maturity at both locations and a few days of continuous 100% R.H. promoted seed germination in the head. This germination was particularly high at the Corpus Christi site, including most materials with excellent grain mold characteristics. Average grain mold ratings were done using a standard 1 to 5 rating system ranging from 1.0 = no grain mold seen to 5.0 = most seed consumed/killed by fungi. A 1 to 5 grain sprouting/seed germination rating was used where 1.0 = no visible germination, 2.0 = trace to 2 % germination, 3.0 = 3 to 10% germination, 4.0 = 11 to 30% germination, 5.0 = >30% germination in the kernels located in the top one third of the sorghum heads. At Corpus Christi, 11 of 30 cultivars in the

GWT had an average grain mold rating (2 reps) of less than 2.0 but their average grain sprouting ratings ranged from 2.5 to 4.5. Cultivar 90B2662 had average ratings of 1.0 for grain mold and 4.5 for grain sprouting. Resistance to grain mold was independent of grain sprouting response in the head. However, plant height, tightness of heads, and other characteristics may have contributed to some sorghums having more or less seed germination than others. Cultivars with the poorest grain mold resistance were more difficult to rate for seed germination because many seed were already killed by grain mold/weathering fungi before germination conducive environments occurred.

Networking Activities

Bacterial Disease of Pearl Millet

A pearl millet disease apparently caused by a bacterial pathogen was noted in a Matopos pearl millet nursery during a trip to Zimbabwe in April 1995. Disease samples were submitted to Dr. D. Frederickson at the University of Zimbabwe for isolation and identification of the causal agent. I established a collaborative relationship with D. Frederickson and initiated her collaboration with L. Claflin of KSU-108 to expedite identification of the bacterial pathogen or other causal agent. The widely adapted Okashana-1 was among the pearl millet cultivars with the highest incidence of the unknown disease and a few other millet cultivars produced very elongate lesions. Recurrence and severity of the disease should be closely monitored at this and other locations, especially for cultivars being considered for release in various SADC locations to prevent widespread deployment of vulnerable varieties.

Germplasm Exchange

Over 400 lines & cultivars were evaluated for disease and drought response in the SADC region in 1994-95 (collaborative with TAM-121, TAM-122, TAM-123, and TAM-124)

Thirty-six accessions with variable disease resistance and drought resistance characteristics were brought into the U.S. from the SADC region in 1994.

Sponsored Trips

TAM-128 sponsored a trip for former graduate student, Anaclet Mansuetus, to attend the Second African Crop Science Conference held February 19-24, 1995 at Blantyre, Malawi, where he made a presentation entitled Mating Populations within *Gibberella fujikuroi* (*Fusarium* section Liseola).

TAM-128 sponsored a six day trip (July 16-21, 1995) for LDC collaborator, Dr Bhola Nath Verma, sorghum breeder, Zambia (SIDA) to review the Texas sorghum program through on-site nursery tours in South Texas and interaction with the TAES sorghum research team.

Research Support

Funds have been provided in 1993-95 to E. Mtisi in Zimbabwe to support collaborative research nurseries investigating foliar disease resistance in sorghum at the Henderson and Panmure stations.

Publications and Presentations

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Sustainable Production Systems

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 Mali and Niger the effects of new cultivars combined with inorganic fertilizers were evaluated after devaluation for the three principal agroecologic zones for crop production in the Sahel. The short run effects of devaluation are for imported input prices, especially fertilizer, to increase at a much faster rate than traditional cereal prices. However, over the next five years the devaluation also should encourage the substitution of domestic for imported cereals. Moreover the new cultivars are also more responsive to inorganic fertilizer than the traditional cultivars.

In the Sudano-Guinean zone of Mali incomes increase with the introduction of increased fertilization and area in cotton and maize. Model results indicated that only with unsubsidized credit directed specifically to the traditional cereals (sorghum and millet) would the new technologies be adopted. In contrast, in the Sudanian zone (Mali), the new cultivars of millet and sorghum, combined with inorganic fertilizer, were introduced after devaluation without any changes in credit policy. This technology introduction was a longer run result once the traditional cereal prices increased by 25%.

In the Sahelo-Sudanian zone (Niger) the inability of organic fertilizer to substitute for inorganic fertilizer was shown. Here farmers with higher asset levels introduced new cultivars of millet and cowpea in an intercrop system including inorganic fertilizers. The introduction of the new technology was largely driven by the high price increases for cowpeas, suggesting the need for more experimentation and promotion of cowpea monoculture systems.

In the mechanized rainfed zone of the Sudan land productivity can be substantially increased with low or moderate levels of nitrogen combined with new sorghum cultivars. These activities were profitable, more sustainable, and would be adopted by farmers according to model results.

Objectives, Production and Utilization Constraints

The objectives of our research were to estimate the potential effects of new technology introduction, to identify the constraints to its introduction, and to suggest complementary policy to accelerate that introduction process.

Mali

The principal constraints here are soil fertility in the Sudano-Guinean zone and the combination of water availability and soil fertility in the Sudanian zone. With ridging, farmers have already introduced a new water retention technique in the Sudanian region, hence the pressing constraint is also soil fertility here. In both zones, once soil fertility is improved, new cultivars become the next critical constraint.

Niger

On these sandy dune soils the critical constraint is soil fertility, specifically the low levels of nitrogen and phosphorus. Once higher levels of these nutrients are available, there will be a much higher return to the introduction of new cultivars. Three farm sizes are modeled with new technologies of different nutrient levels and fertilizer sources. New cultivars of millet and cowpea were also included as activities with and without fertilization.

Sudan

In the mechanized rainfed zone the returns to fertilizer are expected to be principally determined by the initial soil fertility. Once fertilizer is utilized at higher levels sorghum producers are expected to have increased interest in new sorghum cultivars. Various combinations of nitrogen and new cultivars will be analyzed.

Research Approach and Project Output

Mali, Sudanian Zone

Besides the pervasive use of ridging with animal traction there is substantial use of organic fertilizer including improved techniques of augmenting the quality of these fertilizers through compost heaps and utilizing plant residues and manure as corral bedding. Moreover, low levels of use of inorganic fertilizer are also found on the cereals. Around the Cinzana Research Station, farmers are using 10 to 40 kg/ha of compound fertilizer and 10 to 50 kg/ha of Urea on the local cereal cultivars (Coulibaly, 1995, p.101).

An important recent change in the economic policy environment was the devaluation of the CFA in January 1994. One long run objective of this devaluation is to increase the profitability of agriculture by increasing the prices of imported agricultural products. For the Sahel wheat and rice imports have become especially important to urban consumers. Another effect of devaluation is to increase the price of imports used in agriculture especially fertilizers and pesticides.

The short run effects of devaluation, predicted by the model even with the availability of the new technologies, are a decline in incomes (certainty equivalent) and a decrease in the use of inorganic fertilizer. This results from the 50% increase in fertilizer prices with only a 10% increase in cereal prices. The increase in cereal prices was so small because 1993-94 was a good year for cereals and the prices were buffered by substantial storage.

In the longer run (the next five years), the prices of domestic cereals are expected to increase as sorghum and millet are substitutes for the imported wheat and rice. There is also substantial irrigated and upland rice production in most Sahelian countries. With the 25% increase in cereals prices there is a shift to the new cultivars of millet and sorghum along with moderate levels of inorganic fertilizer once these technologies are available to farmers according to model results (Table 1).

Before devaluation there were 2 ha in improved sorghum cultivars at low levels of inorganic fertilizer. With the increase in the fertilizer price relative to the cereal prices, incomes decreased in the short run and cereal technology use disappeared. When the cereal prices increased by 25%, the new sorghum technologies were reintroduced but the predominant introduction was the new millet technologies. With the sandy soils in the Cinzana region, this zone is a millet region and there has been an important varietal improvement program here, including the introduction of IBV 8001 (Coulibaly, 1995, p. 108).

Mali, Sudano-Guinean Region

In this region there has been rapid new technology introduction for cotton and maize over the last two decades, both new cultivars and increasing fertilization levels. Low levels of inorganic fertilization have also been applied to the other cereals (sorghum and millet). Moreover, there is a residual fertility effect from the rotation of two years of sorghum following the cotton. Credit has been provided to farmers by the CMDT (the cotton marketing parastatal) for both

Table 1. Farm-level effects on income and fertilizer use of devaluation and the availability of new technologies in the Sudanian Zone of Mali (Moderate Risk Aversion).

Policy instruments	Incomes (Certainty Equivalent in CFA)	Change in incomes[a] (Certainty Eq. in %)	Area in improved technology (ha)		Fertilizer use (kg/farm)
			Sorghum	Millet	
A. Pre-Devaluation	409,000		2	-	220
B. Devaluation (Short term). Increase in cereal prices of 10%	502,000	23	-[b]	-[b]	175
C. Devaluation (Long term). Increase in cereal prices of 25%	965,000	136	0.5	7.5	1350

[a] This is the percentage increase in nominal incomes. Note that with adjustment for the exchange rate, incomes would need to go up 100% to accompany the potential increased price of tradeables. This assumes that all tradeable prices went up 100%, which obviously they did not do since the government of Niger maintained some subsidies on consumer imports and the elasticity of substitution for many import substitutes was expected to be low.

[b] The only new technology utilized here was an increase in improved cowpea cultivars and fertilization.

Source: O. Coulibaly, 1995, pp. 104, 118, 121, 130.

cotton and maize production. The CMDT credit for maize production was eliminated after 1986.

The potential technologies considered with the modeling are new cultivars of all the crops including groundnut plus higher fertilization levels. Devaluation is also an issue here. The CMDT raised the fertilizer prices 50% and the guaranteed cotton price 35%. In the short run, the cereals prices, including maize, increased by 10%. Another public policy change is the elimination of the 3 ha limit on cotton area. The response by farmers to the combined effects of devaluation and the elimination of the cotton area restrictions is to increase by 50% the area in cotton and maize, as well as to raise the fertilization of these two crops (Table 2). The nominal income increase from these changes is 89%. If farmers only consumed tradeables and the tradeable prices increased 100% associated with a 50% devaluation of the CFA, then real incomes declined. Since the government is expected to continue some subsidies to protect consumers and farmers also consume non-tradeables, this 89% nominal income increase is expected to be a real income increase.

In the longer run (after 1995) the prices of cereals are expected to increase by at least 25%. However, the further income increase is small. With the devaluation and the elimination of the cotton area restriction farmers can make more money by continuing to increase the technology and area in the two principal activities for past technological change, cotton and maize, rather than introducing higher technology levels in the traditional cereals, sorghum and millet.

A further substantial increase in income is possible if credit is also provided for the cereals as it is already provided for cotton. With unsubsidized credit a full 10 hectares of maize and sorghum new cultivars with inorganic fertilizer are planted. Since neither the government nor the banking system are expected to provide credit for the cereals, the prospects for introducing the new cereal technologies in the Sudano-Guinean zone are not promising.

The traditional cereals have always been a dominant activity in the Sudano-Guinean zone. Prior to the devaluation, the model farm had 3 ha in cotton, 0.75 ha in maize, 1.75 ha in groundnut, 6 ha in sorghum and 2 ha in millet. Government policy to promote the introduction of new cereals technologies in this region would be expected to lead to higher productivity gains than in the Sudanian region since this is the region with the best rainfall and soil conditions. One problem with promoting new cereals technologies here is the resulting distribution of income between regions if most technological change is concentrated in this region.

Niger-Sahelo Sudanian Zone

With linear programming the potential impacts of new technologies were evaluated for farms with three different resource endowments (Abdoulaye, 1995). The data for the new technologies were obtained from farm trials conducted over a five year period at various sites in Niger by INRAN (the NARS of Niger). The farm modeling was for a site on the border with Nigeria (Birni N'Konni) with the typical sandy dune soils of the Sahelo-Sudanian zone. This is the predominant agroecological crop zone in Niger. The rainfed predominant activities here are millet-cowpeas intercropped and small animals. The new technologies considered were new millet and cowpea cultivars and various methods of increasing soil fertility. The differences in resource endowment between farmers were those farmers with only small animals, farmers with larger animals, and farmers with access to small areas of irrigated land. The latter group also had cattle.

As in Mali analyzing the potential impact of new technologies requires the incorporation of the price changes resulting from the devaluation of January 1994. In the past year livestock and cowpea prices have increased by 75%. Livestock is the traditional export of the Sahel. The market for cowpea hay as a livestock feed in urban areas also has been increasing rapidly. Millet prices are expected to in-

Table 2. Effects of devaluation and new technologies on farm income, adoption of new technologies, and fertilizer use in the Sudano-Guinean Zone of Mali (Model Results: Moderate Risk-Averse Farmer).

Policy instruments	Incomes (Certainty equivalent in CFA)	Income increase (%)	Area in new technology[a]			Fertilizer use (kg/farm)
			Cotton	Maize	Sorghum	
A. Pre-Devaluation	487,000	-	3.00	0.50	-	635
B. Devaluation (Short term). Increase in cereal prices of 10%	921,000	89	4.50[b]	0.75[b]	-	1,325
C. Devaluation (long term). Increase in cereal prices of 25%	1,003,000	106	4.50	0.75	-	1,310
D. Credit to cereals[c]	1,287,000	164	4.50	5.00	5.0	3,125

[a] Includes both new cultivars and higher levels of inorganic fertilizer.

[b] Reflects higher fertilization levels on both cotton and maize. For cotton, this is 200 kg/ha of cotton compound fertilizer and 50 kg/ha of urea. For maize, this is 100 kg/ha of cereal compound fertilizer and 50 kg/ha of urea. If cotton area is maintained at the restricted 3 ha, the income increase would only be 10% and the consumption of inorganic fertilizer would decrease by 25% (Coulibaly, 1995, p. 96).

[c] Also includes devaluation and 25% cereal price increases.

Source: O. Coulibaly, 1995, pp. 62, 82, 86, 88, 97.

crease by 20% and inorganic fertilizer prices have increased by 100%.

The response to the new economic environment and the availability of the new technologies varies substantially between farmers depending upon their resource endowment. The low income, small animal owners increased their incomes 22% by introducing the new cultivars without fertilizer on 2.8 ha with another ha of the cowpea-millet intercrop fertilized with manure. The farmers with cattle increased their incomes by 26%. They planted 1.4 ha with the new cultivar intercrop alone and another 2.6 ha with these new cultivars and phosphate fertilizer. The high resource farmers planted .2 ha in the new cultivars alone and 1.4 ha with the combined fertilizers of nitrogen and phosphorus plus pesticide on the cowpeas.

Without increasing the levels of available N and P in the soil new cultivar introduction is not a sustainable system. With the livestock available farmers could provide the equivalent of 100 kg/ ha of simple super phosphate (23 kg of P_2O_5) for only .25 to .34 ha of their cropland (Abdoulaye, 1995). Small increases in nutrient availability can be obtained with compost heaps and other techniques. Moreover, the livestock numbers can be increased. However, the basic problem of organic fertilizer is the inelastic supply. At low levels of basic nutrients (N and P), as here in southern Niger, organic fertilizer is not an adequate substitute for inorganic fertilizer because the quantity requirements for manure are too high.

A critical research question is then to identify the constraints to higher levels of utilization of inorganic fertilizers by all three resource endowment farms. Inorganic fertilizer purchase requires that farmers have access to capital. All the farms have livestock so there is internal capital accumulation and this capital is liquid. Are there demand or supply constraints to the utilization of this livestock capital for more inorganic fertilizer purchase?

On the demand side the fertilizer activities were sufficiently profitable compared with other investment options to be utilized by the two higher resource category farmers. One limitation of this analysis was the failure to incorporate risk and nitrogen fertilizer use can be risky. The emphasis here was on the supply side constraints to the use of this capital. Livestock is often owned by women or other family members besides the household head and thus can be difficult to cash in for input purchases by the family head. As new technologies become available, institutional changes are often required to facilitate the access to new income streams. The response to the new opportunities presented by technologies then often depends upon the ability of farmers and societies to make the necessary institutional changes to facilitate access to these new potential income streams. Institutional change is presently occurring for land tenure in many regions with technological change. Similarly, increased changes within family bargaining is expected to make these livestock investments a more liquid capital source as farmers and their wives become more convinced that the investments in inorganic fertilizers and new cultivars will be profitable and not substantially increase their risks.

The low income sector of Nigerien farmers often does not have sufficient livestock assets to purchase much inorganic fertilizer. Moreover, institutional credit programs are often difficult and expensive to aim at this sector. Even with the credit programs there are demand side problems for this group as they often have other potential investments in off-farm activities and acquiring small ruminants.

Sudan, the Mechanized Rainfed Zone

Sudan has developed its enormous frontier by subsidizing land area expansion of large farmers. The area in sorghum in the mechanized rainfed zone has increased from 900,000 ha in 1967 to over 5 million in 1993. In the older settled zones the yields of sorghum have fallen substantially. Moreover, even in the newer regions the costs of continuing area expansion have been increasing.

The vertisol region has good initial fertility except for nitrogen levels. Moreover, the heavy, cracking soils have some water retention capacity. Monoculture sorghum without fertilization is the predominant activity in the mechanized rainfed zone; however, about 12% of the area is planted in sesame. With the declining sorghum yields and the increasing concern with sustainable production methods, policy makers have been reexamining extensive development practices.

One basic problem with introducing more intensive, yield increasing technologies is the lack of experimentation on fertilization for different states of nature and soil fertility conditions. Building upon the available agronomic data and a water-soil-plant simulation model (EPIC), distributions of yields for observed rainfall conditions over time were estimated for different activities. Then the mean yields were calculated (Table 3). Improved sorghum cultivars alone increased yields 15% and 23% for the virgin and exhausted soils. Low levels of nitrogen (46 kg/ha of Urea) combined with the new cultivar increased yields by 44% and 90%. Moderate levels of nitrogen (92 kg/ha of Urea) combined with the new cultivars increase yields by 57% and 144% for the virgin and the degraded soils.

Then the next relevant research question is whether farmers would adopt the new technologies assuming that the seed and the fertilizer were available. To respond to this question a farm programming model was developed. In the virgin soils only the improved sorghum cultivar is utilized (Table 4). Farmers also rent a large area in this scenario. If it were not possible to rent, farmers would begin utilizing a small area (27 ha) of the improved cultivar with 1/2 N (46 kg/ha of Urea):

Table 3. Sorghum yields of alternative technologies at two levels of soil fertility on virgin and exhausted soils.

Crop technology	Virgin soils (metric tons/ha)	Exhausted soils[a] (metric tons/ha)
Traditional cultivar	1.03	0.62
Improved cultivar	1.18	0.76
Improved cultivar +½N[b]	1.48	1.18
Improved cultivar +1N[b]	1.62	1.51

[a] Soil subjected to continuous cropping for 12 years.

[b] 1N= 92 kg urea per hectare.

Source: M. Ahmed, Mohamed, 1994, p. 50. These are mean yields simulated over the observed rainfed distribution with EPIC. For further details, see the above thesis.

Table 4. Impacts of new technologies on sorghum areas and farmers' incomes in virgin and exhausted soils on the mechanized rainfed areas at moderate risk aversion levels (programming results)

Impacts	Virgin soils	Exhausted soils[a]
Improved sorghum cultivar (ha)	653	-
Improved sorghum cultivar + 92 kg/ha Urea (ha)	-	406
Expected profit (Sudanese pounds)	42,631[b]	32,997[b]

a Soil subjected to continuous cropping for 12 years.

[b] Exchange rate, 1992, 142.86 L.S./US$.

Source: M. Ahmed, Mohamed, 1994, pp. 54, 56.

On the exhausted soils (12 years of continuous sorghum production) if new technologies are not introduced, farmers opt not to produce. This is consistent with the observation of farmers' fallowing or moving on to virgin areas after 10 to 12 years. With the new technologies farmers would utilize the highest available fertilizer level (92 kg/ha of Urea) combined with the new sorghum cultivar. Less area is cultivated here and incomes are lower than on the virgin soils. However, these exhausted soils are found in most of the older mechanized region such as the Gedaref zone. There appear to be social benefits to encouraging the utilization of fertilizer before the soils become exhausted. This problem is considered in more detail in M. Ahmed's thesis with dynamic programming (1994).

Southern Africa (Zimbabwe and Namibia)

Besides the above studies estimating the potential effects of new technologies there were two ex post technology evaluations undertaken this past year estimating the economic effects of technologies already successfully introduced. In Zimbabwe an ICRISAT sorghum cultivar was identified by the national research program and released in 1987. Diffusion was accelerated by the activities of SMIP, the regional ICRISAT program for southern African countries, especially the production of seed to respond to the major drought of 1991-92. The national extension service (AGRITEX) also conducted farm trials with SMIP collaboration and provided small quantities of seed and fertilizer to farmers after the two drought years of the early 1990s. In the 1994-95 crop year 36% of the communal sorghum area was planted to SV-2. From the national viewpoint the internal rate of return to the research and extension activity of introducing this new cultivar is 22% (Anandajayasekeram et al., 1995, pp. 90, 99).

In Namibia a pearl millet was identified from an ICRISAT nursery in 1986 by a Namibian Foundation. Again as in Zimbabwe, SMIP facilitated the farm testing and the seed production. Okashana I was released in 1990. In the 1994-95 crop year, there were 17 and 45% of the millet areas planted in this cultivar in the two major production zones. From the national perspective the internal rate of return to the research and extension for Okashana I was 11% (Anandajayasekeram et al., 1995, pp. 103, 110). This is a more marginal investment return than for SV-2 but extending the expected future benefits of Okashana I from 1999 to 2005 increases the rate of return to 17%.

Networking Activities

Workshops

Sanders presented a paper at a workshop on New Technology Introduction in Sub-Saharan Africa at the annual meetings of the American Agricultural Economics Association, San Diego, California, August 1994.

Ousmane Coulibaly and Will Masters presented three invited papers (see *Presentations*) in a four-day USAID workshop on Supporting Sustainable Development in Africa, Harare, Zimbabwe, January 1995.

In April 1995, Sanders presented two invited papers in a four-day workshop on Technology Introduction and Diffusion in West African Agriculture, organized by SAFGRAD/OAU and the African Development Bank.

Mamadou Sidibé and Will Masters conducted a one-week workshop on Impact Assessment for 15 economists from West African national agricultural research systems (NARS) at Bamako, Mali, June 1995. In Bamako in 1994, a similar workshop was given for 22 economists and agronomists from the NARS by Masters and Sanders.

Research Institution Exchanges

Sanders spent two weeks in October 1994 working with ISRA (NARS in Senegal) on impact analysis and training. To date, three bulletins on impact assessment of specific crops for ISRA have been finished and submitted for management review and possible publication as ISRA bulletins. Also in this trip to Senegal, a half-day seminar was given on estimating the impact of research. After this impact work Sanders spent another week in Dakar as a member of the Technical Commission of ISRA to review the research output, planning and management.

Sanders also collaborated on the SADC report evaluating the impact of the ICRISAT-SMIP program in the introduction of new sorghum and millet cultivars in the ten southern African countries involved in this project over the last decade. He analyzed the impacts of new sorghum and millet cultivars in Zimbabwe and Namibia.

Contribution to Networks

In 1994-95 two of the Ph.Ds trained by INTSORMIL-PRF-105 were contracted by international centers as Post-Doc fellows. Mohamed Ahmed began working for the SMIP program of ICRISAT at Bulawayo, Zimbabwe in the fall of 1994. Ousmane Coulibaly went to the Cameroon for IITA in the summer of 1995.

Publications and Presentations

Publications

Journal Articles

M. Ahmed, Mohamed, William A. Masters, and John H. Sanders, 1995. "Returns From Research in Economies With Policy Distortions: Hybrid Sorghum in Sudan," Agricultural Economics, forthcoming.

López-Pereira, M.A., J.H. Sanders, T. Baker, and P.V. Preckel, 1994. "Economics of Erosion Control and Seed: Fertilizer Technologies for Hillside Farming in Honduras," Agricultural Economics 11:271-288.

Books

Sanders, John H., Barry I. Shapiro, and Sunder Ramaswamy, 1995. The Economics of Agricultural Technology in Semiarid Sub-Saharan Africa. Baltimore, MD: Johns Hopkins University Press, forthcoming.

Dissertations, Theses

Coulibaly, Ousmane N., 1995. "Devaluation, New Technologies, and Agricultural Policies in the Sudanian and Sudano-Guinean Zones of Mali," unpublished Ph.D. dissertation. West Lafayette, IN: Purdue University, Dept. of Agricultural Economics.

M. Ahmed, Mohamed A., 1994. "Introducing New Technologies on the Vertisols of Eastern Sudan: A Dynamic Programming Approach," unpublished Ph.D. dissertation. West Lafayette, IN: Purdue University, Dept. of Agricultural Economics.

Abdoulaye, Tahirou, Dec. 1995. "Impact of Opportunity Cost on Adoption of New Technologies in the Birni N'Konni Region of Niger," unpublished Master's thesis. West Lafayette, IN: Purdue University, Dept. of Agricultural Economics. (Adviser: Jess Lowenberg DeBoer) forthcoming

Miscellaneous Publications

Sanders, John H. and B. Kupfuma, 1995. Chapter 10, "Case Study 1 - Zimbabwe: Sorghum SV-2," and Chapter 11, "Case Study 2 - Namibia: Pearl Millet: Okashana," in Report on the Impact Assessment of the SADC/ICRISAT Sorghum and Millet Improvement Program, Volume I, prepared by P. Anandajayasekeram, D.R. Martella, J. Sanders, and B. Kupfuma. Gaborone, Botswana: SACCAR (Southern African Centre for Cooperation in Agricultural and Natural Resources Research and Training).

Presentations

John H. Sanders, Sunder Ramaswamy, and Barry I. Shapiro, "Technology Development for Semi-Arid Sub-Saharan Africa: Theory, Performance, and Constraints," selected paper at the meetings of the International Association of Agricultural Economists (IAAE), Harare, Zimbabwe, August 1994. A variation of this was also presented at the meetings of the American Agricultural Economics Association (AAEA), San Diego, CA, August 1994.

John H. Sanders and Barry I. Shapiro, "Technology Development in Semi-Arid Sub-Saharan Africa With an Emphasis on Livestock," invited seminar presented to the scientists of the International Livestock Research Institute (ILRI), Addis Ababa, Ethiopia, September 1994.

John H. Sanders and Mohamed M. Ahmed, "Impact of Sorghum and Millet Technology Development and Transfer in Sub-Saharan Africa," invited paper for the USAID Regional Workshop on Supporting Sustainable Development in Africa, Harare, Zimbabwe, January 1955.

William A. Masters and John H. Sanders, "Tools and Concepts in Impact Assessment: Research Results and Future Directions," invited paper for the USAID Regional Workshop on Supporting Sustainable Development in Africa, Harare, Zimbabwe, January 1955.

John H. Sanders," Technology Introduction and Policy Changes in Semi-Arid Sub-Saharan African Agriculture," invited paper at the SAFGRAD/OAU and African Development Bank Workshop on Technology Options and Transfer Systems, Abidjan, Côte d'Ivoire, April 1995.

Ousmane N. Coulibaly and John H. Sanders, "Devaluation and New Technology Introduction in the Sudanian and Sudano-Guinean Zones of Mali," invited paper at the SAFGRAD/OAU and African Development Bank Workshop on Technology Options and Transfer Systems, Abidjan, Côte d'Ivoire, April 1995. An earlier version was also presented at the Harare conference in January 1995.

Resource Efficient Crop Production Systems

Project UNL-113A
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Professor David Andrews, Department of Agronomy, University of Nebraska, Lincoln, Nebraska

Summary

This project has been involved with resource efficient crop production systems since the inception of INTSORMIL. Results from this project have illustrated the impact that different cropping practices can have on crop productivity. Scientists in developing countries are now starting to adopt the philosophy that to stabilize and increase production depends very much on moisture availability and adequate fertility. Results show that weeds will compete for nutrients and water and for each kilogram of weed biomass produced, you will loose about 1 kilogram of grain. Also, using legumes in rotation can furnish the equivalent of about 50 kg N, which can lead to a yield of approximately 2.5 Mg ha^{-1}. Control of weeds and use of legumes in rotation with sorghum are practices that all farmers with limited monetary resources can adopt.

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 and weed relationships.

Determine soybean density as it affects productivity of the cereal in rotation or in an intercrop.

Determine what physiological processes may contribute to the growth behavior of the maicillo criollos sorghum in intercropping as compared to other sorghum.

Constraints

Emphasis has been directed towards principles and practices that enhance the availability and use 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 the improved varieties and hybrids that have been developed can express their yield potential. However, this requires special considerations. First, they are long-term investments. Crop rotation or intercropping systems must be continued for several seasons or cycles. Second, a host scientist must be genuinely interested in these long-term projects, and they require stable funding over time. Third, training of scientists in crop production and continued support of their work after return to home countries is needed to improve presently used cropping systems.

Research Approach and Project Output

Sorghum and millet are usually grown in stressful environments with high temperatures and lack of a predictable 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 requires improved genetics combined with production practices (weed control) to provide adequate water and fertility.

Grain Yield and Photosynthesis of Landrace Sorghum- Subsistence farmers in Central America use long season tropical sorghum for intercropping with maize. This unusual cereal-cereal association is suited for their agronomic practices and physical environment. Planting maicillos criollos, as these sorghum populations are called, allow farmers to reduce yield loss caused by drought. Farmers prefer to plant maize and sorghum in *casado* or a mixture (sorghum and maize planted in the same row), or in aporque or row intercrop (sorghum planted between maize rows at cultivation). In aporque, maize provides natural shading that increases until the maize flowers, and then slowly decreases during maize grain fill and maturity. The shade hinders sorghum vegetative growth, but it also helps alleviate leaf desiccation in case of drought. Since maicillo is a long season sorghum, grain fill occurs after maize has been harvested.

Experiments conducted in 1992 and 1993 concluded that maicillo is adapted to reduced irradiance during vegetative growth. These studies showed that maximum photosynthetic rates of TAM428 (a temperate variety) decreased by 53% in *aporque*, while in San Bernardo III (a maicillo) the reduction was less than 5%, when compared to monoculture photosynthetic rates. Due to its tropical origin, sub-optimal (10 ^{O}C) temperatures during germination, growth, and grain fill affect sorghum grain yield in northern latitudes. The A.O. pathway has been associated with increased temperatures in thermogenic species such as *Sauromatum guttatum* (Voddoo lily).

Respiratory studies in sorghum will serve the purpose of understanding the mechanisms involved in the respiratory pathways of sorghum. Preliminary results using monoclonal antibodies against the A.O. enzyme (antibody courtesy of Dr. T. Elthon, University of Nebraska) show that the A.O. pathway is present in sorghum. This is being further explored in trying to determine respiratory relationships to sub-optimal and shade tolerance of sorghum.

Effect of weeds on sorghum grain yield - An experiment was established to determine the partitioning of biomass into sorghum and weeds. Different levels of weed control and nitrogen were used. Weed treatments consisted of a control (no weeding), one cultivation three weeks after planting and complete weed control. Nitrogen levels were 0, 40, and 80 kg ha^{-1} ammonium nitrate side-dressed three weeks after planting. Main plots were levels of weed control and subplots were nitrogen levels. Three replications were used. Samples of weeds and grain were harvested from the middle two rows of six row plots.

Weeds were very competitive with sorghum. Figure 1 shows that for each kg of weeds, there was a loss of about 1.2 kg of grain. Under the poorest management, no weed control, yields were reduced about 80%. Water use efficiency was increased greatly with weed control (INTSORMIL Annual Report, 1992). This shows that farmers could double grain yield with excellent weed control.

Total N uptake by grain sorghum - A sorghum soybean rotation study has been in progress for over 15 years. This

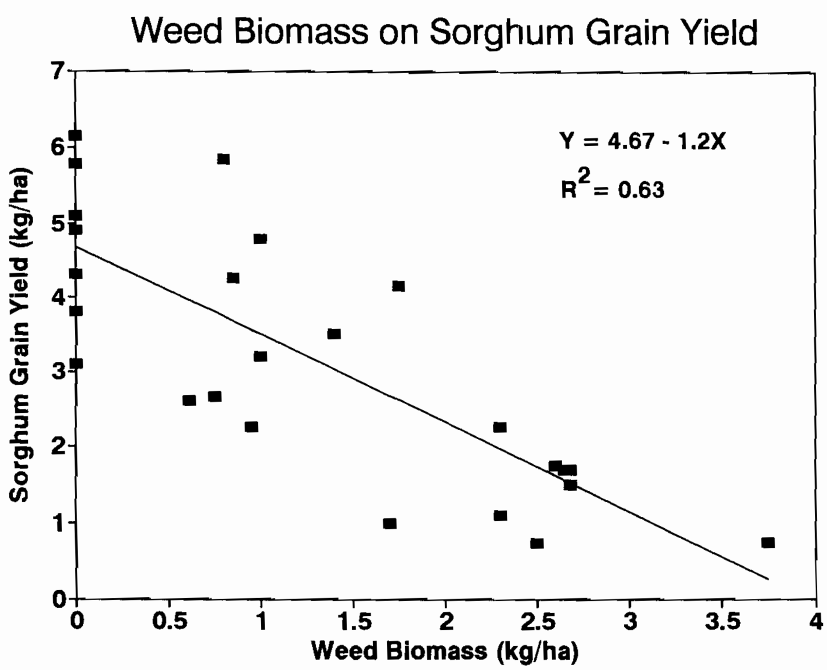

Figure 1. Sorghum grain yield reduction in relation to increasing weed (biomass).

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. Average nitrogen uptake has been determined for all the treatments and the data combined.

Much emphasis has been put on developing high yielding sorghum cultivars and the results have been very successful. For example, Botswana has released three varieties and one hybrid that will yield 3.5-7 Mg ha^{-1}. However, regardless of how superior a genotype is, resources (N,P,K, and H_2O) must be available to express this yield potential. This project's research shows that at least 50 kg ha^{-1} is needed to obtain a yield of 2.5 Mg ha^{-1} (Figure 2). To obtain 7 Mg ha^{-1} would require about 150 kg ha^{-1} N. Yield levels of many (most) farmers are < 1 kg ha^{-1} reflecting a definite lack of resources as many farmers do not apply fertilizer. Also, the N removal is almost doubled if the residue is removed and used. The amount of N in sorghum residue in this study averages around 50% of the total N taken up.

Resource enhancement - In Botswana, a proposal for enhancing crop production with fertilizer, legume/cereal rotations and weed control was adopted. A tillage treatment is included as a factor with a bearing on soil moisture conservation and weed control. Double ploughing (i.e. ploughing following the first rain and ploughing after the second rain), has been found through research in Botswana to effectively control weeds. The weeding treatments suggested are weeding only once and weeding twice. Experimental Design: Two tillage treatments will be assigned to the main plots in a RCBD: (1) single ploughing, (2) double ploughing. Treatments:

1. Continuous sorghum, Ø fertilizer, 1 weeding
2. Continuous sorghum, Ø fertilizer, 2 weeding
3. Continuous sorghum, + fertilizer, 1 weeding
4. Continuous sorghum, + fertilizer, 2 weeding
5. Sorghum after a legume, 1 weeding
6. Sorghum after a legume, 2 weeding
7. Legume after sorghum, 1 weeding
8. Legume after sorghum, 2 weeding

The two weeding treatments will be assigned randomly to subplots and the four treatments: Ø Continuous sorghum, fertilizer; Continuous sorghum, + fertilizer; Sorghum after a legume; and legume after sorghum applied randomly to subplots. The "+ fertilizer treatment" will be 30 kg/ha P plus 40 kg/ha N applied into the seed bed. Segaolane and Tswana cowpeas or blackeye will be planted in six row plots of 10 m length. The following measurements will be made: 1) physical; infiltration rate, moisture retention, bulk density and plant available moisture, 2) soil fertility; soil pH, N, P, K and exchangeable bases at the beginning and end of growing season, 3) weed assessment; before each weeding and at harvest, and 4) agronomic parameters; plant stand, days to flowering and lodging.

Networking Activities

Workshops

Participated in the Regional Sorghum and Pearl Millet Workshop, July 25-29, 1994 in Gaborone, Botswana. Reviewed research and did planning on sorghum in Botswana, August 1-12, 1994.

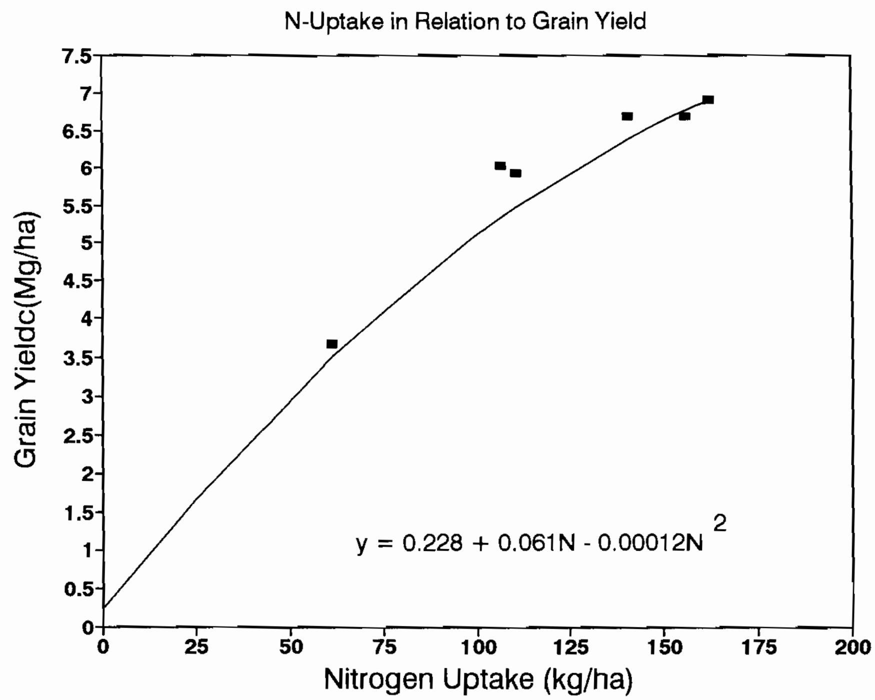

Figure 2. Total N uptake by grain sorghum in relation to grain yield.

Participated in the American Society of Agronomy Meetings, November 13-18, 1993. Seattle, WA.

Publications and Presentations

Publications

Clegg, Max D. 1994. Crop Management: Nutrients, Weeds and Rain. Regional Sorghum and Millet Workshop, Botswana, July 25-29, 1994.

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.

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.

Clegg, M.D. and J.W. Maranville. 1994. N Partitioning and Remobilization. Agron. Abst. p. 140, Seattle, WA.

Presentations

Clegg, M.D. Presented a paper at the Sorghum and Millet Workshop, Gaborone, Botswana, July 27, 1995.

Clegg M.D. Presented a paper at the Symposium: Control of Assimilate Allocation: I. Div. C-2, Crop Physiology and Metabolism, at the ASA meetings, Nov 14, 1994, Seattle, WA.

Clegg, M.D. Presented a paper at the Agronomy Highlight "Sorghum-soybean rotation and fertilizer nitrogen: Continuing saga —". December 20, 1994.

Cropping Systems to Optimize Yield, Water and Nutrient Use Efficiency of Pearl Millet

Project UNL-113B
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Mr. Karim Traore, IER, Cinzana, Mali
Dr. Alex Martin, University of Nebraska, Lincoln
Professor William Stegmeier, Kansas State University, Hays, Kansas
Mr. Antime Sagara and Oumar Coulibaly, IER, Cinzana, Mali. (On-farm agronomists working with the Extension Service and PVOs in the Segou area)

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, and to improve yield, water and nutrient use efficiency through use of improved production practices. The project strengthened research efforts with pearl millet by developing cooperative studies with breeders in Mali, Niger, and the U.S., and participation in the ROCAFREMI Network. Principal Investigator Samba Traore started a Ph.D. program, and both Minamba Bagayoko and Mamane Nouri are scheduled for short-term training in the coming year.

Cropping systems studies in Mali indicated that improved pearl millet/cowpea cultivars combined with recommended practices did not produce greater pearl millet yield nor greatly increase net income, largely due to the costs of controlling cowpea insect infestations. Increased multi-disciplinary efforts to develop a stable, high-yielding, profitable production system composed of improved cultivars with appropriate agronomic practices is needed. Crop rotation with cowpea enhanced pearl millet yield by 74%, and nitrogen fertilizer application increased yield by 30 to 65%.

U.S. studies to develop an agronomic production practices package for dwarf pearl millet as a new alternate crop for the U.S. were initiated. Narrow row spacing, nitrogen application, and good weed control were identified as important practices, although pearl millet appeared to be more competitive with weeds than grain sorghum.

Objectives, Production and Utilization Constraints

Objectives

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 were continued at three locations in Mali.

Long-term studies to determine the influence of crop residue removal, incorporation and leaving on the surface on grain and stover yield of pearl millet were continued at two locations in Mali.

Initiate studies to develop production practices for new pearl millet cultivars to be released by national programs in Mali and Niger.

Initiate studies in Mali and Nebraska to determine dry matter production and nutrient uptake of pearl millet cultivars with different growth habits.

Study the "rotational effect" in pearl millet-soybean rotation by evaluating: 1) grain and stover yields, 2) nitrogen uptake and use efficiency, and 3) soil water relationships.

Determine difference in competitive ability of dwarf pearl millet and grain sorghum hybrids with weeds for water and nitrogen, and initiate studies on the influence of planting date and row spacing on yield of dwarf pearl millet hybrids.

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, fertilizer utilization, and 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 productivity of cropping systems and to maintain the soil/land natural resource.

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 for cultivation due to population growth and land degradation has heightened awareness of this constraint. Rotational or intercropping legumes become a viable alternative for providing some nitrogen and yield enhancement when fertilizer availability are 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 nutrients. The complex interaction of water, N, P and pearl millet cultivars is the focus of Project UNL-113B's research efforts.

International

Mali - Research Methods

Long-term cropping system and residue management studies were continued at Samanko, Cinzana and Koporo. In 1995, more intensive study of N uptake and partitioning of pearl millet/sorghum and cowpea/peanut is underway in these long-term studies.

A study was initiated to develop recommended production practices for soon to be released new pearl millet cultivars. A sequential study was implemented starting with traditional conditions and stepwise increasing management practices/inputs from the traditional system to an intensive set of production practices (plowed soil, high fertility, high plant population).

A study of pearl millet/cowpea cropping systems was initiated in 1993 at Cinzana with collaboration with the ROCAFREMI network. Treatments consisted in combinations of improved and local cultivars, planted in sole and intercrop systems, using IER recommended production practices. This consisted of 1.5 x 0.4m spacing, 2 plants/hill, 33,333 plants/ha, and 22 kg/ha nitrogen side-dressed for pearl millet. For cowpea, 1.5 x 0.25m spacing, 2 plants/hill and 53,333 plants/ha for the improved cultivar, and 1.5 x 0.5m, 2 plants/hill and 26,666 plants/ha for the local cultivar. Cowpea was sprayed twice for insect control. Both crops received 100 kg/ha 15-15-15 at planting. In addition, a traditional check (pearl millet and cowpea seeded in the same hill) was included. In 1994, the study was continued with collection of grain and stover yield, gross and net income, and Land Equivalent Ratios (LER).

Mali - Research Results

The highest pearl millet and cowpea yields were produced by use of sole crops or the traditional intercrop (Table 1). The highest Land Equivalent Ratios, a measure of agronomic efficiency, were produced by intercrop systems using local pearl millet cultivars with either cowpea cultivar, while the improved pearl millet-improved cowpea intercrop system had lower LERs than the sole crops. High cowpea yield treatments resulted in the highest gross income. The high cost of improved cowpea cultivar production resulted in improved millet-local cowpea, sole cropped improved millet, and the traditional intercrop producing the greatest net income. Although improved cultivars with recommended production practices increased land use efficiency and gross income, the highest pearl millet yield and one of the highest net income systems was the traditional intercrop.

In 1994, rotation with cowpea increased pearl millet yields by 74%, as compared to 35, 34 and 56% in 1991, 1992, and 1993, respectively. Intercropping pearl millet with cowpea increased the Land Use Efficiency (LER) by 54, 46 and 8% at zero, 20 and 40 kg/ha nitrogen fertilizer

Table 1. Yield and income of pearl millet/cowpea cropping systems in Cinzana, Mali in 1994.

Cropping System	Pearl Millet Yield		Cowpea Yield		Gross Income	Net Income	Land Equivalent Ratio
	Grain	Stover	Grain	Stover			
	--------- Mg/ha ---------				--- FCFA/ha ---		
Sole Crop Millet:Local Variety	1.5	3.4	--	--	59120	39320	1.0
Sole Crop Millet:Improved Variety	1.9	3.6	--	--	74240	54140	1.0
Sole Crop Cowpea:Local Variety	--	--	0.6	0.5	48300	30800	1.0
Sole Crop Cowpea:Improved Variety	--	--	1.0	0.8	80300	45600	1.0
Intercrop:Local Millet/Local Cowpea Variety	1.3	3.6	0.3	0.2	73600	48300	1.3
Intercrop:Local Millet/Improved Cowpea Variety	1.1	3.5	0.5	0.4	84540	42040	1.3
Intercrop:Improved Millet/Local Cowpea Variety	1.0	2.9	0.5	0.4	82480	56880	1.1
Intercrop:Improved Millet/Improved Cowpea Variety	1.2	1.8	0.2	0.1	71240	28440	0.9
Traditional Intercrop	1.9	3.7	--	--	74200	53200	1.0

Table 2. Influence of nitrogen fertilizer rate on canopy temperature minus air temperature, leaf nitrogen concentration, and sorghum grain yield in 994.

Nitrogen fertilizer rate kg/ha	Canopy temperature minus air temperature (ΔT) °C	Vapor pressure deficit kpa	Flag leaf nitogen concentration %	Grain yield Mg/ha
0	-0.95	2.2	2.0	3.4
45	-2.33	2.2	2.6	6.8
90	-2.95	1.8	3.1	7.6
135	-2.85	2.0	3.3	7.7

application. Nitrogen fertilizer application increased pearl millet grain yields by 30 to 65%.

Niger

The crop history was established for a long-term pearl millet-peanut cropping system study to evaluate production stability and soil fertility was initiated in cooperation with the ICRISAT Sahelian Center. Plans were made to start a sequential experimental design experiment in 1995 to develop recommended production practices for improved pearl millet cultivars for the "sumno" (high rainfall area) and intermediate rainfall areas of Niger, and to conduct a growth analysis/nutrient uptake study for distinctly different pearl millet cultivars under high and low fertility conditions.

Domestic

Water x Nitrogen Interactions

A study to determine the interaction of nitrogen fertilizer application rate on grain yield and canopy water status, using an infra-red thermometer to measure Canopy Minus Air Temperature (DT), was conducted in 1994. A field with low nitrate-nitrogen status was used and 0, 45, 90 and 135 kg/ha was applied 3 weeks after planting to plots planted to DK37. Infra-red thermometer readings were taken during the early grain fill growth stage. Nitrogen application increased grain yield and flag leaf nitrogen concentration (at anthesis) quadratically (Table 2), and reduced the DT quadratically, indicating that grain sorghum plants with adequate nitrogen had less water stress than those with inadequate nitrogen.

Dwarf Pearl Millet Production Practices

Studies were initiated in 1995 to determine appropriate planting date and row spacing for dwarf pearl millet dryland production in western and eastern Nebraska. In 1994, a comparative study on the effect of weed level (complete control, intermediate control, weedy), row spacing (38 and 76 cm) and nitrogen fertilizer application (0 and 76 kg/ha) on pearl millet (MLS x 68A) and grain sorghum (DK28) was conducted. All plots were over seeded with 3.4 kg/ha velvetleaf and 2.3 kg/ha foxtail seed, and weed levels obtained by differential herbicide application and hand weeding. Results showed that narrowing row spacing, applying nitrogen, and controlling weeds increased yields of both crops (Table 3). Yield reductions at the intermediate control level were similar for both crops, but much greater for sorghum in the weedy plots, suggesting that pearl millet was more competitive with weeds than sorghum. Weed level and nitrogen application had little influence on DT of grain sorghum (Table 3), while weed control and nitrogen application lowered DT of pearl millet indicating less water stressed plants. Narrowing row spacing for both crops reduced DT. This study indicates that grain sorghum has higher yield potential on these medium textured soils in

Table 3. Grain yield and canopy minus air temperature (DT) of grain sorghum and pearl millet as influenced by weed level, row spacing and nitrogen application.

Crop	Weed level			Row spacing		Nitrogen	
	Complete control	Intermediate control	Weedy	38 cm	76 cm	0 kg/ha	76 kg/ha
	-------------- Grain yield (Mg/ha) --------------						
Grain Sorghum	8.5	8.1	4.3	7.6	76.3	6.5	7.3
Pearl Millet	5.3	5.0	4.0	5.5	4.1	4.0	5.5
	-------------- Canopy minus air temperature (°C) --------------						
Grain Sorghum	-0.53	-0.51	-0.53	-0.60	-0.46	-0.52	-0.53
Pearl Millet	-0.09	0.22	0.26	-0.21	0.05	0.29	-0.03

Eastern Nebraska, but both crops produce the best yields with good weed control, narrow rows and adequate nitrogen.

Networking Activities

Workshops

American Society of Agronomy Meetings, November 13 - 18, 1994. Seattle, Washington.

First National Pearl Millet Symposium, January 17 - 18, 1995. Tifton, Georgia.

West and Central Africa Pearl Millet Research Network (ROCAFREMI) Meeting, March 28 - April 1, 1995. Niamey, Niger. Presented a one-day training session on pearl millet cropping systems research, and prepared/distributed publications to participants on crop rotation and intercropping.

Research Investigator Exchanges

Visited collaborators and IER scientists in Bamako, Mali, March 21 - 28, 1995. Reviewed research and made plans for 1995.

Visited collaborators and other INRAN scientists in Niamey, Niger, March 28 - April 1, 1995 while attending the ROCAFREMI network meeting. Made research plans for 1995.

Provided funds to allow Minamba Bagayoko (Malian collaborator) to participate in the ROCAFREMI Network meeting March 28 - April 1, 1995.

Ms. Berhane Biru, Crop Physiologist from Ethiopia, received training in water - nitrogen relations of grain sorghum, June 11 - Sept 11, 1994.

Research Information Exchange

Vials and sample bags purchased for Malian (IER) and Nigerien (INRAN) collaborators.

Purchased memberships for Malian collaborators in the American Society of Agronomy.

Pass-through funds were provided to assist with costs of experiments and soil and plant sample testing.

Publications and Presentations

Abstracts

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.

Limon Ortega, A., S.C. Mason, A.R. Martin, and T.J. Arkebauer. 1995. Pearl millet and sorghum response (canopy temperature and grain yield) to competition. First National Grain Pearl Millet Symposium Proc., p. 41.

Limon Ortega, A., S.C. Mason, and A.R. Martin. 1995. Competitive ability of pearl millet and sorghum to weeds measured by canopy temperature and yield. Agron. Absts., (In Press).

Journal Articles

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).

Nutrient Use Efficiency in Sorghum and Pearl Millet

Project UNL-114
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Summary

Research on sorghums, previously selected for high N use efficiency, indicated that genotypes also responded to applied N similar to normal sorghums. This means that breeding for N use efficiency does not diminish fertilizer response while enhancing yields at reduced N levels. In this study, hybrids were earlier in maturity than lines accounting for the greater yield from early versus late groups of genotypes. Nitrogen use efficiency for grain production was also greater for the earlier genotypes. Parents and hybrids were similar for N use efficiency for biomass production.

Results of a continuing study on nitrate metabolism indicated that carbon exchange rate values were not related to biomass production in seven sorghum lines. Nitrate reductase (NRA) values were greater in these lines at greater soil N levels. Genotypes P720 and Malisor 7 were consistently better for NRA, but this was not related to their N use efficiency rankings.

Studies on root morphology were conducted to evaluate root absorbing power and root affinity for nitrate (Km). It was found that root/shoot ratios change at different N fertility levels. The greatest N influx (Imax) value was for M9037R at 0.42 μmole nitrate hr^{-1} $plant^{-1}$ followed by IR204 and TX631. The greatest Km value was found in genotype IR204.

A greenhouse experiment using exotic China lines versus CK60 was conducted to determine the mechanism of N use efficiency. The China lines San Chi San and China 17 had greater carbon assimilation to internal leaf carbon dioxide levels (ACi) under N stress indicating that N storage enzymes responsible for photosynthesis were more stable under stress than U.S. derived material. Carbon discrimination values determined by mass spectrometry were consistent with ACi values and indicated the major enzyme responsible for stability may be phosphoenolpyruvate carboxylase.

Research in Mali to determine the effect of previous crop and different fertilizers on yield and N use efficiency led to the conclusion that dolichos and cowpea in rotation with sorghum produced the greatest sorghum yields. Fertility rates of 50 kg P ha^{-1} in combination with 60 kg N ha^{-1} produced the greatest yields. There was no difference in N use efficiency between 40 and 60 kg N ha^{-1} although these rates produced substantially less N use efficiency in sorghum than the 20 kg N ha^{-1} rate.

Objectives, Production and Utilization Constraints

Objectives

Identify sorghum and pearl millet genotypes which are superior in nutrient use efficiency (primarily nitrogen).

Determine the physiological and morphological mechanisms which allow genotypes to be nutrient use efficient.

Quantify the effects of environment on genetic response at different soil fertilities (primarily nitrogen).

Determine optimum nitrogen and phosphorus management practices for arid and semi-arid environments.

Provide long and short term training experiences for students and scientists of collaborating institutions, as well as certain technical expertise for collaborative efforts related to overall INTSORMIL objectives.

Constraints

Soil nutrient deficiency stresses.

Lack of adequate nutrient use efficiency in current sorghum and pearl millet cultivars.

Inadequate knowledge of proper management practices to help cope with nutrient stresses.

Lack of technically trained personnel who can devise and carry out sound research programs.

Research Approach and Project Output

Domestic Research and Research Related to Student Training

Response of Nitrogen Efficient Sorghums
to Nitrogen Fertilizer. Samuel Buah - Ghana.

Parental lines and their F_1 hybrids were evaluated in field trials at the University of Nebraska Agricultural Research and Development Center and at the Kansas State University Agricultural Experiment Station at Hesston. These genotypes were selected based on previous information related to their nitrogen use efficiency (NUE) or responsiveness to fertilizer N. NUE was determined according to Maranville et al. (J. Plant Nut. 2:577-589, 1980) where NE_1 is total above ground biomass produced per unit total N in the dry matter and NE_2 is the total grain produced per unit total N in the dry matter. Nitrogen rates at both locations were 50 and 100 kg ha^{-1}. For Mead, genotypes were grouped into parental lines vs hybrids and early vs late for comparative analysis. Early genotypes were arbitrarily selected as less than 80 days to 50% bloom and comprised most of the hybrids while the later genotypes were mostly parental lines. The Hesston experiment had predominately parental lines.

Grain yields at Mead (Table 1) were 50% greater for the hybrids than the lines and 35% greater for the early than the late genotypes. The greatest yielding hybrid was TX623/IR204 and the best line was SC566. There was a significant response in yield by all groups to 100 kg N ha^{-1} (Table 1), but very little at 50 kg ha^{-1}. The greater yields for the early genotypes coincides with these types being mostly hybrids.

NE_1 for total dry matter production generally increased from anthesis to physiological maturity and was similar in magnitude for all classifications of genotypes (Table 1). NE_1 decreased as N rate increased which is a common observation in most cereals. NE_2 was greatest for hybrids and earliness, and also declined with increased soil N (Table 1). The hybrid with the greatest values for NE_1 and NE_2 was TX623/IR204 followed closely by TX7000/IR204. The line with the best NE_1 was Naga White, and with the greatest NE_2 was SC566.

At Hesston, hybrids outyielded lines by 47%. At this location, all genotypes were earlier than at Mead by an average of 20 days to 50% bloom. Therefore, early genotypes were arbitrarily those taking less than 62 days to flower, and the late group were 63 days or more. Similar to Mead, the early group was comprised mostly of hybrids which outyielded the late group slightly. The line with the greatest grain yield was SPV475 (6383 kg ha^{-1}) and the best hybrid was KS18/SC279 (6586 kg ha^{-1}).

NE_1 values were similar for hybrids and lines both at anthesis and physiological maturity. NE_2 values were markedly greater for hybrids than lines, and this resulted in the early category being better for NE_2 than the late types. Efficiency values declined with increased fertilizer application similar to that at the Mead location.

In this experiment, there was a genotype by N rate interaction at Hesston but not at Mead which had less stress.

Table 1. Grain yield, NE_1 and NE_2 values at physiological maturity (pm) for parental lines, hybrids, early and late maturity genotypes for different N rates at Mead, NE.

	N rate (kg ha^{-1})				N rate (kg ha^{-1})				N Rate			
	0	50	100	Mean	0	50	100	Mean	0	50	100	Mean
Group	Grain yield kg ha^{-1}				NE_1 (pm) g s^{-1}				NE_2			
Parental lines	4328	4484	4967	4592	109.0	100.5	93.4	101.0	51.0	44.4	42.7	46.0
Hybrids	6478	6488	7643	6870	111.9	103.8	98.1	104.6	57.3	52.0	48.0	52.4
Early	5964	6073	7063	6366	109.8	99.0	95.2	101.3	55.7	50.7	46.9	51.1
Late	4461	4554	5972	4687	110.3	104.1	93.8	102.7	51.4	44.4	42.9	46.3
Mean	5155	5254	5996		110.1	101.7	94.4		53.4	47.3	44.8	

Genotypes specifically selected for large N efficiency values appear to also respond to applied N as a general rule. Grain yield was associated with N harvest index (NHI) grain N, harvest index (HI) and NE_2.

Investigations of Sorghum for Nitrate Metabolism. Abdoulaye Traore - Mali

Seven diverse sorghums have been studied during the past two years to better understand the role of nitrate ion in N use efficiency (see previous annual reports). In the 1994-95 studies, these genotypes were analyzed for dry matter production, total N nitrate reductase activity (NRA) and carbon exchange rates (CER) at vegetative, flowering and physiological maturity growth stages. Nitrogen use efficiency for biomass production was also calculated.

Results indicated that M35-1 had the greatest dry matter production followed by VG146 and S34, a Malian sorghum (Table 2). These are the taller sorghums and the results are expected. However, CER was not consistent with dry matter production in that the greatest rates were by HH640 although this was very growth stage dependent. It is not uncommon to find that CER is not correlated with yield. However, it is the process which generates a necessary cofactor for NRA to occur. NRA values for three growth stages at two soil N levels were greater at the high soil N level. There was a growth stage by genotype interaction so that genotypes with greater NRA values at one stage were the least at another. P720 and Malisor 7 were consistently better than the other genotypes for NRA. However, this was not related to NUE where P720, a much shorter plant, had low NUE values.

Table 2. Total dry matter production and carbon exchange rate (CER) in seven sorghum genotypes at three growth stages.

	Growth Stage			
Genotype	Vegetative	Flowering	Physiological maturity	Mean
	g per three plants			
VG146	57.3	272.8	431.3	253.7
S34	44.5	277.5	414.7	245.6
Malisor 7	46.6	226.7	307.5	193.6
HH640	56.6	208.9	349.8	204.9
CK60	46.1	145.1	303.6	164.9
P720	46.6	171.1	305.9	174.5
M35-1	31.4	375.0	490.1	297.9
Mean	47.0	239.6	371.8	
	$\mu mol\ m^{-2}s^{-1}$			
VG146	28.1	36.2	12.5	25.6
S34	26.1	30.4	17.6	24.7
Malisor 7	28.9	29.3	10.7	23.0
HH640	31.3	41.7	13.7	28.9
CK60	33.7	30.1	15.0	26.3
P720	31.4	33.2	12.8	25.8
M35-1	30.0	15.4	15.2	20.2
Mean	29.9	30.90	13.9	

Studies on Root Morphology, N Utilization and Nitrate-N Kinetics. Cassim Masi -Zambia.

Four diverse sorghum genotypes (WSV387, TX631, IR204, and M90587R) were selected based on their NUE in the field and root fractal dimension from the greenhouse study. These genotypes were earlier screened for rooting patterns and NUE. Genotype WSV387 and M90387R were chosen for higher root fractal dimension (higher root branching) and less NUE. Genotypes TX631 and IR204 were designated low branched rooting genotypes with greater NUE. Plants of these selected genotypes were grown in the hydroponics in the greenhouse. When the plants reached 5-6 leaf stage at approximately four weeks after germination, the plants were transferred to a nutrient medium without N. The plants were allowed to grow in this medium for two days and then transferred to 9-L pots with different nitrate concentrations. Depletion of NO^{-3} from the nutrient medium by 42-day-old sorghum plants were monitored over a 12 hour period to determine kinetics characteristics. The kinetics parameters Imax and Km were determined algebraically by transforming the Michaelis-Menten equation to yield the reciprocal form of Lineweaver-Burk equation:

$$\frac{1}{V}=\frac{Km}{\mathrm{Im}ax}+\frac{1}{C+\frac{1}{\mathrm{Im}ax}}$$

At the termination of the experiment, corresponding to the 15 to 16 leaf stages, the plants in each pot were harvested, divided into roots, stems, and leaves. About 25-30 grams of fresh weight for each genotype was put in 50% ethanol and stored in the cold room for later determination of root length using the T-area meter. Cumulative nitrate uptake, final root volume, leaf, stem, root weights (dry and fresh), root lengths and pH were collected for analysis.

The pattern of NUE, total plant N uptake and dry matter distribution showed that N accumulation of TX631 was relatively unaffected by different concentrations of NO_3^- but increased in M9037R. This pattern of N uptake was dissimilar in the other genotypes. The maximum N accumulation for IR204 was observed to occur at both the concentrations of nitrate of 0.2 and 1.0 mM/L. WSV387 appeared to be unaltered in N uptake across all the nitrate concentrations with the exception of 0,4 mM/L. The N accumulation of less than 5 g N/plant was observed to occur at this level for all the sorghum genotypes. The reason for this appears to relate to root growth and development as indicated by lower root fresh weight, and lower plant dry matter accumulation and shoot to root DM ratio (Table 3). The low S/R DM ratios may be indicative of differences in repartitioning of photosynthetic assimilation into roots versus shoots at this nitrate concentration.

Differences among sorghum genotypes of NUE were not easily noticeable, although the capacity for the genotypes to absorb N differed depending on the type of genotype and

Table 3. Root and shoot dry matter, shoot:root ratio and shoot N content as affected by genotypes and nitrate concentration.

Genotype	NO^{-3} Conc. mM/L	Root dry matter	Shoot:dry matter	Shoot:root ratio	Shoot N content (%)
		(g per plant)			
IR205	0.2	1.15	29.27	25.42	2.03
	0.4	1.36	24.405	17.94	1.70
	0.6	1.35	45.85	33.96	1.70
	0.8	1.34	45.27	33.78	1.84
	1.0	1.31	41.53	31.70	2.09
	1.2	1.34	32.37	24.16	2.41
M90378R	0.2	1.28	43.00	33.59	1.88
	0.4	1.32	23.65	17.92	2.25
	0.6	1.35	37.45	27.74	1.81
	0.8	1.37	32.97	24.07	1.91
	1.0	1.29	38.10	29.53	2.15
	1.2	1.39	37.37	26.88	1.88
TX631	0.2	1.07	30.67	28.66	2.10
	0.4	1.09	20.10	18.44	1.95
	0.6	1.17	38.68	33.06	1.71
	0.8	1.05	22.77	21.69	2.41
	1.0	1.24	42.03	33.90	1.91
	1.2	1.05	24.67	23.50	2.30
WSV387	0.2	1.48	39.13	26.44	1.66
	0.4	1.42	29.27	20.61	1.75
	0.6	1.37	45.07	32.90	1.60
	0.8	1.85	39.70	21.46	1.76
	1.0	1.23	34.33	27.91	1.96
	1.2	1.27	37.10	29.21	1.71

nitrate concentration used. WSV387 consistently responded relatively the same across all the nitrate concentration, although it appeared to be more efficient in NUE at lower nitrate levels and medium concentrations (0.2 and 0.6 respectively). WSV387 was noted to be more efficient at utilizing N when grown at varying nitrate concentrations in the hydroponics than in the field level. This is because of its greater root length exhibited at 0.6 and 0.8 mM/L nitrate. This pattern of response was also consistent with the other sorghum genotypes in terms of NUE efficiency and root length.

Comparison for the sorghum genotypes for nitrate-N uptake parameters indicated that the greatest Imax for nitrate-N uptake kinetics of 0.42 µmole per plant/hr was exhibited by M9037R followed by IR204 and TX631. The Imax value of M9037R was more than seven times that of WSV387 which had the lowest Imax. Km values among the four genotypes varied from 8.33 to 11.99 mM/L. The greatest Km value was exhibited by IR204 and again WSV387 was least.

There appeared to be differences among the four selected sorghum in NO_3^-N uptake which is perhaps genetically mediated. In this study, a greater Imax was not always associated with a lower Km. The results indicated the root system of sorghum genotype, the transport mechanism as demonstrated by the kinetics for nitrate-N behave differently in response to different NO_3^- concentrations exposed to the plant. A lesser Km value indicated that a genotype is more efficient at obtaining relatively more nutrient at low level of that ion. This seems to be true only for WSV387 which had a lesser Km value and a greater NUE at lower concentration of nitrate. It is therefore evident that these genotypes exhibit markedly divergent strategies with regard to growth and morphology of the root systems, regardless of the NO_3^- concentration exposed to the plants. Because of the complexities that exist in nature to which plants are exposed, it is reasonable to take into account both root morphology and physiological efficiency in order to understand the various mechanisms the plant uses to be more efficient in N utilization.

Studies on the Mechanism of N Use Efficiency.

A greenhouse experiment was conducted at the University of Nebraska using two exotic sorghums from China known to be N stress tolerant and provided for Dr. Paula Bramel-Cox of Kansas State University and one U.S. stress intolerant line. The experiment had four replications and three N levels (high, medium, low). The medium and low N treatments resulted in marked N stress by flowering when most measurements were made. Plants were fully irrigated. Chlorophyll was determined using a Minolta SPAD-502 meter. Carbon exchange rates (CER) were determined with a LiCor Li-6200 photosynthesis system. The same instrument was used to plot assimilation (A) versus internal leaf CO_2 concentration (Ci) to estimate carboxylation capacity. Carbon discrimination values ($\delta\ C^{13}$) were obtained using a mass spectrometer.

Table 4 indicated the leaf chlorophyll levels were markedly less in the medium and low N treatments for all genotypes. Chlorophyll and leaf N are well correlated in each genotype and each genotype has its own unique relationship. The slope was greater for CK60 than the China lines but each relationship is strong (r^2 = 0.92 - 0.98). China 17 had the least overall chlorophyll level followed by San Chi San, and CK60 having the greatest chlorophyll concentration indicating its much darker green color.

CERs were greater as N level increased calculated on a leaf area basis (Table 4). This may be misleading since stability of photosynthesis is probably more dependent on enzymes and other factors. When CER was calculated on a chlorophyll (i.e. protein) basis, the values reverse. China 17 was the best line for CER over all N levels followed closely by San Chi San and CK60 markedly less.

A similar pattern emerges with ACI values (Table 5). China 17 has the greatest slope value at any N level followed by San Chi San and CK60 the least. ACi slopes are indicators of photosynthetic enzyme activity. They are indicators of photosynthetic enzyme activity. The greater the slope, the greater the stability of the system.

Table 4. Chlorophyll (chl) contents and carbon exchange rates (CER) at flowering for three sorghum grown in the greenhouse at three N levels.

	chl	CER μmole CO_2	CER nmole CO_2
	μmole m^{-2}	$m^{-2}sec^{-1}$	μmole $chl^{-1}sec^{-1}$
San Chi San			
low N	191	10.58	55.6
med N	239	12.61	53.7
high N	614	15.35	25.6
Mean	348	12.85	45.0
China 17			
low N	198	11.65	58.9
med N	239	12.96	55.6
high N	519	15.16	29.5
Mean	319	13.25	48.0
CK60			
low N	304	13.06	42.8
med N	352	13.86	39.9
high N	726	16.3	23.0
Mean	461	14.41	35.2

Samples were analyzed for carbon discrimination ($\delta\ ^{13}C$) using a mass spectrometer. Results indicated that the variation in $\delta\ ^{13}C$ were most likely not a result of variations in RUBISCO, but presumed to be due to changes in the level of PEP carboxylase. Further clarification of this is necessary.

International Research (Mali)

Sorghum Response to N in Relation to the Previous Crop -Abdoul Toure

A new study was started in 1994-95 to address the following objectives:

To investigate sorghum response to N relative to the previous cereal or legume in rotation.

To build sustainable cropping systems based on the use of Malian rock phosphate as a P source, legumes as a N source, and manure as a K source.

To assess economic risk of such an approach.

Previous crops planted in 1993 were used as main plots and were comprised of three legumes (peanuts, cowpea, dolichos) and three cereals (millet, sorghum and corn). Six levels of fertilizer (F1, F2, F3, F4, F5, F6) were used as sub-plots. All the legumes and cereal crops received 200 kg/ha of rock phosphate on five of the six treatments (F2, F3, F4, F5, F6) while F1, had no fertilizer (ON OP OK OS). In 1994, all the plots were planted with sorghum and treatments F2 to F5 were differentiated by the level of N applied. F6 was different from F2 by the use of manure.

Table 5. ACi values for three sorghum grown in the greenhouse at three N levels.

	ACi values		
Genotype	High N	Med N	Low N
San Chi San	.418 (686)	.144 (251)	.079 (105)*
China 17	.563 (560	.161 (238)	.103 (148)
CK 60	.383 (811)	.144 (245)	.065 (167)

*Numbers in parentheses are chlorophyll concentrations in μmole m^{-2}.

F1 = ON OP OK OS
F2 = ON 5OP OK OS
F3 = F2 + 20 N 50P OK OS
F4 = F3 + 40 N 50P OK OS
F5 = F4 + 60 N 50P OK OS
F6 = F2 + 1000 kg/ha manure

Plants were selected at flowering and physiological maturity to determine their N content. N use efficiency was determined by dividing the differential yield between N treatment and the check to the differential fertilizer applied between N treatments and the check.

Analysis of variance indicated a nonsignificant interaction between previous crops and fertilizer. Crop effect was nonsignificant for all yield components of sorghum, but dolichos seemed to produce a superior effect compared to other crops (Table 6). This needs to be checked through a second cycle of dolichos-sorghum rotation in this study (use of labelled N, moisture...) compared to other rotations using sorghum.

Fertilizer effect was significant. Each increase of N fertilizer leads to an increase of all yield components especially grain (Table 6). However, the increase seemed to decrease with greater N applied. Based on the experimental conditions of this study, the use of a N rate greater than 20 kg/ha may not be economically justified. This needs to be confirmed.

The Effects of Production Practices on Improved Sorghum Cultivars - Sidy Coulibaly

Although management practices have been fairly well established for traditional sorghum cultivars in Mali, it is certain that new improved cultivars will require different management schemes. This may include plant population, fertilizer needs in monocrop or rotation, row spacing etc.

An experiment is currently being conducted to include five varieties grown with six fertility combinations of organic and inorganic fertilizer sources and two plant populations. The objective of this new experiment is to devise the best management of new varieties and make practical recommendations to farmers upon their release.

Table 6. Yield component of sorghum as influenced by previous crops and fertilizer in the 1994 rainy season.

Previous crops	Grain	Stover	Biomass
		kg/ha	
Peanuts	1319	6444	8296
Dolichos	1623	7401	9633
Cowpea	1557	7009	9139
Millet	1394	7136	9088
Millet	1445	7118	9118
Sorghum	1426	6162	8097
Previous crop effect	NS	NS	NS
CV (%)	22	26	24
F 1	1310	5953	7793
F 2	1282	5917	7741
F2 + 20N	1508	7365	9469
F2 + 40N	1610	7307	9431
F2 + 60N	1620	8245	10489
F2 + Manure	1447	6740	8745
Manure effect	*	*	*
CV (%)	22	26	24

Networking Activities

Supplied $7000 to Mali for collaborative research in nitrogen agronomy and physiology.

Purchased a new computer system and supporting equipment for Abdoul Toure in Mali at a cost of $3200.

Shipped glassware and small equipment items to Cinzana Station in Mali for use in the physiology laboratory.

Traveled to Mali exclusively on UNL-114 funds to plan new research and review past collaboration.

Publications

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Germplasm Enhancement and Conservation

Breeding Sorghum for Tolerance to Infertile Acid Soils

Project MSU-104
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Summary

This is a terminal report for MSU-104. It was one of the original INTSORMIL projects and the only one which addressed, through breeding, agricultural production limiting constraints of infertile tropical soils. The MSU-104 PI lived and conducted research in two tropical developing countries since INTSORMIL's inception, two years in Colombia and four and one-half years in Kenya. This report will summarize the productivity of MSU-104 for the last 16 years in Latin America and Africa and discuss the concepts and future needs of adapting sorghum and millet cultivars to the constraints of infertile soils, rather than the prohibitively expensive alternative of changing the soil to meet the crops' requirements.

Over two billion hectares of land with acid soils are distributed throughout the tropics. Nearly all acid soils in the humid tropics are infertile, however, not all infertile soils are severely acidic. Tropical South America has over 860 million hectares of these problem soils with their various chemical constraints to agricultural production and approximately 50% of the arable lands in Africa have soils with low pH production constraints. More marginal infertile soils have been brought into production in the poorest of tropical countries because of food and feed grain deficits and growing populations which have resulted in farmers immigrating to these lands. The lack of screening technology and available sorghum and pearl millet germplasm, with reasonable tolerance to aluminum (Al) toxicity and low levels of phosphorus (P), has in the past prevented NARPs from exploiting these acid soil areas.

The development of a reliable field screening technique to evaluate sorghum germplasm 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. Many superior sorghum breeding lines have also been developed using this technology. Before INTSORMIL began this project, sorghum could not be grown on soils with levels of Al saturation higher than 40-50%. Since 1982, four sorghum cultivars have been released in Colombia as the result of collaboration between ICA, INTSORMIL, and commercial companies. These cultivars produce profitably in soils with Al-saturation levels of 60-80%, immediately making more than 200,000 hectares of marginal farm land available for sorghum production in Colombia alone.

Research initiated by this project has attracted approximately $1,598,500 of buy-ins for INTSORMIL and $585,000 in graduate student assistantships for Mississippi State University. The breeding effort of MSU-104 has resulted in the release of 14 cytoplasmic-genetic sorghum A and B-lines, four acid soil tolerant cultivars, and a hybrid for the dry Caribbean region of Colombia which uses an additional A and B-line developed by this project. We also assisted Purdue University breeders in the release of a high yielding SEPON variety in Niger. Also, world collection sorghum lines identified as being superior in Colombian trials are currently being used in commercial hybrids in the U.S. and in southern Africa, as reported in a recent EEP review.

In the 16 years INTSORMIL funded this project, 20 postgraduate students have been financially supported or associated with the project area of research. Five postgraduate students are currently associated with the project. Approximately 30 theses and dissertations of B.S. and postgraduates have been completed by students from Colombia or other nationalities completing their research in Colombia on sorghum and millet. In addition, two books, 30 book chapters or proceedings of workshops, 28 journal articles, 44 abstracts, and 41 miscellaneous publications on sorghum and millet, relevant to the activities of the PIs and collaborators working on this project, have been published. We have participated in 46 conferences, symposium, colloquium, congresses, and workshops; and made 48 presentations, mostly concerning the acid soil research, at professional meetings.

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

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 are also addressed.

Research Approach and Project Output

Introduction

The first portion of this report will summarize the MSU-104 PI's activities and the productivity of the project in Latin America at the Colombian Prime Site since before its inception, and the second portion will discuss activities in Kenya. The experience gained by living and conducting research in Colombia for two years (1982-1984) and in Kenya for four and one-half years (1990-1994) will be discussed.

The INTSORMIL Director and I developed the 1981 MOU for sorghum research at CIAT which was signed by the Director of INTSORMIL, and the Director Generals of CIAT and ICRISAT. Sorghum breeding research was initiated at CIAT in 1981 and I was the resident INTSORMIL PI from November 1982 until December 1984. A second research site of the germplasm enhancement conducted by MSU-104 was initiated in East Africa in February 1990. This was made possible through a buy-in by the USAID funded MidAmerica International Agricultural Consortium (MIAC) Kenya Country Project and I was seconded to the Kenya Agricultural Research Institute (KARI) as a sorghum and millet technical advisor.

Sorghum and Millet Breeding in Colombia

In the early 1970s, reports appeared in the literature about the vast areas of infertile soils of the tropics, usually those which were very acid and contained levels of Al and/or Mn too high for crop production using available cultivars. A real fear of the world's population increasing faster than food production stimulated funding for research into uses of the under-utilized agricultural lands of the tropics.

Sorghum 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. 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 yields 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, I was assigned by Mississippi State University for a two-year period at CIAT, Cali, Colombia, to initiate a program for breeding and screening sorghum germplasm for tolerance to the acid soil complex of the humid tropics. This 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 would 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.

Because of conflicting reports in the literature and a lack of confidence in the so-called "quick tests" for Al tolerance, a field screening technique was developed at Quilichao, Colombia. The soil used had an Al-saturation level of over 80%, a pH of 4.5, an effective CEC of about 5, and was classified as an ultisol. Five hundred kilograms of dolomitic limestone were added to provide fertilizer quantities of Ca and Mg, and to reduce the Al-saturation level to about 65%. Broadcast applications of N-P-K, Zn and B 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.

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. Breeding research was conducted by ICA at Nataima and La Libertad, with evaluation trials at La Libertad and other acid-soil sites in the region.

Breeding material was 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 most of the acid-soil tolerant lines from the world collection were 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.

By first using 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, variety and hybrid observation nurseries were evaluated at different locations in Colombia, Mississippi, and in Kenya from seed produced by hand-pollinated crosses made in Mississippi or in winter nurseries in Colombia. Advanced hybrid yield trials were being evaluated at the termination of this project.

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. This research was augmented through informal agreements and close linkages with nonprofit organizations such as FENALCE, a Colombian production and extension-oriented organization, and three Colombian universities. The sum of all additional support (land, equipment, human resources, miscellaneous facilities) provided by ICA and these Colombian organizations represented over a 4:1 leveraging of INTSORMIL's financial support.

Research Progress in Latin America

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. Since 1982, CIAT and ICRISAT have supported two International Workshops in Colombia which were organized by INTSORMIL. 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."

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 soon 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 somewhat more drought tolerant than Al-susceptible genotypes.

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. Many of these highly tolerant genotypes were identified in the world collection as originating in acid soil areas in Nigeria, Uganda, and Kenya; and were classified as being from the Caudatum and Caudatum-hybrid races. Several of these lines appear to be from Dr. Hugh Doggett's breeding program at the Serere Research Station in Uganda. However, the Guinea race and the hybrid Guinea-bicolor lines had a higher overall percentage of acid soil tolerant sorghum entries than those of other races and hybrids evaluated. Using the field screening developed for sorghum, preliminary trials showed that pearl millet has excellent adaptation to acid soils even under low P conditions. Several pearl millet varieties, synthetics, and populations showed potential grain yields of 2-3 tons per hectare. Pearl millet appears to tolerate a higher level of Al toxicity than sorghum.

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 earlier program in Uganda. It is interesting that no effort was made to evaluate this material on acid soils during the developmental stages in East Africa. 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 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 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 uses an A-line from this project and an R-line from Texas A & M University.

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.

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.

Sorghum and Millet Breeding in Kenya

Sorghum and millets were the staple crops in most parts of Kenya prior to the introduction of maize, wheat, and rice. The introduction of these crops replaced sorghum and millets in areas of reliable rainfall, and to some extent even in some favorable arid and semi-arid areas. However, the importance of sorghum and millets in arid and semi-arid zones cannot be ignored. Maize is poorly adapted to conditions prevailing in arid and semi-arid regions and is likely to fail six out of every eight seasons. This leaves the increasing population in these arid and semi-arid zones highly vulnerable to frequent crop failure and famine. Sorghum and millets are therefore alternative cereal crops which do not compete with preferred crops for high-potential land and do contribute to overall improvement of food security.

Kenya has recorded the highest population growth rate in the history of the world. Since 1990, this growth rate of 4.1% and average number of births per woman of eight children has declined somewhat from doubling the population every 20 years. But, current birth rate is only an estimate at best. Only about 17% of Kenya is arable and nearly all of that land is under cultivation. There is some seasonal fallow land, but nutrient replacement is declining due to the cost of fertilizer. Farms are shrinking in size due to rapid population growth. Many farms are too small to be considered economic units and in many seasons cannot feed the farmer's family.

Sorghum and millets, in a very complementary way, contribute substantially to the food/feed needs of Kenya. They rank quite high (19th) on KARI's priority list published in "Kenya's Agricultural Research Priorities to the Year 2000." The importance of sorghum and millets is expected to increase because they are better adapted to a wider range of climates than maize.

Initial emphasis was on developing a basic understanding of the available germplasm in both sorghum and the millets, and evaluating the potential of hybrids in sorghum and pearl millet. Based on other work, it was expected that varieties could be improved beyond those currently provided to farmers, but that sorghum and pearl millet hybrids would be superior and offer less risk in the stressful dryland environments. Agronomic, soil management, pest management, and socioeconomic research was encouraged to parallel the genetic evaluation efforts to develop meaningful technology for farmer use.

The major considerations or constraints were addressed. Since sorghum and millets are often grown in less favorable environments there is a higher risk of failure in research trials and commercial production. Thus, cropping strategies needed to be "defensive" against failure as well as low input. In addition to food use, sorghum and millets are also used in beverages and feed. For that reason, some additional scientist time was necessary to evaluate processing and marketing of these cereals, and to conduct socioeconomic analyses during on-farm trials.

When I went to Kenya in February 1990, the sorghum and millet program was small and disorganized. Nearly all of the senior sorghum and millet Research Officers (ROs) were in the U.S. for postgraduate training. It was my responsibility as the KARI sorghum and millet technical advisor to assist in the development of annual work plans and budgets, to guide researchers at seven Centers in the development of research technology which addressed farmer constraints in sorghum and millet production, and to help set research priorities. By advising the National Sorghum and Millet Coordinator, the ultimate goal was to develop a fully coordinated sorghum and millet improvement program.

The western Kenya region is characterized by wet and humid growing conditions where moisture is generally not the major limiting factor. It varies from the very wet Kisii and Kakamega Center areas with a long single season to the dry, near semi-arid Homa Bay and Kendu Bay areas along the shores of lake Victoria with a bi-modal rainfall pattern. The sorghum consumers in the West prefer genotypes with a testa (brown or red-brown colored grain) and semi-soft endosperm. Ideal genotypes should have high tannin concentrations during the milk and soft-dough stages when bird susceptibility is the greatest and low concentrations at harvest when the grain will be consumed. Although varietal development was not overlooked, emphasis was placed on hybrids and utilization of heterosis for efficient and stable grain production.

Major constraints to sorghum production in western Kenya include foliar diseases and stalk rots (particularly rust, anthracnose, and fusarium), grain weathering, *Striga*, erratic rainfall, weeds, bird depredation, shoot fly, stalk borers, and midge.

Sorghum breeding nurseries at Alupe, a sub-Center of Kakamega, are backed up with germplasm supplied from Kiboko, a sub-Center of Katumani, and INTSORMIL breeding projects. Making hand-pollinations and producting quality seed is difficult due to the high rainfall and humid conditions. Bird and weathering resistant varieties and hybrids are required in the western humid areas. National Performance Trials (NPTs) are prepared at Kakamega and distributed for testing within the Kakamega and Kisii mandated areas of responsibility.

Dryland sorghum and millet research is coordinated from the Katumani Center for the Katumani, Embu, Mtwapa, and Perkerra Center mandated areas. Dr. Lawrence M'Ragwa is the National Sorghum and Millet Coordinator and also KARI's pearl millet breeder. Backup sorghum and millet breeding support is provided from Katumani for western Kenya, the highlands, and coastal areas of responsibility. The semi-arid region experiences mainly bi-modal type of rainfall, except Baringo which is represented by the Perkerra Center where a mono-modal rainfall pattern occurs. The annual rainfall is low, averaging below 550 mm with average seasonal rainfall of 200-350 mm. Precipitation is erratic, poorly distributed, and in most cases highly unreliable. The temperatures are high during the short rain season, but more so between the crop seasons. Evaporation is high, sometimes being higher than effective precipitation. The soils are sandy and poor due to low vegetation cover, poor vegetation decomposition, low soil microbiology activity, and over grazing.

The sorghum breeding site at the Katumani sub-Center, Kiboko, is the logical location to spur expansion of the sorghum and millet production area into the semi-arid regions of Kenya. Collaboration with ICRISAT and INTSORMIL scientists at this location has assisted the KARI effort. Katumani breeders prepare the NPTs for their area of responsibility and for Embu, Perkerra, and Mtwapa Centers. Entries in these trials are mainly white or yellow seed colored types with some bird resistant brown seeded check varieties. The sorghum consumers in the East prefer white seeded, corneous-endosperm cultivars.

Breeding and germplasm evaluation are difficult in this environment because of low and erratic rainfall, distances between test sites, and frequent disease and insect outbreaks. Constraints to sorghum production in the semi-arid areas include drought, high temperatures, poor seedling emergence, charcoal rot, long smut, stem borers, and shoot fly. Timely planting, plant spacing, low-input cultivation practices, rotations with legumes, and various types of cropping systems need to be researched.

The pearl millet program is being reestablished since Dr. M'Ragwa returned from the U.S. Constraints to pearl millet production include inadequate cultivars, drought, low soil fertility, ergot, downy mildew, smut, stand establishment, and bird damage. Seed set, early crop maturity, and reduced plant height are being emphasized to offset the low yielding capability of local cultivars.

The Lanet Center program serves all of the highland regions of Kenya, especially the cold and dry eastern Rift Valley and the wet Kisii highland areas. The highland regions experience predominantly a mono-modal rainfall pattern with low temperatures during the crop growing season. Because of the recent settlement of the cold and dry Laikipia plains by small-scale land holders, both grain and forage sorghum development are required.

Constraints to production include poor stand establishment due to cool dry soils, poor seedset due to cool temperatures during pollination, and foliar diseases in the high rainfall highland areas. In some areas, acid soils can limit sorghum production.

Breeding activities at Lanet are limited to selection and evaluation of sorghum grain and silage varieties. Cold tolerant sorghum varieties collected by SAFGRAD/ICRISAT were selected at Lanet for future grain and/or silage trials. High quality dual-purpose sorghum varieties with brown-midrib genes and cold tolerance are being developed. Crosses to accomplish this breeding goal have been made at Kiboko and are being evaluated at Lanet.

Mtwapa is the Center responsible for sorghum and millet research on the eastern coastal zone of Kenya. This region has problems with drought as one moves inland from the coast due to low annual rainfall and sandy soils. High temperatures and humidity cause weathering and other disease problems not normally found in other sorghum and millet production areas of Kenya. Research priority was on development of tropically adapted sorghum germplasm with foliar disease, grain mold, insect, and drought resistance; and heat stress tolerance. Marimanti was the primary site for long smut screening.

Research Progress in Kenya

As an educator, I feel that the most lasting and best investment of USAID dollars in the Kenyan NARP has been in human resource development. This investment will be paying dividends for many years. For the KARI sorghum and millet program, postgraduate training of the ROs was a major accomplishment and most of these individuals were trained at INTSORMIL institutions. Every one of the seven Centers where sorghum and millet research is conducted has at least one RO with advanced training and many Centers have several.

Since the collapse of the East African Community, little adapted sorghum germplasm had been introduced into western Kenya. As an INTSORMIL PI, I had access to all of the germplasm in the INTSORMIL Colombia program and could get any other INTSORMIL germplasm from my breeder colleagues. I brought a large quantity of this material to Kenya in 1990. Since I had started the Colombian program, I knew that most of this material might be adapted to western Kenya because most of the lines had one parent from East Africa and the environment in Colombia is similar to Kenya. Some of the elite lines from the INTSORMIL Colombian program are now in advanced trials at Alupe.

Nearly 5,000 sorghum lines from Texas A & M University were introduced into Kenya in 1990. This was remnant seed of lines that had been evaluated in Tanzania and Kenya in the INTSORMIL program conducted by John Mann in the mid-1980's. All of this material was grown-out in Kiboko and Katumani, because the germplasm was nearly all white. Pearl millet germplasm was introduced by David Andrews (UNL-118). Sorghum and pearl millet germplasm was also introduced by ICRISAT.

Until about 1991, none of the KARI breeders were conducting a traditional sorghum and millet breeding program at any of the Centers. KARI generated recombinant germplasm, from crosses of two adapted lines, was not being developed. The junior sorghum and millet ROs had never made hand emasculated crosses or cytoplasmic male-sterile crosses. In 1990, I conducted a training session in the breeding nursery at Kiboko and crosses were made to start the traditional breeding programs for Katumani, Kakamega, and Lanet. Currently, selections from these initial 42 populations are being evaluated at these Centers.

Sorghum hybrids from this project, Texas A & M University INTSORMIL programs, and ICRISAT were evaluated at several locations in Kenya. Several of these hybrids are superior to any cultivar currently being recommended to the farmers of Kenya. Kenya Seed Company has the inbred lines to produce most of these hybrids and has entered two hybrids in the sorghum NPT trials. I am certain that sorghum hybrids will be used by farmers in Kenya as soon as the economic environment permits the use of this higher level of technology.

The KARI sorghum and millet program has developed into a fully coordinated, comprehensive research program. Many small accomplishments at each of the seven sorghum and millet Centers have made this possible. It is to the mutual benefit of KARI and INTSORMIL that collaboration be continued in the future.

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 project has been successful in developing a theory about the possibility of finding useful genetic diversity for tolerance to low pH soils, proving that this diversity exists, determining the mode of inheritance, and incorporating this tolerance into sorghum cultivars which are now in the hands of farmers trying to support their families on these marginal lands.

In Africa, germplasm from this project 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.

Networking Activities

Workshops

A paper was co-authored by the MSU-104 PI and presented at the American Society of Agronomy Meetings, November 13-18, 1994, Seattle, WA.

The MSU-104 PI assisted in the organization and participated in the Workshop "Sorghum and Millet Crop Management Forum" held at Machakos, Kenya, November 21-23, 1994.

The PI attended the World Bank seminar "Adaptive Research Methodologies and Achievements" held at Machakos, Kenya, November 24, 1994.

The PI presented the Year 3 Sorghum/Millet Progress Report at the MIAC/KARI NARP II Review held at Nairobi, Kenya, November 30, 1994.

Research Investigator Exchange

The MSU-104 PI traveled to Kenya to attend several Workshops and meetings, and to assist KARI sorghum and millet breeders with germplasm evaluation and program formulation, November 11-December 11, 1994. Travel was at no expense to INTSORMIL.

The PI conducted breeding activities in the Puerto Vallarta, Mexico winter nursery and toured the nurseries of Drs. Ken Kofoid and Paula Bramel-Cox, and Professor David Andrews, January 31-February 21, 1995.

The PI harvested and threshed the winter breeding nursery and prepared the seed for shipment to the U.S., Puerto Vallarta, Mexico, April 1-9, 1995.

The MSU-104 PI traveled to the ISNAR Center, The Hague, Netherlands to organize an International ISNAR training Workshop on research priority setting for sorghum and millet researchers in East Africa. The trip was continued to Kenya where the PI participated in an USAID Mid-term evaluation of the MIAC Country Project, assisted in the organization of a Workshop to develop a 5-year sorghum/millet research plan for eastern Kenya, and to assist KARI sorghum and millet breeders with germplasm evaluation and program formulation, June 11-July 10, 1995,

The PI participated in a joint KARI-ICRISAT Field Day for farmers and KARI pearl millet research staff, Kiboko, Kenya, June 21, 1995.

Germplasm and Research Information Exchange

Seed of two hybrid sorghum yield trials, from crosses made in this project, were imported into Kenya for evaluation at several locations by KARI, ICRISAT, and Kenya Seed Company. The hybrid entries were selected to be useful across several ecological zones.

The PI participated in the development of a KARI National Performance Trial handbook for KARI scientists and a KARI National Sorghum/Millet Production Guidelines publication for Kenyan farmers.

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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, Purdue 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 following press release, dateline January 1995, illustrates a breakthrough in sorghum digestibility research done in collaboration with Dr. Bruce Hamaker.

Digestible protein may make sorghum a better food source

West Lafayette, Ind. - "Irregularly shaped protein bodies discovered in sorghum kernels under the electron microscope at Purdue University may signal improved human nutrition in some developing countries and higher-quality livestock feed worldwide."

Bruce Hamaker, Associate Professor of Food Sciences, is conducting sorghum protein digestibility research at Purdue. In testing 25 experimental genetic lines of sorghum, he found two in which protein digestion was significantly faster. Electron microscope photographs revealed the protein bodies of the more digestible sorghum are irregularly shaped. Typically sorghum protein bodies are spherical.

"Increased digestibility in sorghum could be a major step in providing a higher-quality livestock feed in the United States and other developed countries," says Phillip Warren, senior agronomist in the Agriculture and Food Security Office of the U.S. Agency for International Development (USAID) in Washington, D.C. "But also it could have an immense impact on the protein content in diets of people in less developed countries, especially in parts of Africa."

Two more digestible genetic lines of sorghum tested by Hamaker have about 87 percent digestibility; normal sorghum can be as low as 66 percent. Protein bodies in cereal grains, such as wheat, corn, rice and sorghum, have varying degrees of digestibility. This makes some cereal grains more nutritious than others.

"We were surprised and pleased by these findings," Hamaker says. "These two genetic lines of more highly digestible sorghum fall right between corn and wheat in digestibility. That makes them very competitive with other cereal grains as a source of dietary protein for both humans and livestock. Typically sorghum is at the bottom of the list."

After identifying the digestibility differences, Hamaker and his research team turned to the electron microscope to explore basic structural differences between the protein bodies. Under 2,500 times magnification they found spherical-shaped protein bodies actually indenting the larger starch particles of the normally digestible sorghum. However, in the kernels from the more digestible sorghum, they found dramatically different, irregularly shaped protein bodies tucked in among the starch particles.

Hamaker's tests indicate that digestive enzymes of the intestine begin the basic process of digestion much faster on these irregularly shaped protein bodies.

"Sixty-five percent of the stored protein in sorghum is found inside these bodies," Hamaker says. "It appears there is an enzyme-resistant coating around the spherical protein bodies of normal sorghum, so it takes longer for digestive enzymes to break through to the stored protein inside. But in the irregularly shaped protein bodies, digestion appears to begin almost immediately. We don't know, but we assume the more digestible protein bodies lack this enzyme-resistant coating."

Hamaker compared the proteins using two different digestion tests. He found the irregularly shaped protein bodies began to break down in less than 60 seconds, and had reached a significant level of digestion in less than five minutes. Normal sorghum requires 60 minutes.

"This is important," Hamaker says, "because transit time - the time it takes food to move through a digestive system - is relatively fixed for some livestock animals. So, the sooner protein is available in the digestive process, the more will be absorbed for nutritional purposes before excretion."

Also, Hamaker found the more digestible lines maintained 80 percent digestibility, even after cooking. Most sorghum varieties lose digestibility in cooking; some drop to as low as 46 percent.

According to Hamaker, this could improve human nutrition in some semiarid developing countries where up to 70 percent of the dietary protein may come from cooked cereal grain. In the southern part of India and in countries such as Ethiopia and Mali, in the area of Africa below the Sahara desert, sorghum is a food staple for humans.

In more developed countries, sorghum is used as an animal feed, primarily for cattle, poultry and some hogs. John Axtell, Lynn Distinguished Professor of Agronomy at Purdue and the source of the experimental sorghum lines used in Hamaker's research, says Texas, Kansas and Nebraska are the primary areas of sorghum production in the United States, while the mid-south region, including Arkansas, Missouri, southern Illinois, Kentucky and Tennessee, is an expanding production area.

Digestibility affects the value of sorghum as an animal feed. The market price of sorghum is usually about 90 percent of the price of corn, because it typically requires additional processing to increase digestibility of protein and starch. Hamaker's research could change that.

In addition, the trait for higher digestibility appears to be genetically inherited and not a result of the environment of a particular growing location. Hamaker conduced tests on sorghum kernels grown both in Indiana and Mexico, and the results were similar.

Hamaker and his research team, including food science graduate students, Charlotte Weaver (Nappanee, Ind.) and Maria Oria (San Sebastian, Spain), working in collaboration with Axtell's plant breeding research team, still have a full research agenda.

"At this point the irregularly shaped protein bodies seem to be an indicator sign on the road map to more digestible sorghum protein," Hamaker says. "We have come this far in laboratory tests, what we call *in vitro* tests. We need to continue the tests in the field with animals."

Hamaker's research results were presented at the American Association of Cereal Chemists meeting in Nashville, Tenn., in October, 1994. This research is part of the Sorghum/Millet Collaborative Research Support Program funded by the Bureau of Science and Technology, USAID.

Drought Tolerant Hybrid Sorghum for Niger
(Isoufou Kapran, John Axtell and Gebisa Ejeta)

Sorghum is the second most important food crop in Niger, with an estimated acreage on the rise from 768,070 hectares in 1980 to more than two million hectares in 1994 (Anonymous,1995). Productivity has however taken the reverse direction, and the average grain yield is less than 300 kg/ha for the same period. This trend was in fact observed from the late 1960s with average yield dropping from 589 kg/ha in 1969-71 to 390 kg/ha in 1974-76 (Dogget, 1988). This is very alarming because Niger has one of the highest population growth rates (3% per year) being observed for the developing world. The population in Niger has increased from 2.4 million in 1950 to an estimated 9.151 million in 1995 (Center for International Health information, 1995). In a country where more than 90% of the people are involved in farming, there is undeniably a lot of pressure on land use for cropping as well as herding, especially since the rainfall patterns have become more erratic in recent decades, reducing the total available area for agriculture. The consequences on genetic resources and their use are very dramatic as can be observed for sorghum. In the absence of a reassuring alternative, most sorghum growers have the tendency to replace their old later-maturing varieties with new early-maturing types, which are more likely to escape drought periods, often at the expense of higher productivity.

These early selections are taken from any source, even from grain obtained through food aid programs as seems to be the case for a three-dwarf local variety known as Tera; but the most common are in the 'MOTA' group (meaning car in the Hausa language, thus fast moving); selected by farmers from their own landraces probably on the basis of earliness, the Motas are more likely to escape the very frequent drought periods.

Concurrently, landrace varieties like Janjaré, which was considered so well adapted that the French IRAT used it in the early 60s in developing the improved L30, and L30 itself, are becoming practically extinct, and are probably more visible at INRAN research stations than in farmers' fields. Local landraces are certainly the best source for crop improvement in the long term, because they have accumulated many adaptation traits that modern breeders can make use of in scientific approaches for increasing agricultural productivity. However, in the present situation of worsening environmental conditions and population pressure, alternatives are needed that can safeguard local germplasm while improving productivity. With the help of the INTSORMIL project, a new dynamism has integrated the INRAN sorghum breeding program since the early 1980s. While new landraces are continuously brought in for evaluation, especially the early 'dune' sorghums specific to Niger, some of the best adapted have been incorporated in random-mating populations, providing a low maintenance broadbase source of local germplasm that we can select from or improve at any time. At the same time, we conduct variety development through the pedigree method, intercrossing germplasm that we select in Niger and that provided by our collaborators on the basis of its geographical origin similar to that of Niger (e.g., Sudan), and/or because it has been improved for the same objectives as those of INRAN (high yield, early maturity, drought tolerance, *Striga*, mold).

The best success of our collaboration is however the demonstration that sorghum hybrids are an agricultural technology viable even for harsh environments, as is the case in Niger. This is essential, because it is recognized that in the context of today's population growth in developing countries, yield increases offer the best answer to meeting new food demands (Pinstrup-Andersen and Pandya-Lorch, 1995). Adoption of hybrids would also be beneficial to the environment since high and stable productivity may restrain the desperate use of marginal soils. Although introduced sorghum hybrids were tested during the IRAT program of the 1960s, they were not seen as a good alternative for Niger because of grain quality problems (Chantereau and Adamou, 1977), and the perception that they were too much input-dependent.

It was not until two INTSORMIL supervised M.S. research projects were conducted in 1986 by Kapran and Tyler, respectively, that a systematic study of the value of heterosis was conducted in Niger. Kapran (1988) reports the comparison of a group of 90 hybrids to their parents in presence of local adapted checks, at several environments in Niger. Whereas parental lines were comparable to local varieties only under irrigation, hybrids were consistently better yielding than both: they surpassed the locals by 61% with irrigation and 49% under rainfed conditions; yield advantage of hybrids over parents (heterosis) was 45% higher under irrigated conditions, and even higher in the rainfed experiments (66%). Tyler (1988) tested 40 hybrids under the same rainfed environments as Kapran, with male parental lines grouped as exotic, intermediate, or local. He also found that hybrids were higher yielding than parents or checks; grain yield heterosis over male parents was of 127% for exotics, 83% for intermediate, and 66% for locals. Following these clear expressions of heterosis in Niger, the best hybrids from both studies were re-synthesized and evaluated regularly. Over the years, the cross between TX623A and MR732 (later named NAD-1) was consistently high-yielding in comparison with other hybrids or varieties, including the best adapted landraces of Niger. Starting in 1989, it was entered in the regional sorghum trials covering at least six West and Central African countries, and was good yielding under most conditions. Specifically in 1989, it ranked third of twenty entries including a local check and other ICRISAT hybrids or varieties, tested at nine locations in Ivory-Coast, Mali, Burkina-Faso, Cameroon, Nigeria, and Niger (ICRISAT/WASIP, 1989).

Also starting in 1989, an experimental seed production was started at Maradi (Niger), and demonstrated at the level of a national breeding program in West Africa, the feasibility of a large scale hybrid seed production. The same year we also gave the first sample of hybrid seed to a few farmers in the village of Bazaga near the INRAN/Konni station, and the feedback was extremely positive. Incidentally, this is where for the first time, a farmer who heard us explain the system of seed production using A and R lines, compared the hybrid to a mule (Alfadari in Hausa, the 'A' in NAD-1). This was the beginning of our on-going farm-level demonstration plots, which have increasingly attracted more farmer interest, to the point where today it is difficult to satisfy all requests for hybrid seed.

At this point, again with the help of INTSORMIL, additional seed has been continuously produced since 1993 in the U.S. and shipped to Niger for the demonstration plots. Overall, the average yield of NAD-1 between 1986 and 1994 is of 2758 kg/ha on-station, ten times the average yield of the farmer in Niger (273 kg/ha; Anonymous, 1995). Starting in 1993, we have quantified NAD-1's productivity on some of the farm-level plots. For 1993, the average farmer yield for the Konni and Jirataoua region was 2365 kg/ha for

NAD-1. In 1994, NAD-1 yielded an estimated 1725 kg/ha (Say), 3500 kg/ha (Jirataoua), 3800kg/ha (Cerasa), and 4600 kg/ha (Konni), for an overall average farmer yield of more than 3000 kg/ha.

Taking into account the food quality problems of an earlier INRAN release, Kapran (1988) and Tyler (1988) conducted preliminary food (tuwo) quality tests of some of their test-hybrids at the village level, and concluded there was generally an acceptability similar to that of local varieties. This was taken a step further in 1990, in a collaborative INRAN/INTSORMIL wide scale food quality test. Three of the improved genotypes (NAD-1, SEPON-82, SRN-39) were evaluated together with a local variety across four regions, to obtain farmer feedback and compare the ratings with physico-chemical traits in laboratory analyses. NAD-1 was always rated as a good tuwo-making entry. As can be seen, some ten years later after it was selected, NAD-1, is still a high-yielding medium-maturing hybrid, with good drought tolerance and acceptable food quality, both on-station and on-farm. Its consistency of production was also compared to that of other improved and local genotypes, and NAD-1 hybrid was the most stable. The subject of yield stability was recently addressed by another INTSORMIL thesis project (Ibrahim, 1995). A total of 126 genotypes including 90 hybrids, their parents and other checks were evaluated across 15 different environments in Niger, the U.S., South America, and Sudan. Hybrids not only were better yielders in all environments, they in fact showed a greater yield stability under stress than non-stress environments. Ibrahim (1995) concludes that for stress environments in semi-arid tropics, hybrids are more reliable genotypes.

Despite the lack of a modern seed industry in Niger, the program of new hybrid production and testing continues. Hundreds of new combinations are made and tested each year, and our preliminary observations indicate that a number of them have a yield potential similar to that of NAD-1. It is striking, for example, that some of them were obtained using as male parents, lines that we selected in Niger, from early generation germplasm provided by our INTSORMIL collaborators (90SN- series). Also, new A-lines like ABON34 appear to have similar good combining ability as TX623A, the female parent of NAD-1. Based on elements, including the continuously encouraging results obtained on-station since 1986 and farmer enthusiasm since 1989, it is realistic to suggest that hybrids may be the best route for increased sorghum productivity in Niger. The crucial problem to be solved is that of a viable seed production mechanism, and the history of its elaboration in countries like India, Zambia, and Sudan, is an encouraging signal.

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Introduction, Objectives, and Constraints Addressed

Nutritional value of sorghum has long been known to be different from other cereals. This includes the tannin problem, the protein quality problem, the protein digestibility problem, and the local processing methods involved in eliminating these problems in the diets of sorghum consuming people. We have made significant progress in cooperation with Dr. Larry Butler on the tannin problem, and Sam Mukuru has now proven, in studies conducted in our laboratory, that high tannin sorghums traditionally grown at high elevations in Eastern Africa are very satisfactory sources of digestible nutrients if the grain is processed adequately by traditional means. Protein quality improvement will be a major breeding objective during the next five years. We have identified good sources of modified quality protein sorghums which are comparable in yield potential and grain quality to quality protein maize as developed by CIMMYT. The basic high lysine gene, P-721 opaque, has been combined with sources of vitreous endosperm to give the QPS (Quality Protein Sorghum). The high yield potential has been demonstrated by Emmanuel Monyo and the modified vitreous endosperm characteristics have been recently documented. A major unresolved problem is the environmental stability of these modified endosperm sorghums. A recent breakthrough on QPM in maize by Brian Larkins and Mr. Mauricio Lopez has shown a strong relationship between the gamma-zein fraction and modified vitreous endosperm characteristics. An Elisa technique is being developed which will make selection for vitreous endosperm opaque-2 much more reliable and faster. The same technique will be adapted to sorghum P-721 modified lines in improvement programs. Trials will be conducted at several locations during 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 it can be confirmed in the QPS lines. The digestibility problem can also be approached at this time by a better understanding of traditional processing technologies. We believe the identification of a low fraction III (cross-linked kafirin fraction) sorghum variety in the World Collection has the potential to provide a genetic and breeding solution to the digestibility problem in sorghum, which would be a significant achievement in utilization of sorghum as a food grain and also as a feed grain.

A major priority will be the development of a vitreous endosperm high lysine sorghum variety using germplasm developed from crosses with P-721 opaque. This will be a combined effort with 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.

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.

Objectives

Identify, develop and evaluate sorghum lines or mutants with improved nutritional quality and superior food grain quality using both chemical and biological methods.

Develop agronomically elite sorghum lines for Niger, Sudan, and Ethiopia with good adaptability, good grain quality, good drought and *Striga* tolerance, and improved yield potential.

Use new tools from molecular biology, genetics and plant physiology to study the mechanisms of drought tolerance in sorghum.

Investigate the potential for developing varieties of sorghum with high nutritional value and good food properties for potential use as nutritional foods for young children, pregnant women and nursing mothers.

Train LDC personnel in plant breeding and genetics.

Research Approach and Project Output

Research Methods

Much of the breeding activities will be conducted in Niger, Sudan, and also with the ICRISAT Southern Africa and East Africa regional centers. Collaboration with Sudan and Niger will continue on *Striga* tolerance and drought tolerance. Considerable time and effort will be spent working with Sudanese and Nigerien scientists on grain quality using pedigree breeding as well as population and hybrid development. A major effort will be made to develop A&B lines with good grain quality, *Striga* tolerance, and drought tolerance which are adapted to Sudan and Niger.

Breeding for good grain quality and high digestibility in elite sorghum cultivars which also have African adaptability, good yield and other needed agronomic traits will be continued. Characteristics such as kernel hardness have now been identified which will facilitate breeding for grain quality. This program also will be carried out jointly with Niger and Sudan. Much of the breeding work will be done in Niger with backup using laboratory facilities at Purdue. Screening and trials will be conducted at 3 locations in Niger as well as in Sudan.

Our approach to investigating the genetic determinants of the exceptional drought resistance of certain sorghum cultivars (P898012 and P954035) will 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 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

Scattering of ultraviolet and phytosynthetically active radiation by sorghum bicolor: influence of epicuticular wax

Near-isogenic mutants of *Sorghum bicolor* with genetic alterations affecting epicuticular wax (EW) structure, but having similar canopy architecture, provided a model system to examine the influence of EW on plant radiation scattering. Differences in canopies with two different sheath EW amounts showed differences in angular reflectance and transmittance. The differences varied with waveband of radiation. Canopy ultraviolet-B (UVB) and photosynthetically active radiation (PAR) backward reflectance in the principal solar plane were higher by wild-type plants (N-15) bearing reflective stalk EW filaments than mutant plants (bm-15) lacking stalk EW filaments. Between panicle emergence to anthesis the backward PAR reflectance increased more in the N-15 than bm-15 canopy. We suspect that the increase was a result of reflections from stalk facets emerging above the surface plane of the canopy foliage and exposing reflective EW. As panicles emerged above the foliage, canopy UVB and PAR forward reflectance by bm-15 increased while forward reflectance by N-15 decreased. The increased forward reflectance from bm-15 may be because of high specular reflectance from the microscopically smooth bm-15 stalk surfaces. Based on comparisons of probability distributions, significant differences in PAR and UVB canopy transmittance were detected between N-15 and bm-15. The median UVB transmittance was greater in the bm-15 canopy than the N-15 canopy, while the median PAR transmittance was the same for the two canopies. The greater transmittance in the N-15 canopy corresponded with lower EW load of the sheaths, but the difference between canopies was within the experimental error. Distinct influences of the stalk EW on canopy reflectance and transmittance were difficult to assess because of the relatively low proportion of surface area containing EW, the experimental errors associated with UVB irradiance field measurements.

Drought reaction and allelic characterizations of epicuticular wax mutants in *Sorghum bicolor*

Drought resistance has been associated with epicuticular wax in some plant species. Our objectives were to characterize epicuticular wax and to determine its role in drought resistance. We used sets of near isogenic lines of normal, bloomless (no visible epicuticular wax), and sparse bloom (reduced visible epicuticular wax) mutants developed through chemical mutagenesis of two drought resistant sorghum cultivars. We characterized the genetics, biochemistry, and ultrastructure of these isolines. Allelism tests distinguished at least ten loci among 31 mutants characterized. Mutant allelic groups tend to correspond to mutant groups with specific epicuticular wax biochemistry and ultrastructure. Drought reactions were determined by yield trials conducted under a variety of drought stress conditions. Quantitative and qualitative differences in epicuticular wax are associated with the drought reactions of the isolines.

Generation of a genetic map for *Sorghum bicolor*

Sorghum bicolor is an important crop species with good genetic tools but virtually no genetic map. A number of laboratories have initiated mapping studies of sorghum using DNA markers. Many of these mapping programs employ maize restriction fragment length polymorphism (RFLP) markers as probes. Sufficient diversity is present within S. bicolor to allow RFLP mapping without the lowered progeny fertility, severely distorted segregation rations, and undependable map distance determinations that result from wide crosses. Mapping studies indicate that the sorghum genome contains many duplicated loci and that a significant percentage of the maize and sorghum genomes are colinear. Three laboratories have independently generated RFLP maps with 85 to 105 markers each. Since these maps contain some common maize RFLP markers, integration of these data should be feasible. Predictions based on the size of these maps, and the frequencies of markers that remain unlinked, suggest that the sorghum genetic map will range in size somewhere between 1200 and 1800 centriMorgans. Current programs are placing additional RFLP markers (from maize and sorghum) and randomly amplified polymorphic DNAs on the sorghum map. Work also is underway to integrate morphological and isozyme traits into the RFLP maps, to use DNA probes to map important simple and quantitative traits, and to coordinate the efforts of the many groups now involved in sorghum genome analysis.

Involvement of cork cells in the secretion of epicuticular wax filaments on *Sorghum bicolor* (L.) Moench

Tubular epicuticular wax (EW) filaments on *Sorghum bicolor* were shown to be secreted from smooth conical papillae within the apical walls of epidermal cork cells. Ultrastructural changes during light-induced EW secretion were examined in wild-type plants and near-isogenic mutants with reduced total EW deposition. Our results indicated that cork cell ER membranes were involved in the production of epicuticular wax precursors (EWPs). The density of ER increased during light exposure and preceded EW synthesis. The increase in ER was directly related to total EW deposition on wild-type and mutant abaxial sheaths. The orientation of ER membranes toward papillae secretion sites indicated that EWP may undergo ER-mediated directional transport. The high vesicle density in cytoplasmic extensions under papillae indicated that EWPs were vesiculated for exocytosis at the papillar secretion sites. Osmiophilic globules did not appear to be direct EWPs as previously reported. Osmiophilic globules in cork cells were never present in cell walls, cuticles, vesicles, or preferentially associated with ER; globules were randomly dispersed in the cytoplasm and rarely present during the EW-induction period. Distinct microchannels or pores were not evident in the cell wall or cuticle layers, indicating that EWPs diffused to the surface. Wall swellings near the base of papillae where a dense-staining wall modification first contacts the cuticle and where EW filaments emerge indicate a potential preferred pathway for EWP transport. An osmiophilic layer within apical cork cell walls appears to function in EW secretion; however, its exact role is yet unclear.

Chemically induced cuticle mutation affecting epidermal conductance to water vapor and disease susceptibility in *Sorghum bicolor* (L.) Moench:

Analysis of *Sorghum bicolor* bloomless (bm) mutants with altered epicuticular wax (EW) structure uncovered a mutation affecting both EW and cuticle deposition. The cuticle of mutant bm-22 was about 60% thinner and approximately one-fifth the weight of the wild-type parent P954035 (WT-P954035) cuticles. Reduced cuticle deposition was associated with increased epidermal conductance to water vapor. The reduction in EW and cuticle deposition increased susceptibility to the fungal pathogen *Exserohilum turcicum*. Evidence suggests that this recessive mutation occurs at a single locus with pleiotropic effects. The independently occurring gene mutations of bm-2, bm-6, bm-22, and bm-33 are allelic. These chemically induced mutants had essentially identical EW structure, water loss, and cuticle deposition. Furthermore, 138 F2 plants from a bm-22 × WT-P954035 backcross showed no recombination of these traits. This unique mutation in a near-isogenic background provides a useful biological system to examine plant cuticle biosynthesis, physiology, and function.

Networking Activities

Workshop

Organized West African Inter-CRSP Workshop (September 1995)

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. Sam Mukuru, ICRISAT Sorghum Breeder, Kenya

Dr. Osman Ibrahim, ARC/Gezira Research Station, Wad Medani, Sudan

Dr. D.S. Murty, Plant Breeder, ICRISAT, Bamako, Mali

Dr. Lee House, Sorghum Seed Consultant, North Carolina

Dr. Darrell Rosenow, Texas A&M Agricultural Experiment Station, 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

Germplasm and Research Information Exchange

Extensive germplasm has been provided to INRAN/Niger, ARC in Sudan, ICRISAT/SADCC 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. Seed of NAD-1 has been produced for Niger.

Publication

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Peters, P.J., J.D. Axtell, P.J. Rich, and M.A. Jenks. 1994. Drought reaction and allelic characterization of epicuticular wax mutants in *Sorghum bicolor*. Agronomy Abstr., p. 123.

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Development and Enhancement of Sorghum Germplasm with Sustained Tolerance to Drought, *Striga*, and Grain Mold

Project PRF-107 and PRF-107B
Gebisa Ejeta
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Collaborating Scientists

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Dr. Abdeljabar T. Babiker, *Striga* Specialist, ARC, Sudan
Dr. Mohamed El Hilu Omer, Sorghum Pathologist, ARC, Sudan
Dr. Omar Fadil, NSA, Sudan
Dr. Aboubacar Toure, Sorghum Breeder, IER, Bamako, Mali
Dr. D. Dembele, *Striga* Specialist, IER, Bamako, Mali
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 Agricultural Experiment Station, Route 3, Lubbock, TX
Dr. Jerry Eastin, Department of Agronomy, University of Nebraska, Lincoln, NE
Professor David Andrews, Department of Agronomy, University of Nebraska, Lincoln, NE
Dr. Bruce Maunder, DeKalb-Pfizer Genetics, Route 2, Box 56, Lubbock, TX
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, limited 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 has 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 1994, we reported on the results of a Ph.D. study by Ed Grote on selection and genetics of drought tolerance in sorghum. This study involved evaluation of per se and test cross performance of 100 recombinant inbred lines and their hybrids with two seed parents under controlled irrigation, where stress was imposed at key stages of plant development. Using data collected on morphological symptoms of pre-flowering and post-flowering drought under these moisture regimes, we developed indices that succeeded in ranking the parental lines according to their known relative drought responses. Based on these indices, lines combining both pre-and post-flowering drought tolerance have been identified. Evaluation of the RI lines and their hybrids across several environments showed a significant correlation between stability of RI lines and their hybrids. We identified Quantitative Trait Loci (QTL) associated with all agronomic and morphological variables measured under the stress regimes.

We also reported on characterization of grain mold resistance in a diverse landrace collection, where genotypes differed significantly in their reactions to damage caused by individual fungal species. We found that some sorghum lines were free from colonization by one or more fungal species across several sampling dates. This suggests that it may be possible to establish differentials for each fungus, or a fungi group, to facilitate screening of germplasm for resistance to grain mold in a more systematic manner than has been possible.

Finally, we reported on two major germplasm releases. Forty pairs of cytoplasmic-genetic male sterile lines, combining food grain quality and high seed parent, were released to the U.S. sorghum seed industry and to cooperators overseas. We also released eight *Striga* resistant cultivars with high yield, broad agronomic adaptation, and excellent food grain quality attributes. Under an initiative supported by the USAID Office of Disaster Relief, World Vision Relief and Development Inc. (an NGO) is currently distributing these cultivars in 10 African countries. This initiative serves as a good example of an effective collaboration between an NGO and a CRSP in technology generation and transfer.

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 PRF-107B are entirely interdisciplinary. Much of the on-campus research at Purdue is in close collaboration with Dr. Larry Butler (PRF-104B). Our programs are fully integrated, particularly in the areas of pest, disease, and *Striga* resistance, where a concerted effort is underway in elucidating the biochemical and genetic mechanism of resistance to these constraints. Field and laboratory evaluations of sorghum and millet germplasm are coordinated, the results from one often complimenting the other. In addition, there have been collaborative research efforts with colleagues in Africa, primarily with Dr. A.G.T. Babiker in Sudan, where an integrated approach to *Striga* control has been under investigation.

Our germplasm development and enhancement program utilizes the wealth of sorghum and millet germplasm we have accumulated in the program. Intercrosses are made in specific combinations and populations generated via conventional hybridization techniques, through mutagenesis, or through tissue culture in vitro. Conventional progenies derived from these populations are evaluated both in the laboratory and in the field at West Lafayette, Indiana for an array of traits, including high yield potential, grain quality, as well as certain chemical constituents that we have found to correlate well with field resistance to *Striga* or panicle and leaf diseases. We also evaluate our germplasm for tropical adaptation and disease resistance during the off-season at the USDA Tropical Agricultural Research Center at Isabella, Puerto Rico. Selected progenies from relevant populations are then sampled for evaluation of specific adaptation and usefulness to collaborative programs in Sudan, Niger, and more recently Mali. Evaluation of the drought tolerance of our breeding materials have been conducted at Lubbock, Texas in collaboration with Dr. Darrell Rosenow and in a winter nursery at Puerto Vallarta, Mexico. Assistance in field evaluation of nurseries has also been provided by industry colleagues, particularly at Pioneer Hi-Bred and DeKalb Genetics.

The training, networking and institutional development efforts of PRF-107 have been provided through graduate education, organization of special workshops and symposia, as well as direct and closer interaction with research scientists and program leaders of NARS and associated programs. Much of the effort in this area has been primarily in Sudan and Niger, with limited activity in Mali, and some in Southern Africa through SADC/ICRISAT.

Project Output

Research Findings

Drought Tolerance

Although sorghum is one of the most drought tolerant crops, significant variation exists for drought tolerance among sorghum germplasm. Selection efforts for tolerance to drought in sorghum have been hampered due to the complexity of the trait and the associated environmental influences. Attempts to break down drought tolerance into component parts have been helpful. In sorghum, we recognize drought tolerance at three key physiological stages. Seedling drought tolerance enables the plant to establish properly where an optimum plant population can be set for the ideotype of the cultivar under a given environmental condition. Drought at the pre-flowering stage occurs when the sink size for the genotype is being determined. Post-flowering drought reduces the ability of the plant to fill the panicle and causes premature senescence. We recently completed a comprehensive study conducted by Edwin Grote as a Ph.D. dissertation. This study utilized 100 recombinant inbred (RI) lines developed via Single Seed Descent from a cross between two lines that contrast for their drought reactions. Tx 7078 is a pre-flowering drought tolerant line that is susceptible to post-flowering drought. B35, on the other hand, is post-flowering drought tolerant but susceptible to pre-flowering drought. The RI lines and their parents were evaluated under conditions conducive for the onset of pre-flowering drought, post-flowering drought, and also under full irrigation during the 1992,1993, and 1994 seasons in Puerto Vallarta, Mexico. An array of agronomic and morphological measurements were recorded under each of the three irrigation treatments, and the following conclusions were drawn:

To quantify drought tolerance in this population, indices were developed for both pre-and post-flowering drought tolerance based on specific morphological symptoms of pre-and post-flowering drought stress. These indices ranked the parental lines according to their known relative drought responses. The efficiency of these indices was reduced somewhat by correlations among components. Further testing of such indices may be done by characterizing another population with lines of known drought responses to see if these lines are grouped accordingly. If so, segregating populations with drought tolerance could then be effectively characterized for relative drought reactions. Based on these indices, lines combining both pre-and post-flowering drought tolerance have been identified. This suggests that although physiological mechanisms may differ between pre-and post-flowering drought tolerance, lines can be developed that show tolerance at both developmental stages.

We also test-crossed each of the 100 RI lines to two female (male-sterile) lines and evaluated the stability of the experimental hybrids (generated using the factorial mating design) along with that of the parental lines. This experiment was also conducted across three years. The results show that stability measures associated with yield showed a significant correlation between RI line stability and hybrid stability. Stability measures correlated with low yield was also associated with earliness, and conversely stability measures correlated with high yield showed an association with lateness.

The combining ability of the RI lines and the seed parents was also tested. The importance of specific and general combining ability effects depended on the environment in which those effects were measured. Specific combining ability effects were more important in the stress trials than in the nonstress trials for the population of recombinant inbred lines. Likewise, the genotypic correlations between inbred yield and hybrid were lower in the stress environment that in the stress free location. Heterosis was important for yield and yield components.

One of the objectives of this study was to identify Quantitative Trait Loci (QTL) associated with agronomic traits and test cross performance. QTL were identified for almost all variables measured. Non stress environments, with high heritability, allowed the detection of more QTLs than the stress environments.

Striga

Over the last 10 years, considerable effort had been committed to *Striga* research in this project. The research effort on *Striga* has been interdisciplinary and in close cooperation with Dr. Larry Butler at Purdue and Dr. Abdel Gabar Babiker in Sudan. The basis of the research agenda and the progress made in this endeavor has been regularly provided in previous annual reports. We had focused on the key signal exchanged between the parasite, *Striga,* and its hosts. Earlier work stressed understanding of the nature of the signal. On the basis of its characteristics we developed a quick assay to differentiate host germplasm on their ability to produce the signal required for germination. The development of the agar gel assay allowed clearer definition of the nature of the inheritance of the trait. It also facilitated other studies that allowed better understanding of the biology of the parasite and its interaction with its hosts. Perhaps its greatest contribution has been in evaluating host plant germplasm for production of germination stimulant as a predictive measure of host plant resistance to *Striga.* Earlier, the variety SRN39 was identified as low stimulant producer and its stable resistance to *Striga* across an array of ecological environments was established. SRN39 was officially released for wide commercial cultivation in *Striga* endemic areas in the Sudan. Several years of breeding and testing has now led to development and release of eight new sorghum varieties combining *Striga* resistance with high grain yield, excellent food grain quality, and broad adaptation. These cultivars were officially approved for release and distribution by Purdue University late last year, after having been successfully tested in Sudan, Niger, Mali, and Burkina Faso during the last four years.

In anticipation of the release, a pilot seed production was undertaken and a total of eight metric tons of seed was produced to produce nuclear seed to international collaborators. With support from the USAID Office of Foreign Disaster Assistance, a collaborative program on "*Striga* Resistant Sorghum Initiative" was signed between Purdue University and World Vision Relief and Development, Inc., an NGO with an extensive network in several African countries. Under this agreement, the pilot seed produced at Purdue has been provided to World Vision for distribution in 10 African countries working in concert with national seed programs, extension service, and research institutions of these countries. A workshop was held in Nairobi, Kenya during the week of June 5, 1995 to launch the project and finalize the implementation plan. World Vision representatives from Mozambique, Senegal, Mali, Ghana, Ethiopia, Eritrea, Kenya, and Somalia participated in the workshop. A three-tier testing procedure involving experiment station evaluation, on-farm demonstration, as well as farmer-managed tests were planned. To date, seed has been successfully distributed with tests underway in Ghana, Niger, Mali, and Senegal. During the ensuing crop season in the southern hemisphere, tests will also be conducted in Mozambique and Rwanda as per the plans. It is also envisaged that an economic study on the distribution, diffusion and impact evaluation of these cultivars will be undertaken as part of this initiative. This project may serve as a good example for an NGO-CRSP association in development and extension of a technology that is readily acceptable under the conditions of many of these countries. World Vision staff believe this initiative will serve as a model for further associations with the CRSPs and the IARCs.

Grain Mold

Use of resistant cultivars is the most feasible way to minimize crop damage from grain mold when sorghum is grown in environments conducive to mold development. We conducted an experiment to assess relative contribution of fungal species to grain mold damage and to evaluate extent of variation in sorghum for grain mold resistance. A large working collection of diverse landraces were evaluated for mold resistance at different stages of grain maturity. Fungal species infecting sorghum kernels were isolated and counted. Large and significant differences in levels of kernel infection by fungal species and resistance to grain mold were observed among accessions at all stages kernel development. The predominant fungal species isolated from sorghum kernels collected from field grown panicles did not change across different sampling dates and years. We employed a multiple regression model and found that some 64% of the variation in grain mold damage rating can be explained by all the fungal species. Giberella zeae and Fusarium moniliforme each accounted for 46 and 16%, respectively of the variation in the visual grain mold damage rating. Sorghum accessions free from colonization by one or more fungal species across three sampling dates were identified. We, therefore, suggest that it should be possible to establish differentials for each fungus or a fungi group to facilitate screening of germplasm for resistance to grain mold.

Ten sorghum genotypes with differences in phenolic concentration and grain mold resistance were also evaluated over three crop seasons to assess changes in phenolic compounds during seed development and how these changes influence grain molding. Samples were collected for nine weeks at seven day intervals starting seven days after anthesis. We find that the concentration of flavan-4-ol in the kernels is important as reported earlier. However concentration of flavan-4-ol were high and similar for both resistant and susceptible genotypes at early stages of seed development where the fungal population is at its lowest. In susceptible genotypes the concentration dropped by 67% between the third and the last sampling dates compared to only a 20% decline for the resistant genotypes in the same period. Although there were significant differences among genotypes for 3-deoxyanthocyanidins, the presence of these pigments did not differentiate mold resistant and susceptible genotypes. Our results also showed that the highest incidence of seed infection by fungi occurred between 25 and 35 days after anthesis. Alternaria, Fusarium, Cladosporium and Epicoccum species were the major fungi isolated from field harvested seeds.

Germplasm Releases

Eight Striga resistant cultivars were released for cultivation in Striga endemic areas. These cultivars have been extensively tested in several African countries during the last four crop seasons. The cultivars have shown broad agronomic adaptation and stability of resistance to *Striga*. They hold promise for immediate direct use as named varieties at least in the countries in which they have been tested. These varieties combine several desirable attributes including grain quality, high yield potential, and resistance to leaf diseases in addition to *Striga* resistance.

Forty pairs of cytoplasmic-genetic male sterile (A-line) and maintainer (B-line) inbred lines of sorghum. These inbred lines combine high seed parent yield with excellent grain quality and, therefore, should make significant contribution to the development of food-grain commercial hybrids. The new inbred lines and their immediate parents have shown excellent adaptation to both the temperate and tropical sorghum growing environments. With appropriate pollinators, these seed parents can be used for producing hybrids for either the tropics or the temperate environments. We believe that the use of these inbred lines in commercial hybrid seed production should broaden the germplasm base, both in the United States and overseas seed market, as neither the lines nor their parents (except IS2219) have been used in commercial breeding before.

Networking Activities

Workshops and Program Reviews

Served as a Visiting Faculty, University of Wisconsin, Summer Institute for African Agricultural Research.

Member, The Rockefeller Foundation African Dissertation Internship Competitive Grant Selection Committee.

Attended the American Society of Agronomy Annual Meetings at Seattle, Washington.

Attended the Biannual meeting of the Sorghum Improvement Conference of North America (SICNA) at Lubbock, Texas.

Participated in the USAID Technology Development and Transfer (TDT) Collaborators Colloquium and Workshop, Harare, Zimbabwe.

Participated in an INTSORMIL- World Vision organized workshop to launch the Sorghum *Striga* Seed Initiative in Nairobi, Kenya.

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. Sam Mukuru, ICRISAT- Kenya , August 1994.

Dr. Paula Bramel-Cox , Sorghum Breeder , Kansas State Univ., Sept.,1994.

Dr. Kay Porter, Pioneer Hi-Bred Int., October, 1994.

Dr. Brhane Gebrekidan, Director, IPM CRSP , October, 1994.

Dr. John Yohe, Director, INTSORMIL CRSP, October,1994.

Dr. Phil Warren, USAID/Washington, October,1994.

Dr. Athene Lane, University of Bristol, England, October, 1994.

Dr. John Bailey, University of Bristol, England, October, 1994.

Dr. John Leslie, Plant Pathologist, Kansas State Univ., November, 1994

Mr. Tim Lust, National Sorghum Producers Association, June,1995.

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 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 bę 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, are also shared across countries and zones.

Information and germplasm is routinely contributed to national and international sorghum research programs. In 1996, as in other years, an array of sorghum nurseries were distributed to cooperators in Sudan, Ethiopia, Niger, Mali, and Kenya. In addition, the newly released 40 pairs of A&B lines and the eight *Striga* resistant cultivars were widely distributed upon requests received following the wide distribution of our release notices.

Publications

Research 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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Cai, T., G. Ejeta, and L.G. Butler. 1995. Screening for grain polyphenol variants from high tannin sorghum somaclones. Theor. Appl. Genet. 90:211-220.

Cai, T., G. Ejeta, and L.G. Butler. 1994. Development and maturation of sorghum seeds on detached panicles grown in vitro. Plant Cell Reports 14:116-119.

Grote, E., G. Ejeta, and D. Rhodes. 1994. Inheritance of glycinebetaine deficiency in sorghum. Crop Sci. 34:1217-1220.

Reda, F., L.G. Butler, G. Ejeta, and J. Ransom. 1994. Screening of maize genotypes for low stimulant production using the agar gel technique. Afric. Crop Sci. J. 173-177.

Vogler, R. , G. Ejeta, and L.G. Butler. 1995. Integrating biotechnological approaches for the control of *Striga*. Biotechnology and Biosafety Risk Assessment In An African Perspective workshop, Nairobi, Kenya, 27 February- 3, March 1995.

Ejeta, G. 1995. Major Accomplishment in Technology Development and Transfer by the International Sorghum and Millet (INTSORMIL) Collaborative Research Program. USAID Technology Development and Transfer Collaborators Colloquium and Workshop, 24-27 January 1995. Harare, Zimbabwe.

Ejeta, G. and L. G. Butler. 1995. Development and Transfer of Technology for Overcoming *Striga*. USAID Technology Development and Transfer Collaborators Colloquium and Workshop -27 January 1995.

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Cai. T., G. Ejeta, and L.G. Butler. 1994. Effect of genotype, explant source and medium composition on callusing, embryogenesis and regeneration in sorghum. Agron. Abst. p. 206.

Grote, E.M., M. Tuinstra, G. Ejeta, P. Goldsbrough, and W.E. Nyquist. 1994. QTL x Environment interaction for combining ability of sorghum RL lines. Agron. Abst. p. 124.

Ibrahim, Y., G. Ejeta, and D. Rosenow. 1994. Stability of drought tolerant sorghum lines and hybrids. Agron. Abst. p. 123.

Menkir, A., A.M. Berhan, L. Butler, H. Warren, and G. Ejeta. 1994. Grain mold resistance in sorghum. Agron. Abst. p. 123.

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The Enhancement of Sorghum Germplasm for Stability, Productivity, and Utilization

Project TAM-121
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Dr. J. Mullet, Biotechnologist, Texas A&M University, College Station, TX
Prof. Shi Yu Xi, Sorghum Breeder, Sorghum Res. Inst., Liaoning Academy of Agri. Sci., P.R. China
Prof. D.J. Andrews, Sorghum/Millet Breeder, UNL-115, University of Nebraska, Lincoln, NE

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, nonsenscent, 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 collaborating 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 nonsencscence, high yield, and food quality grain. This project draws information and material from 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 $\underline{dw_1}$, $\underline{dw_2}$, $\underline{dw_3}$, 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 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 2 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 1995 there was the normal early season wet cycle followed by significant drought along with high temperatures across much of Texas. Plant expression and disease reactions were good. South Texas adaptation and disease nurseries allowed excellent selection of genotypes from advanced and early generation materials (Corpus Christi, Robstown, and Beeville) for stress conditions. The breeding and testing site, College Station, was very good. Yield potential expression was excellent and grain quality high because of the summer drought. Numerous items were evaluated and selected from the College Station site in 1995. 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 1995.

A basic study was conducted by Klint G. Stewart (U.S.) to assess damage by greenbug (*Homoptera:Aphididae*) to mixtures of resistant and susceptible sorghum, *Sorghum bicolor* (L.) Moench, hybrids as affected by natural enemies.

The greenbug, *Schizaphis graminum* Rondani, is an important pest of sorghum, *Sorghum Bicolor* (L.) Moench in the U.S.. An integrated pest management (IPM) approach has been used to manage greenbug. Green bug biotype formation renders resistant sorghums ineffective as an IPM component. Multilines have been used to prolong duration of resistance genes for pathogens in small grains and may contribute to the effective management of greenbug biotypes. Five biotype E greenbug resistant and susceptible sorghum genotype mixtures were studied. These mixtures were evaluated in greenhouse experiments from 1993 to 1995 and on the Texas A&M Agronomy Research Farm near College Station during 1994 and 1995. Greenhouse experiments assessed effects of mixtures on greenbug and field experiments evaluated mixture effects on greenbug in the presence and absence of natural enemies. Effects were measured by assessment of vegetative data and greenbug abundance.

No mixture in the greenhouse was significantly better despite a two fold difference in means between mixtures with highest and lowest greenbug abundance. Mixtures were statistically equal for plant height and damage, respectively. Data indicated plant size may have confounded results in the greenhouse experiments. Upon consideration of plant height confounding results, mixture 3R:1S may be equal to 1R:0S for greenbug management in seedling sorghum.

Greenbug abundance, plant masses, and yield were significantly less in treatments where natural enemies were allowed access suggesting that natural enemies inhibited the greenbug from reaching economic levels. The combination of rainfall and natural enemies played a significant role in reducing greenbug abundance. Both years, vegetative data indicated mixture 1R:3S is least effective in managing the greenbug. Harvest data were inconclusive for determining differences among mixtures. Experiments do suggest mixtures containing a minimum of 50% resistant plants may be as effective as all resistant stands experiencing moderate greenbug pressure.

Human food quality sorghum types developed in this project performed well in a wide range of environmental conditions. The performance of 40 hybrids in the 1994 IFSAT (International Food Sorghum Adaptation Trial) is presented in Table 1. ATx378*RTx430, a red seed feed grain type hybrid, ranked 5th 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 advantage of these hybrids there is increased leaf quality, disease resistance, and drought tolerance. In 1994, there were 11 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 1994, 11 ITATs (International Tropical Adaptation Trials) were distributed to US 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 hybrid in College Station, Texas (A4R*RTx430=7220 kg/ha); Weslaco, Texas (A1*RTx430=6000 kg/ha); and Mayaguez, Puerto Rico (A9108*RTx430=5558 kg/ha) show a range of type. There are nine 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.

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. Significant 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, 1994

Research Investigation Exchanges

President Yoweri Museveni, President of Uganda

Mr. Dries Booyens, PANNAR Seed Company, Klerksdorp, South Africa, August, 1995

Mr. Enrique Morgan, Morgan Seed Company, Colon, Argentina, September, 1994

Mr. Victor R. Poggi, Morgan Seed Company, Colon, Argentina, September, 1994

Carmine Laserna, Bogota, Colombia, June, 1994

Mr. Antonio Cristiani, Guatemala, June, 1994

Dr. Francisco Gomez, Zamorano, Honduras

Dr. A. Toure, Bamako, Mali

Mr. Tony McCosker, DPI, Queensland, Australia

Germplasm and Research Information Exchange

In 1994-95, 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 3. We distributed more than 675 accessions and 57 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 57 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

Table 1. Performance of white grain food quality sorghum hybrids in the 1994 IFSAT, kg/ha.

Rank	Entry	Pedigree	W	CS	CC	PR	Avg.
1	33	ATx635*86EON361	5663	7866	2800	6760	5772
2	37	ATx631*87EON366	5868	6449	2579	6610	5377
3	6	ATx635*RTx436	4750	7221	3292	5648	5228
4	13	ATx635*R8511	5305	6720	2545	5708	5070
5	1	ATx378*RTx430	5168	6007	2169	6039	4846
6	16	ATx631*R8901	4743	5331	2626	6069	4692
7	31	ATx631*Tx2892	4733	5156	3405	4897	4548
8	4	ATx631*RTx436	5265	5319	2333	4897	4454
9	17	ATx631*R9011	4580	5573	2266	5017	4359
10	21	ATxARG-1*Dorado	4448	6078	2610	4146	4321
11	25	ATxARG-1*Tx2903	4638	4617	4473	3275	4251
12	38	ABON34*86EON361	5310	5890	2397	3305	4226
13	34	ATx631*86EON361	4842	5300	2938	3575	4164
14	35	ATx635*87EON366 SIS	4503	5831	2663	3275	4068
15	26	ATxARG-1*Tx2905	4225	4011	3649	4116	4000
16	36	ATx631*87EON366 SIS	4535	5252	2658	3515	3990
17	28	ATxARG-1*Tx2900	4865	4142	2128	4657	3948
18	11	ATx631*Tx2895	3635	5093	2102	4957	3947
19	18	ATx631*R9205	3923	3563	2569	5708	3941
20	22	ATxARG-1*Tx2892	4605	4718	2181	4206	3928
21	8	A8910*RTx436	4415	4789	2262	4146	3903
22	14	ATx631*Tx2901	3128	4048	3052	5288	3879
23	10	A9017*RTx436	4100	5530	2165	3664	3865
24	12	ATxARG-1*Tx2894	4365	4576	2167	3725	3708
25	7	A9027*RTx436	4533	4734	2029	3485	3695
26	29	ATxARG-1*(((SC120*Tx7000)*Tx430)-4-1-1-2-OP-2*Tx435)-1-?3-L5-B1-T1-CBK-CBK	4118	4821	2190	3575	3676
27	9	A9011*RTx436	4010	5203	2171	3275	3665
28	5	ATxARG-1*RTx436	4148	5170	2005	3245	3642
29	19	ATx631*((TAM428*77CS3)-1-14-3-2-2-1-4*Tx433)-CF2-B16-B	3623	4063	2013	4837	3634
30	20	ATx631*(((SC120*Tx7000)*Tx7000)-10-4-6-2-2-1*Tx2817)-6-?1-L4-B1-T1-B1-B1-B1	3505	4452	2260	4206	3606
31	23	ATxARG-1*R8511	4058	4438	2564	3245	3576
32	2	Sureño	4768	5449	2434	1502	3538
33	40	ATxARG-1*(Tx430*77CS1)-1-1-5-3-1-S5-S3-B3-B1-B1	4230	3393	2317	4176	3529
34	24	ATxARG-1*Tx2896	3858	4333	2104	3305	3400
35	32	ATxARG-1*Tx2895	4100	4202	2069	3076	3362
36	15	ATx631*TP21RB02-128-2-1-2-3-H1-C1-C1-C1-C1-C3-C2-CBK-CBK	2508	3705	2427	4747	3347
37	3	Dorado	3570	3424	1923	4056	3243
38	27	ATxARG-1*Tx2904	4063	2530	2601	3335	3132
39	39	ATxARG-1*(TAM428*CS3541)-180R-1-2-1-S1-S2-S1-B2-B1-B1	2220	2760	2092	5198	3068
40	30	ATxARG-1*(B2Tx636-T3*Tx435)-CF2-B11-B2-B1-CBK	2753	3195	2145	3215	2827

W - Weslaco
CS - College Station
CC - Corpus Christi
PR - Puerto Rico

Christi, Robstown, Beeville, College Station, and Lubbock, Texas.

Sixteen sorghum germplasm lines Tx2892 through Tx2906 and Tx2908 were released in 1995. These *Sorghum bicolor* [L.] Moench inbred germplasm stocks possess unique combinations of seed color, plant color, disease resistance, yield and genetic diversity. All lines are 3-dwarf height except for Tx2906 which is 2-dwarf.

Tx2907, a waxy endosperm, white grain, tan plant color restorer sorghum parental stock was released in 1995. The *Sorghum bicolor* [L.] Moench inbred restorer line is an elite white translucent waxy endosperm grain, tan plant color, and agronomically acceptable parental stock.

Twenty germplasm lines of sorghum (*Sorghum bicolor* [L.] Moench) were released by the Texas Agricultural Experiment Station in cooperation with the USDA-ARS, Tropical Research Station Mayaguez, Puerto Rico in 1994. The lines range in maturities and heights and taxonomic classification. These lines were sterilized in A_3 cytoplasm to provide tools for determining basic inheritance and physiologic patterns for maturity and height within *S. bicolor* diversity.

Publications and Presentations

Publications

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. National Conference on Forage Quality, Evaluation, and Utilization. April 13-15. Lincoln, NE. p. 55.

Table 2. Performance in the 1994 ITAT trials at selected U.S. and international locations. Yield in kg/ha.

Rank	Entry	Pedigree	W	CS	PR	Avg.
1	45	A4R*RTx430	5390	7220	4537	5716
2	44	A1*RTx430	6000	5979	5077	5685
3	49	ATx635*87EON366 SIS	5307	5707	5348	5454
4	21	ATx631*((SC599-6*SC110-9)*Tx2816)-3-3-2-4-1-B2-B1-BBK-B2-CBK	4868	6099	5378	5448
5	48	ATx631*86EON361	5235	6844	4056	5378
6	26	ATx635*RTx436	4145	6741	5186	5357
7	40	A9108*RTx430	5340	5113	5558	5340
8	50	A807*8BE2668	5508	5149	5258	5305
9	46	A1*Tx2908	5895	5339	4567	5267
10	10	ATx2752*RTx430	4290	6404	4927	5207
11	18	ATx635*Tx2894	4070	6684	4837	5197
12	29	ATx638*RTx430	5080	5497	4537	5038
13	11	ATx378*RTx430	4105	6180	4555	4947
14	37	ATx626*(((SC120*Tx7000)*Tx430)-4-1-1-2-OP*Tx434)-CF2-B7-B5-B1-B3-B2-B1	5283	6040	3395	4906
15	20	ATx638*Tx2908	5313	4334	5047	4898
16	30	ATx638*RTx436	4720	5496	4447	4888
17	43	ATx638*R9007	5205	4572	4837	4871
18	41	A9009*RTx436	4185	6086	4206	4826
19	47	A1*RTx436	4810	5329	4176	4772
20	14	ATx626*R8503	5352	5051	3906	4770
21	24	ATx631*((Tx430*Tx2816)-1-1-5-3*Tx433)-C16-B2-T3-CBK	4793	4815	4597	4735
22	16	ATx638*RTx2783	4588	4806	4386	4593
23	28	ATx638*RQL36	4535	5251	3906	4564
24	22	ATx631*(((Tx2816*SC326-6)*Tx430)-2-1-6-3*Tx435)-CF2-B2-CBK	4678	4980	4026	4561
25	36	ATxARG-1*((SC120*Tx7000)*Tx7000)-10-4-6-2-1-3-B1-BBK-B3-B2-BBK-BBK-BBK-BBK-BBK	3985	4856	4507	4449
26	25	ATx638*(R4244*R6956)-C13-C4-C2-C1	4665	5344	3275	4428
27	17	ATx631*RTx436	4003	4549	4477	4343
28	42	ATx638*RTx433	5030	3947	3816	4264
29	33	ATx638*((Tx430*77CS1)-1-1-1-5-3*Tx430)-F2-B8-B1-B2-B2-B1-B3-B3-B1	4435	4710	3605	4250
30	15	ATx638*RTx434	5330	4413	2914	4219
31	39	A9104*RTx436	3655	5080	3635	4123
32	34	ATxARG-1*(((SC120*Tx7000)*Tx430)-4-1-1-2-OP-2*Tx435)-1-?3-L5-L1	4173	4827	3245	4082
33	35	ATxARG-1*((SC599-6*Tx430)-3-6-2-BK-2-2-2*Tx435)-C1-C1-C1-C1	4110	4052	3816	3993
34	32	ATx638*(((SC120*Tx7000)*Tx430)-4-1-1-2-OP*Tx434)-CF2-B16-B2-B2-B1-T1-CBK	4120	3784	3936	3947
35	31	ATx638*Tx2892	4390	4049	3275	3905
36	13	ATx378*RTx2737	3338	4826	3425	3863
37	19	ATxARG-1*Dorado	2990	2892	5318	3733
38	6	RTx430	3105	4070	3996	3724
39	12	ATx378*RTx7000	3642	4726	2373	3580
40	38	ATxARG-1*TP21RB02-106-3-1-2-2-C1-C2-C2-C1-C2-C2-C1-C2-C1	3205	3419	3695	3440
41	3	BTx635	2545	3785	3034	3121
42	23	ATxARG-1*(((SC120xTx7000)*Tx430)-4-1-1-2-OP-2*Tx435)-1-?3-L5-B1-T1-CBK-CBK	2830	3184	3064	3026
43	7	RTx436	2483	3278	3095	2952
44	1	BTx378	2613	3223	2944	2927
45	2	BTx631	2473	2983	3305	2920
46	9	Dorado	2535	2370	2974	2626
47	8	RTx7000	2898	2221	2133	2417
48	4	BTx638	2518	1774	2884	2392
49	27	ATxARG-1*(EBA-1*Tx433)-C4-C1-T1-CBK-CBK	2118	2480	2373	2324
50	5	BTxARG-1	---	---	1112	---

W - Weslaco

CS - College Station

PR - Puerto Rico

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Table 3. Seedstocks distributed from College Station, Texas in 1994-1995 to collaborating programs within the U.S. and internationally.

Materials	International	Domestic
Breeding stocks	166	446
Hybrids	25	38
(Sum)	(191)	(484)
	Trials	
ITAT	6	5
IFSAT	6	5
ISVN	2	1
Experimental hybrids	0	12
Texas State Performance	- -	10
Regional Performance	- -	10
(Sum)	(14)	(43)

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Germplasm Enhancement for Resistance to Pathogens and Drought and Increased Genetic Diversity

Project TAM-122
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Summary

The 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.

Fifty fully converted exotic lines and 253 partially converted bulks from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program were released. Tx2907, a white-seeded, tan-plant, waxy endosperm restorer line developed cooperatively with TAM-121 and TAM-126 was released.

A strong positive relationship exists between stay green, a post-flowering drought resistance trait, and resistant to charcoal rot, as well as resistance to most types of lodging, including: (1) charcoal-rot, moisture-stress type, (2) weak neck, and (3) post-freeze stalk lodging. Sorghum lines with excellent stay green, charcoal rot resistance, and lodging resistance have been developed. A few lines were identified with the dominant type of stay green when used in hybrids. Most of these stay green lines also transmit lodging resistance to hybrids.

Three QTLs were identified by molecular analysis as controlling the stay green trait in sorghum.

White-seeded, tan-plant Guinea type breeding lines involving the Guinea, Bimbiri Soumale, looked outstanding for yield and adaptation in Mali. They should be very useful in Mali and West Africa as an improved guineense type sorghum for enhanced utilization and will be in on-farm trials in 1995. Two non-guineense Malian developed lines, Malisor 92-1 and Malisor 92-2, were entered in on-farm trials in 1994.

Objectives, Production and Utilization Constraints

Objectives

Enhance the germplasm of LDCs by developing and distributing early generation breeding materials involving genetically improved disease and drought resistance and other desirable traits for use and selection in host countries with emphasis on Honduras, Sudan, Mali, and Niger.

Develop high yielding cultivars for LDCs and the U.S. with genetically enhanced resistance to internationally important diseases with emphasis on downy mildew, charcoal rot, grain mold/weathering, anthracnose, head smut, head blight, and foliage diseases.

Develop through breeding and selection, high yielding, agronomically desirable types with superior combination of pre- and post-flowering drought tolerance and lodging resistance 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 preserve new sorghum germplasm and evaluate for traits needed in the U.S. and developing countries, and introgress these traits into improved lines.

Constraints

Drought is the major constraint to sorghum and millet production around the world. Sorghum cultivars differ widely in their response to drought. West Texas has a semiarid environment and 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 similar in response under drought in other countries of the world, including Sudan, Mali, Niger, and Honduras. 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 and are often region or site specific, and on-site evaluation is necessary to determine severity and possible race differences. Most internationally important diseases are present and are serious constraints in Texas, especially downy mildew, charcoal rot, grain mold/weathering, head smut, and head blight. Many other diseases such as anthracnose, leaf blight, rust, zonate, and gray leaf spot are also present in Texas. The Texas environment, particularly South Texas, is ideal for screening and breeding sorghums with high levels of resistance to most internationally important diseases.

Poor grain quality is a major problem in Mali and much of West Africa where guinea type sorghums are almost exclusively grown. This broad band extends from eastern Burkina Faso across all of Mali, except the extreme north, into Senegal and Guinea, and the northern areas of countries bordering on the south. This quality problem is primarily due to the head bug/grain mold complex. Guinea sorghums have quite good resistance to this complex, but their yield is not high and they do not respond well to improved production practices. Also, they are extremely difficult to handle in a breeding program, and efforts to improve them in yield have failed. Also, their unique grain quality adaptation essentially disappears in crosses to non-guinea types. Head bugs are the major constraint to the use of improved high yielding 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, late 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.

Mali and Niger are both drought prone areas. Both pre- and post-flowering drought tolerance are extremely important. 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.

In Sudan, the major constraint is drought, and related production problems. Moisture-stress related charcoal rot and subsequent lodging are serious problems. Many U.S. sorghums perform quite well in Sudan, but improved drought resistance, local adaptation, and kisra food quality are needed.

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 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. Breeding and selection must be done under the specific daylengths and environment in the host region. Improvement in the nonphotoperiod sensitive combine-type sorghum hybrids and varieties used over portions 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 conserving genetic diversity and for new diverse germplasm sources with resistance to pests, diseases, and environmental stress. New collections can provide new sources of desirable traits. Many developing countries are an important source of diverse germplasm in sorghum and millet. The collection, preservation and utilization of genetic diversity in sorghum is tremendously important to long-term, sustainable sorghum improvement programs. Use of genetic diversity is critical to produce sufficient food for increasing populations in the future.

Research Approach and Project Output

Research Methods

Introductions from Mali, Sudan, Niger, Honduras, Zimbabwe, Zambia, Botswana, and ICRISAT with 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 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 disease resistant 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 in large disease screening nurseries utilizing natural infection in South Texas, supplemented by artificial inoculation in the field and laboratory screening. Selected advanced materials are sent to host countries as appropriate for evaluation and are also incorporated into various standard replicated trials for extensive evaluation at several locations in Texas and host countries.

New breeding crosses are made among various sources of pre- and post-flowering drought resistance and elite, high yielding lines. 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 incorporated into standard replicated trials for extensive evaluation at several location in Texas and sent to host countries for evaluation and use.

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 major field drought screening nurseries at Lubbock, Halfway, and Chillicothe. Excellent post-flowering stress was obtained at Lubbock and Halfway, but the extremely dry early season prevented planting of dryland plots until mid July, and little data was obtained on pre-flowering stress. The "stay-green" line B35, appears to be an excellent source of post-flowering drought resistance and lodging 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 when exposed to severe post-flowering drought stress. Breeding derivatives of the parental line, B1, a derivative of B35, showed some good stay-green, and many had outstanding lodging resistance. Several lines from the cross (B1*(B7904*(SC748*SC630))) showed excellent stay green (post-flowering drought resistance) and lodging resistance at Lubbock, Halfway, and Chillicothe. Some short statured white-seeded, tan-plant progeny from the cross (B1*BTx635) showed some stay green along with excellent resistance to lodging and head smut. Sterilization of the above mentioned B lines continued or was initiated. Progeny from drought tolerant breeding lines were backcrossed and intercrossed with agronomically elite lines.

There is a strong positive relationship between the stay green (LPD rating) and resistance to charcoal rot and resistance to most types of lodging (Table 1). The selection methods we use with simultaneous selection for post-flowering drought resistance (stay green) and lodging resistance has resulted in sorghum lines which possess stay green and excellent resistance to several types of lodging including: (1) charcoal rot, moisture-stress type, (2) weak neck, and (3) post-freeze stalk lodging. Many also have a high level of resistance to fusarium head blight, and probably fusarium stalk rot resistance. The classification of selected released and experimental male and female lines for lodging resistance, stay green, and the dominance of stay green in hybrids is presented in Table 2 and Table 3. Some lines such as B35, SC35-14E, SC56-14E, 1790E, 1790L, and (P407*?)UC show excellent dominance of the stay green trait, while some appear completely recessive, and some show partial dominance. Converted sorghum lines have been an excellent source of lodging resistance, and some with excellent overall lodging resistance are listed in Table 4.

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. Major diseases involved were charcoal rot, grain mold/weathering, downy mildew, head smut, anthracnose, and foliage diseases such as rust, zonate, and leaf blight. Derivatives involving the white-seeded, tan-plant B-line, BTx635, showed outstanding resistance to head smut in South Texas.

Table 1. Relationship among stay green (LPD), lodging, and charcoal of selected sorghum lines.

Designation	Lubbock-F403		Lubbock-F407		
	LPD rating[1]	Lodging %[2]	LPD rating[1]	Charcoal rot rating[3]	Lodging %[2]
B1	2.3	0	2.9	0.7	0
B2-2	2.1	0	2.8	0.8	0
B35	2.2	0	2.7	0.5	0
BTx623	3.7	26	4.7	2.0	40
BTx625	4.7	80	4.6	3.4	38
BTx378	4.9	53	- -	- -	- -
Tx7000	- -	- -	4.6	3.4	13

[1]Leaf and plant death rating: 1 = all green, 3 = 50% of leaf area dead, 5 = entire plant dead.
[2]Moisture stress type lodging.
[3]Stalk rated on 1-5 scale: <1 = <one internode infected, 3 = 3 internodes, 4 = > 3 internodes, 5 = death, sclerotia.

Table 2. Classification of restorer lines for lodging resistance and stay green and dominance of the stay green trait in hybrids.

Designation	Pedigree	Lodging resistance[1]	Stay green[2]	Dominance classification in hybrids[3]
SC35-14E	ISI2568C/Durra	VG*	VG	Dom
SC56-14E	ISI2568C/Cau Nig	VG*	VG	Dom
NSA 440	Karper/Gaines/Kafder	VG*	VG	S-Dom
1790E	(SC56*SC33)	VG*	VG	Dom
1790L	(SC56*SC33)	VG*	VG	Dom
R9188	Rioder, SC599-6	G*	VG	Rec
SC599-11E	Rioder,IS17459der	G	G	S-Dom
R1922	(SC56*SC110)	G	G	P-Dom
R1584	(SC56*SC170)	VG*	VG	Rec
(P407*?)UC	SC33 der	VG*	VG	Dom
Karper 669	Karper/Gaines	VG*	VG	- -
KS19	Kansas release	G	G	P-Dom
V1080	(Tx430*R9188)	G	G	Rec
R3224(sh)	(TAM428*(GbTx7000der))	G*	I	S-Dom
R3224(t)	(TAM428*(GbTx7000der))	G*	I	S-Dom
82BDM499	(SC173*SC414)	G	I	P-Dom
R90562	Aust. Line	G	G	P-Dom
88B1016	(Tx430*Rio)UC	G	VG	Dom-PDom
Tx2908/R8503	(SC599-6*Tx430)	G	G	Rec
R3338wxy		G	I	- -
P954035	IS12553der.	G	VG	- -
P898012	Feterita	F	VG	Late
Tx430		I	F-P	Rec
Tx432		I**	I	Rec
Tx433		F	F	Rec
Tx435		VG*	G	Rec
Tx436		I**	F	Rec
BE2668	(Tx2783*(SC748*SC630))	I**	F	Rec
TAM428		I**	P	- -
Tx2895/R7730	(77CS1*Tx430)	P	P	- -
OG4300-5	(Gb430*(SC170*4671))	F	P	- -
88B943	(Rio*CS3541)	I	P	- -
86E0361	(Tx432*CS3541)*SC326-6))	P	P	- -
87E0366	(TAM428*(Tx432*CS3541))	F**	P	- -
P37-3	(Tx2794*K22/35)	F	P	- -
P40-1	(Tx2794*K22/35)	F	P	- -

[1] Classification of restorer line for overall lodging resistance where: VG=very good; G=good; I=intermediate; F=fair; P=poor: VG and G also possess resistance to post-freeze stalk lodging:
* Possess excellent resistance to weak neck lodging.
** Also possess good resistance to post-freeze stalk lodging.
[2] Classification of restorer line for stay green where: VG=very good; G=good; I=intermediate; F=fair; P=poor.
[3] Overall classification of dominance of the expression of the stay green trait in F_1 hybrids where: Dom=strong dominance; P-Dom = partial dominance; S-Dom=slight dominance; Rec=complete recessive; Late = very late F_1 hybrid.

Table 3. Classification of female parental lines for lodging resistance and stay green, and dominance of the stay green trait in hybrids.

Designation	Pedigree	Lodging resistance[1]	Stay green[2]	Dominance classification in hybrids[3]
B35	IS12555der/SC35der.	VG*	VG	Dom
B1	(BTx625*B35)	G*	G	Rec
B4R	(B406xRio)	VG*	G	P-Dom
B2-1	(BTx625*B35)	VG*	G	Rec
B2-2(B)	(BTx625*B35)	G*	G	Rec
B1778	(SC56*SC33)	VG*	VG	P-Dom
B1887	(SC599*SC134)	VG*	VG	P-Dom
B599	Rio Der./SC599-6 der.	G	G	Rec
B803	(BTx3042*(BTx625*B35))	I	I	S-Dom
B805	(BTx3042*(BTx623*B35))	G	F	- -
BQL40	Australian line	G*	G	- -
BQL41	Australian line	I	G	P-Dom
BTx635	White, tan	I	I	S-Dom
BTx638	(?*BTx624)	G*	I	Rec
BTx399	Wheatland	G*	F	Rec
BTx623	(BTx3197*SC170)	P	P	- -
B807	(BTx3042*(BTx625*B35))	I	P	- -
BTx2752	(Wheatland-Redlan)der.	P	P	- -
BTx378	Redlan	P	P	- -

[1] Classification of line for overall lodging resistance where: VG=very good; G=good; I=intermediate; F=fair; P=poor: VG and G also possess resistance to post-freeze stalk lodging:
* Possess excellent resistance to weak neck lodging.
[2] Classification of line for stay green where: VG=very good; G=good; I=intermediate; F=fair; P=poor.
[3] Overall classification of dominance of the expression of the stay green trait in F_1 hybrids where: Dom=strong dominance; P-Dom = partial dominance; S-Dom=slight dominance; Rec=nearly complete recessive.

Table 4. Selected converted sorghums with excellent resistance to stalk lodging.

SC number designation	IS no.	Classification group	Country of origin
SC23-14E	12543C	Durra	Ethiopia
SC33-14E	12553C	Durra	Ethiopia
SC35-14E	12555C	Durra	Ethiopia
SC38-14E	12558C	Durra	Ethiopia
SC56-14E	12568C	Caud-Nigr	Sudan
SC146-14E	12637C	Caud-Nigr	Ethiopia
SC237-14E	3071C	Dobbs	Sudan
SC265-14E	6705C	Guin	B. Faso
SC283-14E	7173C	Consp	Tanzania
SC328-14E	8263C	Dobbs	India
SC330-14E	8187C	Nigr-Fet	India
SC564-14E	7142C	Caud	Uganda
SC587-14E	6356C	Nandyal	India
SC644-14E	8237C	Caff-Darso	India
SC689-14E	2729C	Nigr-Fet	Uganda
SC701-14E	3462C	Caud	Sudan
SC715-14E	6911C	Caud	Sudan
SC751-14E	3546C	Caud-Kaf	Sudan
SC762-14E	5437C	Caud-Kaf	India
SC773-14E	3389C	Caud-Kaf	China
SC1017-14E	11549C	Dur-Doc	Ethiopia
SC1039-14E	12171C	Sub-Dur-Doc	Ethiopia
SC1154-14E	11814C	Dur-Doc	Ethiopia

This line appears to be an excellent source of resistance to head smut in B-lines.

Fifty fully converted exotic lines and 253 partially converted bulks from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program was released and seed distributed. A white-seeded, tan-plant, waxy endosperm restorer line, Tx2907, developed cooperatively with TAM-121 and TAM-126, was released.

Several A-B pairs and R lines were selected 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.

Molecular analysis using RFLP markers, along with drought evaluation, was conducted on 100 F_7 recombinant inbred lines (RILs) each of (B35*Tx430) and (B35*Tx7000). Three QTLs were identified for the stay green trait in the cross B35*Tx7000 with one appearing to be the most important. In the cross B35*Tx430, the same three QTLs were identified for stay green along with two others, and five QTLs were identified for yield. Two populations, B35*Tx7000 and SC56*Tx7000, were developed to attempt marker assisted selection for the stay green trait using the identified QTLs. New crosses were made for molecular analysis involving other sources of drought resistance, grain mold resistance, and anthracnose resistance, and progenies will be advanced for future use.

Several F_3 and F_4 progeny from crosses generated primarily for use in Host Countries looked very good. Important traits include head bug resistance, *Striga* resistance, grain mold/weathering resistance, lodging resistance, sugarcane aphid resistance, as well as drought and disease resistance. Lines giving especially good progeny were Malisor 84-7, ICSV1089BF, Sureno, Dorado, SRN-39, Macia, WSV387, SV1, 86EON361, and 87EON366, all of which are white-seeded, tan-plant types, and TAM428.

Progeny of crosses involving new Australian B and R lines with stay green and/or midge resistance were evaluated for resistance to greenbug, midge, and stay green. Australian lines used include A&BQL41 (stay green), B86815-1-3 (stay green and midge), and R90562 (stay green and some midge).

Guinea type white-seeded, tan-plant F_7 breeding progeny from crosses involving Bimbiri Soumale (a late maturing southern Mali Guinea) looked outstanding in yield trials in Mali. 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, Malisor 92-1 and Malisor 92-2, were selected for increase and on-farm trials in 1994. Two lines from INTSORMIL/Texas, R6078 and BTx635, continued to show excellent head bug resistance.

In Honduras, a sorghum-Sudan forage sorghum, Ganadero (ATx623*Tx2784), was released. The downy mildew resistant male parent, Tx2784, was developed jointly in projects TAM-124 and TAM-122.

Networking Activities

Workshops/Conferences

Presentation on Sorghum Conversion Program at West African Sorghum Workers Workshop on Landraces, Oct. 14, 1994, Sotuba, Mali.

Participated and presented invited paper and poster at the 19th Biennial Grain Sorghum Research and Utilization Conference and SICNA Conference, March 6-7, 1995, Lubbock, TX.

Participated in USAID Management Review of INTSORMIL, December 5-6, 1994, College Station, TX.

Participated and presented paper at the annual American Society of Agronomy Meetings, Oct. 13-18, 1994, Seattle WA.

Participated in Mali IER Administrators Training, May 30-31, 1995, College Station, TX.

Participated in Soil and Crop Science Department Retreat, Aug. 22-24, 1994, Brownwood, TX.

Co-organized Food Type Sorghum Workshop, Sept. 9, 1994, TAES, Lubbock, TX.

Research Investigator Exchanges

Traveled to Mali Oct. 12-18, 1994 to evaluate the INTSORMIL/IER collaborative research program, and plan future collaborative research with the IER National Program.

Traveled to Honduras Nov. 29-Dec. 4, 1994 to evaluate the INTSORMIL/SRN/EAP collaborative sorghum research program, and plan future collaborative research for Honduras and networking possibilities for Central America.

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. 1994, and at SICNA Meeting, March 6, 1995.

Participated in INTSORMIL EZC and PI Meeting, Sept. 28-29, 1994, Kansas City, MO.

Participated in Sorghum Biotech Partnership meetings (Cargill, NK, NC+, Crosbyton, Mycogen), May 9, 1995. Texas Tech Univ., Lubbock, TX.

Traveled to Tampico, Mexico for Texas Dept. of Agriculture Sorghum Advisory Committee evaluation of growouts, Feb. 15-16, 1995.

Met with Dr. Tom Hash, Dr. Kanayo Nwanze, and Dr. John Yohe to plan upcoming Genetic Improvement Conference, May 25-26, 1995. College Station, TX.

The following individuals visited our program during the past year:

Dr. Aboubacar Toure, March 6-10, 1995

Dr. R.E. Schaffert, Feb. 6, 1995

Mr. Richard Walulu, Feb. 23, 1995

Dr. Jeff Dahlberg, Apr. 4-May 5, 1995

Drs. Kay Porter and Jim Wilson, Sept., 1994

Dr. Rod Wing, Feb 27, 1995

Dr. Jerry Johnson, Sept., 1994

Dr. K.F. Schertz, Sept., 1994

Dr. F.R. Miller, Sept. and Oct. 1994

Dr. L.W. Rooney, several, 1994 and 1995.

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.

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.

Dr. Jeff Dahlberg, Sorghum Curator, USDA/ARS, Tropical Agriculture Research Station, Mayaguez, Puerto Rico.

Dr. A. Sotomayor-Rios, Geneticist, USDA/ARS, Tropical Agriculture Research Station, Mayaguez, Puerto Rico.

Dr. L.E. Claflin, Pathologist, KSU-108, Kansas State University, Manhattan, KS.

Dr. L.M. Gourley, Sorghum Breeder, MSU-104, Mississippi State University, Mississippi State, MS.

Prof. D.J. Andrews, Sorghum/Millet Breeder, UNL-115, University of Nebraska, Lincoln, NE.

Dr. J.D. Eastin, Physiologist, University of Nebraska, Lincoln, NE.

Dr. R.R. Duncan, Sorghum Breeder, University of Georgia, Griffin, GA.

Dr. K.F. Schertz, Geneticist, USDA/ARS - Texas A&M University, College Station, TX.

Dr. John H. Mullet, Biochemist, Molecular Biology, Texas A&M University, College Station, TX.

Dr. Andrew Paterson, Molecular Biology, Texas A&M University, College Station, TX.

Dr. A.B. Onken, Soil Scientist, Texas A&M University, Lubbock, TX.

Dr. Henry T. Nguyen, Molecular Biology, Texas Tech University, Lubbock, TX.

Dr. Wenwei Xu, Molecular Biology, Texas Tech University, Lubbock, TX

Germplasm and Research Information Exchange

Germplasm Conservation and Use

Fifty fully converted exotic lines from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program were released and distributed and seed placed in permanent storage at the NSSL at Ft. Collins, Colorado. Two hundred and fifty-three partially converted bulks also were released and distributed.

Over 1300 sorghums from the Sudan Sorghum Collection were evaluated at Lubbock for photoperiod sensitivity, and non-sensitive entries crossed to standard A (male sterile) lines to evaluate for B/R fertility restorer reaction. Other items of the Sudan Collection were evaluated in Puerto Rico, Kansas, and Indiana for photoperiod sensitivity.

Preliminary plans were made to assemble all sorghums of known Malian origin from the ICRISAT Center, ORSTROM/France, U.S. introductions, and those currently stored or in use in Mali. These all would be planted together at one time in Mali, probably in 1996, to evaluate, classify, describe, and increase seed. The increased seed would be made available to all parties, and into long term storage at ICRISAT, NSSL, and ORSTROM. A small Working Collection would be selected for maintenance and active use in Mali. It would be a joint effort among INTSORMIL, IER, ICRISAT, ORSTROM and CIRAD. Some of the collections in the past never were received at ICRISAT and their only known source is ORSTROM in France.

Fifty-six new exotic sorghums were entered 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 selected by J. Dahlberg from various Puerto Rico and St. Croix increases and 25 lines from the Sudan Collection, 12 being similar to or appeared to be derivatives of the midge resistant line, AF28, and the other 13 agronomically elite or high yielding unique guinea/caudatum derivative from southern Sudan.

New introductions from Mali (24), Southern Africa Region (9), China (6), Kenya (2), Burkina Faso (1) and Niger (1) were grown and evaluated in Puerto Rico and seed increased. Five were selected as potential candidates for entry into the Conversion Program.

Seed Production and Distribution

Sets of the 50 converted lines and the 253 partially converted bulks released in May, 1995 from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program were distributed to 10 private companies and 4 public workers. 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 international and domestic collaborators. These contained sources of desirable traits such as resistance to downy mildew, anthracnose, leaf blight, rust, and charcoal rot, 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, Zimbabwe, Botswana, Zambia, and Brazil.

Assistance Given

Joint 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 Geremew Gebeyehu, a sorghum breeder from Ethiopia, and Tony McCosker, research associate from Australia. Pollinating bags and breeding supplies were provided to the Mali breeding program.

Publications and Presentations

Publications

Rosenow, D.T., J.A. Dahlberg, G.C. Peterson, L.E. Clark, F.R. Miller, A. Sotomayor-Rios, A. Queles-Belen, P. Madera, and C.A. Woodfin. 1995. Registration of 50 converted exotic sorghums. Crop Science (accepted).

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Rosenow, D.T. Sorghum Conversion Program, West African Sorghum Workers on Landrace Varieties, Oct. 14, 1994, Sotuba, Mali.

Rosenow, D.T. Sorghum growth and development, Insurance Adjusters Workshop, Sept. 14, 1994, Lubbock, TX.

Rosenow, D.T. Breeding for drought resistance, June 2, 1995, TAES, Lubbock, TX.

Rosenow, D.T., W.W. Xu, and H.T. Nguyen. Identification of molecular markers for stay green in sorghum, TAES Science Conference, Jan. 10, 1995.

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

This project is the breeding for resistance to insects component of the integrated Texas A&M University sorghum improvement program. The objectives are to identify, characterize and utilize the genetic diversity of grain sorghum to develop improved cultivars or hybrids resistant to selected biotic and abiotic stress factors, and to determine the genetic factors responsible for the resistance and their mechanisms. While breeding and selection are be done using conventional methodology, collaborative research projects have been established with biotechnology scientists to map insect traits of economic importance. Insect pests for which resistance has been identified and is utilized for include sorghum midge (*Stenodiplosis sorghicola*), biotype E and I greenbug (*Schizaphis graminum*) and yellow sugarcane aphid (*Sipha flava*).

Extensive research has been done to develop improved sorghum lines resistant to sorghum midge which are suitable for hybrid production. In addition to insect pest resistance, the lines and resulting hybrids should possess excellent yield potential under high pest density, acceptable yield in the absence of the pest, and the other needed plant traits for yield, adaptation, foliar quality, etc. This project, in collaboration with entomologists (TAM-125), has identified three A/B-line pairs which will be of use as sorghum midge resistant hybrid seed parents. In two years of trials each line has produced hybrids with yield significantly greater, under high pest density, than most resistant and susceptible checks. When the insect pest is absent, yield of the experimental hybrids is comparable to that of the susceptible hybrids. These are the first released sorghum midge resistant A/B pairs with the traits needed to produce commercially acceptable resistant hybrids.

Introduction

Sorghum production and yield stability is constrained by many biotic and abiotic stresses. Insects pose a production risk in sorghum production environments, the severity of damage depending on the insect and locale. To reduce the impact of stress, research is needed to develop crop genotypes with enhanced environmental fitness suitable for use in more sustainable production systems. To further reduce environmental risk and contribute to improved productivity in LDC and DC production systems, genetic resistance to multiple stresses should be combined in a single genotype. This is especially important as local production ecosystems (relative to cultivars and technology) experience induced change with the natural balance between cultivars and biotic stresses also being changed and insect damage becoming increasingly severe.

To meet the demands of increased food production in an economically profitable, environmentally sustainable production system genetic resistance can be utilized at no additional cost to the producer. This requires a multi-disciplinary research program to integrate resistance hybrids into the management system. Cultivars resistant to insects will readily integrate with other required inputs as part of an integrated, ecologically sound production and stress control strategy with large potential benefits in subsistence and mechanized agriculture. Host plant resistance to insects is a continual effort in response to a dynamic evolving production agroecosystem.

Among the major constraints to sorghum production in Sahelian Africa are: soil acidity, extremely deficient levels of N and P, spatially variable soil toxicity and limited available water. These factors frequently interact with food shortages being the result. Solutions to these problems must meet site specific needs of soil, rainfall, resources, labor and capital.

Objectives, Production and Utilization Constraints

Objectives

Obtain and evaluate germplasm for resistance to arthropod pests. Determine the resistance source or mechanisms most useful to sorghum improvement.

Determine the inheritance of insect resistance.

Develop and release high yielding, agronomically improved sorghums resistant to selected insects.

Utilization biotechnology to increase understanding of the genetics of plant resistance traits.

Identify and define sorghum genotypes with varying levels or tolerance to drought and chemical stress of Sahelian soils.

Constraints

Sorghum yield stability is constrained by many biotic and abiotic stresses. Insects pose a risk in all areas of sorghum production with damage depending on the insect and local environment. To reduce stress impact, research is needed to develop crop genotypes with enhanced environmental fitness suitable for use in more sustainable production systems. Genetic resistance to multiple stresses in a single genotype will further reduce environmental risk and contribute to improved productivity. This is especially important as production ecosystems experience induced change due to cultivars and/or technology, the natural balance between cultivars and biotic stresses also being changed and insect damage becoming increasingly severe.

Sorghum midge, *Stenodiplosis sorghicola*, is the only ubiquitous sorghum insect pest and may be the *Sorghum* species most destructive insect pest. As LDC programs introduce exotic germplasm with improved agronomic traits into sorghum improvement programs, progeny and eventually cultivars which are more photoperiod insensitive will be developed and sorghum midge damage will become increasingly severe. Depending on the environment other insect pests (including aphids, head bugs and borers) will damage grain sorghum. For all of the insect pests genetic resistance exists and can be integrated into the production system in an ecologically safe, economically inexpensive, and environmentally sustainable manner. Cultivars resistant to insects will readily integrate with other required inputs as part of an integrated, ecologically sound production and stress control strategy with large potential benefits in subsistence and mechanized agriculture. Host plant resistance to insects is a continual effort in response to a dynamic evolving production agroecosystem.

Research Approach and Project Output

Research Methods

The research approach is to conduct collaborative research in LDCs on specific problems. On-site research is supported by participation in graduate education, germplasm exchange and evaluation, site visits, and research conducted at various nursery locations in Texas. Primary LDC involvement is in Africa for resistance to head bugs and identification of sorghum genotypes resistant/tolerant to soil toxicity. For the United States, sorghum midge, greenbug and yellow sugarcane resistant sources have been identified and are used in developing elite resistant sorghums. Through collaborative ties with other projects genetic inheritance and resistance mechanisms are determined, and mapping research for the greenbug resistance genes is on-going.

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 of 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. For studies on head bug resistance using biotechnology, segregating populations will be grown in Mali and tissue samples collected for analysis in the U.S.

For soil toxicity research, diverse cultivars from the breeding programs at Lubbock and introductions from LDCs are evaluated in field nurseries at Cinzana, Mali. Lines which show promise are selected for further evaluation. When possible crosses will be made between soil toxicity resistant sorghums and other elite genotypes to combine the trait into genotypes suitable for use in the local production system.

Research Findings

Research to broaden the genetic base of the sorghum midge resistance breeding program, to incorporate additional sources of resistance into elite lines, to identify new superior R-lines, and to identify new A-lines with excellent resistance and yield potential continued. Significant progress has been made in the last five years in improving the agronomic eliteness of sorghum midge resistant germplasm, and in improving the yield potential of experimental A-lines.

Elite advanced lines were evaluated in the replicated Midge Line Test for resistance to sorghum midge and agronomic desirability (Table 1). Twenty-four of sixty experimental entries were selected for additional evaluation and testing. Ten experimental B-lines which had been sterilized (A1 cytoplasm) were included in the test, and three were selected for release based on line appearance. The selected lines are designated MB104-91NF6, MB110-B92NF3 and MB110-B93NF6. The resistance source for each line is TAM2566. TAM2566 originated as SC175-9 , a partially converted zera zera (IS12666) from Ethiopia. Combining ability of the three lines for yield potential and sorghum midge resistance in hybrids is under investigation. A major constraint to production and use of sorghum midge resistant hybrids has been the lack of superior A-lines which possess excellent resistance and grain yield potential under pest infestation, and excellent grain yield potential in the absence of the pest. If these lines possess the needed characteristics, they represent a significant advance in A-line breeding material and could make a potentially major contribution to use of sorghum midge resistant hybrids.

Grain yield, midge damage rating, and selected agronomic traits for the Midge Hybrid Test are shown in Table 2. The standard resistant hybrid check is ATx2755*Tx2767 and the standard susceptible check is ATx2752*RTx430. Most experimental hybrids produced significantly more grain than did the susceptible checks within and over locations. Additionally, several experimental hybrids produced significantly more grain than the resistant checks. Differences between hybrids were greater at Corpus Christi under high pest density. While the differences were not as large under moderate density (at College Station) the experimental hybrids still expressed better yield potential and resistance than previously available resistant hybrids, or susceptible checks. Differences at College Station under moderate pest density represent grain yield potential under conditions more likely to be encountered in producers fields.

Grain yield by females in the Midge Hybrid Test (Table 3) led to the conclusion that the three lines selected for release possess excellent yield potential and resistance under high population density. Under moderate pest density the lines also expressed yield potential significantly greater than that of resistant or susceptible checks.

Selection continued in the development of new germplasm resistant to biotype E or I greenbug. Advanced hybrid trials were conducted to test new R- and A-lines in hybrid combination. Five superior R-lines resistant to biotype E were selected for final pre-release testing. Two of the lines are in a tan plant, white pericarp genetic background with excellent foliar disease resistance. The lines could be useful in developing food type sorghums with improved biotic stress resistance. Selections to develop biotype I resistant lines were made in F_2 populations, and in BC_1F_2 or BC_2F_2 populations. Selections will be screened against both biotypes to check for resistance. Many crosses were made to introgress the resistance gene(s) into an array of elite germplasm.

Research continued to introgress genes for resistance to yellow sugarcane into elite adapted material. Evaluation of F_4 generation progeny, derived from PI457709, resulted in identification of six progeny which express a useful level of resistance. Selections were made in F_2 populations to combine the PI457709 yellow sugarcane aphid resistance gene with biotype E greenbug resistance. F_2 progeny derived from PI453951 were selected. Due to the high photoperiod sensitivity of PI453951, selection was primarily for types which are short and will flower in a temperate environment.

Populations were grown to develop genetic material to map the greenbug resistance genes using RFLPs. Initial primary emphasis will be on the cross RTx430*PI550607 (greenbug susceptible * biotype E/ I resistant). Preliminary data indicate that segregation will be found for resistance to both biotypes, and that progeny should be screened against both biotypes to insure recovery of resistance. Additional populations are being developed to subsequently map resistance genes in biotype C or C/E resistance sources.

Table 1. Mean midge damage rating, desirability, leaf and plant death, and insecticide phytotoxicity in the Midge Line Test, 1994.

	Midge damage rating[†]			Desirability[‡]			Leaf/Plant death[§]			Insecticide phytotoxicity[¶]		
Pedigree	Mean#	CC	CS	Mean	CC	CS	Mean	CC	CS	Mean	CC	CS
Tx2878	1.7	2.3	1.0	2.6	2.6	2.6	43	43	43	3.4	2.8	4.0
(PM12713*Tx2766)-CM2-CM1	1.7	2.0	1.3	2.6	2.5	2.6	68	73	63	1.7	1.3	2.0
Tx2882	1.8	2.0	1.7	2.5	2.4	2.5	57	60	53	2.3	2.6	2.0
MR126-BM5-BM2-LMBK-CM2-LMBK	1.8	2.3	1.3	2.7	2.6	2.7	45	40	50	1.9	1.5	2.3
(Tx2782*Tx2878)-BM47-CM2	1.8	2.0	1.7	2.7	2.7	2.7	77	83	70	2.8	2.5	3.0
Tx2767	2.0	2.3	1.7	2.7	2.5	2.8	52	53	50	2.6	1.9	3.3
(Tx2782*Tx2878)-BM16-CM2	2.0	2.7	1.3	2.6	2.5	2.6	60	60	60	2.8	2.9	2.7
Tx2782	2.2	2.3	2.0	3.0	3.1	2.9	63	60	67	2.2	2.4	2.0
MR114-90M11	2.2	2.3	2.0	2.5	2.6	2.4	48	43	53	2.3	2.6	2.0
MB120A-BM57-CC1-BM1-LMBK-CMBK	2.2	3.0	1.3	2.6	2.5	2.6	79	88	70	2.2	2.4	2.0
(((SC572-12*SC642-14)-B17-L1-CC1-CC1)*Tx2872)-SM1-CM2	2.2	2.7	1.7	2.5	2.6	2.4	62	57	67	2.9	3.4	2.3
(MR114-90M11&Tx2767)-SM5	2.2	3.3	1.0	2.5	2.5	2.4	63	63	63	2.3	2.7	2.0
(MR114-90M11*6EO361/(R5646*SC326-6))-SM6-CM1	2.2	2.3	2.0	2.5	2.3	2.7	48	37	60	1.5	1.4	1.7
MB110-B92NF3	2.3	3.0	1.7	2.6	2.6	2.6	48	37	60	2.4	2.8	2.0
(Tx2877*86PL2119,20)-BM22-LMBK-CM1-CM2	2.3	2.7	2.0	2.4	2.4	2.4	55	50	60	3.4	3.2	3.7
(Tx2877*86PL219,20)-BM22-LMBK-CM2-CM1	2.3	2.7	2.0	2.5	2.4	2.5	53	60	47	2.0	2.0	2.0
(((SC572-12*SC642-14)-B17-L1-CC1-CC1)*Tx2872)-SM1-CM2	2.3	2.7	2.0	2.9	3.0	2.7	60	53	67	3.0	3.3	2.7
(((Tx2767*SC693-14)-B6-L1-BM1-BM1)*Tx2882)-SM8-CM1	2.3	2.7	2.0	2.4	2.4	2.5	43	27	60	1.8	1.7	2.0
(Tx2782*Tx2878)-SM6-LMBK	2.3	2.7	2.0	2.7	2.6	2.7	65	63	67	2.3	2.3	2.3
(Tx2880*Tx2882)-BM2-LMBK	2.3	3.3	1.3	2.6	2.7	2.5	58	50	67	2.3	2.7	2.0
(MR114-90M11*Tx2767)-SM9	2.3	3.7	1.0	2.4	2.3	2.4	55	47	63	2.3	2.6	2.0
(((SC228-14*Tx2767)-2-B2-MX2-LM2*Tx2876)-CM4	2.3	2.7	2.0	2.5	2.5	2.6	48	40	57	2.1	1.6	2.7
(((Tx2767*SC693-14)-B6-L1-BM1-CC1)*Tx2872)-SM3-CM2	2.5	3.3	1.7	2.4	2.5	2.3	65	67	63	2.8	3.6	2.0
(Tx2872*Tx2880)-SM10	2.5	3.0	2.0	2.6	2.6	2.5	58	60	57	2.3	2.5	2.0
(TX2880*Tx2882)-BM1-LMBK	2.5	3.3	1.7	2.5	2.6	2.5	53	47	60	2.3	2.5	2.0
(MR114-90M11*Tx2767)-SM8	2.5	2.7	2.3	2.4	2.5	2.3	55	53	57	2.4	2.7	2.0
MB108B P.G.	2.7	3.7	1.7	2.0	1.8	2.1	67	63	70	2.2	2.3	2.0
(GB102A-10-6-5-3-1-L3-LBK*Tx2755)-BM43-LMBK	2.7	2.7	2.7	2.6	2.6	2.5	57	53	60	2.6	3.1	2.0
(((TX2767*SC693-14)-B6-L1-BM1-CC1)*Tx2872)-SM3-CM1	2.7	4.0	1.3	2.7	2.8	2.6	48	40	57	2.0	2.1	2.0
(Tx2782*Tx2878)-BM28-LMBK	2.7	2.7	2.7	2.6	2.5	2.8	62	70	53	2.4	1.8	3.0
(MR112-6-B1-L1-CC1*Tx2872)-CM3-CM3	2.7	3.3	2.0	2.7	2.6	2.7	50	57	43	2.2	2.3	2.0
MB104-B92NF9	2.8	3.0	2.7	2.7	2.6	2.7	48	47	50	2.2	2.3	2.0
MB110-B93NF4	2.8	3.0	2.7	2.5	2.4	2.5	52	43	60	2.6	3.2	2.0
(MB110-21-L1-BM2-CC1*Tx623)-CM8-CM1	2.8	3.0	2.7	2.4	2.4	2.4	63	60	67	1.9	1.9	2.0
(MB110-21-L1-BM2-CC1*Tx623)-CM11-LMBK	2.8	3.0	2.7	2.5	2.5	2.5	67	60	73	2.1	2.1	2.0
(Tx2782*Tx2876)-BM13-CM2	2.8	3.0	2.7	2.4	2.4	2.5	64	58	70	2.1	2.2	2.0
(Tx2872*Tx2880)-BM5	2.8	3.7	2.0	2.6	2.5	2.6	58	53	63	2.5	2.9	2.0
(TX2880*Tx2882)-BM2-CM1	2.8	4.0	1.7	2.5	2.5	2.6	57	53	60	2.5	2.7	2.3
(MB108B/P.G.*MB116A-BM10-CS1-CS2-SMBK)-SM1	2.8	3.0	2.7	2.6	2.4	2.7	65	60	70	2.2	2.3	2.0
Tx2880	3.0	4.3	1.7	2.7	2.8	2.5	52	43	60	2.5	2.9	2.0
MR112B-92M5	3.0	4.7	1.3	2.4	2.5	2.3	40	33	47	2.0	1.9	2.0
(Tx2887*Tx2890)-BM2-LMBK	3.0	3.7	2.3	2.7	2.9	2.5	67	63	70	2.4	2.8	2.0
(MB108B/P.G.*MB110-49-B2-CC2-CC1-LMBK)-SM4	3.0	3.3	2.7	2.5	2.3	2.7	58	50	67	2.5	3.0	2.0
MR112BG-92M4	3.2	4.0	2.3	2.6	2.6	2.5	50	47	53	1.9	1.8	2.0
(86E0362*MR106-1/Tx2883)-SM6-CM1	3.2	3.3	3.0	2.4	2.5	2.4	53	53	53	1.8	1.5	2.0
(86E0362*MR103-3/Tx2880)-SM10-CM2-CM2	3.2	4.0	2.3	2.4	2.4	2.4	47	33	60	2.0	1.9	2.0
(Tx2782*Tx2878)-BM12-LMBK	3.2	4.3	2.0	2.7	2.7	2.7	65	60	70	2.4	2.4	2.3
(Tx2782*Tx2878)-BM50-CM2	3.2	3.7	2.7	2.7	2.7	2.8	58	60	57	2.3	2.2	2.3
(Tx2872*Tx2880)-SM6	3.2	4.7	1.7	2.6	2.7	2.5	67	60	73	2.3	2.7	2.0
(Tx2872*Tx2880)-SM7	3.2	4.3	2.0	2.7	2.6	2.7	60	50	70	2.4	2.7	2.0
(Tx280*Tx28820-SM7-LMBK	3.2	3.3	3.0	2.5	2.4	2.5	57	53	60	2.3	2.7	2.0
(PM12713*Tx2767)-CM1-LMBK	3.2	4.0	2.3	2.8	2.7	3.0	53	57	50	1.9	1.7	2.0
MR112B-92M2	3.3	5.7	1.0	2.6	2.8	2.5	53	37	70	1.8	1.6	2.0
MB104-B91NF6	3.3	3.7	3.0	2.7	2.8	2.6	60	57	63	2.2	2.4	2.0

Table 1. - Continued.

Pedigree	Midge damage rating†			Desirability‡			Leaf/Plant deaths§			Insecticide phytotoxicity¶		
	Mean#	CC	CS	Mean	CC	CS	Mean	CC	CS	Mean	CC	CS
MB110-B93NF6	3.3	4.3	2.3	2.5	2.4	2.6	43	33	53	2.6	3.2	2.0
MB120A-BM35-CS1-CM1-LMBK-CM1-CMBK	3.3	4.0	2.7	2.7	2.8	2.6	48	50	47	2.5	3.0	2.0
Tx2755	3.5	4.3	2.7	2.7	2.7	2.6	60	50	70	2.4	2.8	2.0
(Tx2872*Tx2880)-BM8	3.5	5.0	2.0	2.6	2.7	2.5	57	57	57	2.4	2.5	2.3
MB104-B9INF8	3.8	4.7	3.0	2.7	2.8	2.6	53	53	53	2.3	2.6	2.0
MB104-B92NF8	3.8	4.7	3.0	2.6	2.7	2.6	47	43	50	2.4	2.8	2.0
MB110-B93NF5	1.0	5.3	2.7	2.5	2.5	2.6	50	40	60	2.7	3.3	2.0
((SC572-14*SC642-14)-B17-L1-CC1*Tx2872)-CM5-CM2	1.0	5.7	2.3	2.6	2.6	2.5	48	47	50	2.2	2.3	2.0
MB104-B93NF1	4.3	6.0	2.7	2.7	2.9	2.5	58	57	60	2.3	2.6	2.0
MB110-B93NF6	4.3	5.7	3.0	2.5	2.5	2.4	45	37	53	2.7	3.3	2.0
(88B885/(Tx623*CS3541)*Tx2755)-SM3-CM1	4.3	5.3	3.3	2.7	2.6	2.8	67	57	77	2.3	2.5	2.0
(Tx430*Tx2871)-SM13	4.8	7.3	2.3	2.4	2.4	2.3	47	43	50	2.5	2.9	2.0
Tx2801	5.7	7.7	3.7	2.5	2.4	2.6	50	40	60	2.4	2.7	2.0
TAM2566	5.7	8.0	3.3	3.0	3.1	2.9	63	70	57	3.6	3.2	4.0
Tx378	6.7	8.7	4.7	3.2	3.2	3.1	50	40	60	2.0	2.0	2.0
Tx623	6.7	8.3	5.0	2.6	2.4	2.8	42	40	43	2.3	2.6	2.0
Tx430	6.7	8.3	5.0	2.5	2.2	2.7	42	33	50	2.2	2.3	2.0
Tx3042	9.0	9.0	9.0	3.1	3.0	3.2	52	50	53	2.4	2.9	2.0
LSD .05	0.7	1.1	2.4									

† Rated on scale of 1=0-10% blasted kernels, 2=11-20% blasted kernels, ...9=81-100% blasted kernels.
‡ Rated on scale of 1=most desirable to 5=least desirable.
§ Rated on percent death at maturity.
¶ Rated on scale of 1=no phytotoxicity to 5=100% phytotoxicity.

Table 2. Mean, grain yield, midge damage rating, and selected agronomic traits at Corpus Christi and College Station, Midge Hybrid Test, 1994.

Hybrid	Grain yield (kg/ha)			Midge damage rating†			Desirability‡			Plant height (cm)	Panicle exsertion (cm)	Leaf and plant death	Insecticide phytotoxicity
	Mean	CC	CS	Mean	CC	CS	Mean	CC	CS				
A93NF6(MB110)*Tx2880	4581	2885	6277	2.2	2.7	1.7	2.3	2.3	2.4	128	22	47	2.5
A92NF3(MB110)*Tx2882	4457	2277	6636	2.5	3.3	1.7	2.3	2.4	2.2	113	10	40	2.4
A92NF9(MB104)*Tx2767	4325	1777	6874	3.2	4.7	1.7	2.4	2.6	2.2	132	14	45	2.2
A91NF1(MB102)*Tx2880	4223	1326	7120	3.0	4.7	1.3	2.4	2.5	2.2	127	7	43	2.4
A91NF6(MB104)*Tx2880	4162	1851	6472	3.3	4.7	2.0	2.5	2.6	2.4	132	14	45	2.5
A92NF9(MB104)*Tx2880	4138	1546	6729	3.8	5.7	2.0	2.5	2.8	2.3	130	11	45	2.5
ATx2755*Tx2880	4086	2164	6007	3.5	4.7	2.3	2.4	2.5	2.3	122	13	48	2.7
A91NF6(MB104)*Tx2882	4076	2195	5957	3.0	3.7	2.3	2.4	2.4	2.3	122	13	42	2.3
A92NF8(MB104)*Tx2882	4046	1812	6280	3.7	4.7	2.7	2.3	2.4	2.2	118	16	43	2.5
A92NF8(MB104)*Tx2767	3997	1441	6554	3.8	5.3	2.3	2.4	2.5	2.3	136	12	42	2.3
A92NF8(MB104)*Tx2880	3856	1875	5837	3.5	4.7	2.3	2.5	2.6	2.3	131	15	42	2.6
A91NF8(MB104)*Tx2767	3854	1657	6052	3.3	4.7	2.0	2.4	2.4	2.4	136	11	47	2.3
(ATx2755*BTx2801)*MB108B	3854	1668	6039	4.2	5.7	2.7	2.1	2.1	2.2	172	14	45	2.3
A91NF6(MB104)*Tx2767	3788	1310	6265	3.8	6.0	1.7	2.4	2.6	2.2	133	10	47	2.3
(ATx2801*BTx2755)*Tx2767	3774	1496	6053	4.0	5.7	2.3	2.4	2.5	2.3	133	10	45	2.4
(ATx2801*BTx2755)*Tx2880	3774	1580	5969	3.5	5.0	2.0	2.4	2.5	2.3	126	18	50	2.7
(ATx2755*BTx2801)*Tx2880	3770	1720	5821	3.5	4.7	2.3	2.5	2.5	2.4	128	9	47	2.7
A92NF9(MB104)*Tx2882	3769	1944	5593	3.0	3.7	2.3	2.4	2.5	2.3	118	11	43	2.4
(ATx2801*BTx2755)*MB108B	3759	921	6597	5.0	7.3	2.7	2.2	2.3	2.0	168	17	40	2.3
ATx2755*Tx2767	3659	1551	5768	4.0	6.0	2.0	2.5	2.5	2.5	128	12	48	2.3
A91NF8(MB104)*Tx2882	3655	1660	5650	3.4	4.1	2.7	2.3	2.3	2.2	135	12	40	2.4
A93NF4(MB110*Tx2767	3564	1687	5441	3.0	4.7	1.3	2.4	2.4	2.3	143	12	43	2.6
A93NF6(MB110)*Tx2882	3537	1900	5174	3.3	4.3	2.3	2.3	2.4	2.3	119	11	38	2.6
ATx2755*MB108B	3530	1086	5974	5.2	7.0	3.3	2.3	2.3	2.2	158	17	43	2.3
ATx2801*Tx2882	3523	1403	5642	4.2	5.3	3.0	2.4	2.5	2.2	124	12	43	2.4

Table 2. - Continued.

Hybrid	Grain yield (kg/ha) Mean	CC	CS	Midge damage rating† Mean	CC	CS	Desirability‡ Mean	CC	CS	Plant height (cm)	Panicle exsertion (cm)	Leaf and plant death	Insecticide phytotoxicity
A91NF1(MB102)*Tx2882	3498	1432	5564	3.5	4.7	2.3	2.3	2.5	2.1	123	8	37	2.2
ATx2755*MR127-92M5	3496	619	6373	5.3	7.3	3.3	2.1	2.3	1.9	176	19	35	2.3
A91NF1(MB102)*Tx2767	3413	1831	4994	3.0	4.7	1.3	2.5	2.5	2.4	133	7	47	2.2
A93NF5(MB110)*Tx2882	3404	1890	4919	3.2	4.0	2.3	2.4	2.3	2.4	116	11	43	2.4
ATx2801*MB108B	3400	1160	5640	4.7	7.0	2.3	2.0	2.1	1.9	175	14	43	2.1
ATx2755Tx2882	3362	1237	5486	4.5	6.0	3.0	2.4	2.5	2.3	109	9	48	2.4
(ATx2755*BTx2801)*Tx2882	3321	1184	5458	4.5	5.7	3.3	2.4	2.5	2.2	116	9	42	2.5
ATx2755*MR127-92M5	3253	1069	5437	4.3	6.0	2.7	2.4	2.4	2.3	153	18	40	2.4
A93NF4(MB110)*Tx2880	3223	1600	4845	2.8	3.7	2.0	2.4	2.4	2.4	126	13	47	2.5
A91NF8(MB104)*Tx2880	3213	1946	4479	3.5	3.7	3.3	2.4	2.5	2.4	131	11	42	2.5
A93NF4(MB110)*Tx2882	3168	1655	4681	3.2	3.7	2.7	2.4	2.3	2.4	123	8	40	2.4
(ATx2801*BTx2755)*Tx2882	3087	1059	5115	4.5	6.3	2.7	2.4	2.5	2.2	117	9	40	2.6
(ATx2755*BTx2801)*Tx2782	3074	1349	4799	4.0	4.7	3.3	2.6	2.7	2.4	110	11	45	2.5
ATx2755*MR114-90M11	3052	1341	4762	4.7	6.7	2.7	2.4	2.6	2.3	123	16	42	2.3
ATx2755*MR112B-92M2	3017	517	5517	5.2	8.0	2.3	2.4	2.6	2.3	139	18	45	2.9
ATx2752*Tx2783	2981	324	5639	5.8	8.7	3.0	2.5	2.7	2.2	138	7	38	2.3
ATx2755*MR127-92M4	2954	924	4984	4.8	7.3	2.3	2.6	2.7	2.4	121	14	43	2.8
(ATx2755*BTx2801)*Tx2767	2944	1285	4603	4.3	5.7	3.0	2.5	2.5	2.4	132	11	45	2.7
ATx2801*MR114-90M11	2885	947	4823	4.8	7.3	2.3	2.6	2.6	2.6	144	14	47	2.4
ATx2755*Tx2782	2880	1356	4405	5.2	6.3	4.0	2.6	2.6	2.5	104	12	47	2.8
ATx2801*Tx2782	2799	706	4892	5.0	7.0	3.0	2.5	2.6	2.4	130	14	45	2.3
A1*Tx2864	2703	355	5051	6.3	8.7	4.0	2.4	2.3	2.4	128	6	40	2.3
ATx2801*MR127-92M4	2669	496	4841	6.0	8.0	4.0	2.4	2.5	2.2	134	16	47	3.0
ATx2801*Tx2767	2646	818	4475	5.0	7.3	2.7	2.5	2.5	2.5	141	13	47	2.5
(ATx2801*BTx2755)*Tx2782	2625	888	4361	5.3	7.0	3.7	2.5	2.6	2.5	120	11	43	2.5
ATx2801*MR112B-92M2	2543	216	4870	6.0	8.3	3.7	2.5	2.8	2.3	159	20	48	2.5
ATx2755*Tx430	2539	243	4835	6.3	9.0	3.7	2.5	2.4	2.5	129	11	45	2.4
ATx2801*Tx430	2114	171	4057	7.0	9.0	5.0	2.4	2.4	2.3	143	10	38	2.6
ATx2752*Tx2864	1976	339	3613	7.0	8.7	5.3	2.7	2.7	2.7	124	10	37	2.3
A35*Tx2862	1805	118	3492	7.5	9.0	6.0	2.4	2.5	2.3	140	13	37	2.4
A35*Tx2864	1769	208	3329	6.8	8.7	5.0	2.5	2.6	2.4	132	14	33	2.4
ATx399*Tx430	1744	102	3386	7.5	9.0	6.0	2.4	2.3	2.5	123	12	38	2.0
ATx2752*Tx430	1493	57	2929	7.2	9.0	5.3	2.5	2.4	2.6	134	10	37	2.1
A1*Tx2783	1267	185	2350	7.5	9.0	6.0	2.4	2.4	2.4	148	7	38	2.3
ATx3042*Tx2737	321	54	587	9.0	9.0	9.0	2.6	2.5	2.7	135	20	38	2.3
LSD .05	421	379	889	0.8	1.3	0.8							

† Rated on scale of 1=0-10% blasted kernels, 2=11-20% blasted kernels, ...9=81-100% blasted kernels.
‡ Rated on scale of 1=most desirable to 5=least desirable.
§ Rated on percent death at muturity.
¶ Rated on scale of 1=no phytotoxicity to 5=100% phytotoxicity.
# Mean of two locations - CC=Corpus Christi, CS=College Station

A 46 entry paired plot screening nursery for soil toxicity was grown on the Cinzana Experiment Station at a previously selected site. The research was a continuation of activity previously conducted jointly with the Soil Management CRSP. Bagoba was used as the resistant check and Malisor 84-5 was used as the susceptible check. The nursery was evaluated on October 20, 1993. Plant stand counts had been previously taken by Malian collaborators on six dates beginning approximately 10 days after planting. Preliminary indications are that the first 21 days after planting are critical in plant growth and development in soil toxicity areas. A Gadiaba selection from the Cinzana Station had plant counts equal to the resistant check (Bagoba). Genotypes from West Africa such as N'Gaberi Kime' and El Mota performed better than did most introductions. Several genotypes previously identified as tolerant to acid soil conditions in Georgia had poor germination, indicating that different plant response factors were probably involved. Plant and soil samples from sites in the field where plants died were taken but have not been analyzed. Based on data obtained during 1994, another 46 entry paired plot test was sent to Mali for planting at the Cinzana Station. Thirty three genotypes with acceptable performance in 1994 were included in addition to 13 new entries.

Breeding lines were grown at Lubbock to initiate development of populations to use in the study of head bug resistance in sorghum. Populations will be developed for use in Mali to classify for resistance. Molecular marker techniques will be used to identify resistant genotypes when appropriate.

Approximately 1,000 entries from the Sudan sorghum collection were grown at Lubbock to classify for photope-

Table 3. Mean grain yield, midge damage rating, and desirability of entries in Midge Hybrid Test, 1994, by female.

	Grain yield (kg/ha)			Midge damage rating†			Desirability‡		
Female	Mean §	CC	CS	Mean	CC	CS	Mean	CC	CS
A92NF3(MB110)	4457	2277	6636	2.5	3.3	1.7	2.3	2.4	2.2
A92NF9(MB104)	4077	1756	6399	3.3	4.7	2.0	2.5	2.6	2.3
A93NF6(MB110)	4059	2392	5725	2.8	3.5	2.0	2.3	2.3	2.3
A91NF6(MB104)	4008	1785	6232	3.4	4.8	2.0	2.4	2.5	2.3
A92NF8(MB104)	3966	1709	6224	3.7	4.9	2.4	2.4	2.5	2.3
A91NF1(MB102)	3711	1530	5893	3.2	4.7	1.7	2.4	2.5	2.2
A91NF8(MB104)	3574	1754	5394	3.4	4.1	2.7	2.4	2.4	2.3
A93NF5(BM110)	3404	1890	4919	3.2	4.0	2.3	2.4	2.3	2.4
A2801*B2755	3404	1189	5619	4.5	6.3	2.7	2.4	2.5	2.3
A2755*B2801	3393	1441	5344	4.1	5.3	2.9	2.4	2.5	2.3
A93NF4(MB110)	3318	1647	4989	3.0	4.0	2.0	2.4	2.4	2.3
ATx2755	3257	1101	5413	4.8	6.8	2.9	2.4	2.5	2.3
ATx2801	2822	740	4905	5.3	7.4	3.3	2.4	2.5	2.3
ATx2752	2150	240	4060	6.7	8.8	4.6	2.6	2.6	2.5
A1	1985	270	3700	6.9	8.8	5.0	2.4	2.4	2.4
A35	1787	163	3411	7.2	8.8	5.5	2.5	2.6	2.4
ATx399	1652	102	3386	7.5	9.0	6.0	2.4	2.3	2.5
ATx3042	321	54	587	9.0	9.0	9.0	2.6	2.5	2.7
LSD .05	421	889	379	0.8	1.3	0.8			

† Rated on scale of 1=0-10% blasted kernels, 2=11-20% blasted kernels, ...9=81-100% blasted kernels.
‡ Rated on scale of 1=most desirable to 5=least desirable.
# Mean of two locations - CC=Corpus Christi, CS=College Station

riod response. The data from photoperiod response was provided to the USDA Sorghum Curator to add to the descriptive plant traits (over 30) taken at St. Croix during the prior winter growout. The data is available on the USDA GRIN (Germplasm Resources Information Network) system. Eighty-five lines from the collection were planted in a two replication trial at Corpus Christi and 190 entries in an observation trial at College Station to evaluate genotypes for resistance to sorghum midge. During the summer of 1994, crosses were made between Sudan introductions, which flowered at Lubbock, and standard A-lines to check for fertility restoration. These progeny were planted at Lubbock in 1995 and will be scored for fertility restoration at anthesis or maturity.

Networking Activities

Workshops

Served as breeding/genetics discipline chair for the 19th Biennial Grain Sorghum Research and Utilization Conference, Mar. 5-7, 1995, Lubbock, TX. Presented an invited paper and a poster paper.

Research Investigator Exchanges

Traveled to Honduras - July 8-14, 1994. Participated in the USAID Review of CRSPs. The review team met with officials of USAID/Honduras, Escuela Agricola Panamericana (EAP), Ministry of Natural Resources (SRN), and each of the CRSPs active in Honduras. Evaluated field research at Zamorano, Rapaco and the Choluteca region.

Traveled to Mali - Oct. 8-22, 1994. Trained IER breeding collaborators in use of computer software for breeding program management. Evaluated cooperative IER/INTSORMIL research at Sotuba, Cinzana, Sikasso and Longrolla. Met with ICRISAT/WASIP scientists at Samanko. Developed future collaborative research plan for research on soil toxicity and resistance to insects.

Traveled to Honduras - Nov. 29-Dec. 4, 1994. Evaluated collaborative research at Zamorano, Rapaco, Choluteca and Olancho. Discussed collaborative research program activities with representatives of the Escuela Agricola Panamericana (EAP) and USAID/Honduras.

Served as Co-Host for Mr. Tony McCosker, DPI, Queensland, Australia. Mr. McCosker did research on resistance to sorghum midge, greenbug and drought.

Mr. John Jastor and Mr. John Kruger, Pioneer Hi-Bred Intl., Taft, TX.

Dr. Joe Raab, Dekalb Plant Genetics, Robstown, TX.

Dr. A. Touré, IER, Bamako, Mali.

Participated in Sorghum Crop Germplasm Committee (CGC) meeting Mar. 6, 1995, at Lubbock, TX.

Germplasm and Research Information Exchange

Germplasm Conservation Use

Accessions from the Sudan collection and the sorghum conversion program were grown for increase and evaluation. Releases from the sorghum conversion program will be deposited in the National Seed Storage Laboratory. Germplasm was distributed to private companies as requested and to the following countries, including but not limited to: Mali, Botswana, China, Argentina and Niger. Entries in the All Disease and Insect Nursery (ADIN) were evaluated at many locations domestically and internationally.

Seed of three A/B-line pairs was planted to increase for release. Seed of one A-line and two previously released R-lines was provided to a private company to produce two sorghum midge resistant hybrids for large scale testing.

Germplasm previously developed and released by this project is used in hybrid seed production by several private companies. Biotype E greenbug resistant R-lines from this project are widely used in the production of greenbug resistant hybrids.

Provided computer supplies to Malian breeding collaborators. Trained Malian IER breeding collaborators in the use of computer software. Assistance was given to Mr. Tony McCoker, DPI, Queensland, Australia during his study leave at Lubbock. Assistance consisted of research support for the duration of his research program at Lubbock.

Other Cooperators

Collaboration with the following scientists was important in the activities of TAM-123:

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Publications and Presentations

Abstracts

Peterson, G.C., J. Dahlberg, D.K. Mulitze, D.T. Rosenow, and F.R. Miller. 1994. Comparison of nearest neighbor analysis vs randomized complete block analysis for grain sorghum performance trials. Agronomy Abstracts. Nov. 13-18, 1994. Seattle, WA. p. 192.

Anderson, R., J. Jones, B. Pendleton, K. Schaefer, G.C. Peterson, and G.L. Teetes. 1995. Development of germplasm resistant to sorghum midge. 19th Biennial Grain Sorghum Research and Utilization Conference. Mar. 5-7, 1995. Lubbock, TX (in press).

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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 flowering. Crop Sci. 34:1263-1266.

Miscellaneous Publications

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Peterson, G.C., G.L. Teetes, R.M. Anderson, and B.B. Pendleton. 1994. Yield and selected traits of sorghum midge-resistant hybrids. Annual Plant Resistance to Insects Newsletter 20:30-31.

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Breeding Sorghum for Stability of Performance Using Tropical Germplasm

Project UNL-115
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Mr. Issoufou Kapran, Sorghum Breeder, INRAN, B.P. 429, Niamey, Niger
Drs. J. W. Stenhouse and Belum Reddy, Sorghum Breeders, ICRISAT/India
Dr. D. T. Rosenow, Sorghum Breeder, TAM-122, Texas A&M Agricultural Experiment Station, Lubbock, TX
Dr. Paula Bramel-Cox, Sorghum Breeder, Kansas State University, Manhattan, KS
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Summary

Most sorghum is grown for food in low resource semiarid (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. hybrid sorghum parents. In turn the genetic base of hybrid parents in the U.S. is very narrow in terms of the total range of genetic diversity available. There is a fertile breeding area, therefore, that this project seeks to exploit, of crossing higher yielding adapted food quality tropical sorghums and U.S. parents. The resulting segregating populations are selected *in situ* in collaborative LRSA breeding programs to the benefit of developing countries. Segregates from the same crosses are selected for adaptation and combining ability in the U.S. 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.

Dryland hybrid tests in Senegal in 1994 showed that INTSORMIL seed parent AVG1 was superior to existing seed parents in producing adapted hybrids with Senegalese pollen parents. Hybrids and their parent lines were evaluated in Niger by INRAN. Five seed parents gave hybrids that yielded as well as NAD-1 and were retained for further testing. Hybrid and varieties selected from UNL-115 material were again tested in Botswana.

In the U.S., continued testing of hybrids made with new seed parents identified nine further lines for potential release. New male parents, also from crosses with tropical germplasm were identified.

An evaluation of Russian introductions and Nebraska stocks for germination and seedling growth in cool soils ($13^{o}C$) identified lines from both sources with good tolerance, but the frequency of tolerance was highest in the Russian material.

Research by Fabien Jeutong, from Cameroon, 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 so far have 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 land race varieties, though they are well adapted to low moisture and fertility situations and to numerous pests and diseases, are not efficient in converting dry matter they produce into grain. Their harvest index (HI) efficiency is poor. There are breeding stocks such as U.S. hybrid parent lines, which are twice as efficient in this process but they generally perform poorly in African conditions because they have little adaptation or pest/disease resistance. A combination of traits conferring adaptation and grain production efficiency is required through breeding, as well as further improvement in the basic breeding stocks (particularly seed parents) for grain yield potential per se. Combinations (lines/plants) with good adaptation and seed qualities can only be identified *in situ* in developing countries. Thus, segregating material generated from crosses with stocks known to perform well in the region concerned, in crosses with selected high HI lines, are supplied for selection in collaborative projects.

Research Approach and Project Output

Research Methods

The most widely adapted high yielding lines and seed parents from the ICRISAT sorghum food quality breeding program in India and Mexico, the Botswana and Zambia NARS, and the IRAT West African sorghum breeding programs were introduced and crossed with U.S. B- and R-lines. New lines are being produced by pedigree selection during which criteria for agronomic value and evident food quality grain are used. After F_3 evaluation, remnant seed of F_3 and the preceding F_2s of crosses between appropriately adapted exotic lines are provided to host country breeders to initiate collaborative selection programs.

At 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 nonrestorers will be considered for producing new seed parents. Well adapted partial inbred 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

Twenty-eight new F_1s were grown, with emphasis on utilizing tropical, large seeded germplasm from West Africa and Zambia with good evident food grain quality. One thousand three hundred forty F_2 to F_6 lines were evaluated for potential use as varieties or hybrid parents in host country programs and the U.S. Seed parent development was continued on 130 lines and 120 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 27 family groups, were evaluated for the second year 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 equaled the yields of the best checks. Nine different seed parents produced hybrids whose yields in both years equaled the average of the three hybrid checks used in each test. Check yields averaged 9000-9800 kg/ha. Six other seed parents produced good individual hybrids. Twelve different parentages are still represented in these superior seed parents, as compared to 27 parentages in all lines.

One hundred-eighty sorghum genotypes, (58 Russian new Plant Introductions, 108 Mead seed parents and 14 very early maturing lines from western Nebraska) were tested for germination ability and seedling growth under cool soil temperatures at 14^{0} C in soil trays in the growth chamber. Nine of the Russian introductions (which are also early maturing), 10 of the Mead seed parents and 4 of the western Nebraska lines were identified with good to excellent speed of emergence and seedling growth, compared to the checks Shan Qui Red from China, Naga White from Ghana and CK60 from the U.S.

Fabien Jeutong, from Cameroon, conducted the second year of his dissertation research on combining ability. Four different testers, F_1s between these, the combined 4-way tester, and an independent population tester are being compared for their ability to detect and rank the combining ability of a set of potential new seed parents. Results are being analyzed.

Networking Activities

Hybrids made on seed parents selected in Botswana from UNL-115 material were tested at Sebele. Additionally, selections were advanced from new breeding material sent in 1993. Final results are awaited. Further selections were prepared in Nebraska for the Botswana program using three-way crosses of earlier selections to different Botswana parents.

Seven hybrids made on late maturing UNL seed parents with pollinator MR732 (the male parent of Niger hybrid NAD-1) were sent to Niger for testing by Issoufou Kapran. Five hybrids, on seed parents UNL 161A, 225A, 559A, 645A and 6303 A, gave yields equal to NAD-1. The seed parents and their maintainer lines were also sent, so hybrid seed can be made *in situ*.

INTSORMIL has supplied varieties and seed parents from several projects to Senegal over the years. No introduced variety has been superior to the varieties bred by ISRA adapted to the sandy, acid soil and drought conditions of central Senegal. However, INTSORMIL seed parents have continued to show better combining abilities using existing adapted ISRA restorers. In a test at Nioro in 1994, hybrids with AVGI averaged about 150% of the yield of the best check hybrids. ISRA produced germplasm has been useful to the UNL breeding program, providing genetic diversity for good grain quality, earliness and combining ability for yield.

Germplasm Exchange

Seventeen lines were sent to Senegal and seven hybrids to Niger.

One hundred eight lines were sent out and and an additional 27 lines received from other sorghum researchers within the U.S.

Publications

Bramel-Cox, P.J., K. Anand Kumar, J.H. Hancock, and D.J. Andrews. 1995. Sorghum and millets for forage and feed. Chapter 11. p. 325-364. In D.A. V. Dendy (ed.) Sorghum and the Millets: Chemistry and Technology. American Assoc. Of Cereal Chem.

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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 that 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 and millet head-miner. Actual production is a result of the interaction of these production constraints with the yielding ability of the cultivar. Where the physical constraints (drought, low soil nutrients) are strong, agronomic interventions will have large effects on production, however, these are often too expensive, or otherwise unacceptable, to low resource farmers. Seed of new cultivars of higher yielding ability is a cost effective technology, even without agronomic support, but more effective with and encourages the use of better agronomic practices. Seed of new pearl millet cultivars, both varieties and hybrids, have been widely accepted by low-resource farmers in India even without changes of agronomic practices.

The goals of this project are several. To develop parental material of higher yielding ability that can be used in collaborative breeding programs in developing countries, and to develop new varieties and hybrids in the U.S. To research ways of improving breeding populations and the best ways of making varieties and hybrids for developing country breeding programs, and in the U.S., to produce the adapted plant type needed to grow pearl millet as a combine feed crop. And, finally, to provide students' thesis topics from on-going research which are relevant to the problems they will face in their research programs at home.

Pearl millet research continued in Senegal. Variety ISMI 9305, produced in Senegal from crosses of Senegalese va-

rieties and UNL-118 lines, again gave 25-39% more yield than released cultivars. The first backcrosses were made to move the A4 cytoplasmic male sterile (CMS) system into the background of a dwarf Senegalese variety. Seed was distributed to four countries. In the U.S. research continued on producing segregating populations for selection in West Africa, and developing hybrid parent lines both with grey and white grain. Several lines developed in the A_1 CMS System are being prepared for release, but major emphasis has now been placed on using the A_4 CMS System which has major advantages over the A_1 system, and may also be useful in developing agriculture. Initial tests showed that A_4 hybrids are equally as high yielding as A_1 hybrids, and several good (R_4) restorers were identified. 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 1994 pearl millet regional test was expanded to 11 locations. This test program has provided performance data to cooperators and indicated adaptation parameters.

Objectives, Production, and Utilization Constraints

Objectives

The objectives of the breeding program, with slight modifications, remain as in previous years:

To establish a diverse base of agronomically elite inbred and semi-inbred lines from crosses between U.S. parents and introduced tropically adapted stocks and from prior program material. The establishment of such a base of diversity with yield potential is fundamental to practical collaboration on genetic improvement in LDCs in the long-term where populations from specific crosses between superior UNL-118 lines and collaborating country stocks will be selected in that country. It also permits hypotheses to be tested about the relative potential of various types of varieties and hybrids and parental breeding procedures and also enables the identification of parents to make hybrids adapted to the U.S.

A type of modified mass selection (recurrent restricted phenotypic selection) is being tested on a 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 indigenous food grain markets. Many existing landrace varieties, though they are well adapted to low moisture and fertility situations and to numerous pests and diseases, are not efficient in converting the dry matter they produce into grain. Their biomass production may be good but their harvest index (HI) efficiency is poor. There are breeding stocks which are twice as efficient in this process but they generally perform poorly in African conditions because they have little adaptation or pest/disease resistance. A combination of traits conferring adaptation, growth rate, and grain production efficiency is required through breeding, as well as further improvement in basic breeding stocks (particularly seed parents) for grain yield potential per se. Combinations (lines/plants) with good adaptation qualities can only be identified *in situ* in developing countries. Thus, segregating material generated from crosses with stocks known to perform well in the region concerned, to selected high HI lines, are developed for selection in collaborative projects.

The selection criteria used in developing improved basic breeding stocks are numerous and involve morphological and physiological traits and estimates of genetic combining ability for performance. Principal morphological traits involve determinants of seed number/m^2 and seed size. Performance data under moisture stress and lower soil fertility are needed. Both specific and general combining ability estimates are needed. These are principally thought of in the context of hybrid parent development (for pollen and seed parents, respectively), but these estimates are also of use in identifying parents for varieties (synthetics), and possibly for indicating parental worth, which is important in generating collaborative material for selection.

Hybrids use growth resources, particularly when they are in short supply, most efficiently. While varieties in pearl millet are internally 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 material—to supply both hybrids and segregating populations for selection in collaborative host country 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 subsequently 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 semi-dwarf 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. Work has also expanded on the A_4 CMS System, now that good restorers have been found for it. This system has many advantages over the A_1 system and should replace it. However, the reaction of this CMS system to ergot and smut infection has yet to be determined.

Since pearl millet is a cross-pollinating crop, population improvement is a relevant breeding approach, particularly for low resource semi-arid (LRSA) 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 LRSA conditions have been tested. Equally transferable will be the methods and operational techniques being developed.

Research Findings

Research in the U.S.

Germplasm enhancement continued both through pedigree breeding and recurrent selection, lines were evaluated both in hybrid combinations and for variety production. Two types of hybrids were investigated and the seventh year of the regional grain yield test coordinated.

Pedigree Breeding

Three hundred forty-eight new exotic x adapted and adapted x adapted F_1's were grown and 1700 F_2 to F_6 lines evaluated. Selection emphasis continued on per se performance, good seed set, and lodging resistance for material intended for the U.S. Both grey and white seeded lines are being developed. Screening was continued for propachlor and atrazine herbicide tolerance in a separate inbred nursery and in seven populations, three of which were composed by random-mating progeny derived from crosses of herbicide tolerant lines.

The A_1 Cytoplasmic Male Sterility System

The identification of good combining seed parents based on the A_1 cytoplasmic male sterility (CMS) system continued and yield testing (Table 1) confirmed the usefulness of seed parents 293A, 413A, and 59022A and three male parents -086R, 183R and 58058R. Genetic diversity has been maintained in our hybrid development project. Twenty-three new elite A_1 lines derived from 18 genetically diverse families were crossed with R_1 restorers for hybrid evaluation. Good dwarf A_1 restorer lines from 10 different genetic backgrounds are now identified for hybrid yield testing. Segregates of three different A_1 restorers have been converted to white grain color.

Table 1. 1994 Advanced A_1 Hybrid Trial at Mead and Sidney, Nebraska, and Hays, Kansas

	Grain Yields (kg/ha) of 12 out of 25 entries		
Hybrid	Mead	Hays	Sidney
93M59042A x 58058R	5290	4300	1000
413A x 58068R	4840	4310	970
79-2068A x 89-0083R	4730	4490	1550
93P1023A x 58068R	4660	4560	1550
293A x 89-0083R	4500	2590	1970
90M57242A x 8068R	4340	4710	1470
68A x NPM-1	4260	4040	1630
59022A x 086R	4120	5280	2320
413A x 58058R	4090	5110	1000
433A x 0153R	3940	5000	1380
93M59042A x 086R	3630	5010	1960
91M59068A x 0183R	3060	4860	890
LSD 0.05	1600	1130	670

The A_4 Cytoplasmic Male Sterility 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 has increased. Unlike the A_1 system, almost all lines are maintainers in the A_4 system, which means most good B_1 and R_1 lines can be converted to A_4 seed parents. The first yield tests on A4 hybrids were reported in 1993. Yield tests conducted in 1994 confirmed that A4 combinations can give yields equivalent to A_1 hybrids, and identified one combination that exceeded the check yield (Table 2). The performance of other test crosses with this restorer (4Rm) indicate that it has good general combining ability. Male fertility restoration continued to be excellent and reliable in R4 hybrids, with no problems of partial fertility, and more R4 lines have been discovered in eight very different genetic backgrounds, including a few lines that individually are both R1 and R4 restorers. To commence the study of inheritance of restoration of male fertility in the A4 CMS, the F_1s of crosses with different R4 restorers lines and the lines themselves were crossed on to Tift 23D A4. Crosses with F_1s between lines that proved to be homozygous for R4 also gave 100% male fertile progeny, indicating that each of those lines, though of different origin carried the same restorer gene(s). The development of new R4 restorers has been accelerated by using crosses of existing R4 restorers to good, but sterile A4 hybrids. All progeny of these crosses, therefore carry A4 cytoplasm and thus, only those segregates with the desired restorer genes exhibit male fertility. This method can also be used to convert A4 maintainer lines into A4R4 restorers, by back crossing to plants which are male fertile in sterile cytoplasm. Many new A4R4 restorers have been derived from an additional 16 genetic backgrounds by

Table 2. Initial A4 Hybrid Yield Trial, Mead 1994. Bloom, height and grain yield of 8 of 25 entries.

Hybrid	50% bloom (days)	Height (cm)	Grain yield (kg/ha)
54026Mx1RM	71	94	3630
54026Mx5RM	77	113	4200
57218Mx5RM	66	129	4760
1361Mx1RM	66	105	2990
1361Mx4RM	68	121	6130
1361Mx6RM	64	119	5070
0183Mx4RM	69	122	5200
79-2068Ax89-0083R_1	60	126	4893
LSD 0.05	2.0	14.6	1820

Table 3. Three year average grain yields (kg/ha) for seven entries in Pearl Millet Regional Grain Tests.

	Georgia Tifton	Indiana Purdue	Kansas Hays	Nebraska Lincoln	Entry Average
NPM-1 Variety	2640	2920	3660	3020	3060
79-2068A x NPM-1	3110	4460	4280	3690	3880
79-2068A x 086R	3430	3870	5200	4370	4220
79-2068A/89-0083	4300	4260	5510	4110	4540
HGM-100	4140	2740	3710	3070	3410
DK 18 Sorghum	3860	7860	6320	6440	6120

selection per se and these were sent to the winter nursery for test crossing with A4 seed parents.

Recurrent Selection

Recurrent selection in the NTPC population continued in collaboration with Dr. Glenn Burton, Tifton, GA. Eighty-one progeny in the third cycle of recurrent restricted phenotypic selection were again planted at Mead in 1994. Unfortunately the experiment was again damaged by heavy rains after planting. Selection will continue with half sib progeny retained from each of these families.

Selection for Herbicide Tolerance

Currently pearl millet is susceptible to most pre-emergence grass herbicides, except for moderate rates of atrazine. Propachlor (Ramrod) is an economical, low carryover chemical commonly used in herbicide formulations for grassy weed control in grain sorghums, and would prove useful in pearl millet production. In the third year of selection for Ramrod/Atrazine tolerance 1200 of the F_2 to F_4 progeny were planted and screened for tolerance using a pre-emergence application of 13 kg propachlor and 2.2 kg of atrazine/ha. About 10% of lines had some survivors which were selfed for another season of herbicide testing. Seven populations (including MLS, NPM-2, NPM-3 and NCD2)were also advanced in herbicide treated isolation plots, where other desirable agronomic traits are also selected for among the intermated survivors.

Regional Test

The 20-Entry Pearl Millet Regional Grain Yield trial was continued and planted in 1994 at 11 locations in 9 states. Yield results were received from seven locations. Mean yields ranged from 4250 kg/ha at Hays, Kansas to 620 kg/ha at Weatherford, Oklahoma. The average yields of five pearl millet entries, and two sorghum checks grown from 1992 to 1994 at four sites are shown in Table 3. This testing program has allowed breeders to comparatively assess their hybrids and has provided information on regional adaptation. Rust and blast resistance is necessary in the South. Longer day lengths and generally lower average temperatures favor early to very early maturing hybrids in the Midwest. In Indiana, late planting of the regional test indicated pearl millet can be used as a double crop following wheat harvest.

Networking Activities

Variety tests were again planted at Bambey and Nioro in Senegal by Mr. A. Fofana. Synthetic variety ISMI 9305 made from lines selected from Senegalese x UNL-118 crosses gave 25% and 39% more yield than standard variety Souna 3 at the two locations, and showed less downy mildew incidence (Table 4). A4 male sterile and maintainer lines of Senegalese dwarf population IBMV 8401 sent from UNL were grown at Bambey, where the male sterility was perfectly expressed. Backcrosses and about 50 further testcros-

Table 4. Data from Senegal pearl millet variety test, Bambey and Nioro locations, 1994.

	Height (cm)	Downy mildew (%)	Grain yield (kg/ha)	
Variety	Bambey	Nioro	Bambey	Nioro
ISMI 9305	217	22	2780	1440
ISMI 9303	220	23	2560	1010
ISMI 9301	211	21	2370	1070
Souna 3	231	39	2230	1030
ISMI 9203	231	38	2175	1300
IBV 8001	222	27	1953	982
IBV 8004	219	22	1990	1950

ses with plants from the original IBMV 8401 population were made. Top crosses were also made using leading varieties as male parents, so their value as hybrids can be evaluated, and the presence of any A_4 restoration genes detected. The IBMV 8401 A_4 sterile and maintainer lines were also sent to Niger. The report of their performance is awaited.

Germplasm Exchange

Five lines were sent to Egypt, 2 to Uruguay, 29 to Mexico and 7 to Brazil. Thirty-three were sent domestically. Thirteen germplasms were received from ICRISAT, India and 30 from ICRISAT, Niger.

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Crop Utilization and Marketing

Chemical and Physical Aspects of Food and Nutritional Quality of Sorghum and Millet

Project PRF-112
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Summary

Work continued on characterization of the highly digestible sorghum genotype that we identified last year with the objective of better understanding its basis to develop a quick screening assay for breeding programs to use. This sorghum grain has markedly higher *in vitro* protein digestibility than normal genotypes both as raw grain or cooked porridge. Its digestibility using a three enzyme assay was on par with that of wheat and above maize. Studies this year showed that the main storage protein of sorghum, α-kafirin, was more rapidly digested in the highly digestible genotype compared to normal. Using transmission electron microscopy, the microstructure of the protein bodies of the improved genotype was shown to be dramatically different from the normal. Protein bodies were irregularly shaped containing numerous folds, presumably allowing greater accessibility to the digestive enzymes. We are currently working on ELISA and electrophoresis-based screening assays that are based on the rapid digestion of the α-kafirin protein in the highly digestible genotype. Digestibility tests using the chicken as a model are currently being run.

In the sorghum population which contains both the highly digestible trait as well as enhanced lysine content, we are working collaboratively with John Axtell to improve kernel hardness characteristic. In progeny generated from crosses with hard endosperm parents an "intermediate" hard endosperm type was found. This phenotype has a hard or vitreous central portion of the endosperm surrounded by floury endosperm that is unique. We showed that endosperm of opaque and "intermediate" hard types have a range of density and kernel hardness which apparently is the result of differences in starch fill. This variability could conceivably be exploited in a breeding program and has already resulted in the identification of an intermediate hard endosperm sorghum grain type with elevated lysine content and the high protein digestibility.

Work continues with INRAN/Niger scientists on sorghum- and millet-based couscous. We have been funded through the Niger InterCRSP effort to buy small scales couscous processing equipment to be placed at INRAN/Niamey. This unit will be used for testing and demonstration to local entrepreneurs, women's groups, etc. Also, the commercial product will be tested in the marketplace.

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 very popular food of Sahelian West Africa, is prepared from sorghum or millet flour that has been agglomerated, steamed, and dried. 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. Couscous is usually consumed with milk for breakfast, or with a sauce or stew for evening meal. Consumer acceptability of couscous is strongly influenced by the color and texture of the product. Studies were undertaken to evaluate different sorghum cultivars for their couscous making ability and to determine flour properties that affect processing and finished product quality. Eight sorghum cultivars that varied in physical properties such as kernel hardness, particle size distribution, and starch damage were used. Total protein content as well as protein fraction composition, ash, starch and amylose content were significantly different among cultivars.

A texture profile analysis (TPA) was used to evaluate the textural characteristics of sorghum couscous as compared to durum wheat couscous. TPA parameters of cooked couscous varied significantly among cultivars, indicating that the parameters reflected textural differences of couscous. Flour characteristics that appeared to affect couscous texture included starch damage, particle size, and amylose content. Of all the textural parameters, variation in couscous stickiness was more pronounced. A desirable cooked couscous has a non-sticky, fluffy texture with easily separated particles. As shown in Figure 1, a wide range in stickiness was obtained for sorghum couscous. Sorghum

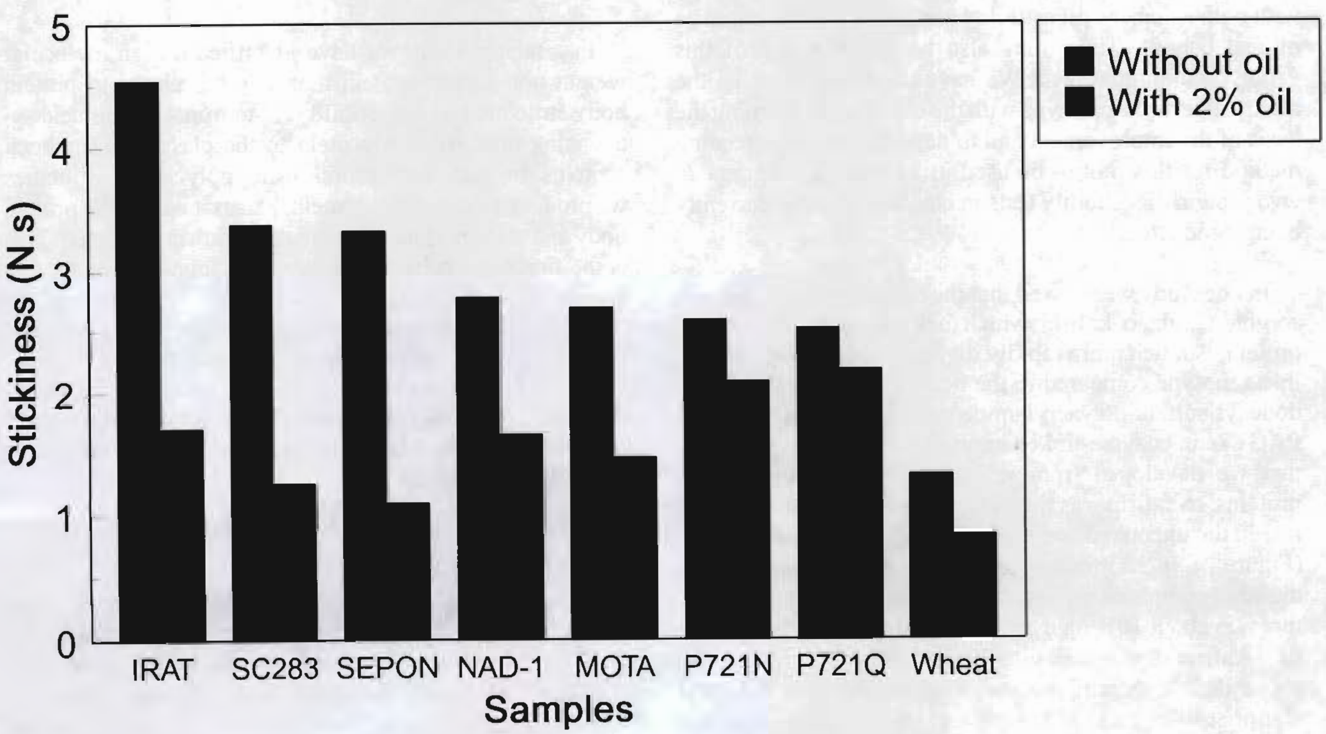

Figure 1. Couscous stickiness differences among sorghum genotypes and wheat with and without added cooking oil.

couscous was stickier than durum wheat couscous. Figure 1 also shows the effect of oil on couscous stickiness. All couscous became softer when cooked in water containing 2% cooking oil. Addition of oil had a much greater effect in reducing stickiness of couscous of some sorghum cultivars compared to others. In particular the stickiest cultivars (IRAT, SC 283, and Sepon) showed the largest reduction in stickiness when oil was added. Sepon couscous with added oil had the stickiness closest to wheat couscous. The sorghum hybrid, NAD-1, developed by INRAN and Purdue breeders, overall made a acceptable couscous product both with or without oil.

We are in the process of purchasing a small scale couscous processing unit with funds from the Niger InterCRSP initiative to be placed at the Laboratoire du Sols/INRAN in Niamey. This will be used for testing and demonstration to entrepreneurs and other interested groups such as women's cooperatives. Our other short-term goal is to a produce a commercial product to be tested in the marketplace. If successful we wish to expand this project to include a village level site or sites.

Digestibility of Sorghum Proteins

Last year we reported on the discovery of a sorghum genotype with high *in vitro* protein digestibility compared to normal sorghum genotypes. This was found within Axtell's high lysine population. *In vitro* digestibility data places this improved type within range of the digestibility of wheat and above that of maize. In populations with marginal or substandard protein intakes the introduction of sorghum with both enhanced digestibility and lysine content could be of real benefit. There may also be potential use of this genotype in animal feed. We have continued work on the highly digestible genotype with the objective of learning the basis of the improvement and to develop a quick screening method for this trait to be used in a breeding program. *In vivo* protein digestibility tests in chickens are also currently being conducted.

In one study we showed that the major storage protein of sorghum grain, α-kafirin, which make up about 65% of total protein, is much more rapidly digested in the highly digestible genotype compared to the normal. Using both sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE) and enzyme-linked immunosorbant assay (ELISA), that we developed from rabbit antisera to three kafirin proteins, α-kafirin was found to be digested at a much faster rate in the uncooked and cooked highly digestible sorghum (Figure 2). In 30 minutes, approximately 70% protein was digested compared to the related normal genotype (P721 N) that was about 10% digested. At 60 minutes, the percentage of α-kafirin digested in the highly digestible sorghum was about double that of the normal type. Because α-kafirin comprises the bulk of the protein in the sorghum kernel (about 65%), its rapid digestion accounts for the increased digestibility of this genotype. We are currently working on a screening assay using ELISA or SDS-PAGE based on the large difference in disappearance of the α-kafirin protein.

Transmission electron micrographs show the remarkable difference between protein bodies of the highly digestible versus normal genotypes (Figure 3). The novel highly digestible genotype has irregularly-shaped protein bodies with numerous folds compared to the uniform spherical shape of normal protein bodies. In further immunolocalization studies (not shown) using antibodies to the α-, ß-, and γ-kafirin proteins, locational differences of these proteins were found between the normal and highly digestible sorghums. α-Kafirin is located in the central light-staining region of both types of protein bodies. This protein comprises the bulk (about 80%) of the protein body structure. ß-Kafirin, a relatively minor protein, was found to be located in discrete dark-staining regions of the protein body and also did not differ between the two genotypes. The γ-kafirin protein, however, was located quite differently. In normal protein bodies, γ-kafirin is found mainly at the periphery of the body and is thought to be more of a structural than storage protein due to its high content of the amino acid cysteine, which can form structurally stabilizing intermolecular disulfide bonds. In the highly digestible genotype the γ-kafirin was localized in dark-staining regions at the inside or base of the folds (see small arrows in photomicrograph), rather than at the periphery (large arrow). Undoubtably, this change in location, due to a mutation, is the reason for both the oddly shaped body and its high digestibility. This is in agreement with our previous hypothesis that γ-kafirin is at least partly responsible for the relatively low digestibility of sorghum protein in normal sorghums.

In a related study we have identified a high molecular weight non-kafirin protein that may be related to protein body structure and digestibility. N-terminal amino acid sequencing matched this protein to the class of heat-shock proteins. Immunolocalization, using polyclonal antibodies we produced against this protein, places it within the protein body and at the periphery where the γ-kafirin is located. This is the first non-prolamin protein to be found inside protein bodies in sorghum or any other cereal. While we do not know what its function may be, one might speculate that it has an assisting role to form the rigid structure of the spherical protein bodies of normal sorghum. In the highly digestible sorghum protein bodies this protein was mainly located again at the site of γ-kafirin accumulation within and at the base of the folds.

Grain Quality

In Axtell's high-lysine sorghum population from which the high protein digestibility trait described above is found, there have been numerous crosses made with normal vitreous (hard endosperm) genotypes. The goal originally was to improve grain quality of the high-lysine lines, but now has expanded to include the high digestibility trait. We have chosen 39 experimental lines within this population that differ in grain type and have determined lysine content,

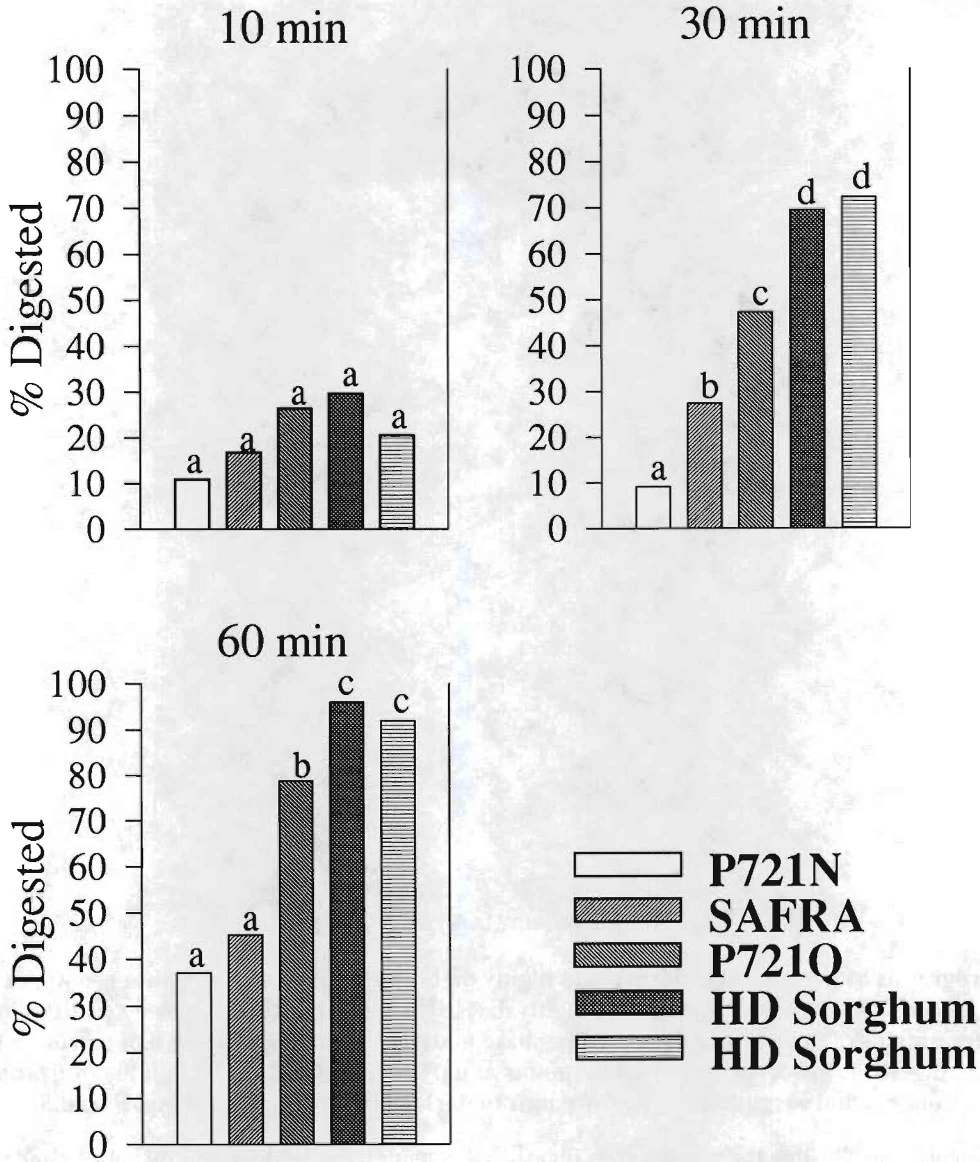

Figure 2. Percentage α-kafirin (major sorghum storage protein) digested in five cooked sorghum genotypes ("HD" indicates "highly digestible") determined using ELISA following 10, 30, and 60 min *in vitro* pepsin digestion. Normal sorghum genotypes are P721N and SAFRA, highly digestible (HD) genotypes are P721Q, and two experimental lines. Mean values within a graph for each bar that does not have a common letter are significantly different at P<05.

kernel density, and kernel hardness. Other determinations currently being done include *in vitro* pH-stat protein digestibility, percent vitreousness, and kafirin (crosslinked and non-crosslinked) and non-kafirin contents. As a collaborative effort between our laboratory and Axtell's breeding program, our objective is to develop a sorghum variety with high lysine content, high protein digestibility, and a hard, vitreous endosperm as is feasible.

Most notably we found that a unique endosperm type within this population contains what we term "intermediate vitreous" or "intermediate hard" endosperm. This phenotype has a kernel density between that of floury and vitreous types and visually is different from those. Cross sections of kernels of the intermediate vitreous lines show a vitreous portion of the endosperm in the center of the grain surrounded by floury endosperm that differs in amount from negligible to considerable. Normal vitreous kernels appear with vitreous endosperm at the outer portions of the kernel with floury endosperm in the center. Kernel density measurements, which is a good indicator of kernel hardness or vitreousness, show that there is quite a range in density among those identified as "intermediate" (Figure 4, denoted as "I"). The large difference in density among the floury and intermediate sorghum phenotypes ("F" and "I," Figure 4) of 1.20 to 1.32 g/cc suggests that this variability can be exploited through breeding to develop an intermediate vitreous type without the typical hard kernel. Since the intermediate

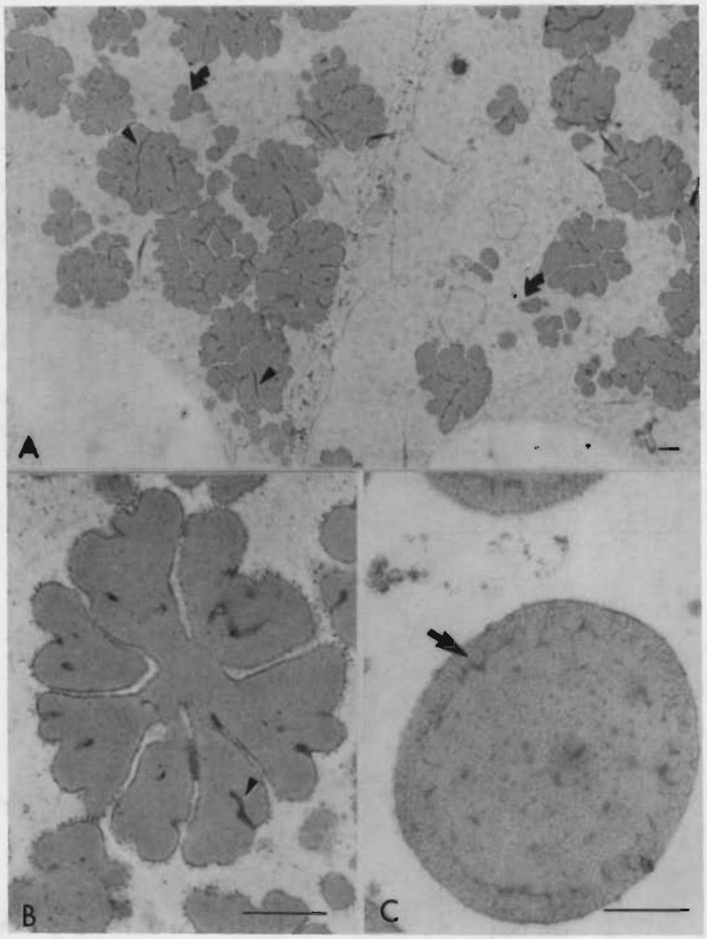

Figure 3. Micrographs of peripheral endosperm of highly digestible and normal sorghum genotypes (30 days after half bloom). (A) Low magnification of highly digestible genotype; curved arrows point to lobes of protein bodies, small arrows point to dark staining base folds. (B) High magnification of a protein body from the highly digestible genotype; small arrow points at dark staining folds. (C) High magnification of a protein body from normal sorghum; the arrow points to dark staining peripheral ring. Bar=0.5 microns.

vitreous types incorporate the high lysine and highly digestible traits, we believe that they may have sufficiently improved grain quality to be used in food preparations requiring hard type varieties. The harder kernels represented by the intermediate vitreous types would most likely have greater resistance to breakage and may be more resistant to insect and fungal attack. These aspects, however, are yet to be tested. We are beginning testing of food processing qualities of this unique sorghum phenotype.

Networking Activities

Research Investigator Exchange

In March 1995 B. Hamaker and A. Aboubacar (INRAN doctoral student at Purdue) traveled to Niger, Benin, and Senegal (A. Aboubacar only) to consult with INRAN Cereal Quality Laboratory scientists regarding ongoing projects and to obtain information about existing appropriate couscous technologies that could be used in Niger. In Niamey, meetings were scheduled with two large cereal processors (biscuit manufacturer and wheat mill) regarding the potential of using locally grown millet and sorghum in their products. They were both very receptive to this idea and plans were made with SNPA (biscuits) for assistance from INRAN for trials with composite flour. Visits were also made to the solar energy office to discuss equipment to be used for sorghum/millet couscous drying. In Cotonou, a day was spent with Dr. J. Hounhouigan of the National University of Benin to observe their work with small-scale couscous processing and their successes with marketing product and working with entrepreneurs. In Dakar, meetings were held between A. Aboubacar and A. N'Doye and M. Diouf of the Institute of Food Technology (ITA) regarding their couscous equipment designs for small-scale processors. Through the Niger InterCRSP initiative a small-scale couscous processing unit is currently being purchased.

Ms. Ellen Hejlsoe, from Denmark, spent six months at Purdue investigating sorghum protein isolation and quantitation using ELISA as part of her Master's degree program from the Royal Veterinary and Agricultural University.

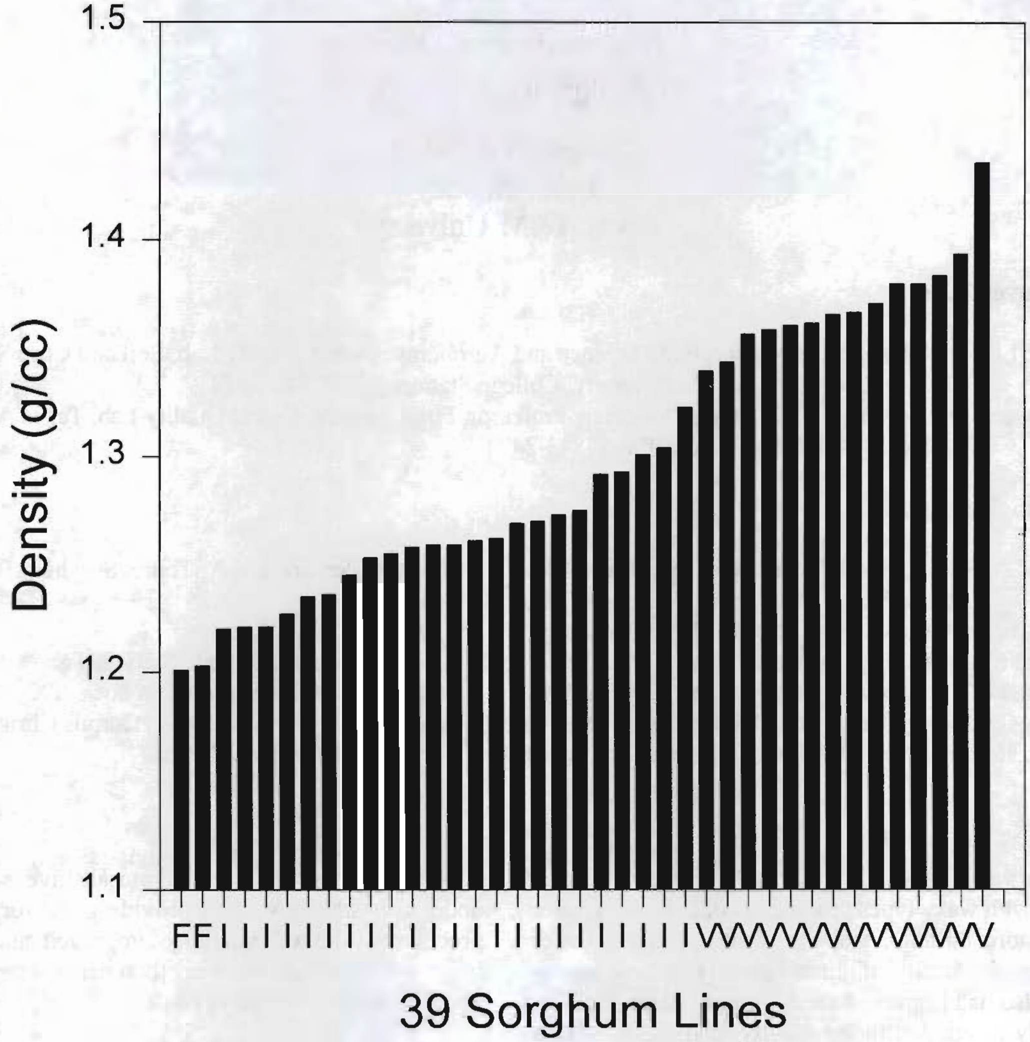

Figure 4. Range in kernel density of floury (F), intermediate vitreous (I), and vitreous (V) sorghum lines. Intermediate vitreous types typically have partial vitreous characteristic in the central endosperm and contain the highly digestible and high lysine traits.

Attended and presented findings from the project at the annual American Association of Cereal Chemists meeting in Nashville, TN.

Publications and Presentations

Abstracts of Presentations

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 39:617.

Weaver, C.A., B.R. Hamaker and C.P. Huang. 1994. Differences in rates of protein digestion due to kafirin-contaning protein bodies. Cereal Foods World 39:618.

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 39:618.

Journal Papers

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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 more closely resembled the non-waxy grains. The Texas Agricultural Experiment Station (TAES) released two waxy females and one waxy pollinator that produce tan plant, white waxy and heterowaxy hybrids. Nonwaxy food-type sorghum hybrids produced flakes with excellent appearance. No significant differences in flake quality were found among commercial red, cream and yellow hybrids.

MILEG, a prepared weaning food from dehulled pearl millet and cowpea flours (3:1 blend), is being produced and sold by a small food company in Bamako, Mali. The product prototype was developed cooperatively by the Institute of Rural Economy Food Technology Laboratory with assistance from TAM-126.

Commercial food-type hybrids with white, tan plant grains and excellent processing properties and good yields are being grown by farmers. These hybrids are based on materials released by INTSORMIL breeders.

Jowar Foods, Inc., a small food company, has begun to market Jowar flour and bakery mixes to ethnic groups familiar with sorghum products. They have contracted with growers to produce the new food-type hybrids that have been developed by INTSORMIL. In addition, prospects appear good to sell identity-preserved U.S. white food-type sorghum to Southern African countries.

White, tan plant, local photosensitive sorghums are under increase in Mali to provide grain for value-added processing. The combination of improved quality grain and better processes should lead to superior commercial sorghum products for sale in Mali.

Progress has been made to understand the antifungal proteins of sorghum and the role they might play in reducing grain molds and deterioration.

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 its 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.

Grain molds cause staining and significantly reduce the quality of sorghum for food and feeds. Information on the factors that affect mold damage of sorghum and methods to develop mold resistant sorghums are needed. This project addresses those critical issues.

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.

Commercial Food Products Available in Mali and U.S.

Jowar Foods, Inc., a small food company, has developed several food products based upon the new food-type sorghum hybrids that have been developed in the INTSORMIL program here in Texas. They are producing a white, tan plant sorghum under contract for production of sorghum flours and bakery mixes, e.g., muffins and pancakes. The company is targeting its products to ethnic groups in the United States who want to consume sorghum products. In addition, the sorghum products can be used by consumers with celiac disease and other dietary problems that prohibit use of gluten from wheat.

The name, Jowar, is used to denote a high quality white sorghum product. This term was suggested in a presentation at the AACC several years ago to avoid the poor marketing image of "Milo" or "sorghum". We think the company will be successful. It appears promising because sorghum from India is currently imported for ethnic foods. The Jowar product is superior to the imported products.

The opportunity to export identity-preserved white food-type sorghums to Southern Africa exists because of the severe drought in that area and the lack of sufficient white maize for porridges. Potential users of white sorghum were impressed with the quality of the Jowar products. Efforts to produce sorghum under contract for use in Africa are currently underway. Some buyers have contracted for identity-preserved white food-type sorghums.

Commercial hybrid seed companies have expanded their efforts to produce white, tan plant, food-type hybrids. We have nearly reached the point where significant quantities of food-type sorghums will be available because the hybrids have good agronomic and yield properties. I have waited 30 years for this day to arrive so it cannot come too fast.

MILEG, a weaning food made from dehulled pearl millet and cowpeas, is on the market in Mali. It is a low-cost, prepared weaning food for children. Most weaning foods in Mali are imported and cost more than most people can afford. MILEG is easy to prepare and the cost is reasonable because it does not contain expensive imported ingredients. It provides significantly improved nutritional value over the usual practice which is to feed children only cereals. The work to develop MILEG was conducted mainly in the IER's Food Technology Laboratory in Sotuba and in several village trials in Mali. TAM-126 has assisted over the years in the effort to develop local reduced cost products for commercialization. We hope the company will be profitable and that it will diversify into other products from sorghum and maize.

The key to introduction of new products is to have a good supply of good quality raw ingredients to process. Some of our previous efforts in Mali to produce milled sorghums and SORI failed because only poor quality grains are available in the market. Currently, in Mali, Dr. Toure hopes to release new white, tan plant, local photosensitive sorghum cultivars specifically designed for use in value- added processing. Already, the major problem of the food company in Mali is to access reliable supplies of millet and cowpeas that are of good quality. The combination of new or improved processes with good quality grain is absolutely necessary if sorghum and millet are to compete with rice and wheat based foods.

Sorghum Malting Quality - Cultivars

Commercial sorghum samples were malted to provide information to buyers from S. Africa on the quality of U.S. sorghum for malting since the short crop in South Africa requires importation of sorghum. Eleven U.S. commercial sorghum hybrids grown in South Texas were malted using a 5 day germination period. The dry matter losses ranged from 8.2 to 10.2%, while α- and ß-amylases ranged from 126 to 280 U/g and 41 to 55 U/g, respectively. The sorghums germinated and produced acceptable malt although the enzyme levels were lower than desired for malting in S. Africa.

Malting studies at the Institute of Technology, Merida, Mexico on male and female sorghum lines show that there is significant variation in the enzymatic activities among sorghums. This confirms some of our earlier work here in this laboratory. This collaborative work is nearly completed and has been supported by non-INTSORMIL funds.

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. These sorghum hybrids were grown near St. Lawrence, Halfway, and College Station, Texas to demonstrate the potential of food-type sorghums. There was some weathering of the grains post-maturity, so the products from white, tan plant sorghums had a very significant improvement in appearance. DeKalb hybrids (DK 77, DK Y388, DK 477), Warner 902W, and ATx631 x RTx436 (TAES) produced excellent products. Warner 902W grain performed well in large commercial dry milling and brewing trials in Mexico in 1993 and 1994. A field day to promote and evaluate food sorghum production and utilization was held by the Grain Sorghum Producers Association, TAES and DeKalb Hybrid Seed Company in September 1994 at Lubbock and Hale Center, Texas. These sorghums also produced steamed flakes with excellent appearance.

Some experimental red, tan plant sorghum hybrids had good dry milling properties and produced decorticated products with reduced red stains. New experimental hybrids have excellent properties and will be released by the breeding projects soon.

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 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 1993-95 experiments confirm our conclusions made in 1992-93.

Waxy and heterowaxy sorghums have improved flakes that would significantly improve the performance of sorghum in livestock feeds. A new white, waxy male was released in 1994 from the TAES, and two female waxy sorghums were released previously. 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. 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.

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, chemicals, tempering and steaming times on moisture uptake, kernel structure and flake quality. This procedure can be used to study the critical factors affecting steam flaking and how they interact with different varieties. This research will be completed very soon.

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, Zamarano, Honduras to select for tortilla quality.

Grain Molds - Antifungal Proteins in Sorghums

Grain molds pre- and post-physiological maturity cause significant losses in grain yields and even more significant losses in grain quality. Molding and weathering in combination cause severe discoloration of the grain, the endosperm is too soft for dehulling and whole grain milled products are dusty and unpalatable when cooked. Sorghum deterioration is a major problem limiting the utilization of sorghum for food in most areas of the world.

Numerous attempts have been made to determine the major factors that enhance the resistance or tolerance of sorghum grain to deterioration. Recently, antifungal proteins (AFP) have been identified in seeds and are thought to provide protection against fungi. We have been examining the role of antifungal proteins in the molding and deterioration of sorghums with the hope that we can find a way to enhance the mold resistance of new sorghum cultivars. This is a longer term project that requires a basic understanding of the AFPs of sorghum and how they relate to grain deterioration.

Breeders have been developing sorghums with improved mold resistance but it is a difficult cumbersome process. Their efficiency in selection for mold resistance could be increased by more knowledge of the bioactivity of antifungal proteins.

Protein Purification and Antibody Production

Antifungal proteins identified in sorghum are sormatin, chitinases, glucanases, and ribosome inhibiting protein (RIP). These proteins were purified from maize, bean or tobacco and small quantities of antibodies were provided by other researchers. We have purified these proteins from sorghum and are raising antibodies against them which will be used for screening sorghum lines for grain mold resistance.

Several of these proteins elute from an anionic column. We have taken advantage of this property to purify three AFPs from sorghum: sormatin, chitinase and glucanase. The protocol in brief is as follows: proteins were precipitated with 55% ammonium sulfate, dialyzed, applied to a CM-Sephadex column and eluted using a salt gradient. One protein peak in the eluant contained all three antifungal proteins. This peak was concentrated by ultrafiltration and individual proteins separated by electrophoresis on SDS-polyacrylamide gels (SDS-PAGE).

Bands containing individual proteins were eluted and the eluants injected into rabbits for antibody production. A composite antibody against three AFPs is being raised by injecting a mixture of these purified proteins into rabbits. This composite antibody will provide a rapid tool to screen for the "antifungal potential" of seeds. Attempts to purify sorghum RIP continue.

Correlation of AFPs to Grain Molding

Sormatin and chitinase levels increased during maturity in most sorghum cultivars (Table 1). The quantities of AFPs varied significantly among different cultivars (Tables 1 and 2). In addition, AFP levels are affected by weathering after seeds reach physiological maturity (30 days after anthesis, DAA). There were no apparent relations between AFP levels and mold ratings in the grains evaluated. Mature seeds appear to be poor test materials for screening of mold resistance. We hypothesize that higher AFP levels at earlier stages of seed development (< 15 DAA) may be related to higher levels of mold resistance. We are therefore in the process of analyzing 25 sorghum cultivars sampled at 8 stages of maturity (7, 9, 11, 13, 15, 30, 40 and 50 DAA). Grain mold ratings of sorghum have been conducted using conventional techniques. Samples will be assayed using Western blots to determine the presence and relative amounts of AFPs in immature seeds.

Migration of AFPs Within Seeds

AFPs have been identified in different tissues within seeds. Sorghum AFPs are present predominantly in endosperm and only trace amounts are present in pericarp. Given that these proteins are bioactive, their mode of action from within the endosperm is intriguing. Sormatin and chitinase migrate from endosperm to pericarp during imbibition in mature seeds. These proteins are mostly bound to pericarp and only trace amounts leach out of the seed. However, preliminary experiments reveal that these proteins readily leach out of fresh, immature seeds. In contrast, chitanases readily leach from barley seeds within 2 hr of imbibition. Further studies are in progress in our lab to determine the significance of this phenomenon as it relates to seed structure and bioactivity *in vivo*.

Antifungal Activity

Specific AFPs have been tested against specific pathogens in the past. Chitinase and glucanase together were reported to be more inhibitory against some pathogens than either one individually. We have purified sorghum proteins such that one fraction contains three different AFPs (chitinase, glucanase and sormatin). This fraction was inhibitory

Table 1. Antifungal proteins of sorghums at different stages of development.

Cultivar	Maturity (DAA)	34 kDa (µg/g)	26 kDa (µg/g)	18 kDa (µg/g)	Sormatin (µg/g)
BTx 3197	15	Trace	3.3	1.5	24.3
BTx 3197	22	Trace	7.9	5.6	89.2
BTx 3197	30	1.9	7.1	8.9	88.3
SC 630-11E	12	0.4	Trace	0.8	3.2
SC 630-11E	22	0.4	Trace	1.3	7.9
SC 630-11E	32	0.7	Trace	0.6	7.6
TX 2536	12	2.7	4.1	3.0	6.5
TX 2536	22	1.3	1.4	2.4	9.6
TX 2536	32	1.7	0.8	1.1	11.7

Table 2. Levels of antifungal proteins in sorghums 30 days after anthesis and their mold ratings.

Cultivar	34 kDa (µg/g)	26 kDa (µg/g)	18 kDa (µg/g)	Sormatin (µg/g)	Mold Rating*
R 9025	0.8	10.1	Trace	190.4	1.5
Malisor 84-7	2.6	11.0	8.2	183.1	1.8
SC 748-5	2.0	8.2	Trace	173.1	2.0
SC 630-11E	0.7	Trace	0.6	7.6	2.0
BTx 635	Trace	1.9	Trace	113.9	2.5
BTx 3197	1.9	7.1	8.9	88.3	3.0
BTx 638	2.1	2.4	1.1	Trace	3.2
Dorado	Trace	4.7	Trace	170.5	3.3
IS 2319	Trace	6.5	2.7	153.9	3.5
TX 2536	1.7	0.8	1.1	11.7	5.0

*Mold Rating: 1 = no mold; 5 = very moldy

against *C. lunata*, *F. moniliforme*, *Aspergillus flavus* and *A. parasiticus*. Hyphal rupture of *C. lunata* and *F. moniliforme* were observed at protein levels as low as 10 µg. Spore germination of *C. lunata*, *F. moniliforme*, *Aspergillus flavus* and *A. parasiticus* were also inhibited at protein levels of 20 µg. Further investigations are in progress to test the activity of these proteins against other seed pathogenic fungi.

The presence of antifungal proteins in sorghum, their ability to migrate to the seed exterior and their bioactivity outside the seed, suggests one possible mechanism by which plants defend themselves against fungal invasion. An understanding of the physiological aspects of seed antifungal proteins will aid breeders and geneticists in using these natural plant defense mechanisms to enhance fungal resistance in sorghum.

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

Lloyd W. Rooney traveled to South Africa with a U.S. trade team to evaluate the potential for marketing white food sorghums in South Africa. The trip was sponsored by the Sorghum Producers Association, Foreign Agriculture Service and United States South African Trade Association. The team met with key large and small-scale food prócessors, maltsters and brewers. South Africa needs to import large quantities of white maize for dry milling to produce meal for pap. South Africans like very white maize; yellow maize is considered to be unsuitable for food. There is insufficient white maize available on the world market, so tremendous interest was shown in acquiring white sorghum for milling.

In meeting with the Black Townships, we heard that "sorghum" was a positive word and that the grain would be consumed, provided good-quality products at competitive prices could be developed. They were impressed with our samples of white sorghum and flour from it. The trip has led to potential sales of identity-preserved white sorghum and red sorghum from the U.S. into South Africa. The white, tan plant food hybrids developed as part of this project form the basis for these sorghum sales. This trip suggested that sorghum could play a major role in years to come in S. Africa since droughts occur frequently enough to devastate white maize production. The South Africans are developing white sorghum hybrids similar to ours.

L.W. Rooney traveled to Mali funded by the Texas A&M USAID/SPARC program to review the current programs in food science and technology and make recommendations for improvements. The laboratory has undergone significant changes in personnel and required additional assistance to achieve its objectives. Major recommendations included the assignment of marketing and economists to the food technology program and shifting emphasis to development of market driven products for manufacture by local business.

A new cereal and legume composite flour product called CERELEG originally, and now called MILEG, is currently being sold in Mali by a small businessman. The product was developed in the Food Technology Laboratory and tested in several villages over the years in Mali. The product consists of one part cowpea flour and 3 parts millet flour and is sold as a weaning food for children. The businessman formerly worked as a technician in the IER Food Technology Lab and was financed by a loan from a Canadian agency. The product has been in production for nearly a year. It is being prescribed by medical staff for children suffering malnutrition. It is not a complete weaning food but it definitely has improved nutritive value at a reasonable cost compared to other more carefully balanced weaning foods.

Increased emphasis on developing improved local photosensitive sorghums with tan plant and straw glume color by the plant breeders will provide grain with adequate quality for processing into high quality milled products which can be sold at competitive prices compared to rice and maize grits and meal. These value-added sorghum cultivars will be the basis for identity-preserved production for processing into higher value products. New products from existing sorghums have off-color and poor quality that cannot be overcome until improved grains are obtained.

L.W. Rooney traveled to Honduras to work with Dr. F. Gomez, Pan American School, Zamarano, to participate in a workshop on Grain Grading for Central America. The three day workshop included 40 participants from Central America. They designed a set of proposed grain standards for maize, sorghum and beans based upon U.S. grain standards. Rooney reviewed "The Criteria for Grain Standards and Quality Evaluations of Sorghum and Maize". Plans to improve the educational programs on post-harvest technology at EAP were discussed.

Dr. Helbert Almeida-Dominguez, Research Scientist, TAMU, Cereal Quality Laboratory, traveled to Merida, Mexico to interact with food scientists and graduate students at the Institute of Technology who are conducting research on sorghum food and malting quality. Grain of 102 hybrids grown near Merida were evaluated for malting and food properties. This research was partially funded by the International Foundation for Science in Sweden. Students from Merida have spent time in the Cereal Quality Laboratory conducting some of the analyses.

Dr. Helbert Almeida-Dominquez participated in the Sixth International Symposium on Food Industry and Engineering held at Monterrey Institute of Technology in Monterrey, Mexico in April. Dr. Almeida-Dominquez was asked to present a lecture on food extrusion with special emphasis on cereals. More than 200 participants from industry and academic institutions in Mexico and South America were present. Discussions of current progress on sorghum quality research at ITESM were held with Dr. Serna-Saldivar, Professor of Food Technology. Two potential graduate students were identified.

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 and Head, 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 wet and dry milling and as adjuncts in brewing. Dr. Serna-Saldivar and three M.S. students conducted sorghum and maize analyses in the Cereal Quality Laboratory for two weeks. The research is supported by industry in Mexico. We have provided samples of sorghum for planting and for analysis in addition to the use of our laboratory for some analytical tests.

Several papers were presented at the annual American Association of Cereal Chemists conference in Nashville, Tennessee and the Sorghum Utilization Conference in Lubbock, Texas. L.W. Rooney presented sorghum quality/ utilization discussions to Texas Sorghum Producers Board Members and other farm groups. L.W. Rooney and R.D. Waniska participated in the annual food technology exposition in Anaheim, California in June.

Training, Education and Human Resource Development

Ms. Aissata Berthe, Food Technologist from Institute of Rural Economy, Republic of Mali, spent five months in the Cereal Quality Laboratory where she conducted research on sorghum quality and food products development. In addition, she audited courses in Baking Technology, Cereal

Technology, and Food Microbiology. She was able to produce a wide variety of food products from sorghum, millet and maize using several processing techniques that are appropriate for Malian conditions. Ms. Berthe returned to Mali in mid-May to resume work in the Food Technology Lab at Sotuba.

Ms. Berthe was provided with a new computer, printer and other accessories for use in Mali. She also took numerous supplies and small pieces of equipment with her for the laboratory. We will ship some used, refurbished equipment for grinding cooked corn and sorghum into masa.

A Honduran graduate student, Mr. Javier Bueso, EAP graduate, was identified by F. Gomez. Mr. Bueso has been admitted into Texas A&M University for a M.S. in food science and technology. He will work on the role of antifungal proteins on grain mold resistance in sorghum, but will also be involved with food processing and quality evaluations of sorghum and maize. Plans are to develop a project to improve the food science and grain quality research and teaching capabilities at EAP. The students at EAP are from all over South and Central America, which provides an excellent opportunity to transfer post-harvest technology.

Four students are currently working on INTSORMIL related research, although they are only partially financially supported. Projects include steam flaking, starch properties, malting and milling.

Dr. A. Louis-Alexandre, Visiting Research Scientist, was partially supported for research on couscous production from sorghum and maize. He has returned to France.

L.W. Rooney currently serves as chairman of the Sorghum and Millet Working Group of the International Association for Cereal Science and Technology.

Publications

Book Chapters

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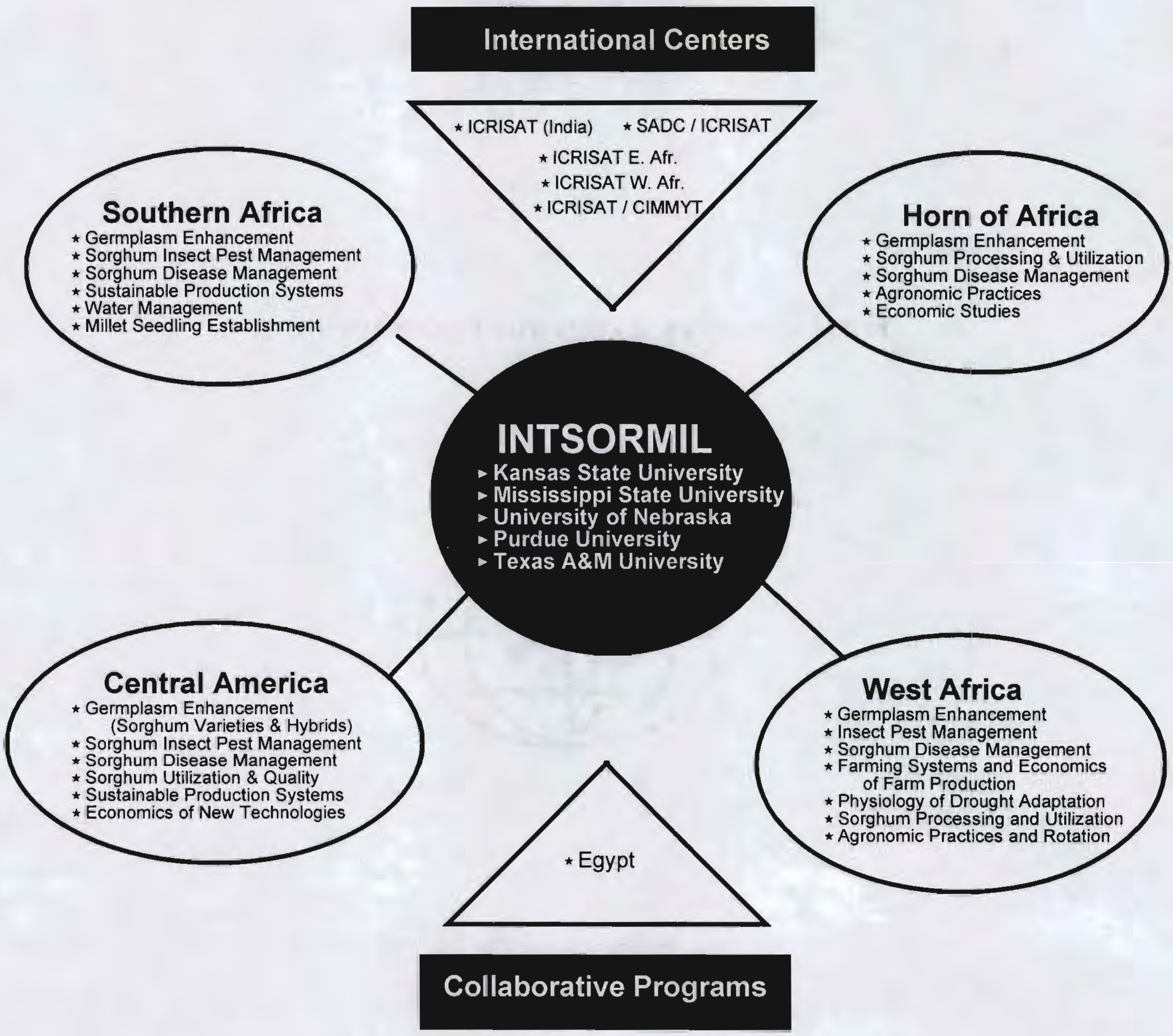
Host Country Program Enhancement


International Centers
★ ICRISAT (India)
★ SADC / ICRISAT
★ ICRISAT E. Afr.
★ ICRISAT W. Afr.
★ ICRISAT / CIMMYT
Southern Africa
★ Germplasm Enhancement
★ Sorghum Insect Pest Management
★ Sorghum Disease Management
★ Sustainable Production Systems
★ Water Management
★ Millet Seedling Establishment
Horn of Africa
★ Germplasm Enhancement
★ Sorghum Processing & Utilization
★ Sorghum Disease Management
★ Agronomic Practices
★ Economic Studies
INTSORMIL
► Kansas State University
► Mississippi State University
► University of Nebraska
► Purdue University
► Texas A&M University
Central America
★ Germplasm Enhancement
(Sorghum Varieties & Hybrids)
★ Sorghum Insect Pest Management
★ Sorghum Disease Management
★ Sorghum Utilization & Quality
★ Sustainable Production Systems
★ Economics of New Technologies
West Africa
★ Germplasm Enhancement
★ Insect Pest Management
★ Sorghum Disease Management
★ Farming Systems and Economics
of Farm Production
★ Physiology of Drought Adaptation
★ Sorghum Processing and Utilization
★ Agronomic Practices and Rotation
★ Egypt
Collaborative Programs

Honduras and Central America

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Ing. Mark Weiholtz, Agronomist, Pioneer of Central America, Honduras
Ing. Laureano Pineda, Agronomist, INTA, Nicaragua
Ing. Oscar Martínez, Agronomist, ICTA, Guatemala
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Objectives, Production and Utilization Constraints

Objectives

- To conduct maicillo research including breeding nurseries, advanced yield tests and on-farm demonstration trials with new maicillo technologies in southern Honduras.
- To implement on-farm demonstration plots of a new red grain sorghum hybrid.
- To conduct the sorghum downy mildew nurseries at Comayagua.
- Develop anthracnose screening methodology.
- To develop sorghum grain standards for Honduras and Central America.
- To develop of broomcorn cultivars with long fiber.
- To publish the results of grain sorghum performance trials.
- To rejuvenate (CLAIS) Latin American Sorghum Commission.
- To develop an agricultural experimental and training station facility.

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 during 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).

Utilization

Sorghum is successfully replacing maize in animal feed and releasing an equivalent amount of white maize for human consumption. Estimated sorghum consumption by the agroindustry in Honduras has increased 1,361 percent for the period of 1985-1993–from a meager 4,091 MT to 55,681 MT. These values represent an average increase of 5,732 MT per year. On the other hand, utilization of maize by the agroindustry has been leveled off at 100,000 MT, primarily because of sorghum and feed wheat replacement in animal rations (UPSA, 1995).

Marketing

Trends in increasing sorghum utilization by agroindustries, have made this cereal a key commodity to overcome maize shortages and consequently an important food security crop. New Central American free market policies require that sorghum and maize prices fluctuate according to world prices, but applies an import tax within the range of 5 and 45 percent, to promote local production and demote speculation. Grain quality standards for regional commercial transactions are needed to promote market prices. Agricultural commodity exchange offices are being established in each Central American country and demanding grain quality standards.

Sorghum Landraces (Maicillos)

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 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 a disease 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 that have low but stable yield. 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 that 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 h 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 domain in the Tropics (12-15° N lat.).

Improved sorghum cultivars

Cultivar evaluation. Commercial seed companies marketing improved varieties and hybrids require an unbiased evaluation of their materials for yield and adaptation. Four large seed companies–Dekalb, Pioneer, Cargill and Cristiani are now marketing a wide variety of hybrids. Multilocation testing is of paramount importance to expose new hybrids to farmers and seed distributors.

Parental lines for hybrid production. Seed industry in Central America is experimenting a revitalization through the new open market initiatives. Even though international seed companies are doing an excellent job in disseminating sorghum hybrids, national seed industries are demanding parental lines for hybrid production.

Uniform regional seed standards. The Central American open market is promoting an exchange of agricultural goods including seeds, among participant countries. Furthermore, the southern Mexican market for seed is seen by some Central American companies as a good opportunity to export tropical adapted sorghum hybrid seeds. Uniform seed standards are becoming important to promote seed exchange. AOSCA's (International Association of Seed Certification Agencies) standards provide the baseline support to use uniform standards.

Management practices. Exploiting high yield potential bred into the improved varieties and hybrids through enhanced management practices, requires a systematic on-farm testing and demonstrations. The low average grain yield (2.5 TM ha^{-1}) attained with improved cultivars is a reflection of several agronomic malpractices ranging from seedbed preparation, plant densities, weed control, early season pest control and irregular harvesting times.

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*—wreck 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.

New low-toxicity seed treatment insecticides provide outstanding early season pest control. This technology needs to be demonstrated and transferred to ensure appropriate plant densities and increased yields.

Sorghum Downy Mildew. Sorghum Downy Mildew 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 that was discovered at Las Playitas Experiment Station, Comayagua, Honduras in 1986. Because maicillo and most sources of resistance in the United States are susceptible to P5, the pathogen threatens the stability of sorghum production in Honduras and Central America. The introduction and deployment of resistant genes offer the best alternative for control. Evaluation of commercial and experimental entries in Comayagua is providing an insurance against this disease.

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 an urgent need. 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, much like 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, since isolates from Honduras have shown to be genetically similar (Rosewich, 1994 personal communication).

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 trends that indicate a slow but steady increase in leaf blight susceptibility, specifically in Tx623, Tx626 and some commercial hybrids bearing susceptible parents. A systematic screening scheme and gene deployment are needed to anticipate epidemics.

Broomcorns

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.

Variety development and adaptation. Two broomcorn varieties developed by the Sorghum Project possess excellent yield and downy mildew resistance; however, most of their fiber does not qualify as hurl, that is the longest fiber used for the broom exterior. There is a need to develop a long fiber broomcorn with the same yield and defensive attributes. Non-government agencies request a steady seed supply of broomcorn varieties with higher yield of hurl type fibers that compete with Mexican imported fiber.

Networking

CLAIS. The Latin American Commission for Sorghum Research (CLAIS), initially supported by ICRISAT, finished 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.

PCCMCA. The 43-year old Central American and Caribbean Agricultural forum is undergoing the consequences of a decrease in public funding. INTSORMIL participation in this forum to rejuvenate CLAIS and the sorghum group requires especial efforts.

Electronic Linkages. New information highway technology is becoming available in Central America through Internet connection. National Sorghum Projects can benefit by connecting to the worldwide sorghum data base at U.S. Universities, ICRISAT and other sorghum projects through the region. E-mail communication technology and an electronic newsletter are seen as a preliminary step to link regional sorghum projects.

Experimental Station Management.

Training. Sorghum scientists in the region are constantly facing the lack of experimental station management capabilities. These scientists, besides conducting their own sorghum research, are frequently asked to manage the experiment station where they work. Basic knowledge on planing and running an experiment station needs to be built into the sorghum scientist curriculum, due to the lack of good specialists.

Mechanization. Proper field operations are of great importance in the process of on-farm demonstration in high yielding sorghum producing areas. Implementing a totally mechanized experimental station at Zamorano, will serve to demonstrate basic agronomic practices such as plant densities, weed control and fertilizer application to sorghum producers. Procurement of equipment for precision planting, soil preparation and harvesting needs to be pursued in the short term.

Research Approach and Project Output

The Honduras/Central America Sorghum program is a small program with headquarters at Zamorano Panamerican Agricultural School. At Zamorano, the Sorghum Project is adjoined to CITESGRAN (International Center for Seed and Grain Technology) heading by Dr. Francisco Gómez. This new arrangement favors a multi-disciplinary approach to solve sorghum production and foster utilization.

The program continues to be very productive. Much of its success stems from the continuity and stability provided by multi-institutional arrangements, USAID/HO local funding, as well as the contributions that the Sorghum Project is continuously offering to the Agronomy Department at Zamorano. 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.

Two technical thrusts that this project focuses on are: 1) conservation of local landrace sorghum populations and their enhancement; and 2) development and adaptation of high yielding improved cultivars. The first thrust deals with maicillo or photoperiod sensitive sorghum and the success of one activity depends upon the other. Our approach to conservation is a passive, *in-situ* approach, whereas enhancement is an active, more aggressive approach. The second thrust deals with insensitive sorghum germplasm and has achieved great importance in augmenting production and productivity

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 farmer's 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 adaptive 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 seed 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 hybrid ATx626 x R8503 that completed his final field evaluation for official release began its on-farm evaluation by farmers. Based on a former study by Ing. Porfirio Lobo on nicking the parental lines of this new hybrid, Ing. Oscar Díaz, from the Production Section at the Agronomy Department of Zamorano, has begun producing basic seed of the A&B parental lines (400 pounds) and certified seed of the hybrid (800 pounds) for on-farm demonstration. Fifty pound bags were given to sorghum producers from several locations across Honduras to measure its acceptability.

Zam-Rojo, the name with which this new hybrid is to be marketed, continued to show outstanding yield performance and adaptation under dry and irrigated areas. During the 1994 Grain Sorghum Performance Trials at four locations, Zam-Rojo yielded over (4.4 t ha^{-1}) together with two other commercial hybrids (P-8315 from Pioneer and AP 9860 from Agripo). Table 1 presents the average yield performance of Zam-Rojo over four locations in Honduras.

In 1994 a set of 185 experimental hybrids from the Texas A&M Sorghum Program and Zam-Rojo (ATx626*R8503) was evaluated at Zamorano for adaptation, grain yield and agronomic performance. Hybrid seed was produced at Comayagua from seed of the parental lines sent by Dr. Fred Miller in 1993. Seventeen hybrids had grain yield over 6.00 t ha^{-1}. Hybrids made with ATx626 presented outstanding grain yield and overall agronomic performance. Zam-Rojo ranked fourth with 6.63 t ha^{-1}. The male lines R9301, R9303 and 80C2241 in combination with ATx626 were ranked slightly higher than Zam-Rojo. These new hybrids will be tested against the commercial hybrids in the 1994-1995 cycle, at least in two locations.

Table 1. Average yield performance of 25 grain sorghum cultivars over four locations in Honduras during 1994.

Hybrid	Company	Days to 50% bloom	Grain yield t ha^{-1}
P-8315	Pioneer	65	4.47
AP 9860	Agripo	62	4.43
Zam-Rojo	E.A.P./SRN	66	4.42
HES 9205	Hoechst	59	4.22
H 886-G1	Cristiani	67	4.16
DK-65	Dekalb	68	4.15
DK-77	Dekalb	69	4.14
DK-64	Dekalb	66	4.13
Y 360	Richardson	64	4.09
Y 344	Richardson	62	4.03
P-8133	Pioneer	65	4.02
AP 9850	Agripo	64	4.00
G 222	Agrigenetics	63	3.96
P-8200	Pioneer	64	3.95
DK-73	Dekalb	71	3.95
H 889-73	Cristiani	69	3.91
HES 8902	Hoechst	66	3.86
H 886-G2	Cristiani	71	3.84
X 166	Dekalb	67	3.75
DK 55	Dekalb	67	3.68
Isiap Dorado	E.A.P./SRN	72	3.63
Sureño	E.A.P./SRN	74	3.58
9300	Richardson	62	3.51
G 125	Agrigenetics	63	3.49
H 889-75	Cristiani	72	3.34
Average		66	3.95

Broomcorn

A significant amount of information on broomcorn production and marketing has been accumulated in the Sorghum Project. "Polígono Industrial Copaneco," a religious NGO funded by the Belgium and Canadian governments, bought seed at Zamorano to plant about 60 ha. The Sorghum Project provided technical advise on agronomic management and marketing. We initially recommended dedicating the first two years to the production of fiber and selling it to "Broom and Mops", a broom export factory located at San Pedro Sula. We based our recommendation on the fact that broomcorn is a new crop and farmers need to get acquainted with fiber quality parameters and marketing. Cost-benefit analysis surpassed their expectancies providing that fiber prices remained at $0.60 per pound for second class fiber. Early this year The "Tequila effect" as the Mexican Economic Crisis was named, lowered the fiber world market price. Consequently, "Polígono Industrial Copaneco" manager is now negotiating new prices with Broom and Mops.

Table 2. New grain hybrids identified at Zamorano 1994.

Female	Male	Days to 50% bloom	Lodging -%-	Grain and plant color	Plant height -m-	Head Exs. -cm-	Panicle length -cm-	300 seed weight -g-	Grain yield t ha^{-1}
ATx626	R.9301	67	0.0	R/Ri	1.60	22	26	7.4	7.23
ATx626	R.9303	65	0.0	R/R	1.4	26	30	6.8	6.83
ATx626	80C2241	67	0.0	R/Ri	1.50	20	39	7.2	6.74
ATx626	R.8503	66	0.0	R/Ri	1.40	8	31	7.2	6.63
ATx631	RTx430	69	0.0	P/wht	1.55	7	30	7.5	6.53
ATx626	RTx2783	68	0.0	R/R	1.50	8	29	6.5	6.45
ATx626	R9311	66	0.0	R/R	1.60	14	32	6.2	6.28
ATx631	R9207	69	14.6	T/wht	2.10	20	35	6.5	6.24
ATx626	R9322	66	0.0	R/R	1.60	16	31	6.6	6.22
ATx626	R9312	63	0.0	R/R	1.60	21	29	5.9	6.16
ATxARG-1	R9201	66	9.1	R/R	1.95	22	31	6.6	6.11
ATx626	R9027	68	0.0	R/R	1.50	23	38	7.1	6.06
ATx626	R9207	67	14.5	R/R	1.90	21	31	6.3	6.05
ATxARG-1	R9211	63	1.9	T/wht	1.40	20	30	6.1	6.02
ATx626	R9032	66	0.0	R/R	1.50	13	33	6.0	6.02
ATx631	(((SC120*Tx7000)* Tx430)*Tx435)-der	73	0.0	R/R	2.20	17	29	7.7	6.01
ATxARG-1	R9320	68	0.0	T/Ri	1.40	17	33	6.1	6.00

Broomcorn research is now aiming to release a long fiber variety to compete more successful with imported fiber. Late in 1994, we carefully began increasing seed of a long fiber broomcorn from our collection at Zamorano, that also exhibits good level of downy mildew resistance. This new cultivar is significantly taller than ZAMES-1 and ZAMES-2. An isolated field using self pollinated seed of this broomcorn is expected to be planted in August 1995 at Zamorano

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 which, in effect, shifts the stem to panicle sink ratio in favor of producing more grain; 2) add tan or lighter 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. Another characteristic that has carried over from maicillo, but we have not directly selected for, is resistance to anthracnose. Because photoperiod sensitivity is maintained in enhanced maicillo cultivars, this work can only be done in the region.

We use three locations to screen segregant populations. We select for drought stress and shade tolerance at RAPACO, resistance to sorghum downy mildew at Comayagua, and resistance to foliar diseases at Choluteca. In 1994 we planted about 5 ha of nurseries at these three locations and made 5633 selections. Most of these selections had tan plant color, white grain and most were 2-3 dw.

As superior lines are identified in more advanced generations, F_6-F_7, they are placed in our International Improved Maicillo Yield Trial (EIME). This is a multi-location yield test, referred to as EIME in Spanish, that is used to select materials for on-farm demonstration plots. The 1994 EIME consisted of 25 entries and was planted at four locations in Honduras: Choluteca, Comayagua, RAPACO, and Zamorano (Table 3).

Two new enhanced maicillo sister lines derived from Sureño*Caturra crosses, showed for the second year, promising characteristics to be deployed on farmer fields in 1996. Even though these new maicillos are not tan plant color, they express a very good adaptation to several environmental conditions

Official release of the two enhanced maicillos that have been tested on farmers' fields since 1992 was delayed until DICTA/SRN authorities are fully installed. 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) had to withstand farmers, housewives and extension personnel criticisms, as well as environmental conditions during the course of evaluations.

On-Farm Research

On-farm demonstration plots of Maicillo Technology. 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.

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). Tables 4, 5 and 6 present a comprehensive outline of the average performance and gross income of these two new enhanced maicillo cultivars from 95 on-farm demonstration plots over several years in southern Honduras

Even though enhanced maicillos are one meter shorter than local maicillos, the amount of forage harvested is practically the same (Table 4). Forage yield is further increased if the number of plants is increased by controlling the langosta complex. By adding 60 kg ha^{-1} of nitrogen, forage yield reaches 20 percent more than with maicillo criollo. At farmer's level, forage yield is measured in bales; each bale consists of 25 plants after mature panicles has been removed. Bales are sold usually during the dry season at costs that may reach US $1.00 per ten bales. Income derived from selling sorghum bales is significant for farmers and its benefit is translated into more animal products.

Table 4 presents forage yield and quality parameters for two enhanced maicillo cultivars deployed in southern Honduras. Data showed in the table easily demonstrate the forage yield and quality parameters in these two maicillos.

The average soluble solid content of these enhanced maicillos was 2 °Brix higher than the average found in the maicillo criollos (Table 4). This, together with resistance to *C. sorghi*, organism that produces the gray leaf spot, and their ability to stay green past maturation, produces a forage of superior quality that is gaining farmers' recognition. Feeding trials in collaboration with animal nutritionists, is the next step to document the weight gain and milk production increase in animals fed with forage of improved maicillos versus maicillos criollos during the dry season.

The gross income obtained by farmers with our technological menu is presented in Table 5. The combined income of grain and forage should satisfy farmer's expectancies. The maximum income is obtained if farmers choose an improved maicillo, control the langosta complex and fertilize with 60 kg ha^{-1} of nitrogen. Information in Table 5 shows

Table 3. Grain yield of 25 maicillo cultivars in the EIME, over four locations in Honduras, 1994.

Entry	Genealogy	DMV	Color	Julian days to 50% bloom	Grain yield (kg ha^{-1}) Average	Zamorano	Olancho	Choluteca	Comayagua
5	(TAM428*Porvenir)-29-2-3-b-b	137	whT/R	305	3.54	6.80	3.07	2.11	2.19
2	(Sureño*Caturra 68)-3-3-2-1	221	whT/R	297	3.13	5.54	2.29	2.52	2.15
1	(SPV346*Gigante Pavana)-1-1-2	179	whTT	310	3.11	6.77	2.11	1.71	1.83
20	San Bernardo III	MC	whT/P	304	2.99	6.11	2.18	1.95	1.72
25	(Sureño*Caturra 68)-3-3-6-6-4	233	WhT/T	307	2.91	5.73	2.60	1.33	1.96
3	(TAM428*MC100)-2-2	210	whT/P	293	2.85	6.06	1.84	1.70	1.78
17	Lerdo Ligero	002	wh/Pss	280	2.75	5.56	1.29	2.67	1.47
18	Pelotón	MC	wh/P	316	2.74	5.56	1.50	1.62	2.29
13	{[SPV346 (81LL691*Billy)]*(SC414*P.N.)}-7-1-b	213	wh/T	312	2.74	5.01	2.59	1.72	1.64
6	[(SEPON77*Sta.Isabel)ICSV 151]-5-7-2-4	222	whT/T	266	2.69	4.43	2.57	1.48	2.29
4	(TAM428*Porvenir)-29-1-1-b-b-1-b	198	whT/R	309	2.64	4.70	2.27	2.09	1.49
14	{[SPV346(81LL691*Billy)]*(SC414*P.N.)}-25-3-4	219	wh/T	309	2.59	4.35	2.35	1.90	1.74
15	{[SPV346(81LL691*Billy)]*(SC414*P.N.)}-41-1-2-2	228	wh/T	310	2.55	4.57	2.00	2.18	1.44
7	[(SEPON77*Sta.Isabel)ICSV 151]-6-1-1-2	223	whT/T	266	2.51	3.09	2.95	1.93	2.05
19	Porvenir	MC	wh/P	305	2.50	3.98	1.05	3.09	1.88
12	{[SPV346(81LL691*Billy)]*(SC414*P.N.)}-4-1-1	218	whT/T	307	2.41	4.35	2.06	1.54	1.67
9	[(Tx435(MB9*Liberal)]-1-2-1-4	225	whT/R	297	2.38	3.54	2.67	1.62	1.70
8	[(SEPON77*Sta.Isabel)ICSV 151]-6-2-1-1	224	whT/T	270	2.25	3.29	2.18	1.97	1.57
11	{[(SC326*SC103)Lib.]SC1207}-10-2-1-5	227	whT/T	315	2.25	3.68	1.06	2.27	1.97
16	ES 727	MC	wh/P	310	2.22	3.72	1.79	1.90	1.45
21	[(SEPON77*Sta.Isabel)-6*ICSV-151}-6-1-1-2-1-bk	229	WhT/T	267	2.19	2.66	2.85	1.50	1.74
22	[(SEPON77*Sta.Isabel)-6*ICSV-151}-6-1-3-3-4-bk	230	WhT/T	269	2.07	3.21	2.24	1.11	1.71
23	[(SEPON77*Sta.Isabel)-6*ICSV-151}-6-2-1-2-4-bk	231	WhT/T	311	2.00	4.45	1.03	1.08	1.45
24	[(SEPON77*Sta.Isabel)-6*ICSV-151}-6-2-1-2-5-bk	232	WhT/T	279	1.82	3.96	1.26	0.56	1.50
10	[(Tx435 (MB9*Liberal)]-3-3-1-1	226	whT/T	280	1.73	2.09	1.73	1.51	1.59

Table 4. Forage yield of two enhanced maicillo cultivars in Southern Honduras, from several on-farm demonstration plots harvested in 1993-1994 and 1994-1995 cycles.

Technological level	Forage yield† (t ha^{-1})	Number of bales‡ (ha^{-1})	Soluble solids† (° Brix)
Gigante Mejorado			
T1 = Maicillo Criollo	55	931	13
T2 = Enhanced Maicillo	54	1275	15
T3 = T2 + "Langosta control"	61	1631	16
T4 = T3 + 60 kg ha^{-1} of Nitrogen	66	1828	15
Porvenir Mejorado			
T1 = Maicillo Criollo	54	994	13
T2 = Enhanced Maicillo	62	1428	15
T3 = T2 + "Langosta control"	64	1554	14
T4 = T3 - 60 kg ha^{-1} of Nitrogen	65	2097	16

† Data from 1993-94 cycle.
‡ Data from 1994-95 cycle. A bale is equivalent to 25 plants after harvesting the panicles. In 1994 a bale was sold for Lps 1.00 ($0.11). 1 USdollar = Lps9.2248

Table 5. Combined yield of grain and forage and gross income of two enhanced maicillos under different technological level

	Yield		Value (Lps)		
	Grain (kg ha^{-1})	Forage bales† (ha^{-1})	Grain	Forage	Total
Gigante Mejorado					
T1 = Maicillo Criollo	764	931	1176	931	2107
T2 = Enhanced Maicillo	1056	1275	1627	1275	2902
T3 = T2 + "Langosta control"	2413	1631	3715	1631	5347
T4 = T3 + 60 kg ha^{-1} of Nitrogen	2960	1828	4558	1828	6387
Porvenir Mejorado					
T1 = Maicillo Criollo	922	994	1419	994	2414
T2 = Enhanced Maicillo	1396	1428	2150	1428	3578
T3 = T2 + "Langosta control"	1510	1554	2325	1554	3879
T4 = T3 - 60 kg ha^{-1} of Nitrogen	2185	2097	3364	2097	5461

† A bale is equivalent to 25 plants after harvesting the panicle. In 1994 a bale was sold for Lps1.00 ($0.11). 1 USdollar=Lps 9.2248

very clear the importance of the characteristics bred into the improved maicillos, that not only produce an abundance of harvested products (grain and forage), but also a significant income to small sorghum producer. Small farmer income can reach 162 percent higher if he were to apply the technologies that the Sorghum Project is promoting.

The effect of the technological level and the enhanced characteristics bred into the enhanced maicillos are illustrated in Table 6. Enhanced maicillos are 10 days earlier than original maicillo. This increases the chances for them to fill grain before the rainy season ends early in November. Also, this maturity is adequate to avoid mold and bird damage. Reduction in plant height significantly reduces lodging and increases harvest efficiency, since almost all family member can participate in harvesting.

The number of plants shown in Table 6 indicates very clearly that the langosta complex is a constraint to establish an adequate plant density. With no control of this pest complex, 15,000 plants per hectare are lost, which in turns reduces the grain yield and forage (Table 6).

The expected quantic leap with the application of 60 kg /ha^{-1} of Nitrogen and cultivars that respond to an improvement of management conditions, is well documented in Tables 4, 5 and 7. Each kilogram of nitrogen applied represents 22 kilograms of grain and 10 additional bales of forage. This response is larger in areas were sorghum is grown with soil conservation structures and in flat agricultural lands.

Special Projects

The Sorghum Project coordination 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 on-farm demonstration plots and maicillos nurseries, which are sponsored by the PRIAG/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. The Project On-Farm Demonstration Plots and Maicillos Nurseries financed by PRIAG/EEC ended in April of 1995, with the recommendation that the findings were to be spread through the maicillo growing area in Central America.

Table 6. Agronomic characteristics of two improved maicillos evaluated in Southern Honduras in 95 on-farm demonstration plots during the time period of 1992-1994.

	Agronomic characteristics			
	Days to 50% bloom	Plant height (-m-)	Plant density (plants ha^{-1})	Lodging (-%-)
Gigante Mejorado				
T1 = Maicillo Criollo	140	2.4	37,250	16
T2 = Enhanced Maicillo	125	2.3	51,000	4
T3 = T2 + "Langosta control"	123	2.3	65,250	2
T4 = T3 = 60 kg ha^{-1} of Nitrogen	123	2.3	73,125	3
Porvenir Mejorado				
T1 = Maicillo Criollo	139	2.8	39,779	8
T2 = Enhanced Maicillo	128	1.8	57,125	3
T3 = T2 + "Langosta control"	127	1.8	62,162	1
T4 = T3 - 60 kg ha^{-1} of Nitrogen	125	1.9	83,860	1

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 available, their 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 40 percent or 20,000 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 3.0 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 and contacts have been made with Cargill and Asgrow to evaluate their hybrids. For the cycle of 1995-1996, and according to the deliberations of CLAIS members gathered at the PCCMCA during the last week of March, 1995, in Honduras, this service will be provided on a regional basis. This agreement establishes a regional scope to the INTSORMIL activities, and marks the beginning of a rejuvenated CLAIS network, that will plunge into more sustainable and diversified sources of funds, and avoid collapses by depending solely on ephemeral donors.

Control of Sorghum Downy Mildew

A minigrant from the European Community was awarded to conduct, for the fourth year, the International Sorghum Downy Mildew Nursery. 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. Recall that P5 is the most virulent pathotype of *P. sorghi* reported in the Americas.

Although the International Sorghum Downy Mildew Nursery was first established at the Las Playitas experiment station, we relocated it to the adjacent Center for Agriculture Development (CEDA) in 1991, after monitoring for virulence indicated that P5 existed there as well. The nursery was managed with the collaboration of Ing. Hector Tablas, 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.

Sorghum Grain Quality Standards for Central America

On the third week of May 1995, CITESGRAN/Zamorano held the "Grain Standard for Central America Workshop for Central América." The Workshop was sponsored by the international donor community, including INTSORMIL, FAO, Swiss Corporation for Development, Collaborative Agribusiness Support Project, Canadian Grain Commission, Federal Grain Inspection System of USDA, and others. Participants worked during three consecutive days on developing the grain standards that will regulate the grain trade among Central American countries. Dr. Lloyd Rooney, from the Cereal Quality Laboratory of Texas A&M University, actively participated in advising the local participants in developing the sorghum and maize standards. This activity should capitalize in the near future where individual users will adopt these standards through a systematic promotion.

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 and grain molds. To produce good quality seed, Sureño must be planted in places were its maturation occurs in dry environments.

Efforts are being made to concentrate Sureño production in Choluteca for the 1995-1996 cycle. Initially three farmers have agreed to produce Sureño's seed. One of them, Ing. Ramón Rueda, has been producing Sureño as commercial seed with excellent profits. Now, he is ready to move one step further and be a certified seed producer. The Sorghum Project will be monitoring his seed quality.

Institution Building

Upon initiation of collaborative activities in 1981, the INTSORMIL Project in Honduras has played an impressive role in developing human resources and contributed significantly to strengthening the institutional building at Zamorano. Even though previous accomplishments in this matter are very well addressed in previous annual reports, it is worth commenting on some aspects.

The Agronomy Department of Zamorano has effectively built upon the Sorghum Project to develop the capability of the International Seed and Grain Technology Center (CITESGRAN), by nominating Dr. Francisco Gómez as Coordinator. This decision is rapidly bringing about a spectacular burst in grain and seed technology for the region. Talks have already begun with Dr. Lloyd Rooney to start collaborative activities aimed to develop a cereal quality laboratory and a pilot plant system for training and research purposes on processing of sorghum and maize into different food products.

One very important aspect of the institutional building efforts of the Sorghum Project to Zamorano University, is through teaching, research and outreach. Scientists and other collaborators in the Sorghum Project teach two formal courses: Grain Production for second year students and Statistical Methods to the senior group. Since 1988, with funds from INTSORMIL, we have purchased an annual license for SAS® that has greatly improved the statistical analysis. Additionally, the Project participates in the on-farm modules and other academic endeavors, such as thesis advisors.

Experimental Station

Construction began on the experimental station at Zamorano. In November of 1994, we made contact with ASSIST, a project especializing in providing technical assistance through private U.S. enterprises. Two projects were initiated with the help of ASSIST: one dealing with CITESGRAN's new Seed Plant and the other with the experimental station to conduct our sorghum field trials. Two ex-agronomists from Pioneer Overseas Corporation were sent to help outline the station. In April, 1995, we initiated some work with a small grant from Dekalb. We expect to conclude this work during the dry season in 1996.

Networking

PCCMCA

During the last week of March 1995, Honduras held the XLI PCCMCA Annual Meeting at Tegucigalpa. Dr. Francisco Gómez, from the Sorghum Project, was designated by the EAP as a liaison to help in the organization.

Dr. Gómez presided over the discussion in the Sorghum Meetings. There were representatives from four countries: Guatemala, Nicaragua, Panama and Honduras. Eight papers were presented: three on breeding and enhancement, one on seed physiology, two on technology transfer, one on sorghum nutrition and one on plant protection.

The Sorghum Project leader from Honduras was named the coordinator for the PCCMCA Sorghum Performance Trials that now will cover all Central American Region. Commercial companies agreed to finance the evaluation costs and a regional bulletin is to be published in 1996.

CLAIS

During the PCCMCA meetings, there was a consensus to rejuvenate CLAIS, since sorghum cultivation is increasing in importance in the semi-arid areas of Central America. Initially, PRIAG/CEE considered to finance CLAIS; however, 1995 is the last year of this Project and it was difficult for them to justify new activities in the region. There was an election and Dr. Francisco Gómez was named the Regional Coordinator for the period of 1995-1996.

Three objectives were defined for the CLAIS network:

1) Promote germplasm and research results exchange in Central America.

2) Foster the development of the sorghum industry in Central America through the diffusion of sorghum technologies.

3) Promote efficient utilization of human and financial resources for conducting sorghum research in Central America.

Five projects outlining sorghum production constraints in the regions were proposed to be addressed by CLAIS:

1) Evaluation of nonphotosensitive lines for hybrid and open pollinated variety development.

2) Evaluation of photosensitive lines for open pollinated variety development.

3) Downy mildew control and monitoring.

4) Anthracnose monitoring in Central America.

5) Conduct the Grain Sorghum Performance Test for the PCCMCA.

Institutional Arrangements

MNR-EAP Memorandum of Agreement. In 1991, the MNR signed an MOA with the EAP which places the responsibility of sorghum research with the Zamorano. This MOA was elevated to the status of Acuerdo (no. 3524-91) when it was approved by the Honduran President 9 Dec. 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.

DICTA, the new Directorate of Research and Technology Transfer from the MNR, was officially created in January 1995. The Sorghum Project has assisted DICTA on several occasions to formulate research strategies.

PL480 support. The GOH and USAID/H provide local currency support for the sorghum project through the Title I PL480 program. The present funding level was raised to 538,000-lempiras which is equivalent to 58,000 dollars where PL480 and GHO will both cover 50 percent of the total. Local currency covered most of in-country costs, including counterpart and support staff salaries.

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 (7,200-dollars) from the EEC this year for the control of sorghum downy mildew in Honduras.

Germplasm Exchange

Seed (400 g) of two improved maicillos was distributed among 35 farmers in southern Honduras.

Seed of 53 male lines for hybrid seed production was sent to Guatemala to reinforce the private seed industry.

Genetic seed of ATx623 (1 kg) and BTx623 (5 kg) were donated to the seed production unit at the EAP.

One long-fiber broomcorn variety was increased (2 kg) .

Basic seed of Tx2784 (2 kg lb.) 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 lb.) was donated to the seed production unit at the EAP. These are the parental lines of Zam-Rojo.

Publications and Presentations

Publications

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Gómez, F. , G. Peterson. 1994. Honduras Country Report. In 1994 INTSORMIL Annual Report. Lincoln Nebraska.

Presentations

Gómez F. Conservation and enhancement of maicillo. PCCMCA, 27-31 Mar. 1995. Tegucigalpa, Honduras.

Gómez F. The Honduras National Sorghum Project: an Overview. PCCMCA, 27-31 Mar. 1995. Tegucigalpa, Honduras

Rooney, L. W. Grain Sorghum Quality Standards. Presented at Grain Quality Standards for Central America Workshop. May 17-20, 1995. Zamorano, Honduras.

Rooney, L. W. Grain Maize Quality Standards. Presented at Grain Quality Standards for Central America Workshop. May 17-20, 1995. Zamorano, Honduras.

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, IER, Sotuba, Bamako, Mali

Collaborative Program

Program Structure

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 and in concert with, and as a part of, 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 research review and planning. These plans are reviewed by the country coordinators, consolidated, and coordinated with IER research project plans for approval or modification. This insures that the research fits into the annual overall IER plan. The plans then become part of the annual Amendment to the MOA. 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 and allowing the transfer of funds was signed in Mali on October 10, 1984. The annual Amendment to the MOA, which consists of the 1994-95 work plan and budget, was developed jointly by the country coordinators in March-April, 1994, and approved by IER and INTSORMIL in May, 1994.

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 for all external funding to be managed thru 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 at Nebraska 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 PIs transfer pass-through funds to Malian counterparts or purchase equipment or supplies for Mali directly from their project funds.

Collaborating Institutions

Institute of Rural Economy (IER), Bamako, Mali
Texas A&M University
University of Nebraska
Purdue University
Kansas State University
SPARC (USAID/TAMU) Project
USAID/Bamako
ICRISAT/WASIP/Mali
Soil Management CRSP (formerly TropSoils)

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; and 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, Ousmane Cisse (Sorghum), Mamadou N' Diaye (Millet), IER; R.A. Frederiksen, INTSORMIL; and M. Diourte, KSU student (IER).

Crop Protection Systems - Striga/Weed Science

Bourema Dembele, IER; G. Ejeta, INTSORMIL.

Crop Production Systems - Agronomy/Physiology/Soils

Sidi Bekaye Coulibaly, Abdoul Wahab Toure, Minamba Bagayoko, Zoumana Kouyate (Soil Management CRSP), Mamadou Doumbia (Soils Lab) IER; S.C. Mason, J.W. Maranville, A.B. Onken, INTSORMIL; Abdoul Sow, TAMU student, (IER/Soil Management CRSP), Abdoulaye Traore, UNL student, (IER/Agronomy), Samba Traore, UNL student, (IER/Weed Science/Agronomy).

Utilization and Quality

Mde. Aissata Berthé, IER; L.W. Rooney, INTSORMIL.

Economics

Ousmane Coulibaly, IER (Purdue student); J.H. Sanders, INTSORMIL.

Production and Utilization Constraints

Yield level and stability in sorghum/millet production is of major importance in Mali where food production is marginal in the presence of a 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 lack of 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 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. 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 would help stabilize 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 three years. New tan-plant Guinea-type breeding progeny offer an opportunity to develop new food products and industrial products which could enhance demand and stabilize prices. New commercial products using sorghum and millet are being developed and marketed.

Research Progress

Germplasm Enhancement

Pearl Millet Breeding

Emphasis is on selection within local landraces to disease resistance and yield and adaptation traits. The population technique is being used to improve harvest index, using primarily Malian cultivars, plus some use of introductions from ICRISAT and INTSORMIL. Some effort is also directed towards hybrids, using introduced A-lines crossed with local Malian males. The program received a setback in early 1995 with the departure of Karim Troare for two years to WARDA.

Sorghum Breeding - Crossing and Breeding Nurseries

In the 1994 rainy season, 151 new crosses were made. Emphasis was on intercrosses among the best white-seeded, tan-plant guinea type lines from the cross (Bimbiri Soumale*87CZ-Zerazera), and the elite local guineas, CSM388, Tiemarfing, and Bimbiri Soumale, with the best new advanced breeding non-guineense lines, (89-CZ-CS-F5-3AF; 89-CZ-CS-F5-21AF; 89-SK-F4-53-2PL; 89-SK-F4-184-1PL: 89-SK-F4-192-2PL) and established elite improved lines, ICSV1078, ICSV1063, 82/Vartan 16, CE151, Malisor 84-7, and Nagawhite. The "89-" lines will all be used in on-farm tests in 1995.

Over 800 individual selections were made in F_2, F_3, and F_4 progenies grown at Sotuba, Cinzana, Longorola, Bema, and Kolombada. Selected F_4 progenies were identified for advance in the off season to be entered as F_6s in Preliminary Yield Trials. Selected lines in the 1994 Preliminary Yield Trials were to be placed in the 1995 Advanced Trials.

Six new non-guineense advanced generation breeding lines were selected for seed increase to be placed in selected 1995 on-farm trials. Three lines, 89-CZ-CS-F5-3AF, 89-CZ-CS-F5-21AF, and 89-CZ-CS-F5-137AF were selected for early maturing areas (Cinzana and north). The three selected for use in medium maturing zones were 89-SK-F4-53-2PL, 89-SK-F4-184-1PL, and 89-SK-F4-192-2PL (Introduction Africa Sud). A bulk of the pedigree (Bimbiri Soumale*87CZ-Zerazera) was made for 1995 on farm trials in the medium maturity zone (Cinzana and Bamako). This is the white seeded, tan-plant guinea type which should be useful for enhanced quality, value added commercial food products.

Plant Protection

Entomology

Research activities in 1994 focused on the evaluation of new breeding lines and the identification of new sources of resistance to the head bug *(Eurystylus marginatus)*. The breeding line 89-CZ-CS-F5-137 and 87-SB-LO-F4-155 along with the line ICSV401 compared favorably to Malisor 84-7 in head bug/grain mold ratings. In the advanced trial 90-CZ-CS-Tx-2, 90-CZ-CS-Tx-1, and PR2562 had a good visual score. All are Malisor 84-7 derivatives originally selected in Texas.

Pathology

Selected breeding lines, introductions, and the ADIN were evaluated for resistance to anthracnose and sooty stripe. Seven showed good anthracnose resistance. IS6991 had very good sooty stripe resistance.

Apron® Plus and Oftanol-T were effective in control of covered kernel smut. In millet, Apron® plus is being used to effectively control downy mildew, but it is quite expensive.

Striga

Twenty-three sorghum lines from Purdue were evaluated under field conditions. Eight showed good resistance to *Striga* and five had excellent yield. Several breeding lines from the IER breeding program also were evaluated.

Dr. Gebisa Ejeta has made plans with World Vision to distribute and evaluate several improved *Striga* resistant lines in Mali in on-farm trials in 1995.

Crop Production/Agronomy/Physiology

Seedling Screening for Drought and Heat Tolerance

Screening in charcoal pits during the hot off-season at Cinzana indicated that in both millet and sorghum, local varieties showed more resistance than improved breeding lines or improved varieties.

Drought Evaluation of Millet Populations

Ten selected millet cultivars were evaluated for grain yield and other traits related to drought response under two planting dates and two plant densities at Cinzana, Bema, and Koporo. No consistent pattern resulted, indicating a genotype interaction with rates and dates, which was somewhat different at each location.

Cropping System and Nitrogen Rates

In 1994, the increase in pearl millet grain yield due to N application was 31% and 66% with 20N and 40N, respectively, in monoculture and 64% and 66% for 20N and 40N respectively, in millet-cowpea rotation. Crop rotation (millet-cowpea) alone without N increased millet grain yield by 74%. The increase was 35%, 34%, and 56% the past three years. The legume effect appears worth 30 to 40kg N/ha.

The land equivalent ratio (LER) of cowpea-millet intercropping was increased by 56% with 0N, and 46% and 8% with 20N and 40N, respectively. A study comparing improved millet-improved intercrop to local cultivars intercrop showed no increase in net income with improved varieties. This was largely due to the costs of controlling cowpea insect infestations.

In a sorghum, cowpea, millet, dolichos, peanut, N fertilizer cropping study, crop effects were not significant as affecting yield components of sorghum, but dolichos had a beneficial effect on other crops. Fertilizer effects were significant for all crops, but the effect was less at higher N rates of 40N and 60N. It appeared that 20N was the best treatment economically in this trial. A millet residue management study showed no significant benefit with millet residue application in 1994.

Soil Toxicity-Sorghum Study

A 46 entry screening nursery was grown at Cinzana on a previously selected site in a cooperative project with the Soil Management CRSP. Damage was extremely severe with the damage occurring in the first 21 days after planting. Gadiaba (Cinzana sel) from northern Mali and Bagoba (Niger) were the best entries. N'Gaberi Kime and El Mota, both also from Niger, did better than most introductions. Several genotypes previously identified as tolerant to acid soil in Georgia had poor performance.

Grain Quality Studies

The advanced medium-early and early trials from the sorghum breeding program were evaluated for physical kernel characteristics, decortication yield, and tô properties. The local guinea landrace types generally had the best performance, but some non-guinea lines performed well such as (ICSV1002*S-34) and (Malisor 84-7*S-34).

Economics

Research was conducted on the adoption of new cereal technologies in the Sudano-Guinean and Sudanian zones of Mali. In the Sudano-Guinean (higher rainfall) zone, new millet and sorghum cultivars are not well adopted due to lack of credit for these crops, whereas cotton and maize do receive favorable credit. However, improved sorghum technology (varieties, fertilizer, etc) would be adopted with an improved credit policy. In the Sudanian zone some improved management of sorghum and millet has been adopted such as ridging for water retention and low levels of inorganic fertilizer. There is much more potential for rapid adoption of new technologies in the Sudanian (drier) zone as they do not have to compete with new technologies for cotton and maize. The January, 1994 devaluation of the CFA had a detrimental effect on technology adoption, due to reduced farm income, with only a 10% increase in cereal prices compared to a 50% increase in fertilizer prices.

Mutual Benefits

All research results reported should be a benefit 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 field and laboratory research equipment for the breeding, agronomy/physiology, and entomology program and the food technology laboratory. Also, computer software (plant breeding management system) was provided for Sotuba and Cinzana. Training in computer use was provided by G.C. Peterson. Subscription to ASA and CSSA were provided for researchers at Cinzana, Mopti, and Sotuba. Support from the INTSORMIL budget, 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 (Soil Management CRSP) at TAMU, Mr. A. Traore in agronomy at Nebraska, Mr. M. Dioute in pathology at KSU, and Mrs. N. Diarisso 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. The contribution of INTSORMIL trained Dr. Moussa Traore (Ph.D Nebraska), former physiologist and Mali Country Coordinator, now the Permanent Secretary to the Minister of Agriculture, has been huge in the reorganization and current operation of IER. The contribution of Dr. Oumar Niangado, Director of General of IER, has also been significant. He is a former INTSORMIL collaborator and millet breeder, and has been instrumental from the beginning in INTSORMIL's working in Mali. Dr. Aboubacor Touré, Ph.D from TAMU in breeding, is currently a sorghum breeder and the INTSORMIL Country Coordinator, and has served as Head of the Mali National Sorghum Program.

INTSORMIL travelers to Mali during the year included: Drs. D.T. Rosenow and G.C. Peterson, sorghum breeders; Dr. L.W. Rooney, food scientist: Drs. J.D. Maranville and S.C. Mason, agronomists from Nebraska; and Dr. J.H. Sanders, economist, from Purdue. Mr. Ousmane Coulibaly, Malian Ph.D student in economics at Purdue, traveled to Mali to conduct his thesis research. Dr. Aboubacar Touré traveled to the U.S. in March to attend the SICNA Conference and to develop work plans with PIs. Mde. Aissata Berthé spent four months in training in the Cereal Technology Laboratory of Dr. L.W. Rooney and took some classwork in cereal chemistry. Dr. Y. Doumbia, entomology, spent July 18-24, 1994 at Texas A&M working with Dr. Teetes and evaluating the research of Ms. Niamoye Diarisso, IER/Malian Ph.D. student in entomology.

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 and grain mold is a world-wide problem. Exchange of elite germplasm with useful traits is an excellent means of networking among breeders.

Efforts are underway to utilize existing networks to extend technology to the region in both sorghum and millet. Drs. Steve Mason and Frank Gilstrap participated in the ROCAFREMI meeting in Niamey, March, 1995, representing INTSORMIL, presenting papers, and developing linkages with the millet network. Minamba Bagayoko represented IER's millet research program at the Niamey ROCAFREMI meeting. 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. Dr. Gebisa Ejeta has initiated a plan with World Vision to distribute some improved *Striga* resistant sorghum through on-farm trials in Mali in 1995. 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 Agreement was signed with IER in 1984. The program has interacted with ICRISAT-WASIP, Soil Management CRSP (formerly 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 one of 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 Secretary to the Minister of Agriculture - Previously, INTSORMIL Country Coordinator and Dr. Aboubacar Touré - Currently Sorghum Breeder and INTSORMIL Country Coordinator.

Infrastructure

- Designed and equipped food technology laboratory at Sotuba.
- Built and equipped physiology laboratory at Cinzana
- Provided computers/word processors, printers, and software for sorghum and millet 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.
- The seed cold storage room at Sotuba is being renovated.

Germplasm Enhancement

- Elite sorghums from over the world have been incorporated into Malian breeding programs.
- Genotype drought response in Mali is similar to that in West Texas.
- Elite U.S. pearl millet lines crossed to Malian pearl millets have been introduced into Mali.
- Seven improved sorghum lines from the Malian program have been released.
- Malisor 84-7 has shown some advantages to traditional guineas 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.
- CSM-388 and CSM-219, improved local photosensitive Malian sorghum cultivars through mass selection, are currently grown by farmers on significant area.
- 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 revised.
- Equipment for the 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 are definitely required for efficient traditional hand pounding, and thick pericarp is preferred.
- 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.
- Mileg, a weaning food using primarily millet flour, has been developed by private enterprise and marketed in stores in the Bamako area. The product was developed using technology developed in the IER Cereal Technology Laboratory.

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 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 non-guinea type sources of head bug resistance have been identified in addition to Malisor 84-7.
- Head bug damage drastically 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 to *S. asiatia* in the U.S. works under field conditions with *S. hermonthica* 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 perforated 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/Soil Management CRSP collaboration.
- Some Durra varieties from Niger (Bagoba, Babadia Fara) and northern Mali (Gadiaba) 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.

Economics

- Lack of farm credit for millet and sorghum, compared to cotton and maize, discourages adoption by farmers of improved millet and sorghum technology, especially in the Sudano-Guinean zone.

Niger

John Axtell and Ouendeba Botorou
Purdue University and INRAN/Niger

Coordinators

Abdoulaye Gouro, INRAN Director General
Ouendeba Botorou, INRAN Scientific Director & Niger Country Coordinator
Issaka Mahamane, INRAN/InterCRSP Coordinator
John Axtell, U.S. Coordinator, Department of Agronomy, Purdue University, W. Lafayette, IN 47907

Collaborative Program

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

A major InterCRSP activity was initiated in 1995 with USAID/Washington support in coordination with the Niger USAID Mission. INTSORMIL activities will include a seed production project of the new sorghum hybrid NAD-1 at Lhossa and *Striga* research using INTSORMIL/INRAN developed *Striga* resistant varieties at the Konni station. Cropping systems research was initiated with the Soil Management CRSP and the Peanut CRSP at Hamdallaye and a new site, Gaya, near Bengou.

The ICRISAT Sahelian Center continues to be 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 15 years, there have also 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, and IN.E.R.A. in Burkina Faso.

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. Ouendeba Botorou, Scientific Director, 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

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 16 years. INTSORMIL has played some part through training and through collaborative research efforts in the institutional development of INRAN. INTSORMIL scientists have also grown during this period in terms of their collaborative research capabilities in sorghum and millet research and technology. The collaborative research relationship now is an effective system for delivering excellent research and for the application of this research for the benefit of farmers in Niger and in the United States. INRAN now has excellent leadership, excellent scientific direction and excellent scientists, either fully trained or in the final stages of their Ph.D training programs. They now have a critical mass of excellence in research capability for the agricultural sciences. When one looks at progress in institutional developments over a longer time frame, it is easy to be optimistic about the future of INRAN/INTSORMIL collaborative research. A total of six Nigeriens have received Ph.Ds and five have received M.S. degrees under this program. (Listed in the 1994 Annual Report).

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.

An InterCRSP project in Niger was funded for 1995-96 involving three active CRSPs in Niger: INTSORMIL, the Soil Management CRSP and Peanut. These CRSPs developed collaborative research programs focused on application of research results from the past 10 years on impacting at four sites in Niger: The Soil Management CRSP site at Hamdallaye, a new site at Bengou, seed production site at Lhossa and irrigation site at Konni. Research activities began with planting in June 1995 and results will be available in the next annual report.

A Natural Resource Management InterCRSP workshop for West Africa was held in September 1995 to develop an extensive CRSP activity for West Africa.

Research Accomplishments

Cereal Quality - Moussa Oumarou, Adam Aboubacar and Bruce Hamaker

The Niger InterCRSP will be providing substantial financial support for the Cereals Laboratory. Several important pieces of equipment will be purchased for the preparation of couscous and for grain milling. In addition, the Niger program funded travel for Adam Aboubacar and Bruce Hamaker to visit a Cereal Quality Laboratory in Benin. Adam also traveled to Senegal to meet with scientists at the Institute of Food Technology who developed small scale couscous processing equipment. It is planned that Adam will assist in the installation of this equipment and in training the Cereals Quality Laboratory scientists when the new equipment arrives in Niamey.

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

During the summer of 1994, 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 University 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, Professor D. 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 94 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 University, 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 others' demonstration plots and research plots in nearby INRAN stations.

Sorghum Hybrids - Issoufou Kapran, John Axtell, and Gebisa Ejeta

Summary: Sorghum is the second most important food crop in Niger, with an estimated acreage on the rise from 768,070 hectares in 1980 to more than two million hectares in 1994 (Anonymous, 1995). Productivity has however taken the reverse direction, and the average grain yield is less than 300 kg/ha for the same period. This trend was in fact observed from the late 1960s with average yield dropping from 589 kg/ha in 1969-71 to 390 kg/ha in 1974-76 (Dogget, 1988). This is very alarming because Niger has one of the highest population growth rates (3% per year) being observed for the developing world. The population in Niger has increased from 2.4 million in 1950 to an estimated 9.151 million in 1995 (Center for International Health Information, 1995). In a country where more than 90% of the people are involved in farming, there is undeniably a lot of pressure on land use for cropping as well as herding, especially since the rainfall patterns have become more erratic in recent decades, reducing the total available area for agriculture. The consequences on genetic resources and their use are very dramatic as can be observed for sorghum. In the absence of a reassuring alternative, most sorghum growers have the tendency to replace their old later-maturing varieties with new early-maturing types, which are more likely to escape drought periods, often at the expense of higher productivity. These early selections are taken from any source, even from grain obtained through food aid programs as seems to be the case for a three-dwarf local variety known as Tera; but the most common are in the 'MOTA' group (meaning car in the Hausa language, thus fast moving); selected by farmers from their own landraces, probably on the basis of earliness, the Motas are more likely to escape the very frequent drought periods. Concurrently, landrace varieties like Janjaré, which was considered so well adapted that the French IRAT used it in the early 1960s in developing the improved L30, and L30 itself, are becoming practically extinct, and are probably more visible at INRAN research stations than in farmers' fields. Local landraces are certainly the best source for crop improvement in the long term, because they have accumulated many adaptation traits that modern breeders can make use of in scientific approaches for increasing agricultural productivity. However, in the present situation of worsening environmental conditions and population pressure, alternatives are needed that can safeguard local germplasm while improving productivity. With the help of the INTSORMIL project, a new dynamism has integrated the INRAN sorghum breeding program since the early 1980s. While new landraces are continuously brought in for evaluation, especially the early 'dune' sorghums specific to Niger, some of the best adapted have been incorporated in random-mating populations, providing a low maintenance broadbase source of local germplasm that we can select from or improve at any time. At the same time, we conduct variety development through the pedigree method, intercrossing germplasm that we select in Niger and that provided by our collaborators on the basis of its geographical origin similar to that of Niger (e.g. Sudan), and/or because it has been improved for the same objectives as those of INRAN (high yield, early maturity, drought tolerance, *Striga*, mold). The best success of our collaboration is the demonstration that sorghum hybrids are an agricultural technology viable even for harsh environments, as is the case in Niger. This is essential, because it is recognized that in the context of today's population growth in developing countries, yield increases offer the best answer to meeting new food demands (Pinstrup-Andersen and Pandya-Lorch, 1995). Adoption of hybrids would also be beneficial to the environment since high and stable productivity may restrain the desperate use of marginal soils. Although introduced sorghum hybrids were tested during the IRAT program of the 1960s, they were not seen as a good alternative for Niger because of grain quality problems (Chantereau and Adamou, 1977), and the perception that they were too much input-dependent. It was not until two INTSORMIL supervised M.S. research projects were conducted in 1986 by Kapran and Tyler, respectively, that a systematic study of the value of heterosis was conducted in Niger. Kapran (1988) reports the comparison of a group of 90 hybrids to their parents in presence of local adapted checks, at several environments in Niger. Whereas parental lines were comparable to local varieties only under irrigation, hybrids were consistently better yielding than both. They surpassed the locals by 61% with irrigation and 49% under rainfed conditions; yield advantage of hybrids over parents (heterosis) was 45% higher under irrigated conditions, and even higher in the rainfed experiments (66%). Tyler (1988) tested 40 hybrids under the same rainfed environments as Kapran, with male parental lines grouped as exotic, intermediate, or local. He also found that hybrids were higher yielding than parents or checks; grain yield heterosis over male parents was of 127% for exotics, 83% for intermediate, and 66% for locals. Following these clear expressions of heterosis in Niger, the best hybrids from both studies were re-synthesized and evaluated regularly. Over the years, the cross between TX623A and MR732 (later named NAD-1) was consistently high-yielding in comparison with other hybrids or varieties, including the best adapted landraces of Niger. Starting in 1989, it was entered in the regional sorghum trials covering at least six West and Central African countries, and was good yielding under most conditions. Specifically in 1989, it ranked third of twenty entries including a local check and other ICRISAT hybrids or varieties, tested at nine locations in Ivory Coast, Mali,

Burkina Faso, Cameroon, Nigeria, and Niger (ICRISAT/WASIP, 1989). Also starting in 1989, an experimental seed production was started at Maradi (Niger), and demonstrated at the level of a national breeding program in West Africa, the feasibility of a large scale hybrid seed production. The same year we also gave the first sample of hybrid seed to a few farmers in the village of Bazaga near the INRAN/Konni station, and the feedback was extremely positive. Incidentally, this is where for the first time, a farmer who heard us explain the system of seed production using A and R lines, compared the hybrid to a mule (Alfadari in Hausa, the 'A' in NAD-1). This was the beginning of our on-going farm-level demonstration plots, which have increasingly attracted more farmer interest, to the point where today it is difficult to satisfy all requests for hybrid seed. At this point, again with the help of INTSORMIL, additional seed has been continuously produced since 1993 in the U.S. and shipped to Niger for the demonstration plots. Overall, the average yield of NAD-1 between 1986 and 1994 is 2758 kg/ha on-station, ten times the average yield of the farmer in Niger (273 kg/ha; Anonymous, 1995). Starting in 1993, we have quantified NAD-1's productivity on some of the farm-level plots. For 1993, the average farmer yield for the Konni and Jirataoua region was 2365 kg/ha for NAD-1. In 1994, NAD-1 yielded an estimated 1725 kg/ha (Say) , 3500 kg/ha (Jirataoua), 3800 kg/ha (Cerasa), and 4600 kg/ha (Konni), for an overall average farmer yield of more than 3000 kg/ha.

Taking into account the food quality problems of an earlier INRAN release, Kapran (1988) and Tyler (1988) conducted preliminary food (tuwo) quality tests of some of their test-hybrids at the village level, and concluded, generally, an acceptability similar to that of local varieties. This was taken a step further in 1990, in a collaborative INRAN/INTSORMIL wide scale food quality test. Three of the improved genotypes (NAD-1, SEPON-82, SRN-39) were evaluated together with a local variety across four regions, to obtain farmer feedback and compare the ratings with physico-chemical traits in laboratory analyses. NAD-1 was always rated as a good tuwo making entry. As can be seen some ten years later after it was selected, NAD-1 is still a high-yielding medium-maturing hybrid, with good drought tolerance and acceptable food quality, both on-station and on-farm. Its consistency of production was also compared to that of other improved and local genotypes (Visser, 1992), and NAD-1 hybrid was the most stable. The subject of yield stability was recently addressed by another INTSORMIL thesis project (Ibrahim, 1995). A total of 126 genotypes, including 90 hybrids, their parents and other checks were evaluated across 15 different environments in Niger, the U.S., South America, and Sudan. Hybrids not only were better yielders in all environments, they in fact showed a greater yield stability under stress than non-stress environments. Ibrahim (1995) concludes that for stress environments in semi-arid tropics, hybrids are more reliable genotypes. Despite the lack of a modern seed industry in Niger, the program of new hybrid production and testing, continues. Hundreds of new combinations are made and tested each year, and our preliminary observations indicate that a number of them have a yield potential similar to that of NAD-1. It is striking for example that some of them were obtained using as male parents, lines that we selected in Niger, from early generation germplasm provided by our INTSORMIL collaborators (90SN- series). Also, new A-lines like ABON34 appear to have similar good combining ability as TX623A, the female parent of NAD-1. Based on elements, including the continuously encouraging results obtained on-station since 1986, and farmer enthusiasm since 1989, it is realistic to suggest that hybrids may be the best route for increased sorghum productivity in Niger. The crucial problem to be solved is that of a viable seed production mechanism, and the history of its elaboration in countries like India, Zambia, and Sudan, is an encouraging signal.

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Entomology -Hamé Abdou Kadi Kadi, Frank E. Gilstrap, Imad Bayoun, and Ousmane Youm

The research program is organized as a collaboration between INRAN and INTSORMIL through an agreement signed by both parties. It is joint research which receives additional funds from Texas A&M/Entomology in support of the program. Prior to each cropping season the entomologists discuss the work plan before submitting it to INTSORMIL. The management is organized in that INTSORMIL supplies funds to the Niger INTSORMIL Coordinator who dispatches the money to the principal investigators (PIs). The coordinator supervises the accounting of expenses and serves as an administrator for the PIs.

During 1994-95, we benefacted from the funding of $1,000 from Texas A&M/Entomology in order to support our collaborative research program on the Millet Head

Miner (MHM) at Maradi. Also, the ICRISAT/ISC Millet Entomology program supported our activity by providing gas and per diem for travel between Maradi and Niamey to participate in the discussions between INRAN/INTSORMIL and ICRISAT on the 1994 research plan.

Our collaboration is basically with ICRISAT/ISC at Niamey. The entomologist from this institution provided us valuable counseling on how to conduct our program, he also supplied us some scientific research materials used in the laboratory or/and in the field. Throughout this collaboration, we also received many scientific articles on the MHM subjects. In 1995, we were invited to the ROCAFREMI meeting at which the INTSORMIL U.S. entomologist had given a training session useful for our 1995 research program on the "Evaluation of Mortality in Millet Head Miner (MHM), *Heliocheilus albipunctella*."

Millet Constraints Researched

Millet production constraints: In Niger, pearl millet [*Pennissetum glaucum* (L.) R.Br] is a subsistence cereal grown for human nutrition and for animal feeds. Many abiotic and biotic stresses are known factors that affect the production of pearl millet. Insects, in particular the MHM, is a major constraint that causes severe crop losses and millet grain deterioration.

Research methods: As discussed in the 1994 Millet Head Miner research plan, we were to conduct sampling of different stages of MHM in soil and on the plants. The soil sampling was executed in three plots/farm, each plot was 1 m^2 and 30 cm deep. Soil was removed and sifted through a fine mesh screen to remove all MHM prepupae and pupae. The millet panicule sampling was done in the same fields, panicules were taken each week during August through September. On each sample date, the 25 panicules collected were split longitudinally into four pieces of equal size and carefully examined for presence of the various MHM stages.

Examples of research progress findings and results with millet production: Surveys conducted in Niger since 1983 showed that the pest is present in all regions of West Africa millet production, but the areas of high infestations are located in the regions of Fillingué, Say, Guéchémé, Birni N'Konni, Maradi, Mayahi, Tessaoua, and Magaria. In these areas, more than 70% of spikes are attacked and the severity of damages is also very high (M'Baye, 1990). Studies conducted in Sénégal and Niger revealed the presence of natural enemy, *Bracon hebetor,* a larval ectoparasite which is most abundant during the past season as indicated by 95% parasitism in Niger 1982 (Guevremont, 1983).

Research Accomplishments

Research accomplishments: After two (2) years (1992 and 1993) of screening, we noted that among 25 cultivars, only four (4) Texas sorghum varieties (TAM 2566, TX2782, TX2755, and TX2890) were resistant to sorghum midge, *Contarinia sorghicola* Coquillet damages (Abdou, 1994). The results obtained in the 1994 research on the seasonal abundance of MHM (*Heliocheilus albipunctella* de Joannis) infestations in farmers' fields in Tarna, Maradi are: Soil Sampling conducted before and after the cropping season revealed that the abundance of *Heliocheilus* sp. is related to the soil texture. More prepupae and pupae were sampled in the sandy soils farms than in the farms with soils containing some clay. For the millet panicle sampling, we noted that the MHM eggs are also more abundant in the sandy soils farms. The numbers of young and old larvae and pupae sampled were proportional to the numbers of hatched and intact eggs. In the farms, we also encountered some parasitic insects (wasps and spiders). From some prepupal mummies parasitized and exposed in the laboratory, we isolated some parasites of *Heliocheilus* sp. known as *Copidosoma* (*Litomastix* sp.).

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Pathology -Issoufou Kollo Abdourhamane
and Richard Frederiksen

Millet

In 1994 a trial was conducted at the research station of Kollo to evaluate the efficacy of the herbicide Dicamba (3.6-dichloro 0-anisic acid) against *Striga hermouthica*, and its interaction with nitrogen. Four rates of nitrogen 0, 30, 60 and 90 kg/ha and two rates of Dicamba 0 and 0.2 kg ai/ha were used. Dicamba was applied at 35 and 50 days after sowing. *Striga* emergence was monitored up to the physiological maturity of the host plant. For *Striga* counts, the interaction between nitrogen and Dicamba and the main effect of nitrogen were not significant. The application of Dicamba resulted in a significant reduction (67%) of the number of *Striga*. Time of application of Dicamba had no effect on *Striga* emergence but influenced significantly yield of pearl millet. Our results indicated that yield is increased by 21% and is decreased by 8% to 15% when Dicamba is applied respectively at 35 and 50 days after sowing. Therefore timing of application of the herbicide is very important.

The seed dressing fungicide Apron® Plus (metalaxyl, carboxin and furathiocarb) have been tested on three millet cultivars in two localities, Kollo and Tara. Two improved cultivars of pearl millet (T18 L and HKP) and the local landraces (as susceptible checks) from each locality, have been used. Apron® Plus was used at 0, 25, 50, 75, and 100% of the commercial rate (14.3 gr/kg seeds). At Kollo the trial was conducted at the research station while at Tara it was conducted on farm.

In all localities millet yield increased with the rates of Apron® Plus, despite the very low pressure of Downy mildew. In fact the severity of Downy mildew was insignificant.

At Kollo the yield responses of the three millet cultivators to Apron® Plus were similar; millet yield increased linearly on the average by 63 kg/ha for each gram of Apron® Plus. In the locality of Tara much lower yields were observed. The interaction between cultivars and rates of Apron® Plus was highly significant. With the local landrace the rate of the yield increases was not significant. But the improved cultivars responded positively to the seed treatment. For the cultivar HKP yield increase is best described by a quadratic curve, but for T18L yield increased linearly with a rate of 19.6 kg/ha for each gram of Apron® Plus.

The yield response of pearl millet to seed treatment with Apron® Plus cannot be attributed exclusively to the tonic effect of the furathiocarb component. In fact, evidences which showed an association between external feeding nematodes and *Fusarium* ssp (mainly *F. moniliform*) are being accumulated. Samples of nematodes isolated from the rhizosphere were sent to Dr. Etienne Sarr (DFPV, Agrhymet; Niamey) for identification. Previous results obtained with Apron® Plus in Niger (and maybe in other West African countries) and these findings reported here, suggest that nematodes may constitute a major constraint to millet production.

Sorghum

Seventy-two entries from the national sorghum germplasm collection have been screened for resistance to grain mold. The nursery is located in Bengou in the southern part of Niger. The entries were planted early in June so that they can mature before the end of the rainy season. On the basis of the cycle (number of days to 50% flowering must be less than 90) and the notation (1 or 2) the following entries have been selected for a second stage of screening: CS V4, CS V16, El Keress, El Dazanga (13-28), El Dazanga (128-28-20326), Wadakoubey, Gurazaky, Gourma, CS V15, El Dele (128-25-9596), Gourma-Gourma, CS V23, CS V25, S-Girl Mel Sorgho, El Keress (137-34-20270), Abora (1-204-60), CS V5, El Birni (134-31-20331), CS V2, CS V18, and CS V11.

Several fungi have been isolated from molded sorghum grains. The most frequent ones in decreasing order belong to the following genera: Fusarium, Curvularia and Helminthosporium. *Rhizoctonia solani* have been isolated sometimes. Although more than 40% of the grains were covered with pycnidia of *Phoma sorghina* this pathogen is seldom isolated when molded grains were incubated on culture plates containing PDA.

Seven sorghum populations from Purdue University have been screened for resistance to *Striga* in Konni. But *Striga* emergence have been erratic because of repeated floods. So we decided to conduct the experiment again in 1995.

One of the lines from Purdue University, 92PR215, was compared to SRN 39 and the susceptible check Mata Ja under different regimes of nitrogen. Five rates of nitrogen were used: 0, 30, 60, 90 and 120 kg/ha.

The results indicated a highly significant interaction between cultivars and nitrogen. With resistant cultivars little amount of nitrogen (no more than the recommended rate) is needed to control *Striga*. The level of resistance of 92PR215 is comparable to the resistance of SRN39. In addition 92PR215 out-yielded SRN39 by 960 kg/ha.

Millet Agronomy - Mamane Nour
and Steve Mason

General Objectives

To determine dry matter production and nutrient accumulation of three millet cultivars under low and high management intensity conditions.

To better define the conditions for intensive management of millet.

General Comments

Sowing was done on 20 June 1995. So far, three sampling procedures have been carried out. All mensurations and weighing operations are completed, with the exception of the plant grinding, due to the lack of appropriate equipment. Improved millet varieties are at the flowering stage (Zatib and 3/4 HK) and the local variety is at the heading stage. A pest control treatment was done against insects observed on flowers.

Southern Africa (Botswana, Zimbabwe, Namibia, Zambia)

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Summary

Everyone should read the speech delivered by Dr. Norman E. Borlaug upon receipt of the 1970 Nobel Peace Prize, Oslo, Norway, December 11, 1970, *The green revolution, peace and humanity*. His remarks regarding the breakthrough in wheat production .."It was in Mexico that the high-yielding, Mexican dwarf varieties were designed, bred and developed. There was also developed the new production technology which permits these varieties, when properly cultivated, to express their high genetic grain-yield potential—in general, double or triple that of the best yielders among older, tall-strawed varieties". In Africa, we have good yielding varieties and hybrids. Now we need to put together a production package that will stabilize and increase production of grain by farmers. More emphasis needs to be put towards crop production and management. This was evident at the Sorghum and Pearl Millet workshop as only two papers were presented in this area.

Collaborative Program

The collaborative program in Southern Africa has been U.S. Project oriented, i.e., U.S. Project Leader and the Southern Africa Project Leader. Collaborative activities are continuing with ICRISAT in Bulawayo. A sorghum/millet network has been developed with the SADC countries. This activity is supported by SMIP. The country scientists are now taking a more active role in this network.

Sorghum/Millet Constraints

Production Constraints

Sorghum and pearl millet are important crops in the SADC countries. Both grain and stalks of these crops are used. The grain is used mainly as food and some grain and stalks are used as livestock feed. Farmers' yields remain low (< 500 kg ha^{-1}). This is because the fertility of the soils are low and nutrients are removed at an accelerated rate when both grain and stalks are removed. The critical point of 1.5 to 2.0 Mg ha^{-1} grain requires the uptake of 45 and 60 kg ha^{-1} for N and 16 and 20 kg ha^{-1} P. This is required regardless of whether the cultivars and hybrids are improved.

The low, irregular, and low-efficiency rainfall pattern, sandveld and hardveld soils with low moisture retention and poor weed control also contribute to the low yield of sorghum and millet. A program that would address improving soil fertility (legume rotations, fertilizer, manure) and water use (conservation methods and weed control) would result in at least doubling grain yield.

Research Methodology

Because of the diverse nature of research being conducted, it is not possible to outline specific research procedures. These will be included in the various PIs collaborative research reports.

Research Progress

Good progress has been made in developing sorghum hybrids and sorghum and millet varieties in most of the Southern Africa countries. Efforts are also being made to improve the cultural practices to improve fertility and water use. For example, in Botswana they have initiated a study to improve water infiltration, retention and use by controlling weeds in a low rainfall environment. The procedure proposed is as follows:

Tillage treatment is included as a factor with a bearing on soil moisture conservation and weed control. Double ploughing (i.e., ploughing following the first rain and ploughing after the second rain), has been found, through research in Botswana, to effectively control weeds.

The weeding treatments are weeding once or weeding twice.

The two weeding treatments will be assigned randomly to subplots and the four treatments: continuous sorghum, zero fertilizer; continuous sorghum + fertilizer; sorghum after a legume; and legume after sorghum applied randomly to subplots. The "+ fertilizer treatment" will be 30 kg/ha P plus 40 kg/ha N applied into the seed bed. Segaolane and Tswana cowpeas or blackeye will be planted in six row plots of 10 m length.

The following measurements will be made:

Physical - Infiltration rate, moisture retention, bulk density and plant available moisture.

Soil fertility - Soil pH, N, P, K and exchangeable bases at the beginning and end of growing season.

Weed assessment - Before each weeding and at harvest.

Mutual Research Benefits

All research results reported by the various PIs should be beneficial to the Southern Africa countries. In the U.S., food types of sorghum and millet are being utilized. Value added to sorghum can be obtained with studies of sorghum flour use in products such as noodles and improved malting characteristics of the grain.

Institution Building

Currently most of the SADC/ICRISAT/INTSORMIL trained scientists have returned home and are productive scientists within their national programs, some have moved into administration and others into the private sector or some other venture. Inaccessibility to current literature, new technology, and maintaining contact with scientists in their professional disciplines are constraints which affect the research and morale of scientists in developing countries. It has been proposed that short term developmental leaves (five months or less) to U.S. Universities, public or private facilities, be available on a competitive basis. This would enhance these scientists research capabilities. INTSORMIL scientists and previous scientists with INTSORMIL continue to maintain collaborative contacts with national scientists.

Networking

The SADC/ICRISAT Sorghum and Millet Improvement Program (SMIP) organized a collaborative workshop with the Botswana Department of Agricultural Research which was held July 25-29, 1994. This was an opportunity for sorghum and millet researchers in the SADC countries to present papers of their original research. It was also an opportunity for them to meet and plant research strategies of a regional nature.

Papers were presented by scientists from Botswana, Malawi, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia, Zimbabwe and the U.S. The largest number (24) were in the area of on-farm research and technology. Seven papers were presented in plant breeding, eight in plant protection, two in economics and three in resource management. One and one-half days were devoted to country planning sessions and general discussions. All of the papers will be published in a proceedings.

The SADC scientists met as members of the "Southern Africa Sorghum and Millet Research Network". Dr. Chris Manthe was elected Chair. Regional research objectives were developed. This is a very positive direction for these scientists in Southern Africa to maintain a scientific community and exchange ideas and research results.

Only 12 of Africa's 54 countries now have a link to the INTERNET. However, Peter Knight (World Bank) says that "Africa doesn't have huge investments in copper wiring, and in a sense that is to its advantage. They can go straight into things like fiber optics and wireless communications, and if they do it right, overnight they can be pretty close to the leading edge." (New York Times, November 17, 1995 A8). Electronic mail linked through national programs and universities would be an excellent vehicle for a sorghum/ millet bulletin board. The scientist would then be in almost instantaneous contact.

Research Accomplishments

Research accomplishments are given in the various project reports of collaborating scientists.

Horn of Africa

Gebisa Ejeta
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Coordinators

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Collaborative Program

The Horn of Africa is a new INTSORMIL initiative proposed to regionalize collaborative research efforts in Eastern Africa. INTSORMIL has had a productive collaboration with the Agricultural Research Corporation in Sudan. Our collaboration has resulted in an array of technical developments that have impacted on sorghum agriculture in Sudan. Sudanese scientists have been trained in INTSORMIL institutions. U.S. scientists have traveled extensively in Sudan and worked alongside their Sudanese counterparts. Joint workshops and conferences were organized and attended. Results of joint research efforts are published and distributed widely. Extensive raw and improved germplasm have been identified, assembled, and catalogued for the benefit of U.S. and Sudanese agriculture. The Horn of Africa initiative is, therefore, an attempt by INTSORMIL to share many of these developments with NARS in the Eastern Africa region through an organized and functional network.

Organization

While the Horn of Africa project is a new initiative, the Sudan country program has continued to function in the existing mode of 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 are 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.

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, Bruce Hamaker, INTSORMIL.

Economic Program - Hamid Faki, 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

Sorghum/Millet Constraints Researched

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), 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 research. Research Scientists are closely in tune with crop production, protection, and utilization constraints encountered by farmers in the various agricultural schemes in the country. Research constraints are assessed and prioritized on a regular basis, often annually and in collaboration with production scheme managers. Field facilities at ARC stations and particularly at the Gezira Research Station are excellent. Machinery and equipment often have been adequate and appropriate. Technical support has always been good. Laboratory facilities are modest and efforts 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 Plant Pathology Report
Evaluation Of Seed Dressing Chemicals
El Hilu Omer

This season the screening trials against covered and loose smut included seven products beside the standard seed dressing, Fernasan D. The trials included 14 treatments in a randomized complete block design replicated four times. All products were fungicides except one known insecticide (lindane). Test seeds were dressed with teliospores of the respective causal organism prior to treatment with the dose of the pesticide. Subplot size, method of cultivation and observations were as described in previous reports.

Captan at the two dosage rates, Vitavax at the two application rates, Apron+Vitavax, TMTD 25, and Divident at two and four g/kg were all as effective as Fernasan D, the standard fungicide for the control of covered smut. Captan at the two dosage rates were superior to all other treatments in controlling loose smut, followed by Apron+ Vitavax and the higher rate of Vitavax (Table 1). The yield data (Table 2) showed no significant effect due to seed dressing against covered smut, however the loose smut yield trial gave significant differences which more or less followed infection incidence.

Table 1. Effect of seed dressing on covered and loose smut of sorghum.

Product	gorcc/kg	Covered smut		Loose smut	
		Actual	Trans	Actual	Trans
Vitavax	2	5.38	8.78 DE*	5.10	12.27 DE
Vitavax	3	2.50	6.72 DE	1.33	5.76 EFG
Captan	2	0.28	2.41 E	0.00	0.57 G
Captan	3	0.73	3.53 DE	2.43	2.66 G
Divident	2	5.60	6.42 DE	4.73	11.00 DEF
Divident	3	3.80	11.02 CD	8.88	16.17 D
Divident	4	3.00	9.58 DE	8.90	16.50 D
Celest	3	8.90	16.84 BC	32.25	34.35 B
Celest	4	13.90	21.64 AB	27.70	26.10 C
Apron+Vitavax	3	1.10	5.70 DE	5.93	3.47 FG
Fernasan D	3	2.15	7.12 DE	10.93	17.31 D
Lindane 20	3	12.05	19.83 B	29.68	32.89 BC
TMTD 25	3	3.06	3.64 DE	7.03	11.66 DE
Check	-	21.40	27.24 A	39.23	42.72 A
SE +			2.304		2.579
CV (%)			42.9		30.9

*Means followed by a different letter are significantly different at the .05 probability level.

Table 2. Effect of seed dressing on sorghum yield (kg/ha).

Product	gorcc/kg	Covered smut	Loose smut
Vitavax	2	2837	3262 A
Vitavax	3	2508	3084 AB
Captan	2	2426	2673 ABCD
Captan	3	2782	3288 A
Divident	2	2714	1755 D
Divident	3	2699	2892 AB
Divident	4	2796	2152 BCD
Celest	3	2228	1905 CD
Celest	4	2382	2714 ABC
Apron + Vitavax	3	3646	3084 AB
Fernasan D	3	3221	2276 BCD
Lindane 20	3	2878	2755 ABC
TMTD 25	3	3523	2647 ABCD
Check	-	2440	2599 ABCD
SE +		267	284
CV (%)		35.87	21.46

Downy Mildew of Pearl Millet in the Sudan

Hassan A. Elmahi And M. El Hilu Omer

Disease Survey: The downy mildew of pearl millet, *Sclerospora graminicola*, is universally known as the most serious disease on the crop. Where it occurs, the disease is responsible for yield losses ranging between 10-60%. The disease has been known to occur in Sudan for quite a long time, but its incidence became serious only recently, possibly instigated by seed movement and massive introduction from foreign countries of planting material during years of drought. So far, we are not sure how many biotypes exist in the country. Literature refers to differences in varietal reaction between India and West Africa sources. In fact most of the introductions to Sudan came from West Africa.

Recent surveys during 1993-94 in the Kordofan States reflected a horrifying situation where the disease is predominant in all places covered. Moreover, areas in the rainlands of the eastern region put under the crop also became devastated with downy mildew. The survey included 36 farms in five provinces in 1993 and 39 farms distributed over six provinces of the three States of Kordofan in 1994. The result of this extensive survey is given in Table 3. It shows that the disease is present with varying intensities in all locations.

This disease is both soil-borne and seed-borne. Infected trash carries the resting stage (oospores) of the organism which can survive adverse conditions and can remain viable in the soil for a number of years. The disease affects the vegetative growth as well as the reproductive part of the plant where all the floral parts are transformed to leafy structures, thus the disease has a direct impact on yield.

Effect of seed Protectants on Pearl Millet Germination. The only product known to have good effect against downy

Table 3.Incidence of pearl millet downy mildew in Kordofan provinces, 1994.

	% Incidence							
		1993-94				1994-95		
Province	No. of locations	Highest	Lowest	Mean	No. of locations	94/95 Highest	Lowest	Mean
Sheikan	10	69	3	29	1000	82	15	58
EnNHUD	14	54	20	58	14	95	45	70
Dilling	4	54	41	49	4	62	13	37
El Salam	3	85	76	82	3	75	45	62
Um Rawaba	5	23	1	11	5	60	17	35
Bara	-	-	-	-	3	45	15	29

mildew is Letalaxyl. It has been tested as a single product, a ready mix with Carboxin and as a mix with Vitavax (Carbxin) in the laboratory in Petri dishes using plotter filter papers to test different rates of these two products on termination. Generally the germinability of the seeds was not as good as expected. The untreated control did not give more than 60%, but there was a marked drop in seed germination with increase in chemical dosage applied to the seed. This was true in case of Metalaxyl and also Vitavax.

Screening Chemicals for the Control of Pearl Millet Downy Mildew. This was a pot trial replicated three times. The products used for dressing were Apron (Metalaxyl + Carboxin) Metalaxyl alone and Vitavax (Carboxin). Variety Baladi yellow was used for screening. Dressed seeds were planted in pots pretreated with viable inculum. Soon after germination the pots were covered with polythene during the night and kept in the open during day time. Maintaining high humidity during the night sustained good production of sporangia on infected plants and easy detection of symptoms. Plant showing symptoms were recorded every other day for 40 days.

All treatments receiving Apron or Metalaxyl remained free of the disease for the length of observation period. The Vitavax and Vitavax combinations with Metalaxyl showed increasing rate of control with increase in dosage rate whereas Vitavax alone treatments were less effective.

Effect of Sowing Date on Incidence of Millet Downy Mildew. Bauda, Dembi, Aish barnu, Ugandi, Heraihri and Kordofani were sown at two sowing dates in El Obeid. The first sowing date was July 4 and the second was July 14. The experiment was a replicated randomized complete block. Since the inoculum was present in the area, varieties were left for natural infection. Observation were made on leaf infection and towards the end of the season a record was made on head infection. All varieties treated were susceptible to the disease. However, Ugandi showed less infection than the other test varieties. As expected, the second sowing date, in spite of being less subjected to rains, showed more infection than the first sowing date. One exception to that was Aish barnu, but all the other varieties consistently had more infection on the second sowing date and this was mainly due to build up of inoculum and the extended rainy season.

Institution Building

Research Equipment Purchased

The program continues to provide ARC with research supplies and equipment on a request basis. During Year 16 the following items were purchased and shipped to Sudan: Laser printer Model C2039A, IBM Proprinter XL Brand New Print Head, Ribbons for IBM Proprinter, Arabic Keyboard, Seed envelopes, pollinating bags, staples, Laserjet transparencies, and overhead transparency film.

Host Country Researchers Trained

A number of Sudanese Scientists have been trained in INTSORMIL institutions in the past. Many have returned and assumed key responsibilities within the Agricultural Research Corporation. Two ARC scientists are currently studying at Purdue University. Mr. Yahia Ibrahim completed his M.S. under Dr. Gebisa Ejeta in sorghum breeding. He was approved to continue for his Ph.D. and is currently conducting field studies on the genetics of *Striga* resistance at Wad Medani, Sudan. He is expected to return to Purdue in November. Another Sudanese Scientist, Mr. Abdalla Mohammed is studying under Dr. Tom Housley, at Purdue University. His research is partially supported through the projects of Drs. Larry Butler and Gebisa Ejeta. He is also working on *Striga,* attempting to clarify the physiological basis of dormacy that takes place prior to initiation of seed germination.

Host Country Scientist Visit

Dr. El Hilu Omer, Sudan Country Coordinator, is currently spending his sabbatic leave at Texas A&M University working with Dr. Richard Frederiksen. He is scheduled to return to Sudan by October 1, 1995.

Networking

The new Horn of Africa initiative is primarily to be a network based program that would bring together the concern and expertise of sorghum and millet research scientists in the Horn towards developing a collaborative research agenda on a regional basis. To this end correspondence has been exchanged between INTSORMIL/ME and the Institute of Agricultural Research in Ethiopia. A

Memorandum of Agreement between IAR and INTSORMIL is scheduled to be signed in September 1995. A regional workshop is planned to be held in Kampala, Uganda organized jointly with ICRISAT and a new regional program the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA). This workshop may serve as a forum to launch a collaborative research network that will bring the talents and resources of INTSORMIL, ICRISAT, and the NARS in the region to address key sorghum and millet research constraints in the Horn of Africa.

Research Accomplishments

Continuous collaborative research on *Striga* between ARC and INTSORMIL has led to two significant releases and recommendations.

Eight *Striga* resistant sorghum varieties that combine high grain yield potential, leaf disease resistance, and good food quality have been released and recommended for wide use and distribution in several African countries, including Sudan.

Several years of testing in Sudan by Dr. A.G.T. Babiker has led to the recommendation by the Crop Husbandry Committee of the Sudan for the use of Chlorosulfuron and Dicamba as effective chemical measures for *Striga* control.

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, 75 students from 22 different countries were enrolled in an INTSORMIL advanced degree program. Approximately 73% 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.

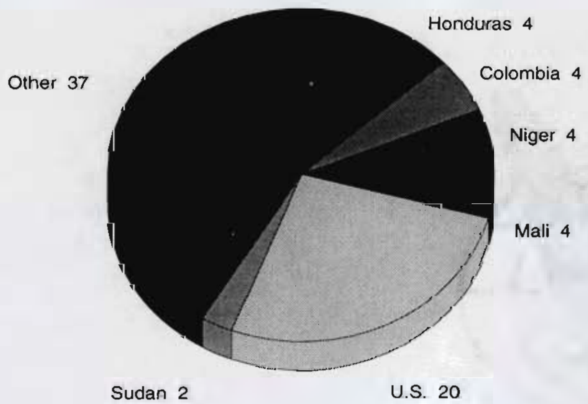
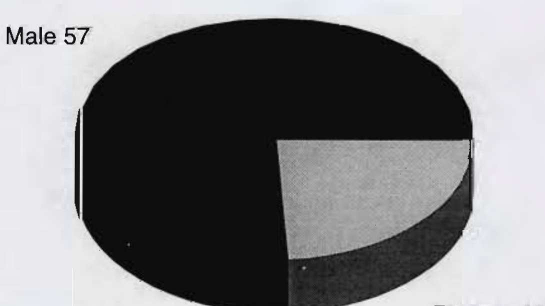
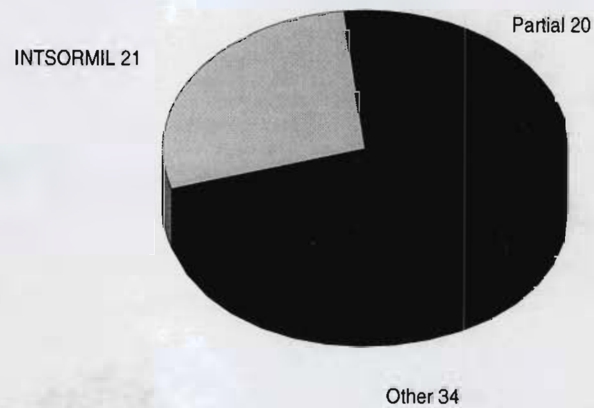


Figure 2. Training analysis - gender breakdown.



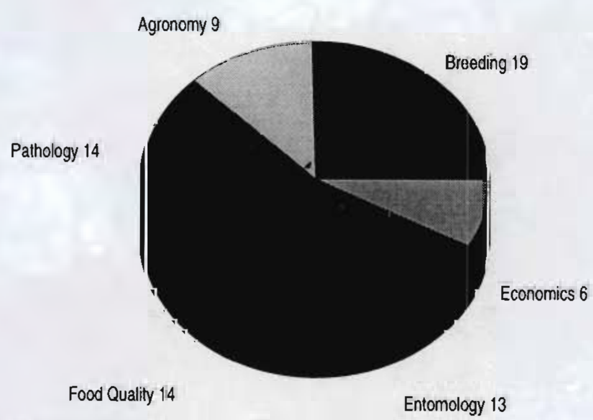
INTSORMIL also places a high priority on training women which is reflected in Figure 2. In 1995, 24% of all INTSORMIL graduate participants were female. Twenty-One of the total 75 students received full INTSORMIL scholarships. An additional 20 students received partial INTSORMIL funding and the remaining 34 students were funded from other sources as shown in Figure 3.

Figure 3. Training analysis - source of funding.



All 75 students worked directly with INTSORMIL principal investigators on INTSORMIL projects. These students are enrolled in graduate programs in all seven INTSORMIL disciplines. Figure 4 also shows that there has been a significant increase in the number of students enrolling in food techology, reflecting the importance of product development and food processing.

Figure 4. Training analysis - discipline breakdown.



Total student numbers decreased in 1994-95 as compared to 1993 and 1994. 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. Two visiting host country scientists and one post doctoral scientist were provided the opportunity to upgrade their skills in this fashion during 1995.

The following tables is a compilation of all INTSORMIL training activities for the period July 1, 1994 through June 30, 1995.

Year 16 INTSORMIL Training Participants

Name	Country	Univ.	Discipline	Advisor	Degree	Gender	Funding*
Gutierrez, Patricio F.	Ecuador	UNL	Agronomy	Clegg	PHD	M	I
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	O
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
De Carvalho, Carlos H.S.	Brazil	PRF	Breeding	Axtell	PHD	M	I
Kapran, Issoufou	Niger	PRF	Breeding	Axtell	PHD	M	P
Peters, Paul	U.S.	PRF	Breeding	Axtell	PHD	M	I
Cisse, N'Diaga	Senegal	PRF	Breeding	Ejeta	PHD	M	O
Ibrahim, Yahia	Sudan	PRF	Breeding	Ejeta	PHD	M	I
Tuinstra, Mitchell	U.S.	PRF	Breeding	Ejeta	PHD	M	O
Nesbitt, T. Clint	U.S.	TAM	Breeding	Miller	MSC	M	P
Stewart, Klint G.	U.S.	TAM	Breeding	Miller/Peterson	MSC	M	P
Katsar, Catherine Susan	U.S.	TAM	Breeding	Peterson/Teetes	PHD	F	I
Crasta, Oswald	India	TTU	Breeding	Rosenow	PHD	M	P
Mkhabela, Milton	Swaziland	TTU	Breeding	Rosenow	PHD	M	P
Munera, Alvaro	Colombia	TTU	Breeding	Rosenow	MSC	M	P
Rodriguez, Raul	Mexico	TAM	Breeding	Rosenow	PHD	M	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
Coulibaly, Ousmane	Mali	PRF	Economics	Sanders	PHD	M	O
Lilja, Nina	U.S.	PRF	Economics	Sanders	PHD	F	O
Nagubadi, Venkatarao	U.S.	PRF	Economics	Sanders	PHD	M	I
Sidibe, Mamadou	Senegal	PRF	Economics	Sanders	PHD	M	O
Calderon, Pedro	Honduras	MSU	Entomology	Pitre	MSC	M	I
Calderon, Roberto	Honduras	MSU	Entomology	Pitre	MSC	M	I
Vergara, Oscar	Honduras	MSU	Entomology	Pitre	MSC	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/Peterson	PHD	F	O
Jensen, Andrea	U.S.	TAM	Entomology	Teetes	PHD	F	I
Lingren, Scott	U.S.	TAM	Entomology	Teetes	PHD	M	O
Magallenes, Ricardo	Mexico	TAM	Entomology	Teetes	PHD	M	P
Mott, Dale Allen	U.S.	TAM	Entomology	Teetes	MSC	M	O
Alkire, Mark	U.S.	PRF	Food Quality/Util	Butler	MSC	M	O
Aboubacar, Adam	Niger	PRF	Food Quality/Util	Hamaker	PHD	M	I
Buckner, Becky	U.S.	PRF	Food Quality/Util	Hamaker	PHD	F	O
Mamadou, Lewamy	Niger	PRF	Food Quality/Util	Hamaker	MSC	M	O
Oria, Maria P.	Spain	PRF	Food Quality/Util	Hamaker	PHD	F	I
Weaver, Charlotte	U.S.	PRF	Food Quality/Util	Hamaker	MSC	F	O
Acosta, Harold	Colombia	TAM	Food Quality/Util	Rooney	PHD	M	P
Asante, Sam	Ghana	TAM	Food Quality/Util	Rooney	PHD	M	P
Cepeda, Minerva	Mexico	TAM	Food Quality/Util	Rooney	MSC	F	P
Floyd, Cherie	U.S.	TAM	Food Quality/Util	Rooney	PHD	F	P
Kunetz, Christine	U.S.	TAM	Food Quality/Util	Rooney	MSC	F	P
Seetharaman, Koushik	India	TAM	Food Quality/Util	Rooney	PHD	M	P
Suhendro, Elly	Indonesia	TAM	Food Quality/Util	Rooney	PHD	F	I
Wright, Lee	U.S.	TAM	Food Quality/Util	Rooney	MSC	M	P

Name	Country	Univ.	Discipline	Advisor	Degree	Gender	Funding*
Diourte, Mamourou	Mali	KSU	Pathology	Claflin	PHD	M	O
Mei, Wang	China	KSU	Pathology	Claflin	VS[1]	F	O
Lu, Ming	China	KSU	Pathology	Claflin	PHD	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
Xu, Xiude	China	KSU	Pathology	Claflin	VS[1]	M	O
Amoah, Ben	Ghana	KSU	Pathology	Leslie	PD[2]	M	I
Anderson, Cindy	U.S.	KSU	Pathology	Leslie	MSC	F	P
Arjula, Vaishal	India	KSU	Pathology	Leslie	MSC	F	O
Kedera, C.J.	Kenya	KSU	Pathology	Leslie	PHD	M	O
Osorio, Jairo	Colombia	TAM	Pathology	Frederiksen	PHD	M	O
Rosewich, Ute L.	Germany	TAM	Pathology	Frederiksen	PHD	F	I
Torres-Montalvo, Jose H.	Mexico	TAM	Pathology	Frederiksen	PHD	M	P

* I = Completely funded by INTSORMIL
P = Partially funded by INTSORMIL
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

Appendices

INTSORMIL Buy-Ins

University/ Project No.	Buy-In	Year	Life of Buy-In	Annual Amount	Total
KSU-106	Kansas Sorghum Board	1985	6 years	17,500	105,000
	Kansas Agric. Exp. Station	1989	3 years	19,000	57,000
	Kansas Agric. Exp. Station	1989	3 years	13,333	40,000
	Kansas Sorghum Board	1991	4 years	15,334	61,338
	Kansas Agric. Exp. Station	1990	3 years	19,000	57,000
	EPA/Univ. of Nebraska	1990	2 years	32,518	65,036
					$ 385,374
KSU-108	Kansas Sorghum Board	1985	9 years	18,482	166,338
	Kansas Corn Commission	1988	3 years	16,845	50,535
	Kansas Sorghum Commission	1989	1 year	7,166	7,166
	Kansas Sorghum Commission	1989	1 year	6,500	6,500
	EPA	1990	3 years	39,523	118,569
	Kansas Agric. Exp. Station	1991	3 years	19,000	57,000
	USDA/ARS	1992	1 year	14,400	14,400
					$ 420,508
KSU-108B	Myco Pharmaceuticals	1993	2 years	25,000	50,000
	Kansas Agric. Exp. Station	1993	3 years	17,500	52,500
	USDA/Pioneer Seed Co.	1994	2 years	75,000	150,000
					$ 207,500
MSU-104	MIAC/Kenya	1990	2 years	115,725	231,450
	MIAC/Kenya	1992	3.5 years	142,000	497,000
	USAID/MIAC	1992	5 years	35,000	175,000
					$ 903,450
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
	Midwest Biotechnology Consortium	1993	1 year	32,627	32,627
	Purdue Agronomy Dept.	1994	1 year	1,000	1,000
					$ 1,675,320
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
	Dept. of Energy	1993	2 years	56,780	113,560
	Rockefeller Foundation	1993	2 years	45,000	90,000
	USAID/PSTC	1994	2 years	50,000	100,000
	McKnight Foundation	1994	1 year	85,000	85,000
	National Science Foundation	1994	1 year	85,000	85,000
					$ 1,347,752
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
	USAID/AFT/ARTS	1994	2 years	150,000	300,000
					$ 421,500

University/ Project No.	Buy-In	Year	Life of Buy-In	Annual Amount	Total
PRF-107	Purdue Agronomy Dept.	1988	1 year	1,500	1,500
	State of Indiana	1990	1 year	7,000	7,000
	McKnight Foundation	1990	3 years	20,632	61,896
	USAID PSG	1990	2 years	14,000	28,000
	McKnight Foundation	1990	3 years	22,000	66,000
	Pioneer Seed Co.	1991	2 years	30,000	60,000
	State of Indiana	1991	1 year	1,200	1,200
	Rockefeller Foundation	1992	3 years	33,335	100,000
					$ 325,596
PRF-109	USDA Grant	1990	2 years	60,000	**$ 120,000**
PRF-112	Purdue Agronomy Department	1994	1 year	12,000	**$ 12,000**
TAM Joint	USAID/TAMU	1989	3 years	15,000	45,000
	USAID/TAMU	1991	3 years	15,000	45,000
					$ 90,000
TAM-122	State of Texas Grant	1989	2 years	20,000	40,000
	USAID/TAMU	1990	2 years	10,000	20,000
	USAID/TAMU	1990	3 years	13,000	39,000
	Texas Higher Coordinating Board	1991	2 years	27,000	54,000
	USDA	1991	2 years	7,500	15,000
	USAID/TAMU	1992	2 years	28,000	56,000
					$ 224,000
TAM-123	Texas Grain Sorghum Producers	1990	5 years	50,000	250,000
	USAID/TAMU	1990	1 year	17,000	17,000
	USAID/TAMU	1991	1 year	28,000	28,000
	TAES	1993	2 years	22,500	45,000
	USDA/Sorghum Advisory Committee	1994	1 year	5,000	5,000
					$ 345,000
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
	Rockefeller Foundation	1994	3 years	25,000	75,000
	Pioneer Seed Company	1994	2 years	30,000	60,000
	TAES	1994	2 years	50,000	100,000
					$ 543,000
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
	USDA/APHIS	1994	2 years	25,000	50,000
	TAES	1994	2 years	5,000	10,000
					$ 398,000
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
	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
	Texas Grain Sorghum Board	1994	2 years	20,000	40,000
	Pioneer Seed Co.	1994	2 years	30,000	60,000
					$ 864,320

University/ Project No.	Buy-In	Year	Life of Buy-In	Annual Amount	Total
TAM-128	TAES	1993	2 years	10,000	**$ 20,000**
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
	Nebraska Foundation	1994	2 years	15,000	30,000
					$ 80,000
UNL-114	German Acad.Exchange Serv.	1993	2.5 years	11,000	$ 27,500
	FAO/IAR/Ethiopia	1994	.5 year	14,900	14,900
					$ 42,400
UNL-115 & 118	Michigan State/Senegal Agric.	1989	3 years	46,700	140,000
	USAID/Dakar	1992	5 years	70,000	350,000
	Nebraska Grain Sorghum Board	1994	1 year	20,900	20,900
					$ 510,900
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					**$ 18,623,481**

INTSORMIL Sponsored and Co-Sponsored Workshops 1979 - 1995

	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	Improvement and Use of White Grain Sorghums	El Batan Mexico	12/90
39.	Sorghum for the Future Workshop	Cali, Colombia	1/91
40.	INTSORMIL PI Conference	Corpus Christi, Texas	7/91
41.	Social Science Research and the CRSPs	Lexington, KY	6/92
42.	Seminario Internacional Sobre los Cultivos de Sorgo y Maiz sus Principales Plagas y Enfermedades	Colombia	1/93
43.	Workshop on Adaptation of Plants to Soil Stresses	Lincoln, NE	8/93
44.	Latin America Workshop on Sustainable Production Systems for Acid Soils	Villavicencio, Colombia	9/93
45.	Latin America Sorghum Research Scientist Workshop (CLAIS Meeting)	Villavicencio, Colombia	9/93
46.	Disease Analysis through Genetics and Biotechnology: An International Sorghum and Millet Perspective	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	Federaci6n 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