INTSORMIL

Annual Report 1992

SORGHUM/MILLET COLLABORATIVE RESEARCH SUPPORT PROGRAM (CRSP)

Fighting Hunger with Research ... a team effort

Funding support through the Agency
for International Development

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Cover Photographs
(top to bottom)

1. Researchers in Mali use cages to protect sorghum from head bugs to establish base line data. Photo courtesy of Dr. Lloyd Rooney.

2. A young farmer in Maradi (Niger) stands in front of NAD-1 hybrid, a product of INRAN/INTSORMIL collaborative research. Photo courtesy of Mr. Issoufou Kapran.

3. Malian food scientists conduct parboiling cooking trials in a village near Cinzana, Mali. Photo courtesy of Dr. Lloyd Rooney.

4. Village grain storage huts in Mali (West Africa). Photo courtesy of Dr. Timothy Schilling.

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

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EXECUTIVE SUMMARY

John M. Yohe
INTSORMIL Program Director

Introduction and Program Overview

Sorghum and millet are important food and feed crops. They remain the staple crop for millions of people in semi-arid regions of the world. Their unique ability to withstand periods of drought and other adverse edaphic and climatic factors have led to their widespread cultivation, utilization and consumption in Latin America, Africa and Asia. Sorghum and millet are grown in some of the harshest environments and most fragile lands in the world resulting in low and unstable grain production. As population pressure increases in these areas, the need to boost production in environmentally sound ways becomes increasingly urgent.

To increase sorghum and millet productivity and utilization, INTSORMIL was created in 1979 by the U.S. Agency for International Development (USAID) and operates under the Office of Agriculture, Bureau for Research and Development. Over the past 13 years, INTSORMIL has established a dynamic, multi-institutional and interdisciplinary collaborative research and training program. INTSORMIL currently links the expertise of 30 U.S. scientists from five american universities with over 100 international scientists in 6 key sites and 15 other countries. Individual country programs respond to National Agricultural Research Systems' (NARS) requests for research support. INTSORMIL provides technical backstopping, conducts collaborative research, trains national staff and students, and contributes to overall NARS sorghum and millet program operations support. The success of INTSORMIL can be attributed to four unique features.

- INTSORMIL capitalizes on over 90% of U.S. University sorghum and millet expertise where most basic and strategic research is conducted. This allows the unique opportunity to support and complement applied field work conducted at NARS by adding an otherwise unknown dimension to the research.
- INTSORMIL is an integrated, interdisciplinary organization encompassing breeding, agronomy, physiology, insect and disease management, food quality, economics, and sociology.
- INTSORMIL enhances the capacity of NARS to solve country and region specific problems through collaborative research, thus increasing NARS technical and institutional productivity.
- INTSORMIL activities are constraint and NARS driven: identification and alleviation of priority production constraints are achieved in concert with collaborating National Agriculture Research Systems, NARS.

Productivity constraints were identified in joint meetings with Host Country scientists and became the basis by which the program matrix was developed. The matrix was utilized to create and implement a comprehensive interdisciplinary research program. Progress has been made to alleviate the constraints but some problems have not yet been eliminated. The constraints listed below are resolvable impediments to productivity both economically and institutionally.

- Poor and unstable yields due to low and erratic rainfall.
- Biotic stresses such as plant disease and insects.
- Lack of appropriate value-added crop utilization technologies.
- Lack of productive resource efficient germplasm.
- Lack of profitable and sustainable production systems.
- Need for human resource development.
- Need for effective research infrastructures and operations.

These and other constraints are addressed in a well planned approach described in a Global Plan which outlines a comprehensive approach to the resolution of the constraints. The INTSORMIL strategy focuses on five technical thrusts, each aimed at increasing productivity:

- Germplasm Enhancement - the development of resource efficient cultivars.
- Sustainable Production Systems - establishment of environmentally sound and financially profitable production systems.
- Biointensive Plant Protection Systems - the development of environmentally and economically sound pest control systems.
- Crop Utilization and Marketing - development of shelf stable processed foods with good marketing potential.

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

INTSORMIL collaborative research programs are directed at alleviating the priority constraints within a collaborating host developing country through interdisciplinary research. American scientists work together with host country scientists to resolve priority constraints. The U.S. Land Grant Universities actively participating with INTSORMIL are:

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

INTSORMIL collaborates with many different countries and institutions. Of these institutions, INTSORMIL has designated six country/institutions as prime sites for long term collaborative research because of their ecogeographic location, national importance of sorghum and millet, and their desire to collaborate. The INTSORMIL prime sites and institutions are currently as follows:

The Department of Agricultural Research, DAR, Botswana
The Institute of Rural Economy, IER, Mali
The National Institute for Agricultural Research, INRAN, Niger
The Agricultural Research Corporation, ARC, Sudan
The Secretariat for Natural Resources, SRN/ Escuela Agricola PanAmericana (EAP), Honduras
The Institute for Colombian Agriculture, ICA, Colombia.

This report summarizes the program effort during the thirteenth year of implementation. These thirteen years of experience continue to reaffirm the global need for INTSORMIL to improve sustainable and profitable sorghum/millet production systems in developing countries. The report is organized by discipline and project and provides a detailed description of relevant annual activities at the project level. These activities have been summarized by subject and presented in the following pages in summary form.

1991/92 Activities

Administration and Management

The University of Nebraska (UNL) is the Management Entity (ME) for the Sorghum/Millet CRSP and is the primary grantee of A.I.D. 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 board for the CRSP. The Technical Committee (TC), Ecogeographic Zone Council (EZC), External Evaluation Panel (EEP) and A.I.D. personnel advise and guide the ME and the Board in areas of policy, technical aspects, collaborating host country coordination, budget management, and review.

The 1991/92 year was a very busy, but fruitful one, for the ME, BOD, TC and EZC. Below are listed several major accomplishments for the year.

- INTSORMIL participated in an ICRISAT sponsored consultative meeting on the establishment of a sorghum research network for Asia, September, 1991.

- Organized and implemented an international sorghum/millet research conference in Corpus Christi, Texas. The conference, attended by 200 persons from 21 countries, addressed issues of sustainable sorghum/millet production, biotechnology issues in sorghum/millet research and crop utilization advances in sorghum and millet utilization.

- Presented CRSP activities to U.S. Congressional, World Bank, Environmental, A.I.D, and USDA delegations in Washington, D.C. This initiative results in higher visibility and recognition among important domestic and international groups for the CRSP Programs.

- INTSORMIL scientists met with Dr. Lewis Mughogho, Acting Cereals Program Leader, ICRISAT, to discuss INTSORMIL and ICRISAT collaboration in Central and South America. It was agreed that INTSORMIL and ICRISAT should submit a joint proposal to the Inter-American Development Bank to fund a Central and South America Sorghum Network.

- The INTSORMIL External Evaluation Panel (EEP) conducted a review of the Kansas State University, Mississippi State University, University of Nebraska, Purdue University, and Texas A&M University INTSORMIL research projects from February 17-26, 1992.

- INTSORMIL, on behalf of the CRSP Council, organized the first Inter-CRSP Workshop, "A New Agenda for CRSP Social Science Research". Participating CRSPs were INTSORMIL, Bean/Cowpea CRSP, Peanut CRSP, Pond Dynamics/Aquaculture CRSP, Sustainable Agriculture and Natural Resources Management CRSP (SANREM), Soil Management CRSP and the Small Ruminant CRSP

Training

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

During 1991/92, 95 students from over 35 different countries were enrolled in an INTSORMIL advanced degree program and advised by INTSORMIL principal investigators. Eighty percent of these students are from countries other than the U.S. which illustrates the emphasis placed on international development. INTSORMIL also places importance on training women which is reflected in the fact that 20% of all INTSORMIL graduate participants are women.

The number of students receiving 100% funding by INTSORMIL in 1991/92 totaled 27. An additional 16 students received partial funding from INTSORMIL. The remaining 52 students are funded from other sources but are working on INTSORMIL projects. Total student numbers has decreased by 4 as compared with last year. This is a decrease of 8 compared to 1988. The number of students receiving 100% funding from INTSORMIL dropped from a high of 71 in 1986 down to 27 in 1992. This is, in part, due to training taking place under other funding sources, but an even more significant factor is that budget flexibility for supporting training under INTSORMIL projects has been greatly diminished because of inflationary pressures.

The SADCC/ICRISAT Southern African training program continues to hold a high profile in INTSORMIL training activities. Of 49 students matriculating in the U.S., Canada and Brazil, 24 are studying under INTSORMIL scientists while the remainder are with subject matter specialists not covered by INTSORMII scientists. There were 11 degree completions in 1992.

Networking

Established networking activities have continued with ICRISAT, SADCC/ICRISAT, SAFGRAD, ICRISAT Sahelian Center, ICRISAT West Africa Sorghum Program, East Africa ICRISAT, ICRISAT/CIMMYT and CIAT. There has been excellent collaboration with each of these programs in cosponsoring workshops and conferences, for coordination of research and long term training.

INTSORMIL is collaborating with the Soil Management CRSP in Mali with extremely good results. Collaboration among CRSPs is essential for providing a broad systems approach to addressing many of the natural resource constraints that now face us. New opportunities for Inter-CRSP collaboration are of concern to all CRSPs. INTSORMIL hosted a meeting between the Soil Management CRSP, Peanut CRSP, Bean/Cowpea CRSP and the Small Ruminants CRSP to discuss development of an integrated project for West Africa.

Current Country Specific Activities

Botswana

The Botswana program is essentially two related components: an INTSORMIL researcher stationed in country and scientist to scientist collaboration in areas of agronomy, plant breeding, plant pathology and entomology.

Various aspects of collaboration can be seen in other projects. Principal in country collaboration has been with the Department of Agriculture Research (DAR), however, collaboration also occurs with the Palapye Development Trust, Arable Lands Development Program, and FAO sponsored Soil Survey and Mapping services. Entomology, pathology, and plant breeding also collaborate with ICRISAT in Bulawayo, Zimbabwe.

Sorghum is an important crop in Botswana. The grain is a food source for the general population and the stalks are used as cattle feed for livestock. Even in dry years 70% of the land planted is harvested. However, over the last 10 years (1980's) farmers' yields have averaged 161 kg ha^{-1}. These low yields somewhat reflect hectares that are planted but are not harvested. The low, irregular, and low-efficiency rainfall pattern, sandveld and hardveld soils with low moisture retention, low N and P content, broadly graded sand fractions, and unstable surface all contribute to the low yield of sorghum and millet. In addition to yield enhancement and crop protection activities, greater effort is required for moisture conservation and redistribution technologies, fertility improvement, residue incorporation, and weed control in order to improve soil structure and rainfall infiltration and availability for promoting crop establishment and improved grain and stover yields.

Research to date has demonstrated:

- The importance of primary tillage in achieving better crop stands and yields.
- Generally, it is better to apply fertilizer broadcast before planting rather than banding next to seed.
- In general, lower yields were obtained with animal versus tractor power for tillage operations. However, comparison of the economic benefits from using animal versus tractor power showed no clear trend. Benefits were comparable for the two systems, with lower yields under animal power being offset by its lower costs.

- Fertilizer studies showed significant response to P when the initial soil P level (Bray 2) was less than 10 mg kg^{-1}. However, the response was not economical where the soil P level was greater that 5 mg kg^{-1}. A significant response to N was obtained only when rainfall was well established throughout the growing season.

- Ms. Dollina Malepa, working on her Ph.D. dissertation study under the SADCC/ICRISAT/INTSORMIL training program, is continuing to establish critical baseline levels for soils from 14 sites across the major grain producing regions of Botswana. Those soils are subjected to adsorption isotherms and soil analysis using a variety of soil extractants for N, CA, Mg, K, S, P, Mn, Cu, Fe, and Zn. Results from this research will allow more precise interpretation of soil test analyses.

- Chris Manthe, Entomologist, DAR has completed his Ph.D. dissertation under the guidance of INTSORMIL entomologist, Dr. George Teetes. Mr. Manthe's work was based upon research conducted in Botswana and Zimbabwe on sorghum resistance to sugarcane aphid. Resistance to the sugarcane aphid has been identified. The source of resistance has been found to be simply inherited and controlled by a single completely dominant gene. He is now coordinator of the cereals working group.

- Professor David Andrews, University of Nebraska, continues to foster collaboration between INTSORMIL Projects UNL-115 and UNL-118 and Dr. Louis Mazhani at the DAR Sebele station. This collaboration involves both sorghum and millet germplasm improvement. INTSORMIL involvement has principally been in the supply of both segregating populations and advanced lines in sorghum and information on and participation in recurrent selections in pearl millet. PI visits have been timed so material can be jointly evaluated and selected in the field.

- Training of Botswana students through SADCC/ICRISAT/INTSORMIL, INTSORMIL, USAID/Botswana, and ATIP educational programs is continuing. Some of the students that have or are obtaining advanced training are, Mr. Willie Emmanuel, seed technology, Mississippi State University (B.Sc.); Mrs. Dollina Malepa, soil fertility, University of Nebraska (Ph.D.); Ms. Rosemary Lekalake, food science. Texas A&M University (M.Sc.); Mr. Etani Lele, agronomist, Kansas State University (M.Sc.); and Mr. Ernest Makhwaji, FSR/economics, Kansas State University, (M.Sc.).

Colombia

The INTSORMIL program in Colombia has effectively engendered the support of the National Agricultural Research Institute, ICA, Colombian Universities, private companies, CIAT, and extension organizations to form a dynamic program on sorghum improvement. In 1988, research was initiated in the acid savannas of Arauca State through a Memorandum of Agreement between INTSORMIL and the El Alcaravan Foundation - a consortium of petroleum companies (Shell, Ecopetrol, and Occidental de Colombia). Informal agreements and very strong links have been established with nonprofit organizations such as FENALCE - a production extension-oriented organization and three universities in Colombia. Program focus has been on the adaptation of sorghum varieties to the acid and aluminum saturated soils of the savannah region.

Collaborative research on germplasm enhancement was originally established to help solve problems related to sorghum and pearl millet production on acid soils. Even though this is the program's primary research objective, emphasis is being placed on other activities, largely because of the diversity of institutions involved. For example, FENALCE's main interest is to develop lines for semiarid areas (e.g., drought tolerance - Project TAM-122) and lines resistant to grain mold diseases. ICA aims to develop drought-tolerant lines, adapted to acid soils and resistant to grain mold diseases (Project TAM-124). The Colombian universities' main objective is research in agronomy and physiology (Project UNL-114), and entomology (Projects TAM-124 and MSU-105). The El Alcaraván Foundation aims to develop germplasm adapted to acid savannas and slightly acid soils ("vegas"). This institution is also increasingly interested in grain quality and utilization (Projects TAM-126 and PRF-103B).

Two varieties, Sorgho Real-40 and Sorgho Real-60, were released in January, 1991 from the program and have been accepted by growers as reflected by the documented demand for seed. These varieties have the potential to allow over 200,000 hectares of acid savannah soils to be utilized for sorghum production where other crops cannot grow.

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

Three new lines are being evaluated for release in Arauca as a result of significant advances in the ICA/El Alcaraván breeding program, thanks to collaboration with INTSORMIL and the El Alcaravan Foundation. Research conducted by INTSORMIL has developed specific varieties for the poorly drained savannas of Arauca.

Selections were made for different ecosystems from 500 F_4 lines sent by Project MSU-104; short lines with good yield capacity are being evaluated in regional trials. These lines considered as second generation, are of a better agronomic type than the world collection lines.

Twenty F_2 populations from Mississippi were screened in different environments (both vega and savanna), resulting in promising breeding material available for future work. The lines selected are short, with good yield potential. These selections are the third generation.

Egypt

In July, 1991 INTSORMIL received a grant from USAID/Cairo to implement a three year collaborative research program with the National Agricultural Research Project (NARP) of the Egyptian Ministry of Agriculture, Agricultural Research Center (ARC). Participating institutions under the grant are Field Crops Research Institute (FCRI), ARC and the Plant Pathology Institute of ARC. This collaborative research activity is divided into a plant pathology component and a physiology/production component.

The objectives of the plant pathology component are to: 1) Determine whether arerial infestation with a spore/hyphal fragment suspension, toothpick infestation, or soil infestation is the most effective method for assaying sorghum resistance to *Acremonium strictum*, 2) to identify sorghum germplasm with tolerance to pokkah boeng and fusarium stalk rot and 3) to characterize genetic diversity within the pathogen population and to identify pathogenic strains to be used in breeding challenges and nonpathogenic strains to be used in a biological control program.

An extensive survey to the sorghum production regions of Egypt was conducted in September, 1991. The major disease of sorghum identified during this survey included: sorghum downy mildew, *Acremonium wilt*, pokkah boeng, maize dwarf virus, long smut, and covered kernal smut. Vegetative Compatibility Groups (VCG) are very useful techniques for detecting different strains within the same genus and species of fungi. Of 120 Egyptian isolates collected, there have been 58 different VCGs identified. Twenty-one of these groups have more than one strain; 13 can be found at more than one location, and 7 of these 13 were found on both maize and sorghum. This will likely be a very important parameter for breeding for resistance to fusarium stalk rot and root rot in maize and sorghum. Contamination of seed and feed grains with fumonisin mycotoxins is also an important aspect of the VCG strain variability within *Fusarium moniliforme*. Some VCG's have negligible amounts and other strains produce fumonisin at unacceptable levels for food products.

The objectives of the physiology/production component are to: 1) Develop water control irrigation systems which permit control and measurement of water applied to research plots for water and nutrient use efficiency investigations, 2) determine the influence of water level and nutrient level on water use efficiency (WUE), and nutrient use efficiency (NUE), and 3) evaluate short, white seeded, tan plant selections at Shandoweel for general adaptability in preparation for later stress screening tests when sprinkler systems become available.

Honduras

INTSORMIL works in conjunction with the National Research Institution, Secretary of Natural Resources (SRN), the Pan American Agricultural School (EAP), and The Soil Conservation Program, LUPE. In December, 1991, an MOU was signed between SRN and EAP, which officially placed the responsibility for sorghum research with the EAP and established a collaborative relationship between SRN and the EAP in the conduct of sorghum research throughout Honduras.

The INTSORMIL collaborative program in Honduras is multidisciplinary, and multi-institutional in scope. The program includes all aspects of sorghum improvement with major emphasis on the tall, photoperiod-sensitive local landrace varieties called maicillos criollos, which are grown in association with maize by subsistence farmers on small hillside farms. Research is also focused on the development of female and male maicillo derivative parental lines to be used in the production of photoperiod sensitive hybrids. The experimental hybrid maicillos, containing varying proportions of maicillo criollo germplasm, show outstanding yield potential, demonstrating the advantage of hybrids over pure line varieties. The program effectively integrates the disciplines of pathology, entomology, food quality, agronomy and economics into a powerful technology generating unit.

The enhanced maicillos show advantage in yield, especially when combined with improved agronomic practices, as well as in traits such as grain quality and disease resistance. Some of the improved maicillos have been saved and used by farmers after collaborating in on-farm testing trials.

Several excellent hybrid parental lines and breeding germplasm source lines were identified in the INTSORMIL/Texas A&M International Sorghum Tropical Adaptation Trial (ISTAT), the International Food Sorghum Adaptation Trial (IFSAT), the International Tall Variety Adaptation Nursery (ITVAN), the All Disease and Insect Nursery (ADIN), and the Grain Weathering Test (GWT). These trials contain a wide array of elite Texas A&M developed parental lines and hybrids, elite germplasm sources, and elite new breeding lines form the various Texas A&M sorghum improvement programs.The best male parents were 86EON361, 87EON366, R8510, R8503, Dorado, 84C7730, Tx434, R8606, SC1207-2, and some new lines (R8505*Tx430) der., (Tx430*Tx2816) der., and (Tx435*Tx430) der. The best females were ATx626, ATx631, ATx635 (A Var), ATxArg1(AArg34), A1, A8106, and A4R.

The sorghum-sudan hybrid, ATx623* Tx2784, was in plot production by EAP, and performed well in feeding trials. It is planned for release in early 1993. It is resistant to pathotype one of downy mildew.

Evaluation of grain from improved maicillos (IM's), DMV-179, DMV-197, local criollo, from on-farm trials, compared to Sureño indicated the improved maicillos to be equal to, or superior to, the local maicillo criollo in most traits. The IM's require a greater cooking time than the criollo, but the vastly improved color of tortillas and keeping quality of the harder grain of the IM's are excellent advantages. Farmers are planting Sureño because of its enhanced tortilla quality.

Disease ratings were made in the (ISDMN) International Sorghum Downy Mildew Nursery and International Sorghum Anthracnose Virulence Nursery (ISAVN) screening trials, grown at several locations in Honduras in 1991/92. Although downy mildew is now found in most sorghum producing areas, the ISDMN indicates that Pathotype 1 only is present, except for P5 found in the Comayagua Valley. Anthracnose is a problem primarily in the areas of commercial hybrid production, such as Olancho and Danli regions. Rust is a severe foliar disease. The more common sorghum diseases in Honduras are leaf blight, gray leaf spot, rust, grain mold, anthracnose, MDM, acremonium wilt, zonate, oval leaf spot and downy mildew.

Research has continued on the langosta complex (a group of four lepidopterous larval insect pests) which causes extensive damage to sorghum and maize seedlings in Southern Honduras. Noncrop host plants in and around intercropped sorghum and corn fields were identified. A grass weed *Ixophorus unisetus* was observed to be a good ovipositional host plant. The importance of noncrop vegetation around sorghum or maize as preferred or not preferred by young larvae is elucidating information about the fitness, of the insect pest after feeding on certain host plants. This explains in part, the decline in numbers of this pest as the season progresses. Those insects feeding on corn or sorghum do not have a high survival rate.

The economics program continued to publish results of earlier research on the introduction of new cultivars and associated technologies in Honduras. These results demonstrated the high returns to research and the need for complementary agricultural policy to avoid the price collapses resulting in good rainfall years.

The INTSORMIL/Honduras variety, Sureño, has found widespread acceptance throughout the sorghum growing regions. As of 1991, Sureño had substituted for 28% of the maicillo area. Much of its success is due to its improved cereal quality (tan plant color, and grain traits), yield potential, and dual purposes for use as forage and grain.

Mali

The program in Mali is a coordinated effort between INTSORMIL and the IER. In Mali, each Malian scientist develops research plans cooperatively with an INTSORMIL counterpart which provides for effective research planning, communication and coordination. Major INTSORMIL collaborators travel to Mali annually during the critical period of the crop year to consult, review progress and plan future activities with their Malian counterparts. INTSORMIL cooperates with the TROPSOILS CRSP in the area of soils and plant/soil relationships. Individual INTSORMIL investigators transfer funds to Malian counterparts to provide support to accomplish the research.

Yield stability in sorghum/millet production is of major importance where food production is marginal relative to population. Low soil fertility, drought, diseases, and insects are major factors affecting yield stability. Milling properties are critically important. Head bugs and molds adversely affect grain quality, especially of the high yielding introduced sorghum lines, sometimes rendering the grain unfit for human food. Surplus production of grains in good years causes reduced prices. Transformation of sorghum and millet into new shelf stable foods and industrial products is required to encourage local production of grains and to enhance agribusiness activities, i.e., food processing and poultry feeding.

The Mali program has continued to work on millet entomology, breeding, quality and cropping systems. Work to develop *Striga* resistant sorghums and photosensitive late maturing sorghums to escape the head bugs and molds was expanded. InterCRSP activities (INTSORMIL/TropSoils CRSPs) were initiated for breeding and selection for nutrient efficiencies during the 1992 cropping season by a Malian sorghum breeder who returned to Mali.

Striga resistance and breeding continue to be a major emphasis in the program. Segregating selections from SRN-39xMalisor 84-7 have shown promising potential for tolerance to *Striga* and improved production potential. In addition several local Guineense cultivars collected in Southern Mali have a local name, Séguétana, which means *Striga* resistant in the local (Bamana) dialect. These have been sent to Purdue University for laboratory evaluation.

The head bug/grain mold complex is a serious problem in development of improved cultivars. The combination of head bugs, grain molds and weathering causes significant damage to the quality of the grain that is produced in addition to yield reduction. Malisor 84-7 has proved to be an excellent source of resistance to head bugs. A larger number of progenies from Malisor-84-7 have been identified as resistant to head bugs and have been entered into multilocation trials across Mali. R-6078, a grain mold/weathering resistant type from Texas, was identified as tolerant to head bugs by Dr. Y. Doumbia in Mali. It now appears that the combination of head bug resistance with grain mold and weathering resistance is possible.

Downy mildew resistance in pearl millet is absolutely required in West Africa. U.S. pearl millets do not have acceptable downy mildew resistance. Therefore, crosses of elite U.S. millet with Malian millet are made in the U.S. and returned to Mali as F_1, F_2, or S_1 selections, possessing the desired characteristics.

An effective level of drought tolerance is obtained by selecting millet lines that produce root systems that penetrate and extract moisture from soils with fine-textured, dense subsoil profiles. Crosses between elite Kansas lines and materials from Mali have produced material exhibiting good yield potential and drought tolerance.

Drought resistance and tolerance are associated with soil fertility. Due to a lack of nutrients, principally N and P, usable water is left in the soil profile even by native range plants in the Malian Sahel. Thus, work continues on the relationship between soil nutrients and water use efficiency in sorghum and millet grown at different fertility levels. To make the best possible progress in grain production in Mali, the development of an effective knowledge of soil properties is required. Hence, the strong interaction between TROPSOILS and INTSORMIL has been developed from the inception of the Malian program.

Research continues in Mali, in the Food Technology Laboratory, to improve methods of selecting sorghums and millet for tô quality. Milling and tô properties of grain showed that head bugs and grain mold soften the grain and significantly reduce the yield of decorticated grain. A few cultivars have been found to have acceptable milling properties. Dorado, an introduction from the Honduras INTSORMIL program had acceptable milling properties with high grain yields. The Food Technology Laboratory continues to conduct demonstrations of various food products prepared from sorghum, millet, maize and various grain legumes to distribute information to potential users. Popped sorghum, sorghum, noodles, and other products were made.

Progress has been made to determine factors affecting the "soils problems" in Mali through joint INTSORMIL/TROPSOILS collaboration. Some "dune varieties" of millet originating in Niger are tolerant. A common feature of each experiment has been the high variability within and between experimental units. There has also been large differences in genotype responses from growing season to growing season. Definitive conclusions cannot be made, however, it is clear that Babadia Fara is the best sorghum variety for soils under severe nutrient stress.

Two long term cropping system studies were established (1990) at Samanko (high rainfall/sorghum-peanut based site) and at Cinzana (lower rainfall/pearl millet-cowpea based site). Data being collected include grain and stover yields and yield components.

The rotation of sorghum with peanut and millet with cowpea, increased both grain and stover yields.

Under institution building, INTSORMIL has built and equipped a physiology/agronomy laboratory at the Cinzana Agricultural Research Station to provide support for the expanded activities in agronomic and drought research being conducted by IER scientists. A new vehicle was purchased for cooperative programs in cropping systems and other activities conducted at Cinzana.

Several students are training at INTSORMIL institutions. Scientists trained in food technology, pathology, breeding, physiology and agronomy have returned to Mali and collaborate in the program. Eight graduate students are currently training in INTSORMIL universities to provide personnel to continue the programs. The programs include agronomy, breeding, physiology, economics, utilization, and soils.

Research accomplishments in Mali are immediately and directly transferable to most countries in West Africa. The work on sorghum and millet technology applies to Africa and many areas of the world. Head bug and drought research are common to West African areas. Dr. M. Traoré and Dr. O. Niangado serve as Chairmen of the Steering Committee of the West and Central African sorghum and millet networks, respectively. INTSORMIL has collaborated closely with SAFGRAD and the ICRISAT/West African Sorghum Improvement Program for Africa (ICRISAT/WASIP)

Niger

There are several interdisciplinary activities involved in the INTSORMIL/INRAN/Niger Collaborative Research Program. They 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 the INRAN Director General for his approval. INRAN has appointed Dr. Ouendeba Botorou as host country coordinator for this project. Dr. Moussa Adamou has been nominated as Scientific Director for INRAN. The *Striga* resistant sorghum breeding program continues to be a major initiative of sorghum breeding research in Niger. INTSORMIL scientists have developed the following method for identifying *Striga* resistance.

- devise a way to disrupt the host-parasite interaction,
- designed a new genetic screening technique that consistently predicts *Striga* resistance,

- developed a time-consuming field trial with a new laboratory assay that allows for much wider genetic screening.

This method could be important to resolving the problem of the parasitic weed, *Striga*, in Africa and India.

Genetic studies on resistance to long smut have been initiated. The data will be ready for analysis after the 1991/92 cropping year. Research on studying the relationship between date of flowering and incidence of disease is continuing. This was the last year results are being analyzed. Preliminary analysis indicates that the relationship between date of flowering and incidence of disease was high, suggesting that all lines flowering early are subject to escape.

Field surveys have indicated that another sorghum disease, sooty stripe, is not a constraint for sorghum in Niger.

Preliminary trials with Apron Plus® indicated that it will be important to continue the evaluation of this product, where stand establishment and downy mildew is a problem in pearl millet. Data from trials in Mali have shown a 20% or greater improvement in yield.

Field research in farm production economics has made important contributions to the INRAN economics and on-farm testing programs.

The impacts of new early cultivars of millet and cowpeas was evaluated. This research evaluated in which regions, and with which changes in policy or technical conditions, chemical fertilizer would be utilized.

Research is now underway on biological control of the major insect pest of millet, the millet girdler.

Significant advances have been made in the breeding program at INRAN, primarily on sorghum, as a result of collaboration with INTSORMIL. Intercrossing of adapted exotic germplasm with local Nigerien varieties has yielded useful selections that are currently under regional evaluation.

A hybrid sorghum breeding program, initiated at INRAN, in collaboration with INTSORMIL, has also made useful contributions. A new hybrid, NAD-1, is a hybrid which is well adapted and excellent yielding. NAD-1 has performed well in the West African Sorghum Hybrid Adaptation Trial (WASHAT). NAD-1 has been the farmers choice in all INRAN demonstration plots since 1989 and especially in 1992 when this activity expanded.

Germplasm collection trips for millet germplasm have been conducted. The objective was to add genetic variability to the existing collection. Trips were organized to collect late maturing millet varieties. A genetic study of these late millets will start in 1993.

New projects were initiated in 1992 on utilization of millet and sorghum in Niger. The long range objective is to produce a commericalized millet or sorghum couscous product, that could compete with imported wheat couscous in urban areas. The emphasis is on small scale couscous processing operations in semirural areas.

Senegal

Pearl millet and sorghum production in Senegal suffers from the same general farm and market constraints as in other West African countries. Pearl millet and sorghum are the countries' major dryland food cereals with pearl millet accounting for about 70% of the total area planted to cereals (0.8 to 1.1 million ha). Yields are limited primarily by variable rainfall, poor cultivation practices, low soil fertility and no fertilizer use, diseases and pests (principally downy mildew, smut and the pearl millet head worm - *Raghuva*) and poor markets with a narrow range of end-uses. The collaborative research program between the Institut Senegalais Recherche Agronomique (ISRA) and INTSORMIL has been supported by the Senegal Agricultural Research Project II from A.I.D./Dakar, managed by Michigan State University. There are two principal thrusts in the ISRA/INTSORMIL collaborative research activity; 1) to evaluate sorghum and pearl millet germplasm, both existing and introduced, in the Senegal River Valley under irrigated conditions in both the summer season and the dry season, and 2) to supplement the ongoing dryland sorghum and millet breeding programs at the central research station (CNRA) of ISRA at Bambey.

Good progress has been made in introducing new parental genetic diversity into the Senegal millet breeding program and selecting downy mildew resistant derivatives. These will form the basis of new synthetic varieties. This collaborative project has broadened the useful genetic variability in the sorghum variety breeding programs for rainfed and irrigated environments. New hybrid parents have been introduced and better hybrids have been identified for both rainfed and irrigated conditions. Through the provision of parental lines, hybrid seed can now be made in Senegal.

Sudan

The INTSORMIL program in Sudan has worked closely with the Government's Agricultural Research Corporation, (ARC), to build a strong national program for its most important staple crops, sorghum and millet. The INTSORMIL U.S. principal investigators develop their work plans jointly with ARC Scientists. These workplans are in turn approved by the ARC Director General, the ARC/INTSORMIL Coordinator and the U.S. INTSORMIL/Sudan Coordinator.

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 which 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 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 the lack of knowledge on sources of germplasm with useful traits. 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 germplasm with resistance to *Striga* and the mechanism that renders resistance to *Striga* is only beginning to be 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 limits the utilization of high yielding 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. 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. 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 production.

The sorghum breeding program has focused greatly on synthesis and evaluation of hybrids, primarily for the irrigated Gezira Scheme. A number of experimental hybrids have emerged as being superior in several multilocational test sites including the Gezira Research Station and farmers fields in the Gezira. Currently, a large and extensive experiment is underway to evaluate the performance and stability of many of the parental lines for those experimental hybrids.

ARC, in collaboration with INTSORMIL food utilization scientists, developed a composite flour using 30% sorghum and 70% wheat, which can reduce wheat imports, thus economizing precious foreign exchange.

Collaborative studies are continuing between the Food Research Center (FRC) and sorghum breeders in the Central and Eastern Regions on investigating the physical characteristics of various sorghums. The performance of new hybrids under dehulling and milling processes has been determined according to AACC and ICC approved methods. Sorghum flours produced as whole meal and decorticated were evaluated for kisra preparation. Results do not show any pattern to indicate direct relationship between milling characteristics of the grains and kisra quality.

Striga research activities are underway at ARC, Sudan. Several years of testing has confirmed the superior *Striga* resistance of the SRN39 cultivar. This line also has a good level of drought tolerance and possesses good stand establishment characteristics. The SRN39 is a tan plant with good grain quality characteristics. SRN39 has been intercrossed to other genotypes and progenies were selected for agronomic superiority as well as grain quality. Field tests have confirmed that many of the new elite progenies derived from crosses to SRN39 are resistant to *Striga*.

The USDA National Sorghum Crop Advisory Committee, in conjunction with INTSORMIL and ICRISAT, grew the international Sudan sorghum collection at ARC in 1991. The purpose of this was to provide proper documentation of this valuable germplasm for the benefit of Sudanese, U.S. and other international sorghum scientists.

In the summer of 1990, Mohammed M. Ahmed and John H. Sanders did fieldwork in the Gezira irrigation project to estimate the returns to research from investment in the Hageen Dura 1 (HD-1) hybrid. HD-1 is in the early stage of diffusion on 17,000 ha, or 9% of the sorghum crop area. Even at this early stage of diffusion, there is a reasonable financial rate of return of 23-31%.

United States

INTSORMIL research is performed at all participating universities. INTSORMIL investigators routinely evaluate international material for disease and insect susceptibility which is beneficial to all sorghum producers, U.S. and international. Much of the U.S. research conducted utilizes "upstream", hi-tech approaches to solve "downstream", farm level problems. Other research is being performed to alleviate constraints in the U.S. that are very similar to those in the developing world.

Drought is a worldwide constraint to the sorghum producers. INTSORMIL workers at Texas A&M, Purdue, and the University of Nebraska have begun to study drought effects from physiological, biotechnical, and genetic perspectives utilizing drought tolerant germplasm from Africa. Breakthroughs from stateside efforts will be readily transferable to other countries since germplasm sources are similar.

Recent economic studies have revealed that funds appropriated for INTSORMIL research have resulted in dividends that exceed initial expenditures several fold through the use of technologies generated by the programs utilized for U.S. agriculture.

Future Directions

Over the past 13 years the INTSORMIL program has developed an effective research network on grain sorghum and pearl millet which is bringing about improved production and utilization of these crops in the developing world. The research in each of the collaborative countries has grown and the operational needs of the programs are now exceeding the resources of the program. It is also recognized that these programs must be nurtured until they become self sustaining and can move into a different phase of collaboration. New research emphasis must be given to sustainable production and utilization systems which conserve natural resources and at the same time utilize those resources efficiently and effectively. In order to address these concerns, greater emphasis and resources are needed to address the following concerns:

- Sustainable millet production and protection systems.
- New sorghum/millet food product development.
- Development of stable marketing systems for sorghum/millet.
- *Striga* control.
- Quela bird control.
- Biotechnology for understanding the host/pathogen gene relationships, disease/insect control, *Striga*, nutritional quality, and other abiotic stresses.
- Adaptation of crops to stress soil environments.
- Communications for developing materials for technology dissemination. This includes development of materials to enhance technology dissemination between host country research and extension programs.

The new directions build upon the necessity to approach constraints to production and utilization from an ecological setting. INTSORMIL has organized its whole program approach around protection and enhancement of biological diversity, integrated pest management, sustainable production systems, and sustainable product utilization and marketing systems. The four global technical thrusts of the program are germplasm enhancement, sustainable production systems, sustainable plant protection systems, and crop utilization and marketing. A fifth global thrust is host country program enhancement.

Sustainable Plant Protection Systems

Agroecology and Biotechnology in Stalk Rot Pathogens of Sorghum and Millet

Project KSU-108

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Summary

Stalk rots of sorghum and millet are a continuous problem wherever these crops are grown and yield losses usually range from 5-10% annually. *Fusarium moniliforme* is one of the causal incitants of stalk and root rots and cause other diseases such as grain mold. The genus *Fusarium* is diverse and identity of these fungal strains associated with sorghum and millet is unclear. The strains attacking sorghum and millet in Africa appear to be even more diverse.

Fusarium moniliforme can be broken down into a series of mating populations (biological species) on the basis of sexual mating behavior. Within each population, isolates can be further classified into vegetative compatibility groups (VCG) based on the ability to form a stable heterokaryon with other strains. Some strains within the *F. moniliforme* group produce a number of secondary metabolites including fumonisins. These compounds are known to be toxic to horses and swine, and are correlated with serious diseases in humans and other nonhuman primates.

The "F" mating population of *F. moniliforme* is primarily limited to sorghum. Strains belonging to the mating populations common on maize ("A" & "D") usually produce high levels of fumonisin. The "F" mating population produces little, if any, of this toxin.

Objectives, Production and Utilization Constraints

Objectives

Identify and characterize *Fusarium moniliforme* isolates to determine mating type and vegetative compatibility group.

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

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

Finalize research for development of a semi-selective medium and a cDNA probe for *Pseudomonas andropogonis*.

Characterize various strains of *Fusarium moniliforme* for fumonisin B_1 production and to refine the RAPD technique for use in identification of mating types.

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

To identify antifungal proteins in sorghum grain.

Constraints

It is imperative that causal agents of plant diseases be correctly identified. However, most laboratory facilities in LDCs lack equipment and/or chemical supplies for diagnosing plant diseases. In this context, researchers may evaluate germplasm in a screening program based solely on disease symptoms without any attempt to ascertain the causal agent. A definitive diagnosis is mandatory when the causal agent is seedborne, such as bacterial leaf stripe and bacterial leaf streak in sorghum. More importantly, many countries require a phytosanitary certificate that states that the seed or feed grain is free of specified bacteria.

Diagnostic kits that utilize immunological procedures developed from biotechnological research such as the dot-immunobinding assay or Western blots are ideal alternatives to equipping extensive laboratory facilities in developing countries. The procedure is simple, inexpensive and requires only limited equipment such as a refrigerator. Availability of antisera of high quality and sufficient quantity to researchers in LDCs would alleviate some problems such as limited equipment and/or personnel with limited or no training in bacteriology.

Stalk rots of sorghum and millet are a continuous problem wherever these crops are grown, and average losses usually range from 5-10% annually. Some of the fungi that can incite these diseases also cause other problems such as grain mold. These fungi are essentially endophytes that coexist with the plant from seed to harvest, and may be seedborne and reinfest the next crop the following year. The identity of many of the fungal strains within the genus *Fusarium* associated with sorghum and millet is unclear. One of the most fertile areas of research for *Fusarium* taxonomists has been the strains associated with sorghum and millet from Africa. We have been developing techniques based on sexual and vegetative compatibility that provide accurate identification of species and fine levels of genetic discrimination that require little more than petri dishes, microbiological media and incubator space. The vegetative compatibility traits that we have pioneered may be applicable to other fungi and should be useful in identifying particular races and/or strain types for use in resistance breeding programs. Many of the fungi from this group that are common on maize are known to produce mycotoxins that adversely affect humans and domestic animals, and analysis of populations from sorghum and millet will be needed to determine the relative risks to consumers of these grains.

Kernels of sorghum are resistant to many fungi. Antifungal proteins are important constituents of the grain and have two potential uses: 1) in breeding programs to reduce the incidence of seed-associated diseases such as grain mold, and 2) as antifungal agents in medical and veterinary contexts. Medical and veterinary uses of these proteins could lead to new uses for sorghum in both the United States and in LDCs.

Research Approach and Project Output

Research Methods

Development of monoclonal antisera involves a hybridoma technology in which mice are injected with a purified antigen from the bacterium. We utilized a 32 kilodalton protein from the bacterial cell wall that was determined by sodium dodecyl sulfate - polyacrylamide gel electrophoresis (SDS-PAGE) to be unique to *Xanthomonas campestris* pv. *holcicola* (causal agent of bacterial leaf streak of sorghum). The bacterial cells were grown to log phase in nutrient broth then washed in protein isolation buffer and sonicated for removal of the cell wall. The cell wall components were dialyzed in 1 M PBS overnight and then centrifuged at 15,000 x g. Twenty to 40 µl of total protein were loaded into 12.5% agarose gels and run at a constant current of 30 mA for 6 hours and then stained overnight with Coomassie blue.

The target proteins were transferred from the acrylamide gel to a nitrocellulose membrane in an electric field at a constant current of 30 V for 16 hours at 4 C. This transfer process was repeated until approximately 50 µl was obtained for immunization. BALB/c mice were immunized intraperitoneally with the protein fraction for 10 weeks. The mice were then sacrificed and the spleen removed. Spleen cells were fused with myeloma cells (cell line P3X63Ag8) to produce the hybridomas. Myelomas are essentially malignant cells that secrete antibodies and provide the immortality factor needed for continuous antibody formation. Spleen cells impart the specificity of the serum.

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

The dot-immunobinding assay described above is easy for scientists in LDCs to use since it requires minimal equipment and is rapid and easy to perform. If even this minimal level of equipment is lacking or nonfunctional, then cooperators could apply the leachate from the diseased tissue to the nitrocellulose and mail the impregnated membrane to us. We have shown that the test can be completed up to three months after the bacteria have been placed on the nitrocellulose. USDA permits for importing plant materials or cultures are not required because the process requires that the nitrocellulose strips be soaked in ethyl alcohol and acetic acid prior to shipment (APHIS, Personal Communication).

To determine if the bacterial streak pathogen is systemic within the sorghum plant, wild-type and streptomycin (100 µl/ml) resistant strains of *Xanthomonas campestris* pv. *holcicola* were utilized. Seventy grain sorghum accessions from the Texas A & M University All Disease and Insect Nursery (ADIN) were planted at KSU's Rocky Ford experimental farm near Manhattan, KS. Each accession was planted in 4.6 m rows with three replications. Plants were inoculated at the 12-leaf stage with a Cornwall repeating syringe equipped with a 20-gauge needle. The first five plants in a row were inoculated with the wild-type strain and the last five plants with the streptomycin mutant. One month after inoculation, one gram of tissue was collected from roots, lower, middle and upper internodes (including peduncle), leaves and seed. The tissues were pulverized with a mortar and pestle. One ml of the extract was serially diluted and plated on YDCA and MXP media. The plates were incubated at 28 C for 7-15 days. Plants were assayed at monthly intervals from June through October. The experiment was repeated under greenhouse conditions, except that only one cultivar (80B3039) was tested and the plants were inoculated by wounding the roots. Inoculum was then placed in the soil. One gram of plant tissue was tested at monthly intervals until physiological maturity.

Survival of *X. c.* pv. *holcicola* over winter was tested by collecting leaves, stalk and seeds at monthly intervals from October through May in 1991 and 1992. The tissue was cut into small sections, surface disinfected with ethyl alcohol and serially diluted on the semi-selective medium, MXP, and the complete medium, YDCA. Plates were incubated at 28 C for 7-15 days.

Antifungal proteins from sorghum grain were assayed by Western blots using antibodies raised against some sorghum proteins and against similar proteins in barley and maize. Activity gels were run with the chitinases and the β-glucanases to determine if any isozymes were present that were not being detected in the Western blot procedure.

Fusarium moniliforme is the name applied to a group of related fungi that can be broken down into a series of mating populations (=biological species) on the basis of sexual mating behavior. Within each mating population, isolates can be further classified into a VCG (vegetative compatibility group) based on the ability to form a stable heterokaryon with other strains. The diversity within the population, as measured by the number and distribution of VCGs, can indicate the amount of genetic recombination that is occurring within the pathogen population and the ease with which new pathogenic combinations may arise.

VCG testing usually involves the generation of nitrate non-utilizing (*nit*) mutants to be used in forcing heterokaryons. These mutants can be generated spontaneously at high frequency in a number of fungal species, including *F. moniliforme*, by culturing the target strain on a medium containing potassium chlorate, an analog of nitrate. We have continued to refine this process to reduce the amount of labor involved in its implementation and to increase its ease of application in poorly equipped laboratories. Indeed the biggest problem in some countries has been to obtain two of the reagents - potassium nitrate and potassium chlorate - that have alternative uses.

Some fungi within the *F. moniliforme* group are known to produce a number of secondary metabolites. One of the most prominent classes of these compounds is the fumonisins. These compounds are known to be toxic to laboratory animals, horses and swine, and to be correlated with serious diseases in humans and other nonhuman primates. Reliable tests for fumonisin production require either HPLC or GC/mass spectrometry and were conducted by our collaborators at USDA in Peoria.

Research Findings

The second year of an experiment to determine the overwintering of cells of *X. c.* pv. *holcicola* in infested grain sorghum debris has been completed. Bacteria were in all sorghum plant tissues from July through September. From October to February, *X. c.* pv. *holcicola* cells were recovered from the peduncle, leaf tissue and seeds. Bacteria were recovered only from seeds in March, April, and May.

A search for a complementary DNA (cDNA) specific probe for detection of *Pseudomonas andropogonis* (causal agent of bacterial leaf stripe) continues. The vector, pBluescript, and genomic DNA from *P. andropogonis* have been isolated. Ligation of the DNA insert into the vector remains a problem. Development of a more efficient transformation system is in progress.

Development of a selective or semi-selective medium for isolating *P. andropogonis* from plant tissue is continuing. Incorporation of sodium acetate and adonitol into the medium has restricted or eliminated growth of numerous nontarget organisms. We are testing this medium's efficacy in the recovery of various strains of *P. andropogonis* from sorghum tissue.

Approximately 1200 hybridomas were screened for specificity and cross-reactivity against 30 strains of *X. c.* pv. *holcicola*, 18 other pathovars of *X. campestris*, and several representatives of *Pseudomonas* spp. that incite bacterial diseases in sorghum. Six hybridoma clones were selected and the antisera is being evaluated in the dot-immunobinding assay. Background problems have developed and the cause was identified as an improper dilution with the rabbit anti-mouse serum. When this problem is resolved, ascites fluid will be produced and the antisera will be made available to cooperators.

We examined crude protein extracts of grain from twelve different sorghum cultivars for the presence of four antifungal protein classes: chitinases, β-glucanases, ribosome-inhibiting proteins (RIPs), and permatins. Chitinases were detected using both Western blots (antisera was raised to a sorghum chitinase) and activity gels. The same bands were identified using both techniques. One major chitinase band was identified in all of the cultivars along with two or three minor chitinase bands in each cultivar. Some differences in the intensity of the major band were detected, and a great deal of variability, with respect to both isozyme and intensity, was detected among the minor chitinase bands. β-glucanases were also visualized on both Western blots (antisera was raised to a barley β-glucanase) and activity gels, and again the same bands were identified using both techniques. A single β-glucanase band was identified in all of the cultivars and modest variations in intensity were observed. RIPs were assayed using Western blots (antisera were raised against a barley RIP), but none were detected. The sorghum permatins, termed sormatins, were assayed using Western blots (antisera was raised to zeamatin, the maize permatin). One sormatin band was found in all of the cultivars examined, and a second isozymic band was found in one of the cultivars. Sormatins are known to have activity against strains of *Candida albicans* of significance in human and veterinary medical settings.

We continue to characterize *F. moniliforme* populations and to develop better tester strains for identifying the constituent mating populations. We have recently completed a formal description of the "F" mating population, which is limited primarily to sorghum. We have provided over 600 strains from our collection to other investigators during the past year. Although we have usable testers for all of the mating populations at this time, additional work is needed on the testers in the "C" and "E" mating populations to improve their reliability. Based on the number and distribution of strains that we have that do not cross with testers from any of the known mating populations, we think it likely that several new mating populations remain to be identified, and that at least one of these mating populations appears to be relatively common on sorghum.

VCG characterizations of the "F" population within Kansas have been a primary focus. It appears that one VCG, perhaps a single race or clone, accounts for as many as 30% of the isolates we have recovered from the state. This VCG has been recovered over several years and in widely separated parts of the state. We are planning further studies to determine the amount of genetic variability within this VCG and to determine if this VCG is common outside of Kansas.

Studies of the ability of *F. moniliforme* to produce the fumonisin toxins have also been a major focus. We have shown that strains belonging to the mating populations common on maize ("A" and "D") generally produce high levels of this toxin. Strains in the "F" mating population, which are common on sorghum, produce little, if any, of this toxin, but concern for toxin levels on sorghum remains 1) because members of the "D" mating population can also be recovered from sorghum at a significant frequency, and 2) because in laboratory tests maize on which strains belonging to the "F" mating population, which do not produce any detectable fumonisins, is as toxic to ducklings as is maize on which strains belonging to the "A" mating population, which are known to produce in excess of 1000 ppm of fumonisins.

Networking Activities

Workshops

Dr. Leslie participated in a USDA Workshop on Fumonisins in Raleigh, North Carolina in April 1991. He presented work on the population structure of *F. moniliforme* and the relationship between population structure and the production of the fumonisin mycotoxins.

At the 1991 American Phytopathological Society meeting, Dr. Leslie presented his research in an invited paper session that he organized that focused on vegetative compatibility in fungi; attendance was in excess of 150. Dr. Leslie also presented a second invited paper in a session focusing on issues related to the release of genetically-engineered microbes into the environment.

Dr. Claflin assisted Dr. Guillermo Munoz in planning a crop protection workshop for Central and South American scientists in Colombia. The conference was subsequently canceled for security reasons.

Research Investigator Exchanges

Drs. Claflin, Frederiksen and Leslie spent four weeks in Egypt in September 1991 surveying for sorghum and millet diseases. Dr. Leslie returned for an additional two weeks in Giza in December 1991 to further the planning process and to identify participants for the collaborative research exchanges. Several long-term and short-term visitors from Egypt are expected during the next two years under the auspices of USAID/NARP.

Dr. Demba Mbaye, ISRA/CNRA, Bambey, Senegal worked in the laboratory of L. E. Claflin from July 12-20, 1991. Dr. Mbaye conducted experiments to identify bacterial diseases of sorghum and pearl millet. He also utilized our scientific journal reprint file on diseases of millet and sorghum.

A consulting trip to Senegal was made by Dr. Claflin to determine the incidence of plant diseases on sorghum and pearl millet. Activities also included training in-country plant pathologists and breeders, and recommending protocols for screening germplasm for resistance to long smut, covered kernel smut, downy mildew of sorghum, and smut of pearl millet. This visit was sponsored by Michigan State University/ISRA/USAID.

Dr. J. R. Reddy took an additional year of leave from the Plant Quarantine Unit, ICRISAT to continue working on development of monoclonal antibodies. He is also researching the overwintering effect of bacterial pathogens of sorghum.

Dr. Leslie is serving on the supervisory committee of Mr. Anaclet Mansuetus, a Ph.D. student from Tanzania who is presently studying at Texas A & M. Mr. Mansuetus spent two months in Dr. Leslie's laboratory learning techniques in use there. He is now applying these techniques to studies of grain mold in Tanzania under the supervision of Drs. Odvody and Frederiksen.

Dr. Walter F. O. Marasas of PROMEC, Medical Research Council, Capetown, South Africa, spent three months on sabbatical with Dr. Leslie. He taught a mycotoxicology class (attended by several SADCC students), provided additional expertise on fumonisins, and learned genetic procedures used in Dr. Leslie's laboratory for identifying *Fusarium* species and in studying *Fusarium* populations. Dr. Marasas's research group was the first to identify and characterize the fumonisin mycotoxins.

Assistance Given

Chemicals, antibiotics, and stains were given to Dr.El Hilu Omer, ARC, Wad Medani, Sudan for preparing selective media.

Scientific reprints and chemicals for preparing media were given to Dr. Demba Mbaye, ISRA, Bambey, Senegal.

Scientific reprints were sent to Mr. Petros Zvoutete, Ministry of Agriculture, Harare, Zimbabwe.

Bacterial cultures, antisera, antibiotics and back issues of scientific journals were given to Dr. Molapo Qhobela, Ministry of Agriculture, Maseru, Lesotho.

Chemicals, bacterial and fungal strains, and materials were given to Drs. Elhamy El-Assiuty and Ibrahim Mansour, Plant Pathology Research Institute, ARC, Ministry of Agriculture, Giza, Egypt.

Publications and Presentations

Publications

Anderson, J. B., L. M. Kohn, and J. F. Leslie. 1992. Genetic mechanisms in fungal adaptation. In: *The Fungal Community: Its Organization and Role in the Ecosystem*, 2nd ed. (G. C. Carroll and D. T. Wicklow, eds.), pp. 73-98. Marcel Dekker, New York, 976 pp.

Bowden, R. L., and J. F. Leslie. 1991. Vegetative compatibility groups in *Fusarium graminearum* from wheat head scab. (Abstract) Phytopathology 81:1168.

Bowden, R. L., and J. F. Leslie. 1992. Evidence for outcrossing in *Gibberella zeae* (Fusarium graminearum). (Abstract) Phytopathology 82: 1065.

Bowden, R. L., and J. F. Leslie. 1992. Nitrate-nonutilizing mutants of *Gibberella zeae* (*Fusarium graminearum*) and their use in determining vegetative compatibility. *Experimental Mycology* 16: in press.

Campbell, C. L., J. F. Leslie, and R. Farrokhi-Nejad. 1992. Genetic diversity of *Fusarium moniliforme* in seed from two maize cultivars. (Abstract) *Phytopathology* 82: 1082.

Claflin, L. E., B. A. Ramundo, J. E. Leach, and M. Qhobela. 1992 Bacterial diseases of sorghum. In: *Sorghum and Millet Diseases: A Second World Review* (W. A. J. de Milliano, R. A. Frederiksen, and G.D. Bengston, eds), pp. 135-151. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, A. P., India.

Desjardins, A. E., R. D. Plattner, D. D. Shackelford, J. F. Leslie, and P. E. Nelson. 1992. Heritability of fumonisin B_1 production in *Gibberella fujikuroi* mating population A. *Applied and Environmental Microbiology* 58:2799-2805.

Dickman, M. B., and J. F. Leslie. 1992. Complementation of a *nnu* mutant of *Gibberella zeae* (*Fusarium graminearum*) by the regulatory *nit-2* gene of *Neurospora crassa*. *Molecular and General Genetics* in press.

Doe, F. J., and J. F. Leslie. 1992. A laboratory exercise for isolating and characterizing microbial mutants with metabolic defects. *The American Biology Teacher* in press.

Farrokhi-Nejad, R., and J. F. Leslie. 1990. Vegetative compatibility group diversity within populations of *Fusarium moniliforme* isolated from corn seed. (Abstract) *Phytopathology* 80:1043.

Hetrick, B. A. D., G. W. T. Wilson, and J. F. Leslie. 1991. Root architecture of warm- and cool-season grasses: Relationship to mycorrhizal dependence. *Canadian Journal of Botany* 69:112-118.

Jardine, D. J., and J. F. Leslie. 1992. Aggressiveness of *Gibberella fujikuroi* (*Fusarium moniliforme*) isolates to grain sorghum under greenhouse conditions. *Plant Disease* 76:897-900.

Kedera, C. J., J. F. Leslie, and L. E. Claflin. 1992. Systemic infection of corn by *Fusarium moniliforme*. (Abstract) Phytopathology 82:1138.

Klittich, C. J. R., and J. F. Leslie. 1992. Identification of a second mating population within the *Fusarium moniliforme* anamorph of *Gibberella fujikuroi*. *Mycologia* 84: 541-547.

Leslie, J. F. 1990. Genetic exchange within sexual and asexual populations of *Fusarium*. In: *Fusarium Wilt of Banana* (R. C. Ploetz, ed.), pp. 37-48. APS Press, St. Paul, Minnesota, 140 pp.

Leslie, J. F. 1991. Collecting free spores for genetic analysis without violating independence assumptions. (Abstract) *Fungal Genetics Newsletter* 38:52.

Leslie, J. F., F. J. Doe, R. D. Plattner, D. D. Shackelford, and J. Jonz. 1992. Fumonisin B_1 production and vegetative compatibility of strains of *Gibberella fujikuroi* mating population "A" (*Fusarium moniliforme*). *Mycopathologia* 117:37-45.

Leslie, J. F. and R. D. Plattner. 1991. Fertility and fumonisin B_1 production by strains of *Fusarium moniliforme* (*Gibberella fujikuroi*). *Proceedings of the Sorghum Improvement Conference of North America* 17:80-84.

Leslie, J. F., R. D. Plattner, A. E. Desjardins, and C. J. R. Klittich. 1992. Fumonisin B_1 production by strains from different mating populations of *Gibberella fujikuroi* (*Fusarium*) Section *Liseola*). *Phytopathology* 82: 341-345.

Qhobela, M., and L. E. Claflin. 1992. Eastern and southern African strains of *Xanthomonas campestris* pv. *vasculorum* are distinguishable by restriction fragment length polymorphism of DNA and polyacrylamide gel electrophoresis of membrane proteins. *Plant Pathology* (U.K.) 41:113-121.

Qhobela, M., L. E. Claflin, and D. C. Nowell. 1992. Comparison of techniques useful in the characterization of *Xanthomonas campestris* pv. *zeae*, the causal agent of bacterial leaf streak of maize. In: *Proceedings, 9th South African Maize Breeding Symposium* (H. O. Gevers, ed.), pp. 136-139. Technical Communication No. 232, Department of Agricultural Development, Republic of South Africa.

Raju, N. B., and J. F. Leslie. 1992. Cytology of recessive sexual-phase mutants from wild strains of *Neurospora crassa*. *Genome* 35: 815-826.

Xu, J.-R., N. M. DuTeau, and J. F. Leslie. 1991. Identification of the *nit-6* gene from *Neurospora crassa*. (Abstract) *Fungal Genetics Newsletter* 38:48.

Xu, J.-R., and J. F. Leslie. 1992. Electrophoretic karyotypes of *Gibberella fujikuroi* mating populations A-F. (Abstract) *Phytopathology* 82: 1150.

Yan, K., M. B. Dickman, J.-R. Xu, and J. F. Leslie. 1992. Sensitivity of field strains of *Gibberella fujikuroi* (*Fusarium* section *Liseola*) to benomyl and hygromycin B_1. *Mycologia* 85: in press.

Zvoutete, P., L. E. Claflin, and B. A. Ramundo. 1991. Susceptibility of *Xanthomonas campestris* pv. *holcicola* to various antibiotics. *Proceedings of the Sorghum Improvement Conference of North America* 17:96-98.

Presentations

Dr. J.F. Leslie presented seminar at Department of Plant Pathology, University of Kentucky, Lexington, Kentucky.

Dr. J.F. Leslie, Department of Plant Pathology, North Carolina State University, Raleigh, North Carolina.

Low Input Ecologically Defined Management Strategies for Insect Pests on Sorghum

Project MSU-105
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Summary

Non-crop host plants in and around intercropped sorghum and maize fields in southern Honduras were identified. A grass weed, *Ixophorus unisetus*, was observed to be a good ovipositional host plant. This information will be used in developing sampling procedures for fall armyworm eggs and/or young larvae in early season.

Three armyworm species, *Spodoptera frugiperda*, *S. latifascia*, and *Metaponpneumata rogenhoferi*, in the langosta complex were observed in larval host preference and host feeding performance studies. Results have elucidated the importance of non-crop vegetation around the crops as preferred or not by young larvae. Larval and adult developmental studies with *S. latifascia* included observations on mortality, weight gain, developmental time, sex ratio, fecundity and adult mortality. The influence on fitness of the insect pest fed certain host plants explains, in part, the decline in numbers of this pest as the season progresses. The insects feeding on sorghum or maize do not have a high survival rate.

Larval feeding induction studies were conducted to determine if larvae that initiate feeding on a weed plant get induced to it and are less likely to move in search of another host than those that do not get induced. Information obtained included sequence of hosts visited, time spent on host, weight of food consumed and weights of the insects. This information will assist in determining the extent of weed management necessary for specific production areas having different plant communities.

Several Honduran landrace sorghums were identified with antibiosis resistance to fall armyworm, *S. frugiperda*. Insects responded to feeding on resistant plants by having low net reproductive rate and/or low intrinsic rate of natural increase of the population. Antixenosis (non-preference) and/or antibiosis resistance mechanisms were identified. Levels of resistance in some sorghum lines were maintained over five generations.

Objectives, Production and Utilization Constraints

Objectives

1. Determine host plant ovipositional preferences of *S. latifascia* and *S. frugiperda*, two armyworm species in the langosta complex.

2. Determine host plant feeding preference of *S. latifascia* and *S. frugiperda*.

3. Determine feeding performance of *Metaponpneumata rogenhoferi*, a third species in the langosta complex, and *S. frugiperda*.

4. Determine larval feeding induction (induced feeding on host plants) with *S. frugiperda*, *S. latifascia* and *M. rogenhoferi*.

5. Identify sorghum with resistance to fall armyworm and determine mechanism of resistance.

6. Observe flight and oviposition behavior of *S. frugiperda*: Development of pest management tactics.

Constraints

Insects have been identified as a principal constraint to sorghum and maize production in Honduras and other areas in Central America. Some of the insect pests on these crops are important internationally. Some species that occur in Central America also occur in the United States. Many species survive from one year to the next in both areas, or they may migrate from south to north, arriving in the United States during the crop growing season. The economic significance of the different insect pests that move long distances is influenced by a number of factors, including, time of arrival of immigrant populations, stage of crops in the affected area, fitness of the migrant insects, level of insecticide resistance, if any, in the migrant population, and other factors influencing the population dynamics of the immigrant population.

MSU-105 has worked closely with TAM-131 and the Department of Research, Honduras Ministry of Natural Resources in defining the most critical insect problems on sorghum and maize in Honduras. The INTSORMIL research during the early stages of MSU-105 in Honduras emphasized identification and control of soil inhabiting seed and seedling pests of interplanted sorghum and maize. Studies also emphasized the identification of insect pests in the langosta complex and aspects of their biology, ecology, behavior, and population dynamics in relation to development of effective and practical insect pest management strategies for pests in subsistence farming systems.

MSU-105 research in Honduras and the United States emphasizes biological investigations involving relationships between insects and plants to develop an ecological framework for understanding the structure of organisms in different sorghum cropping agroecosystems. This information will allow for integration of cultural, biological and chemical control tactics in the implementation of insect pest control programs. The MSU-105 project is designed to provide entomological assistance to low income subsistence farmers in developing countries, and also is designed to facilitate the development of strategies for managing insect pests of international importance, especially those entering the continental United States. Methods of insect pest control that have been investigated emphasized host plant resistance, cultural control, biological control and selective use of insecticides.

Insect pests common to the Americas, have been investigated in the United States to elucidate the biological and ecological relationships of populations and influence of these populations from specific geographical areas upon the population densities and crop damage by the pests in other geographical areas. Yield losses and costs of control attributed to the complex of insect pests (e.g., fall armyworm, stalk borers, sorghum midge, webworm, and corn earworm) on sorghum in the southeastern United States are considerable. Crop and insect pest management systems have been developed, but must be improved to provide the sorghum producer with a reliable scheme for management of pests with minimum use of toxic chemicals to achieve an environmentally acceptable and sustainable sorghum production system in the United States. This must be achieved in regions where insect pests on sorghum have historically been controlled with insecticides.

Research Approach and Project Output

Oviposition Preference by Armyworms in the Langosta Complex

Additional studies on oviposition preferences with *S. latifascia* and *S. frugiperda* were conducted in field cages in 1992. Moths reared in the laboratory on a meridic diet were used. For each insect species, 25-50 mated, five day-old females were released inside a cage (1.8 x 1.8 x 1.8 m). Weed plants were transplanted from the field into pots; sorghum and maize plants were obtained from seeds planted in pots. Five seedling plants of each species were used per replication. One ounce plastic cups containing cotton balls soaked in honey water were hung inside the cage screen to provide food for the moths. After three nights of exposure all plants were searched for eggs.

Data have not been analyzed, but preliminary observations indicate that there may be some ovipositional preference for sorghum, maize, and grass weeds over broadleaf weeds. However, replications resulted in eggs laid on almost all of the hosts offered. Further analyses are necessary and will be performed to better understand the ovipositional preference of these two insect species. Knowledge of preferred hosts for oviposition can be used for management of insect populations in different ways, including mowing to eliminate the host plants, applying insecticide when the host is utilized as a trap crop, and creating better sampling techniques to estimate future populations.

Host Plant Feeding Preference of S. latifascia and S. frugiperda

These studies were coinducted to complement similar studies conducted in 1991. Neonates of *S. latifascia* and *S. frugiperda* from laboratory colonies were randomly selected from an egg mass and placed individually in a 9 cm diameter petri dish with a thin layer of agar (to maintain leaf turgor) containing pairs of foliage disks of two hosts arranged alternately in a circle. Comparisons of hosts were: sorghum and *Ixophorus unisetus*, sorghum and *Amaranthus hibridus*, sorghum and *Portulaca oleracea*, sorghum and *Ipomoea* sp., and sorghum and *Melampodium divaricatum*. Maize was also paired with all of the above plus sorghum.

Larval choice was recorded for a period of six hours and will be assessed statistically using a test for goodness of fit to a binomial distribution. Although the data have not been analyzed, preliminary observations indicate that broadleaf weeds are preferred over sorghum, maize, and the grass weed, *Ixophorus unisetus*, by *S. latifascia* neonates. In the case of *S. frugiperda* there was no apparent trend in neonate preference. Results from this study will elucidate the importance of vegetation around the crops as they are preferred or not by neonate larvae. This information will be used in pest management programs with recommended weed management tactics as this relates to the insect's behavior.

Feeding Performance by M. rogenhoferi and S. frugiperda

Metaponpneumata rogenhoferi

Because this insect species is difficult to culture in the laboratory, early instar larvae collected from maize fields early in the season were used to conduct the study. Treatments (diets) included: four broadleaf weeds, sorghum, maize, and one grass weed. Initial larval weights were taken and then larvae were placed individually in 29.6 cc plastic cups with agar (2 mm) in the bottom and the plant material (leaves from top one-third of the plants). The agar was changed weekly, and new plant material was offered every two days or as needed. The plant material was rinsed with a 0.0525% sodium hypochlorite solution to kill any bacterial or fungal organisms prior to insect feeding. Mortality throughout larval development was recorded and pupae were weighed on day two. Sex ratio and pupal mortality were also determined. Preliminary results have shown a lower larval and pupal mortality and higher pupal weights when this insect species was fed the non-crop vegetation than when fed sorghum, maize or the grass weed. Similar results were obtained in a previous study. Similar feeding performance studies were conducted in 1990 and 1991 with *S. latifascia*. Results obtained with other species in the langosta complex agree with those observed in this study with *M. rogenhoferi*.

These results indicate that broadleaf weeds are suitable hosts for *M. rogenhoferi* and *S. latifascia* population buildup early in the season or can serve as an alternate host before they move to sorghum and maize plants.

Area wide management of these pests on the more suitable host plants can be implemented in a such way that population buildup (assuming they can go through one generation on these weed hosts) can be reduced, or movement from these weeds to the crops can be prevented, so that they do not cause economic damage on the crops. The importance of early non-crop vegetation in population buildup of *Helicoverpa zea* and *Heliothis virescens* and the practice of mowing and/or the use of herbicide on non-crop hosts for the control of these insect species have been shown. Spraying biological insecticides, such as the bacteria *Bacillus thuringiensis* or nuclear polyhedrosis virus, on these early season hosts may also be feasible.

Spodoptera frugiperda

Neonates were placed individually in 29.6 cc plastic cups with agar (2 mm) in the bottom and plant material (leaves from top one-third of the matured plants) from each of the same diets for *M. rogenhoferi*. The cups and treatments were arranged in a completely randomized design. Larvae were handled as with *M. rogenhoferi* and larval weight was taken at day 15. Preliminary results indicate that unlike *S. latifascia* and *M. rogenhoferi*, *S. frugiperda* larvae fed sorghum, corn, and the grass weed were heavier than those fed broadleaf weeds.

Feeding Induction with S. frugiperda, S. latifascia and M. rogenhoferi

Earlier MSU-105 investigations revealed the importance of non-crop weed and grass host plants in the establishment and buildup of economically damaging lepidopterous larval populations (Langosta complex) on intercropped sorghum and maize in Honduras Armyworm feeding and behavioral studies indicated preferences by species for specific host plants. The close proximity of the crop and non-crop plants in the agricultural system presents interesting views of the role of the different types of host plants of these larvae in relation to the damage they may cause to sorghum and maize.

The ability of insects to discriminate among host plants based on host quality can be important in considering the degree of damage caused to the host. This relationship is important for insects in the langosta complex because the non-crop host plants appear to be more suitable hosts than either sorghum or maize. If an insect is induced to feed on a particular host plant (e.g., non-crop weed or grass host), they will most likely continue to feed on this host than move to search for another more suitable host. Thus, crop damage would be expected to be lower in areas where insect pests are induced to feed on non-crop vegetation. If the preferred host plants are absent or destroyed, the pest insect will become established on the crop plants and cause economic injury. This information, along with information on oviposition and feeding preferences, can be used in defining weed and insect management strategies for implementation in different geographical areas having different types of vegetation.

Induction studies were conducted with *S. frugiperda, S. latifascia* and *M. rogenhoferi* in both 1991 and 1992. First instar larvae were reared on broad leaf weeds (seven species) a grass host, sorghum or maize in the laboratory. Plant material was offered to the larvae in confinement containers. Sorghum or maize was arranged alternately around the perimeter of the container which was lined with a thin layer of agar to maintain leaf tissue turgor. Larvae (starved 24 h) were placed in the container for 3h. Sequence of hosts visited, time spent with the host, and leaf material consumed was recorded. Weights of larvae were calculated. A mean consumption index will be calculated.

Preliminary observations indicated that all three species were able to be induced to feed on the same host plant on which they were reared when given a choice of host plant materials for feeding. Further studies indicated that *S. latifascia* and *M. rogenhoferi* reared on sorghum or maize appeared to randomly choose host plant material for feeding in the laboratory tests. Additional studies are needed to elucidate this insect-plant relationship.

Host Plant Resistance

The tropical landrace sorghum, colloquially called "maicillo criollo," is widespread in Central America. Although little is known about its genetic makeup, it comprises primarily caudatum-kafir and caudatum-dura integrated races. More than 90% of the sorghum grown in Honduras and El Salvador is maicillo criollo intercropped with maize. The sorghum and maize in the intercropped plantings in these areas experience severe damage by insect pests annually. *Spodoptera frugiperda* is the principal lepidopterous pest in the langosta complex, thus host plant resistance studies with the maicillo criollo sorghum have emphasized this species. Studies have been conducted in Honduras and in the United States 1) to determine if resistance is present in commonly used sorghum cultivars, as well as improved sorghum lines, and 2) to determine types and levels of resistance (particularly antibiosis and non-preference). The uses of a resistant cultivar for management of this insect and possibly other closely related pest species, if used alone or in combination with other components of insect pest management, would provide a biologically, economically and socially feasible insect pest control program. Resistant cultivars would reduce insecticide inputs and provide a sustainable insect pest management alternative that would be persistently effective, ecologically compatible, and safe to humans.

Because fall armyworm populations decline after a brief buildup on landrace sorghum, the maicillo criollos have been studied to determine if host plant resistance was involved and whether antibiosis was a mechanism of resistance. Feeding experiments were conducted in the laboratory using whorl-leaf material collected daily from sorghum grown in the field. Experiments were initiated with first instar (newly hatched) larvae and mortality, pupal weight, generation time, intrinsic rate of population increase and relative fitness of the insects were used to make inferences about antibiosis resistance. Several landrace sorghums and improved lines exhibited plant resistance to fall armyworm. Previous studies have shown that the landrace San Bernardo III significantly suppressed fall armyworm population density increase. The resistance was enhanced when San Bernardo III was combined with a sorghum line, TAM428, showing levels of insect resistance. Several landrace accessions showed measurable levels of antibiosis resistance. A hypothesis, based on differential selection and increased selection pressure, brought about through intercropping with maize, has been presented to explain the development of antibiosis in the Honduran landrace sorghum populations.

Hypothesis. It may be that intercropping of maicillo criollo sorghum with maize and local selection have resulted in the selection of genes that confer antibiosis in local landrace sorghum. Key to this hypothesis is the abundance of alternate hosts and the relatively small number of fall armyworm generations on sorghum each year. These factors produce a differential selection for resident-virulent genes in host-insect populations in which all sorghums are subject to fall armyworm attack but not all fall armyworm larvae are forced to develop on sorghum. Consequently, resistant genes are selected; however, the virulent genes that enable fall armyworm to overcome resistance are diluted by a much larger insect population which develops on alternate hosts such as maize. The result of this differential selection has been observed when indigenous sorghums (maicillo criollo) exhibited antibiosis, but exotic sorghum did not.

Differential selection apparently has been the practice for many, many years and because of this process, maicillo criollo has accumulated antibiotic genes which appear to confer a broad level of intermediate resistance through reduced fecundity. The inclusion of the antibiosis traits into conventional cultivars not only will enhance productivity and make the environment safer by reducing dependency on insecticides, it will also conserve these genes in situ where evolutionary processes can continue.

Recent studies suggest that antibiosis resistance is expressed differently in various landrace sorghums. Developmental times may be longer (thus fewer generations per year), pupal weight may be reduced (thus, influencing fecundity) and mortality may be increased. The level of resistance was increased in F_3 and F_4 progeny when two sorghums with low levels of antibiosis were combined. The inbred line AF-28, which increases larval mortality, was crossed with San Bernardo III, which reduced fecundity. These crosses were tested in the field in Central America. Damage by *S. frugiperda* was significantly less in some F_4 lines compared to their parents. Inbred lines with the least amount of foliage damage were (AF-28 x SBIII)-17, (AF-28 x SBIII)-19, and (AF-28 x SBIII)-28, (AF-28 x SBIII)-31. In another study, (laboratory) evaluating crosses of (AF-28 x SBIII) previously selected from resistance tests in Honduras and Tifton, Georgia, (AF-28 x SBIII)-28 showed a significantly high level of larval and pupal mortality, (AF-28 x SBIII)-28, -17 and -10 showed significant increases in larval developmental times (ca. 3 days), and (AF-28 x SBIII)-28, -17 and -10 showed significantly lower intrinsic rates of natural increase (fitness).

In a study to determine if the resistant sorghum San Bernardo III maintained resistance over time, *S. frugiperda* larvae were reared on the resistant plants for several insect generations. This sorghum maintained initial levels of antibiosis resistance through five generations (test concluded after five generations).

The economic importance of *S. frugiperda* as an international pest of sorghum is emphasized in collaborative research with USDA scientists at Tifton, Georgia. Sorghum materials from the Honduran breeding program and other countries have been evaluated for resistance to this insect pest. Scientists at Tifton have many years of experience in the conduct of insect host plant resistance studies in the field, laboratory and greenhouse. The MSU-105 project utilizes the expertise of these scientists for continued progress in sorghum host plant resistance (INTSORMIL, MSU-105, Objective 5).

In recent studies at Tifton, a new type of non-preference resistance to *S. frugiperda* whorl stage feeding by larvae was observed among selected converted sorghum accessions (IS 7794C, IS 7947C, IS 7273C, IS-7444C, IS-12573C, and IS-12679C). Host evasion, a type of pseudo-resistance, was the basis for resistance. Resistance in these sorghum accessions was mainly due to their rapid rate of growth which induced a quick change in the plant morphology from the whorl-to the panicle-stage and did not permit a sustained colonization by the larvae. This new type of resistance could be referred to as "morphological non-preference," as opposed to chemical non-preference where non-preference is due to plant chemical factors.

For a number of years, studies in Tifton have emphasized screening sorghum genotypes for *S. frugiperda* resistance, and determining mechanisms of resistance. Though several converted sorghum accessions were significantly more resistant in the whorl stage than the resistant CM 1831 (tolerance resistance), efforts to identify sorghum germplasm with more resistance in the whorl stage to *S. frugiperda* should continue because a high level of resistance has not been identified in the genotypes tested. Studies should be initiated to test the more promising sorghum accessions for agronomic characteristics in order to incorporate them in a *S. frugiperda* management program.

Spodoptera frugiperda Flight and Oviposition Behavior

The MSU-105 project has emphasized research on the *S. frugiperda* (fall armyworm), an insect pest of international importance, and one that annually migrates into the southern United States where it causes economic injury to a large number of crops; including sorghum and maize. This pest shows a desired preference for plants in the grass family, and particularly sorghum and maize. The literature reports conflicting views on egg laying behavior of *S. frugiperda* on sorghum and maize in relation to age (size) class of the plants. Since this insect is a migratory species and may immigrate into areas in the United States at different times during the growing season, when the crops may be in different stages of plant development, MSU-105 research was initiated to investigate stage of maturity of sorghum crops as a factor influencing plant acceptability by *S. frugiperda* for oviposition. This information will be useful in sampling programs for timing of sampling of different age crops for detection of pest infestation, and for determining levels of infestation on crops in different stages of plant development.

The objectives of this research are 1) to determine oviposition preference by *S. frugiperda* moths of different ages for sorghum plants at various stages of maturity, and 2) to assess the effect of flight on oviposition by *S. frugiperda* moths of different ages on sorghum plants at various stages of maturity. This research was conducted by a Master of Science student from Malawi (SADCC program). The data is being analyzed for completion of the student's program. The results will be presented in the 1994 annual report.

Networking Activities

Research Investigator Exchanges

Sudan. Collaborative INTSORMIL relationships between research entomologists in the Sudan (ARC) and at Mississippi State University were established in 1987 in association with the Purdue (PRF) Project. The principal pest constraints to sorghum production in Sudan are shoot fly, stem/stalk borers, American bollworm, aphids and sorghum midge. The levels of damage caused by these pests vary in rain-fed areas and irrigated areas.

Present studies by in-country scientists emphasize screening of insecticides against sorghum shoot fly and stem borers. Results have been limited to providing information for pest control recommendations. Accordingly, only Sevin is the insecticide recommended for stem borer control. Tests to evaluate selected insecticides for efficacy against shoot fly and stem borers on sorghum seedlings and whorl stage plants have been conducted.

Sorghum breeding lines have been and will be screened in the field for resistance to stem/stalk borers.

Malawi. The participation in MSU-105 of a graduate student, (M. S. level) from Malawi in 1991-93, will provide opportunity for further expansion of research on insect pest constraints on sorghum in Africa. The SADCC student is currently investigating aspects of insect migration, using fall armyworm, in relation to age of the insect and phenological growth stage of sorghum plants (Objective 6).

Germplasm and Research Information Exchanges

Impact of CRSP-produced or Recommended Technology

Host plant resistance screening techniques and procedures that have been developed by U. S. scientists (Wiseman, GA, MSU-105) for laboratory, greenhouse and small field plot evaluations of plant materials for insect resistance continue to be used in the U.S. and some have been accepted in most programs in Third World Countries. An INTSORMIL graduate student in MSU-105 obtained training in these new host plant resistant methods in 1991 and is utilizing these techniques in research in the United States and Honduras. This technology is being disseminated into Honduras.

Assistance Given

One (1) hygrothermograph hand-carried to the Panamerican School of Agriculture in May, 1992 for use by INTSORMIL students and collaborating scientists conducting research in Honduras. INTSORMIL students transport materials and supplies from Mississippi State University for use in the conduct of their research in the laboratory and in the field. INTSORMIL collaborators use some of these supplies as well.

Other research equipment shipped to the Panamerican School in May, 1992 included 1 tape recorder for use in field studies, insect rearing supplies, and office supplies for student research projects. The research and office supplies are shared by students and collaborators at the Panamerican School of Agriculture.

Publications and Presentations

Abstracts, Articles, Reports and Other Publications

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

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

Castro, M. T. , H. N. Pitre, D. H. Meckenstock, and F. Gomez. ____. Some phytophagous insect pests, and aspects of control in intercropped sorghum and maize in southern Honduras. Tropical Agriculture. (Submitted).

Diawara, M. M., B. R. Wiseman, and J. Isenhour. 1991. Spodoptera frugiperda (Lepidoptera: Noctuidae) resistance in converted sorghum accessions: a research summary. Sorghum Newsletter. 32: 46-47.

Diawara, M. M. , B. R. Wiseman, and D. J. Isenhour. 1992. Morphological nonpreference resistance to fall armyworm (Lepidoptera: Noctuidae) among converted sorghum accessions. Seventeenth Biennial Grain Sorghum Research and Utilization Conference. Sorghum Improvement Conference of North America. February 17-20, Lubbock, Texas. 1991 (Abstract).

Portillo, H. E. 1991. Insect pest ecology, population dynamics, and partial crop life tables and loss assessments, in intercropped sorghum and maize in southern Honduras. M. S. Thesis. Mississippi State University, Mississippi State, MS.

Portillo, H. E., H. N. Pitre, K. L. Andrews, and D. H. Meckenstock. ____. Partial life tables of intercropped sorghum and maize and influence of non-crop vegetation on insect-related crop mortality in southern Honduras. Tropical Agriculture. (Submitted).

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

Project PRF-104B and PRF-104C

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Dr. J. Rutto, Deputy Director, Kenya Agriculture Research Institute, Nairobi, Kenya
Drs. J. Axtell (Agronomy), J. Rogler (Animal Science), B. Hamaker (Food Science), R. Nicholson (Botany and Plant Pathology), R. Bressan, R. Woodson and M. Hasegawa (Horticulture), all at Purdue University, West Lafayette, IN 47907

Summary

Striga is a parasitic weed which is becoming the greatest biological constraint on cereal production in much of Africa. *Striga* is exquisitely adapted to its role as a parasite, as well as to its hosts and environment. We are discovering that *Striga* uses a variety of chemical signals to communicate intimately with its cereal host. Our goal is to use this new information to develop effective methods by which African subsistence farmers can control this devastating parasite.

Striga seeds germinate only after undergoing periods of after-ripening and moisture conditioning, followed by exposure to a specific chemical signal produced by host roots. We found that sorghum roots exude two different classes of compounds which trigger *Striga* seed germination. The sorgoleones, which we reported in 1986, were the first host-derived *Striga* germination stimulants to be identified. We have shown, however, that it is not the sorgoleones that control *Striga* seed germination in the field. The second class of stimulants, more stable and more soluble in water than the sorgoleones, is the key to *Striga* germination. Some sorghums produce extremely small amounts of these materials, and as a result perform well in *Striga*-infested fields. Stimulants in this group are chemically similar to strigol, previously reported to be exuded from the roots of cotton, which is not a host for *Striga*. Others have reported that the major stimulant of sorghum is a strigol analog, sorgolactone. We have recently found that strigol itself is exuded by sorghum roots, accounting for about 1% of the *Striga* germination stimulant activity, and that strigol accounts for almost all of the stimulant exuded abundantly by maize and Proso millet roots. Sorghum roots exude small amounts of two other stimulants similar to strigol but not yet identified. The pearl millet cultivar we have tested does not produce significant amounts of Strigol or any other stimulant to which our *Striga* seeds respond. The species differences we find in stimulant production are consistent with widespread reports of species and strain specificity of *Striga* infestation.

A second developmental signal, which causes *Striga* to form a specialized structure (haustoria) and attach to a host root, is produced in about the same amounts by all the sorghums we have screened. Sorghums seem to differ in the amount they produce of this signal much less than they vary in production of germination stimulant. We have, however, found two lines of maize which produce relatively little of this second signal. It may eventually be possible to introduce this trait into sorghum.

We have evidence for yet another host-derived *Striga* developmental signal. After *Striga* attaches to the host root, this chemical from the host plant causes it to form shoots and fully developed plantlets. We can replace this signal with purified compounds known to serve as growth regulators in other plants, and we can modify the resulting *Striga* response by using herbicides. This finding may lead to resistance mechanisms and potential control strategies not previously considered.

Finally, we find that *Striga* also produces a chemical signal that strongly influences the growth of its host plant, and in high concentrations can kill it. Using tissue culture techniques, we are developing sorghums which should be less sensitive to this *Striga*-derived signal. When we test them in *Striga*-infested fields we expect these sorghums to have superior productivity.

In adapting to a parasitic lifestyle, *Striga* has become dependent upon its host not only for nutrients but also for crucial developmental signals. Moreover, *Striga* also produces chemical signals which to some extent controls growth of its host plant. Identification or development of host crops which produce abnormal amounts of signals required by *Striga* may provide a low-input form of *Striga* control for African subsistence farmers.

Objectives, Production and Utilization Constraints

Objectives

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

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

To eliminate or diminish the antinutritional effects of sorghum tannins and other phenols while maintaining or enhancing their agronomic benefits.

To minimize the effect of *Striga* on sorghum and millet production in Africa.

Constraints

This project addresses some of the most important worldwide constraints to sorghum and millet production and to sorghum utilization. These include grain-eating birds and the parasitic weed *Striga* in much of Africa, grain molds and weathering in India, and grain-eating birds and weathering in the southeastern U.S. The occurrence of phenolic components, especially the flavonoids and their polymers the condensed tannins of sorghum, correlate to some degree with resistance to the above constraints, with the probable exception of *Striga*. However, it is widely recognized that the presence of these phenolic materials in the seed of sorghum and millet also constitutes a formidable constraint to their utilization as food and feed. Phenolic materials, usually assumed to be tannins, are thought to diminish the palatability and digestibility of the food prepared from sorghum, and create undesirable colors in both sorghum- and millet-based foods. Until now it has been considered necessary, in several areas of the world, to accept the utilization constraints in order to overcome the production constraints by growing "high-tannin" pest resistant sorghums, or in the case of *Striga*, simply to abandon infested fields.

Research Approach

This research is coordinated closely with that of Dr. G. Ejeta. It is a fully integrated interdisciplinary program, with the breeding done by Dr. Ejeta and the laboratory work done here. Our students share the field and laboratory work.

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

Project Output/Research Findings

Antinutritional effects of high tannin sorghums: Lilian Jimenez-Ramsey, a Brazilian Ph.D. student under Dr. John Rogler, poultry nutritionist in Animal Sciences, has in our laboratory shown that low MW polyphenols from high tannin sorghum grain metabolically labelled with $^{14}CO_2$ are absorbed from the chick digestive tract, but condensed tannins are not absorbed. Thus the systemic effects (in bodily tissue, not just in the intestinal tract) of consuming high tannin sorghum cannot be due to tannin. Lilian prepared large amounts of these various polyphenol fractions, including tannin, in nonradioactive form and fed them individually to both rats and chicks to determine which fraction is responsible for the major antinutritional effects, especially inhibition of growth. In contrast to our earlier results which suggested systemic effects (presumably due to low MW absorbable phenolics) are primarily responsible for the antinutritional properties of high tannin sorghums, Lillian found that the tannin fraction was far more effective as an inhibitor of rat and chick growth than are the low MW absorbable polyphenols. The basis for this apparent anomaly may be clarified by a detailed analysis of the experimental data now underway. It seems possible that polyphenols, as they occur naturally in the seed, produce effects quite different from those caused by polyphenols purified from the grain and then added back to polyphenol-free diets.

Identification of the tannin-associated component responsible for the antinutritional effects of high tannin sorghum will allow us to develop a specific assay for it, screen for it, and eventually develop sorghums which have little of it and are nutritionally superior. We expect that these sorghums will maintain the pest resistant characteristics of high tannin sorghums.

Tannin-free bird resistant sorghums: We previously obtained two sorghum genotypes which have excellent bird resistance yet have no tannin, one from Brazil, Dr. Robert Schaffert, and one from Arkansas, Dr. John York. We have shown that these have good bird resistance in our trials, and that the Arkansas line has excellent nutritional quality as determined in rat feeding trials. The Brazilian sorghum is a hybrid, and we only recently obtained seed of its parents and found that they both have significant bird resistance. From progeny of this hybrid we have three selections with useful resistance. With a PSTC/USAID grant we are characterizing the bird resistance of these sorghums with Kenyan and Brazilian collaborators. Thadeo Tarimo, a SADCC supported Ph.D. student from Tanzania is working on this project, although he is formally in the Forestry Department's Wildlife Management program, with Dr. Harmon Weeks as his major professor. Tarimo has shown with trapped wild sparrows that a repellant component can be extracted with nonaqueous solvents from the mature grain of the tannin-free bird-resistant sorghum, Ark 3048, and that the repellant component is rapidly deactivated by contact with moisture. Tarimo is currently at the SADCC/ICRISAT Center in Bulawayo, Zimbabwe conducting repellancy trials on caged Queleas. Comparison of his results with results already obtained here with caged sparrows should determine whether bird repellancy tests conveniently conducted here with sparrows will yield results applicable to Queleas in Africa. The repellant characteristic of these unique tannin-free sorghums will be useful in developing improved bird resistant sorghums with good nutritional quality. If the gene controlling synthesis of the active compound(s) can be isolated, perhaps other crops can eventually be transformed with it.

Mold resistance in sorghum: Dr. Admasu Melaky Berhan, postdoc from Ethiopia currently supported by McKnight funding, continues his studies on this problem, currently looking at proteins which may play a role in resistance. Richard Johnson, graduate student (under Dr. Ejeta) , supported by a grant from Pioneer Seed Co., has compared several tan/red pairs of isogenic sorghum lines and shown that tan plants accumulate apigenin (yellow) and red plants instead accumulate apigeninidin (orange-red). Although the latter has been shown by R. Nicholson's group to be fungitoxic in sorghum seedlings under laboratory conditions, we observed no difference in leaf disease resistance (anthracnose and rust) of the tan/red isogenic lines in field conditions. Our original observation was that mold resistance is more highly correlated with seed content of flavan-4-ols than with tannins or with 3-deoxyanthocyanidins such as apigeninidin.

Striga: Role of ethylene in germination: Dr. Abdel Gebbar Babiker, Weed Scientist from ARC/Wad Medani and our major Sudanese collaborator, has been on sabbatical leave from ARC and working in our laboratory since January 1992. Using gas chromatography in the laboratory of Dr. Randy Woodson, Horticulture Department, Dr. Babiker has shown that the ultimate signal for *Striga* seed germination is ethylene. Dr. Babiker has characterized a wide variety of plant hormones and growth regulators, as well as specific herbicides and inhibitors of protein synthesis, with respect to their effect on ethylene formation and *Striga* seed germination. He has not only demonstrated the crucial role of ethylene but also has provided insight into the early stages of the germination process and has illuminated metabolic steps in ethylene biosynthesis possibly vulnerable to attack (for controlling *Striga*) by manipulation of hormones and herbicides in combination.

Striga: Tissue culture: Tishu Cai, visiting scientist from the Peoples Republic of China, now has established *Striga* in tissue culture, both callus and suspension culture. Cai has been able to demonstrate the role of host-produced differentiation factors in *Striga* development. On a particular growth medium, *Striga* differentiates mainly into roots characteristic of a nonparasitic mode of growth, If sorghum roots have previously been grown in the same medium, *Striga* cultures rapidly differentiate into shoots and intact plantlets characteristic of the parasitic growth mode. Manipulation of cytokinins and other plant growth factors can mimic the effects of natural differentiation signals provided by host roots. It seems clear that the host-derived signals which control *Striga* are not limited to germination stimulant and haustorial initiation factor, but include factors which control differentiation subsequent to haustoria formation and attachment to the host root. This finding may lead to *Striga* control measures based on mechanisms of resistance not previously considered.

Our suspension cultures of *Striga* will be utilized to test host crop genotypes for incompatibility with *Striga*. With our restrictions, which prevent us from growing *Striga* plants, tissue culture offers an attractive approach to this speculative effort to identify host genotypes which are incompatible/toxic to *Striga*. If we can find (or produce via somaclonal variation or mutagenesis) such genotypes, they should exhibit true resistance, rather than tolerance, to *Striga*.

We continue to develop high quality suspension cultures of sorghum suitable for transformation with exogenous DNA using a particle gun (supported by Pioneer). We also continue to select for resistance to *Striga* toxin in what we call liquid cultures of sorghum. Cai now has a large number of sorghum plants regenerated from clones of cells which survived exposure to *Striga* toxin. Their progeny will be evaluated for tolerance to the *Striga* toxin. In this way we hope to develop new sources of resistance/tolerance to *Striga*.

Striga: "Toxin": Dolly Bell-Lelong, Ph.D. student supported by McKnight funds, has found that sorghum seedlings are vulnerable to *Striga* toxin only after they have exhausted the nutrients stored in the seed and are dependent upon photosynthesis for growth. This is consistent with previous reports that *Striga* decreases the efficiency of host photosynthesis. Sorghum genotypes differ in their susceptibility to the toxin. The *Striga*-resistant sorghum SRN 39 is relatively little affected by the toxin, in addition to its low production of germination stimulant. Dolly has preliminary results showing that *Striga* toxin may not be unique to *Striga*, but may be produced by many plants. Thus, the unique aspect of *Striga* toxin may not be its chemical nature but its access to host metabolism.

Striga: Screening for germination stimulants and haustoria initiation factor: The rapid agar gel assay originally developed for screening sorghums for low stimulant production has now been adapted by Mark Alkire, *Striga* technician, to screen for production of the second host-derived *Striga* developmental signal, haustoria initiation factor. Fasil Reda, visiting scientist from the Ethiopian national program, adapted the agar gel assay to screen maize as well as sorghum, and Cisse' Ndiaga, graduate student from Senegal (under Dr. G. Ejeta) is adapting it to screen cowpeas. Dr. D. Hess is adapting the assay to pearl millet at the ICRISAT Sahelian Centre. Large numbers of samples are being screened in our laboratory, particularly of sorghum in various studies directed by Dr. G. Ejeta. In addition to low stimulant producing sorghums, we have identified two maize genotypes which produce significantly low levels of both germination stimulant and haustoria initiation factor. So far, all the sorghums screened produce equivalent amounts of haustoria initiation factor.

Yohan Weerasuriya (Sri Lankan Ph.D. student with Dr. G. Ejeta) has developed an alternative assay for *Striga* germination stimulant that is much more quantitative than the agar gel assay and more adaptable to all crops including those which are difficult to screen in the agar gel assay. The procedure uses glass wool as the substrate for growing crop seedlings. Using this assay, Yohan has shown that pearl millet does not produce significant levels of stimulant to which our *Striga asiatica* seeds respond. Rice and barley are likewise low producers of stimulant for our *Striga* seeds, which appear to be a strain with specificity for sorghum and maize. Interestingly, Yohan finds that cowpeas produce a stimulant to which our *Striga* seeds respond, although it is a different *Striga* species (gesneroides) which parasitizes cowpeas. Cowpea genotypes differ by at least 100 fold in the amount of stimulant they produce. The single soybean cultivar tested produced active stimulant at relatively low levels.

Striga: Identification of germination stimulants: Bupe' Siame, Ph.D. student from Zambia, developed methods for concentrating and purifying water-soluble *Striga* germination stimulant a thousand-fold from root exudate produced in glass wool as described above. Chromatographic fraction of the purified material indicates that root exudates of sorghum (several cultivars), maize (one cultivar tested), and Proso millet (one cultivar) contain the same three compounds with germination stimulant activity. Chemical derivatization and mass spectral analysis resulted in the recent identification of the major component from maize and Proso millet as strigol, the water soluble *Striga* germination stimulant previously identified from the root exudate of cotton, a non-host. Strigol is also produced by sorghum, but it is not the major component. The major germination stimulant produced by sorghum was recently reported by German scientists to be a strigol analog they called sorgolactone. Our findings are consistent with this report. The third active component from these root exudates and a fourth found only in sorghum exudate were not identified, but almost certainly are analogs of strigol.

Networking Activities

Workshops

Fourth Chemical Congress of North America, Symposium on Phenolic Compounds in Foods and Health III Natural Phenolic Antioxidants, New York, NY, August 25-30, 1991.

NC-189 (Forage Protein) Annual Meeting, St. Louis, Sept. 24, 1991 (invited speaker).

16th International Conference of the Groupe Polyphenols, 12-16 July, 1992, Lisbon, Portugal (invited speaker)

Other Collaborating Scientists

Dr. Sam Mukuru, SAFGRAD/ICRISAT, Nairobi, Kenya
Drs. L. Rooney, R. Waniska, D. Rosenow, and R. Frederiksen, Texas A&M University
Dr. R. Duncan, University of Georgia
Dr. A. Hagerman, Miami University, Oxford, Ohio
Dr. J. Riopel, University of Virginia

Research Investigator Exchange

Dr. A. G. T. Babiker, Weed Scientist on sabbatical leave from ARC, Sudan, Jan. 1992 through Jan. 1993, supported by INTSORMIL.

Tishu Cai, Visiting Scientist, People's Republic of China

Fasil Reda, Research Officer in Weed Science, IAR, Ethiopia, supported by CIMMYT/Nairobi, Jan.-April, 1992.

Dr. Paulo Magalhaes, EMBRAPA/Brazil, October-Dec. 1991.

Begona Bartolome, Instituto de Fermontaciones Industriales, C.S.I.C., Spain, Oct.-Dec. 1991.

Research Information and Material Exchange

Polyphenol and *Striga* germination analyses and samples of sorghum, tannin, sorgoleone and other materials were provided for several of the collaborators listed above and for many others not listed.

Laboratory supplies were provided for Dr. A. G. Babiker, ARC, Sudan; Fasil Reda, IAR, Ethiopia; and Dr. Dale Hess, ICRISAT Sahelian Center, Niger.

Publications and Presentations

Publications

"Traditional Processing of High-Tannin Sorghum Grain in Uganda and Its Effect on Tannin, Protein Digestibility and Rat Growth", (with S. Mukuru, J.C. Rogler, A. Kirleis, G. Ejeta, J. Axtell, and E. Mertz) J. Agric. Food Chem. 40:1172-1175 (1992).

"Sorghum Suspension Cultures" (with T. Cai), Sorghum Newsletter, in press.

"Effect of Genotype, Explant Age and Medium Composition on Callus Production and Plant Regeneration from Immature Embryos of Sorghum" (with H. Elhag), Arab Gulf J. Scient. Res. 10: 109-119 (1992).

"Structure and Evolution of the Genomes of Sorghum bicolor and Zea mays" (with A. Melake Berhan, S. H. Hulbert, and J. L. Bennetzen), Theoretical and Applied Genetics, in press.

"Biochemical Mechanisms of the Antinutritional Effects of Tannins" (with J.C. Rogler) in Phenolic Compounds in Food and Their Effects on Health, C.T. Ho, C.Y. Lee and M.T. Huang, eds., ACS Books, Washington, DC., pp. 298-304 (1992).

"Host Plant Resistance to *Striga*" (with G. Ejeta) in International Crop Science I, D.R. Buxton et al. eds. Crop Science Society of America, in press.

"Polyphenols and Herbivore Diet Selection and Nutrition", Polyphenols Actualities (Commemorating the 20th Anniversary of Groupe Polyphenols), in press.

Abstracts

"Biochemical Mechanisms of the Antinutritional Effects of Tannins" (with J.C. Rogler), Symposium on Phenolic Compounds in Food and Health, Fourth Chemical Congress of North America, New York, August 1991, abstract #149.

"Inheritance of Low Stimulation of *Striga* Seed Germination in Sorghum Cultivar SRN-39" (with R. Vogler and G. Ejeta), Am. Soc. Agronomy Annual Meeting Abstracts, Oct. 1991, Denver, p. 120.

"Phenolic Profiles and Leaf Disease Reaction of Tan and Red Isogenic Lines" (with R. Johnson, B. Siame, and G. Ejeta), Am. Soc. Agronomy Annual Meeting Abstracts, Nov. 1992, Minneapolis.

"Production of Host-Derived Developmental Signals for Witchweed" (with Y. Weerasuriya and G. Ejeta) Am. Soc. Agronomy Annual Meeting Abstracts, Nov. 1992, Minneapolis.

Presentations

Presentations relating to INTSORMIL: with Dr. Ejeta, presentations of our *Striga* work at USAID/Washington and at the World Bank/Washington, Feb. 13, 1992.

Disease Control Strategies for Sustainable Agricultural Systems

Project TAM-124

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Summary

Additional cooperation with ICRISAT was initiated through the development of a joint International Anthracnose Virulence Nursery. The enhanced collaboration stems from the recognition of the importance of this disease in the more humid sorghum growing regions of the developing world. Anthracnose collaboration will permit a better evaluation of the durability of host resistance and a better estimate of the variation in pathogenicity among isolates of the pathogen worldwide. Participating regions include West Africa, Mali and Niger; East Africa, Sudan; Southern Africa, Zambia and Zimbabwe; and Brazil. Our work has demonstrated that there is tremendous variation among isolates from locations and between locations. Evaluation of resistance to long smut in Niger became a routine procedure with the development of a reliable inoculation technique for the evaluation of resistance under conditions in West Africa. Sorghum downy mildew has become less and less of a problem because of global cooperation in the development of host resistance, characterization of isolates and through the use of highly effective fungicide seed dressings. In 1991, a new product with a mixture of pesticides was developed that has the potential of inexpensively controlling downy mildew of pearl millet. Preliminary data are remarkably impressive. Work on the product Apron® Plus will be conducted in Niger and Sudan.

The International Sorghum Antiserum Bank supplied antiserum on request to three LDC's, Australia and four U.S. locations. From over 500 sorghum accessions tested, 378 were resistant to sorghum yellow banding. Sorghum yellow banding virus is synergistic with maize dwarf mosaic virus strains A and O. Mechanical inoculation of sorghum with maize dwarf mosaic strain A affects both the virus titer in inoculated plants, as well as, symptom development and reaction type.

Research Objectives

Sudan

Long Smut

- Identify sources of resistance in Sudan collection.
- Identify plant traits leading to disease escape.
- Collaborate with all African Long Smut Nursery.

Anthracnose

- Identify sources of resistance from the Sudan collection

Covered Kernel Smut

- Evaluate fungicides for control of covered kernel smut

Striga

- Begin studies on histopathology of resistant sorghum.

Honduras

- Evaluate sources of resistance to *Peronosclerospora sorghi* in Honduras.

Brazil

- In 1991/1992, we will continue our collaborative work on anthracnose, particularly in the area of dilatory resistance and pathogen variability.

India

- A proposal, the "Cytogenetic and molecular mapping of pearl millet chromosomes with particular reference to resistance to downy mildew and smut" was prepared by G. K. Gupta and R. K. Chatwal, Puntjab Agricultural University, Ludhiana. R. A. Frederiksen will serve as the project advisor for USDA.

Mali

- Study the epidemiology of long smut.
- Develop an inoculation procedure for the sooty stripe and anthracnose pathogens.
- Evaluate the Texas A&M/INTSORMIL nurseries for reaction to the prevalent pathogens in Mali.
- Study the interaction of mold and insects on grain deterioration.

Niger

Long Smut

- Evaluate reaction of high and low smut selections made in 1989.
- Continue monitoring survival of long smut inoculum.
- Inoculation and evaluation of long smut nurseries at Kollo and Tilabery.

Sooty Stripe/Kollo Spot

- Evaluate yield effects caused by sooty stripe.
- Determine effect of "Kollo spot" on production at various stages of plant growth.

Striga

- Evaluate reaction of 25 cultivars of pearl millet to *Striga* at Bengou.
- Repeat 1989 study on effect of soil amendments (organic matter).
- Study effect of organic matter on *Striga* infection in sorghum (in cooperation with Agronomists).
- Begin study on *Striga* - sorghum host - parasite - interactions.

Macrophomina

- Cross inoculate sorghum/millet/cowpea with isolates of *Macrophomina phaseolina* using both natural hot spots and laboratory approaches.

Venezuela

- Evaluation of sorghum virus strains using both the ISVN and the Antisera Bank.
- Determine the incidence of SYBV.

Zambia

- Evaluate sorghum virus and strains using both the ISVN and the Antisera Bank.

Tanzania

- To characterize the diseases caused by *Fusarium* spp. on sorghum in Tanzania.
- To identify various mechanisms of genetic resistance in sorghum to the various diseases caused by different *Fusarium* species.

Domestic

- Identify sources of resistance to disease.
- Assist in the incorporation of multiple sources of resistance to disease.
- Determine inheritance of resistance.
- Improve disease screening methods.
- Complete biology of disease where needed.
- Evaluate epidemiology of anthracnose and leaf blight.
- Organize, maintain, and distribute in collaboration with ICRISAT, and with TAM-121 and 122 the international sorghum disease and pathogen identification nurseries.
- Identify sources of resistance to viruses and strains.
- Incorporate multiple virus resistance to type viruses and strains into new sorghum genotypes.
- Determine inheritance of virus resistance in sorghum.
- Produce, distribute and evaluate the International Sorghum Virus Nursery both domestically and worldwide.
- Maintain and strengthen the Sorghum Virus Antiserum Bank and provide antisera internationally. Pro-

duce monoclonal antibodies to sorghum yellow banding virus.
- Detect, identify and catalogue sorghum viruses and strains worldwide.
- Study the effects of sorghum viruses on the host plant including yield.
- Collect and evaluate populations of plant viruses for range or changes in virulence and develop disease diagnostic systems including immunoblot assay for strain comparisons.
- Employ the new serology technique ELISA to determine virus concentration in sorghum. Virus concentration is being used as a new tool to breed for MDMV resistance in sorghum.

Research Approach and Project Output

Several approaches continue to be used to control sorghum and millet diseases. Our system of networking includes the growing of several uniform nurseries in locations where certain diseases are important, such as the joint ICRISAT/INTSORMIL International Sorghum Anthracnose Virulence Nursery (ISAVN) which is grown in areas where anthracnose is endemic. Other nurseries include the Uniform Head Smut Nursery, the Sorghum Downy Mildew Virulence Nursery and the International Sorghum Virus Nursery. These nurseries are distributed on request to interested parties worldwide and provide information on sources of disease resistance and pathogen variability. In 1991, for example, Mr. Diourte in Mali found isolates of *Colletotrichum graminicola* which he believed to be different from those present in the U.S. based on the ISAVN. This would be an expected observation and has been confirmed in field trials. Dr. R. W. Toler and colleagues supplied antiserum from the International Sorghum Antiserum Bank upon request to three LDC's, Australia and four U.S. locations and distributed the International Sorghum Virus Nursery to two countries in 1991. Work continues on *Colletotrichum graminicola* utilizing RFLP and PCR/RAPD technologies to characterize variability among the pathotypes. Advances have been made in the characterization of differences between the varieties of *Sporisorium reilianum*, the causal organism of head smut, that attack sorghum and corn using various electrophoretic techniques to separate chromosomes. Work continues to identify the sorghum genes responsible for resistance to head smut. Progress has been slowed by the unique biotropic relations between the host and pathogen and by difficulties in isolating DNA. We have also screened and evaluated thousands of sorghum entries for resistance to the major diseases of sorghum. This work is done annually and continues as long as sorghum will need to be improved genetically. Another approach asks the question about durability of the disease resistance. In this approach we seek to characterize resistance that may prove to be more durable by augmenting the resistance in a variety of ways to increase its durability. This is important because the effort and time spent in developing superior sources of resistance need not be lost because of failure, on the part of someone on the team, to anticipate a change in the pathogen population or to deploy a cultivar susceptible to a damaging disease. Most of the work is interdisciplinary and involves specialists from many areas. The wide acceptance of germplasm developed from INTSORMIL institutions and the use of this germplasm in national programs demonstrates the importance of this approach.

Finally, we work to augment host resistance by integrated procedures. Seed treatments of pearl millet with Apron® plus represents a major advance in controlling disease and improving stand establishment.

Sorghum Smuts

Long Smut

Isolation and culturing of *Tolyposporium ehrenbergii*, the causal agent of long smut, along with careful inoculation of sorghum at the boot stage resulted in excellent infection of the pathogen with sporidia (Note Tables 1 and 2). The teliospore inoculation procedure was not effective in Niger, while it worked to some extent in Sudan. Dr. El Hilu and I do not find these differences to be alarming but recognize that in a controlled test, sporidia will cause the highest amount of infection. Issoufou Kollo noted that he must avoid plant injury in order to obtain high levels of infection. Based on inoculation during the off-season, Mr. Kollo classified MR732, MR803, MR864 and MR926 as resistant to long smut. Survival of teliospores (spore balls) was evaluated over a period of two years at three month intervals (trimesters). Desiccated spores remained viable at a higher rate over a longer period of time than those not desiccated. Very few spores survived over one year unless they were desiccated.

Head Smut

Present techniques for evaluating resistance of sorghum to infection by *Sporisorium reilianum*, the causal organism of head smut, involve trials in field nurseries using natural or artificial inoculation. These trials can be expensive in terms of time and money and are restricted to the growing season. Natural infection requires repeated trials for reliable results due to environmental effects, whereas, artificial inoculation of sporidia is labor intensive and can bypass resistance factors that provide satisfactory levels of natural resistance in the field. A technique has been developed by Dr. J. Craig (Craig and Frederiksen, 1992) to evaluate head smut resistance at the seedling stage. Seedlings of sorghum genotypes resistant and susceptible to *S. reilianum* were grown in peat pellets and inoculated by infesting vermiculite surrounding seedling epicotyls with 7- to 10-day-old teliospore cultures. Four days after inoculation, the seedlings are removed from the pellets, placed in test tubes containing water deep enough to completely submerge the first leaf, and incubated in darkness at 24 C for five days. After incubation, symptoms on the first leaf blade differentiated susceptible and resistant genotypes. Symptoms on the

Table 1. Number of sori per panicle after inoculation with sporidia and teliospores of Tolyposporium ehrenbergii (1991).

Inoculum	Number of sori/panicle*			
	REP 1	REP 2	REP 3	REP4
Sporidia	45	52	39	43
Teliospores	7	1	3	1
Water (Control)	0	0	0	0

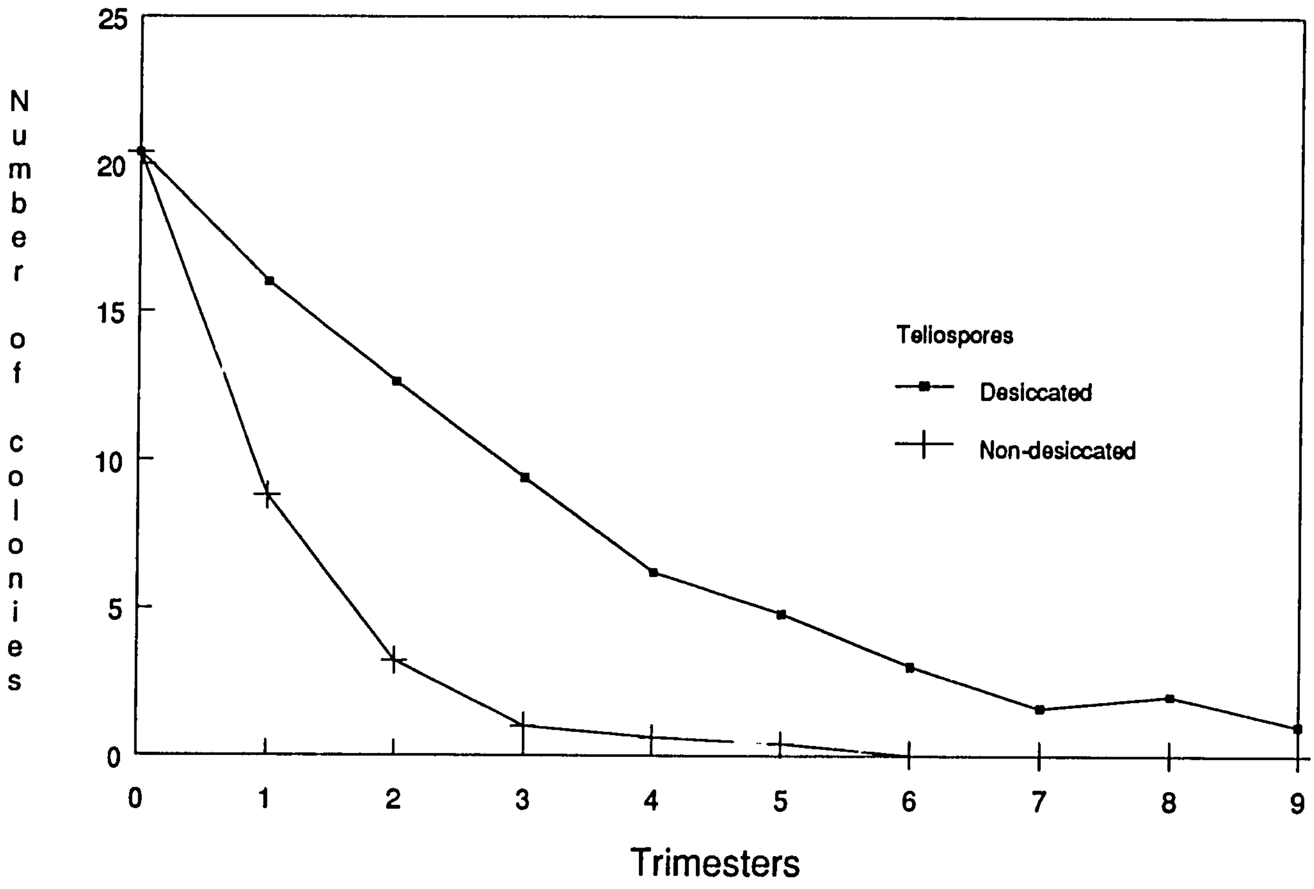
*Each number is the average of 8-10 heads.

Table 2. Number of sori per panicle after inoculation with sporidia and teliospores of Tolyposporium ehrenbergii (1992).

Inoculum	Number of sori/panicle*			
	REP 1	REP 2	REP 3	REP4
Sporidia	41	38	47	44
Teliospores	0	0	0	0
Water (Control)	0	0	0	0

*Each number is the average of 8-10 heads.

Figure 1. Effect of desiccation on the survival of germinating teliospores of Tolyposporium ehrenbergii



first leaf blades of susceptible genotypes were general chlorosis and brown spots. Leaf symptoms of resistant genotypes consisted of interveinal chlorosis and an absence of brown spots on the leaf blade. The inoculation and incubation procedures used in this study identified types of head smut resistance that prevent the pathogen from reaching the apical meristem of the sorghum plant. This type of resistance appears to be effective against the variability in virulent biotypes of *S. reilianum* that have overcome the race-specific head smut resistance factors deployed in the past.

Dr. Gnanambal Naidoo completed her work on the differentiation of host specialized isolates of *S. reilianum*. Texas populations of *S. reilianum*, the causal agent of head smut in maize and sorghum, exhibit two levels of host specificity. Certain isolates are restricted to the maize host, while other isolates infect sorghum predominantly. The latter type can be further divided into four races based on its reactions on a series of sorghum differentials. Head smut of both maize and sorghum is a disease of worldwide importance and is controlled by host resistance. Markers associated with pathogen variability will be extremely valuable in the disease management program. An examination of morphological and physiological traits, including a previous study employing isozymes failed to provide markers to distinguish the host specialized isolates. The objective of Dr. Naidoo's study was to find unique molecular markers which would clearly differentiate between the host specialized isolates of *S. reilianum*. Polymorphisms were sought by using an arbitrary primer-PCR based assay and pulse field gel electrophoresis. Karyotype analysis of the haploid sporidia revealed a polymorphism that seems to be associated with the host specificity. The maize pathotype of *S. reilianum* possesses 15 chromosomes, while only 13/14 bands were separated from the sorghum pathotype. This difference of 750 kb in the sorghum pathotype was common in all 15 isolates examined. The additional chromosome was unique to all maize pathotypes examined. No other size or length polymorphism was observed among the samples examined. The genome size was estimated to be 11 Mb using *Saccharomyces cerevisiae* as a standard size marker. No length heterogeneity was observed in the ITS region of the rDNA of the different pathotypes when the genes were amplified by PCR. PCR with single ten nucleotide long arbitrary primers resulted in DNA polymorphisms between the isolates of a pathotype and among the pathotypes. Amplifications at lower annealing temperatures were more successful and reproducible. Almost all of the 40 primers assayed resulted in polymorphisms. DNA fragments that were polymorphic between the pathotypes should be useful in pathotype differentiation and need to be tested on a larger number of isolates. This assay has provided markers which can be used in future genetic and population studies of the head smut organism.

Downy Mildew

Dr. Chenglin Yao completed his work on *Peronosclerospora* spp. Length heterogeneity in the internal transcribed spacer 2 (ITS 2) of the rDNA repeat units of four species of *Peronosclerospora* was revealed by PCR amplification and Southern hybridizations. In addition to one dominant fragment for each species, there are several less frequent fragments of different sizes, and each species has a unique banding pattern for ITS 2. The absence of 5-methylcytosine residues in CCGG and GCGC sequences, in the ribosomal genes of four *Peronosclerospora* species, was demonstrated by the production of identical banding patterns with ribosomal DNA probes following digestion of genomic DNA with *Msp*I and *Hpa*II, and by complete digestion with *Cfo*I. The application of these findings has permitted the naming of a species of downy mildew *Peronosclerospora zea*, formerly *P. sorghi* Thailand, and the lumping of *P. philippinensis* with *P. sacchari*.

Anthracnose

Two projects studying variability in anthracnose have been completed and one continues. Dr. Carlos Casela demonstrated evidence of dilatory resistance to *Colletotrichum graminicola* under field conditions which was closely correlated to latent period. The role of sclerotia of *C. graminicola* was also evaluated. Plants in plots with these sclerotia had disease earlier and at a greater intensity than control plots. The significance of this work demonstrates that the sclerotia are important in the disease cycle of this pathogen and probably account for much of the inoculum survival in fields with short term rotations or no rotation.

Mr. Phil Guthrie obtained 119 isolates of *C. graminicola* from around the world (104 from sorghum, 10 from maize, and 5 from johnsongrass). Their DNA was compared using RAPD markers. The level of genetic diversity was found to be high: approximately 85% of isolates could be uniquely identified. Geographical origin of the isolates was found to be more significant than the cultivar from which they were obtained, as far as genetic relatedness was concerned; sorghum isolates from Puerto Rico, for example, formed a genetically distinct group. Six differential cultivars were used to group a representative subset of sorghum isolates (72) into 12 pathotypes, but no pathotype-specific RAPD banding patterns could be found. By choosing an isolate with a sufficiently unique RAPD signature, we have shown that it should now be possible to monitor the fate of that isolate over the course of a season, and thus determine the effect of different cultivars on components of the pathogen population. RAPDs have been shown to have great potential for certain applications where molecular markers are needed, especially when speed and cost of processing are important factors. However, occasional lack of consistency remains a problem, and the researcher needs to be aware of this and to ensure that suitable controls are included in the DNA amplification process.

Ms. Ute Rosewich is following up the work from Dr. Casela and Mr. Guthrie. Whereas they were both working with populations from large areas (Brazilian and mainly African isolates, respectively) and often only considering a few single-spored isolates from any one region, she is taking the next logical step with a close-up look at a population from a small, confined area. The sorghum disease nursery in Athens, Georgia (University of Georgia) conducted by Dr. R. R. Duncan was chosen for study based on the well documented history of: (a) a high amount of variability observed for isolates from this location based on host differentials, (b) the frequently reported breakdown of resistance in various sorghum genotypes in this nursery, (c) conducive environmental conditions that produce yearly epidemics of this fungus, and (d) isolation from other commercial sorghum fields so that presumably asexually reproducing, splash-dispersed organisms can develop with a minimum amount of outside influence (closed system). About 100 single spored isolates have been established from the 1991 leaf samples and about 100 should be established from 1992 samples and from 1993 samples. These isolates will be characterized by RFLP signatures. The project will also include population studies on johnsongrass isolates. *C. graminicola* is also able to infect johnsongrass (*Sorghum halepense*), a very common perennial weed. There have been speculations that johnsongrass might serve as a reservoir for *C. graminicola* and as an overwintering host. Currently, Ms. Rosewich has about 100 single-spored johnsongrass isolates collected from various places in Texas and she is evaluating the variability among johnsongrass isolates. She will test the hypothesis that johnsongrass isolates comprise a single, homogeneous group which can be separated from the sorghum isolates based on RFLPs and virulence.

Anthracnose has become a major concern in Mali and the level of disease remains high. Susceptible cultivars in 1991 were IS2057 and Tx434. Both of these differentials are resistant at other locations, adding to the speculation that the isolates of *C. graminicola* in Mali are different from those in other regions of Africa and the Americas.

Grain Mold

Mr. A. Mansuetus traveled to Tanzania in June, 1991 and surveyed the diseases of sorghum caused by *Fusarium* spp. Cultures of *Fusarium* spp. collected by Mr. Mansuetus are being evaluated as a part of his dissertation research. He will compare the population structures using mating types and vegetative compatibility markers. During June 1992, he traveled to Kansas State University under the guidance of Dr. John Leslie. While there he studied the techniques for vegetative compatibility testing of *Fusarium* spp. section *Liseola*.

A major aspect of the collaborative research in Mali has been to examine the relation between head bug damage and grain mold on seed deterioration. It was observed that known mold resistant sorghums, such as SC748 and Sureño, develop extensive mold damage if the sorghum heads are not protected from head bugs. Protection from head bugs will be a requirement for evaluation of grain mold resistance. This is important because grain mold resistance, as well as resistance to head bugs, will be required in an improved sorghum cultivar for Mali. Fungi isolated from damaged sorghum seed in 1991 were predominantly *Colletotrichum graminicola*, *Phoma* spp. and *Curvularia* spp. The infrequent isolation of *Fusarium* spp. may reflect the method used or unique environmental conditions.

Chemical control of grain mold using benomyl was ineffective in Mali.

Sorghum Virus

The number of sorghum cultivars tested for susceptibility to SYBV has increased to 516 since 1988. One hundred thirty-eight cultivars were susceptible to the virus and 378 were resistant. In total, more that 516 sorghum cultivars have been tested for host range to SYBV including those tested by Giorda and Toler. St. Augustine grass was determined not to be a host to SYBV.

A pathogenic interaction between SYBV and maize dwarf mosaic (MDMV-A) virus was proved. Inoculation of MDMV-A 3 days before inoculation with SYBV resulted in a more severe disease and the resultant disease symptoms were different from those caused by either virus alone. Both viruses were serologically detected in a treatment in which MDMV-A preceded SYBV. Inoculation with SYBV 3 days before inoculation with MDMV resulted in the multiplication of SYBV only. When SYBV was mixed in equal proportion to MDMV-A and then inoculated onto healthy sorghum plants, which are susceptible to SYBV, MDMV-A was the only virus that was serologically detected. SYBV infected root tissue revealed the presence of SYBV particles in the mitochondria and not in the nucleus. Maize dwarf mosaic strain O also produces a pathogenic synergistic interaction similar to that produced by MDMV-A and SYBV.

Use of a spray gun for mechanical inoculation of viruses could result in different pressures during inoculation, affecting disease ratings of two sorghum cultivars. This experiment evaluated the effect of mechanical inoculation pressure on virus titer as measured by double antibody sandwich method of enzyme-linked immunosorbent assay (DAS-ELISA), disease incidence and severity in sorghum cultivars differing in reaction to MDMV-A. Positive correlations ($r=0.58$ and $r=0.53$ for RTx420 and BTx378, respectively), were obtained between disease incidence (percentage infection) when inoculation pressure was in the range of 5.28 to 7.06 kg/cm^2. Neither disease severity nor titer was correlated to inoculation pressure. However, inoculations resulted in higher virus titer compared to non-inoculated plants.

Twenty accessions of the 1991 International Sorghum Virus Nursery were mechanically inoculated with MDMV-A. Infection levels and disease symptoms in the inoculated and control plots were recorded five weeks after inoculation and the grain was collected at maturity. The weights and volumes of five 100-kernel lots from each treatment of each accession were measured and kernel densities were calculated. Comparisons of kernel weights, volumes and densities between treatments were made within each accession and standardized. These results were correlated with symptoms expressed by the accessions when infected with MDMV-A. In accessions with mild to moderate mosaic symptoms, kernel volumes were less and kernel densities were greater relative to controls. Kernel volumes were slightly greater and kernel weights were slightly reduced, resulting in reduced densities in the accessions which displayed strong mosaic symptoms and general chlorosis. Kernel densities, volumes and especially weights were reduced in the accessions which had severe chlorotic and necrotic symptoms.

Other virus related research included distribution of the International Sorghum Virus Nursery, supplying of antiserum upon request from the International Sorghum Virus Antiserum Bank. Antiserum to sugarcane mosaic virus strain H was produced for the antiserum bank. The host range of Sorghum Yellow Banding Virus (SYBV) was studied.

MDMV-B plants with necrotic reactions were reduced in height, panicle length, and stem diameter by 40%, 40% and 25%, respectively. Yield was reduced an average of 70% in plants with necrosis.

Networking Activities

John Leslie and R. A. Frederiksen submitted a proposal to the Rockefeller Foundation for support of a conference on the application of genetics and biotechnology to the characterization of fungal pathogens of sorghum and millet. This program, would include participants from scientists in the newly developing countries, those from genetics and microbiology laboratories along with participants from INTSORMIL laboratories. R. Frederiksen also reviewed collaborative research in Mali and in Niger as well as took part in a training session on quarantine of sorghum and maize at Puerto Rico. Dr. Frederiksen also participated in the Conference on Durable Resistance to Disease held at Wageningen in the Netherlands. Visitors to the program included Drs. Ram Thakur and Lewis Mughogho, ICRISAT; Dr. Joseph Mukiibi, Director of Agricultural Research in Uganda and IER Director Mamadou Goita from Mali. Dr. B. L. Renfro worked in Frederiksen's laboratory as a Visiting Professor during 1991-1992.

We introduced 198 sorghum lines, mostly from India and China with others from Mali through our quarantine greenhouse. Seed of these lines were released to the scientists requesting the accessions.

Sorghum virus antiserum was supplied to Australia, Colombia, Ethiopia, Iran and 4 U.S. locations.

During the visit by Dr. Thakur from ICRISAT, we established a new International Anthracnose Virulence Nursery with ICRISAT as the coordinator. We will continue as a cooperator and principal repository of isolates of *Colletotrichum graminicola* attacking sorghum, johnsongrass and related *Sorghum* spp.

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Laboratory supplies were provided to M. Diourte, IER, Mali and I. Kollo, INRAN, Niger.

Publications and Presentations

Publications

Bhaskaran, S., R.A. Smith and R.A. Frederiksen. 1991. A factor that promotes mycelial development in *Sporisorium reilianum in vitro*. Botanical Gazette 152:4.

Casela, C.R. 1992. Investigations on the variability of the sorghum anthracnose fungus *Colletotrichum graminicola*. PhD Dissertation. Texas A&M University, College Station, Texas. 166 pp.

Casela, C.R., P. Guthrie, R.A. Frederiksen and U. Rosewich. 1992. Anthracnose in the 90's. Sorghum Newsletter (In Press).

Craig, J., and R.A.Frederiksen. 1992. Comparison of sorghum seedling reactions to *Sporisorium reilianum* in relation to sorghum head smut resistant classes. Plant Dis. 76:314-318.

Esele, J. P. 1991. The genetics of grain mold resistance in sorghum (*Sorghum bicolor* (L.) Moench). PhD Dissertation Texas A&M University, College Station, Texas. 139 pp.

Guthrie, P.A.I., C.W. Magill, R.A. Frederiksen and G.N. Odvody. 1992. Random Amplified Polymorphic DNA markers: A system for identifying and differentiating isolates of *Colletotrichum graminicola*. Phytopathology 82:832-835.

Kunene, I.S. 1991. *Gaertneriomyces* species as a potential biological control agent of sorghum downy mildew. PhD Dissertation. Texas A&M University, College Station, Texas. 100 pp.

Mahuku, G.S., and R.W. Toler. 1992. Effect of inoculation pressure on maize dwarf mosaic virus strain-A disease incidence, severity and titer in sorghum. Tex. Agri. Exp. Sta. Bul. B-1706. 6pp.

Naidoo, G. 1992. Identification and differentiation of host-specialized isolates of *Sporisorium reilianum* using molecular markers. PhD Dissertation. Texas A&M University, College Station, Texas. 100 pp.

Theu, M.P.K.J., and R.W. Toler. 1992. Pathogenic interactions between sorghum yellow banding virus and other viruses infecting sorghum. Tex. Agri. Exp. Sta. Bul. B-1708. 3pp.

Theu, M.P.K.J., R.W. Toler and F.R. Miller. 1992. Increased host range of sorghum yellow banding virus in sorghum cultivars. Tex. Agri. Exp. Sta. MP-1739. 8pp.

Yao, Chenglin. 1991. Classification and detection of *Peronosclerospora* species on the basis of DNA southern hybridization and the polymerase chain reaction. PhD Dissertation. Texas A&M University, College Station, Texas. 74 pp.

Yao, C., R.A. Frederiksen and C.W. Magill. 1992. Length heterogeneity in ITS 2 and the methylation status of CCGG and GCGC sites in the rDNA genes of the genus *Peronosclerospora*. Current Genetics (In Press).

Presentations

Casela, C. R., and R. A. Frederiksen. 1992. Variability in the sorghum anthracnose fungus *Colletotrichum graminicola* in Brazil and USA. Abstr. D-6. *In* Proceedings of Durable Resistance, A Symposium on Durability of Disease Resistance. IAC. Wageningen, The Netherlands. February 24 - 28.

Guthrie, P.A.I. 1992. The potential of PCR/RAPD markers to determine differences in variability of *Colletotrichum graminicola* isolates. *Presented at*: Genetics of Host-Parasite Interactions Between Plants and Fungal Pathogens in the Genus *Colletotrichum*. Whitney Marine Lab, University of Florida, Marineland, FL. January 23-26.

Frederiksen, R.A., D.T. Rosenow, F.R. Miller and G.N. Odvody. 1992. Disease resistance in sorghum. Abstr. D-9. *In* Proceedings of Durable Resistance, A Symposium on Durability of Disease Resistance. IAC, Wageningen, The Netherlands. February 24-28.

Plant Pathogen RFLP Mapping

Project TAM-124A
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Summary

There are two sorghum genome mapping projects at TAMU. We are cooperating with both in attempting to find RFLP or RAPD markers associated with traits conditioning disease resistance in sorghum. Most of our work to date has been on diseases caused by the highly variable pathogens *Peronosclerospora sorghi, Sporisorium reilianum* and *Colletotrichum graminicola* that cause downy mildew, head smut and anthracnose, respectively. At least one gene has been mapped for sorghum downy mildew, but is some distance away from genomic markers. Crosses between susceptible and resistant parents and their respective progeny have been made and are ready for use in screening by potential probes. Work on the variability in the pathogens (See TAM-124) is closely monitored as a strategy for selecting pathogen isolates to be used in evaluation of host reaction to disease. Even though some pathogen isolates can overcome some host resistance genes, these genes can still be located by using less virulent isolates .

Research Objectives

To map the relative location of each resistance-gene-linked-RAPD marker by using it as a restriction fragment length polymorphism (RFLP) probe on an F_2 mapping population that is already available.

To identify different genes that confer resistance for each disease and genes that potentially provide resistance to more than one disease.

Research Methods and Project Output

Downy mildew

Dr. P.S.B. Gowda is attempting to tag downy mildew resistant genes in sorghum with RFLPs and PCR/RAPD markers. Five sorghum lines (IS22227, IS22230, SC155, SC414, and QL3) resistant and two lines (RTx7078 and SC326-6) susceptible to all pathotypes of *Peronosclerospora sorghi* and one line (RTx430) susceptible to pathotype 3 were selected for this study. F_2 progenies obtained from the crosses of RTx7078 X SC414 and RTx7078 X QL3 have been grown in the greenhouse. These plants were tested for SDM reaction at the seedling stage. The healthy susceptible plants were recovered by spraying the infected plants with the systemic fungicide metalaxyl. One hundred-thirty RAPD primers have been screened with DNA extracted from the parental lines. Some of the primers amplified unique bands in susceptible or resistant lines. Seventy-four polymorphic RAPD loci have already been analyzed for cosegregation with the resistance genes. One of them was found to be linked to the resistance gene in SC414, at 14.9 cM. Genomic DNA (from all the sorghum lines) was digested with five restriction enzymes (*Bam*H I, *Eco*R V, *Hind* III and *Xba* I). A total of 72 probes (16 maize, 29 sorghum and 27 RAPD fragments) have been screened so far. Sixty RFLP loci have been identified between susceptible and resistant parents. F_2 segregation analysis of 30 polymorphic loci revealed that they were not linked to any of the resistance genes. Eighty polymorphic loci have been noted between susceptible and resistant parents using a new set of 100 RAPD primers. The screening of these loci for linkage with resistance genes is in progress. Further, segregation analysis of remaining RFLP loci is also in progress. Additional resistant varieties will be analyzed with the linked markers to understand the nature of resistance genes in other cultivars and in cultivars resistant to pathotype 1. Linked markers will be placed on a sorghum map being developed in the Sorghum RFLP program at Texas A&M University. The linked markers will be helpful in locating the resistance genes on the map, eventually leading to map based cloning of these genes.

Head Smut

Sporisorium reilianum, the causal organism of head smut in sorghum, is generally found wherever sorghum is grown. Chemical controls and agronomic practices have not been effective in efficiently reducing disease incidence. Resistant cultivars have been used to control this disease, but head smut remains as a potentially important disease because of the pathogen's variability.

The construction of a genetic map for the sorghum genome would provide plant breeders and geneticists with a more direct method for selecting desirable genes via their linkage with easily detectable molecular markers.

RFLP analysis has recently offered a more rapid approach to generate genetic maps. Construction of an RFLP map for sorghum is being undertaken to assist breeding efforts for head smut resistance and other important characters. If a resistance gene could be tightly linked to an RFLP marker, it would be possible to efficiently identify those plants carrying that gene. In order to select parental material for a mapping population, RFLPs were identified in four resistant lines (White Kafir or PI48770, Lahoma Sudan, SC325 or IS2463der., CS3541 or IS3541der.) and four susceptible lines (RTx7078 or IS415, SC170-6-17 or IS12661der., BTx399 or IS169, BTx623) by using three enzymes (*Eco*RI, *Eco*RV, *Hin*dIII) and 43 maize genomic clones. Of 16 potential crosses using these lines as parents in crosses, the maximum polymorphism detected, 41.9% (18/43), was between SC325 (R) and RTx7078 (S). As a consequence of these results, the F_2 population derived from the cross of SC325 and RTx7078 was selected as a mapping population. Resistant and susceptible genotypes of F_2 mapping population were identified by F_2 and F_3 inoculation tests. Inoculation of seedlings with teliospores of *S. reilianum* resulted in brown spots and general chlorosis on the first leaf blade of susceptible genotypes. Hypodermic inoculation of sorghum plants (about three weeks old) with sporidia of *S. reilianum* caused smutted and sterile panicles in susceptible genotypes. By a screening of parental lines (SC325 and RTx7078) with 10 maize genomic clones and 122 sorghum genomic clones, an F_2 mapping population could be compared with the RFLP linkage map of sorghum. No polymorphisms were detected in 2 of the 10 maize genomic clones when screened against the parental lines, while 8 of the 10 segregated in the F_2 mapping population. No polymorphisms were detected in 22 of 122 sorghum genomic clones, while 61 of 122 segregated. Seven big and seven small linkage groups were constructed by F_2 segregation analysis. Unfortunately, none of these linkage groups have been linked to sorghum head smut resistance genes; therefore, it will be necessary to screen more RFLP markers.

Recently, a method that employs random primers in a PCR to rapidly generate polymorphic markers has been developed and should be useful to create a genetic linkage map. These polymorphic markers appear as DNA segments that are amplified from one parent but not the other and are inherited in a Mendelian fashion. This technique is used as an alternative way for detecting markers that are linked to resistance genes. A total of 100 random primers, ten nucleotides long, was surveyed between SC325 (R) and RTx7078 (S). Amplifications were performed in a Perkin-Elmer/Cetus DNA thermal cycler programmed for 45 cycles of 1 min at 94 C, 1 min at 36 C, 2 min at 72 C, and 15 min at 72 C. Approximately 500 discrete products were amplified by the 100 primers tested. The majority of the products were identical from both SC325 and RTx7078. However, some primers produced fragments that appeared in one but not the other. The polymorphic product was used as a probe for RFLP analysis. When radiolabeled and hybridized to blots containing parental line DNA restricted with five enzymes (*Bam*HI, *Eco*RI, *Eco*RV, *Hin*dIII and *Xba*I). This probe (OPA13) showed polymorphisms between the parentals in all restriction digests. In further experiments, OPA13 polymorphic product segregated in the F_2 mapping population and was linked with another RFLP marker. Therefore, we are surveying more polymorphic products that have a possibility of linking to disease resistance genes by random primer and bulked segregant analysis.

Publications and Presentations

Oh, B.-J., G.-W. Xu, R.A. Frederiksen and C.W. Magill. 1991 Developing RFLP markers for sorghum head smut resistance genes: A progress report. A poster presented at: Third Annual Texas Plant Protection Conference, College Station, Texas December 2-4, 1991.

Oh, B.-J., G.-W. Xu, R.A. Frederiksen and C.W. Magill. 1992. Developing RFLP markers linked to head smut resistance genes in sorghum. Sorghum Newsletter. (In press).

Xu, G.-W., K.F. Schertz, C.W. Magill, R.A. Frederiksen, J.E. Mullet and G.E. Hart. 1991. Construction of an RFLP linkage Map of *Sorghum bicolor*. Agronomy Abstracts. p. 202. American Society of Agronomy, Madison, Wisconsin.Plant Pathogen RFLP Mapping - TAM-124A

Integrated Insect Pest Management Strategies for Sustainable Agricultural Systems

Project TAM-125

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Part I

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Summary

Project TAM-125 is developing integrated pest management strategies for sustainable sorghum production with concentration on plant resistance. On-site collaborative research activities take place in Mali. Research in Texas contributes to technology development, graduate student training, and short-term training. A major effort is made for development of insect resistant cultivars to sorghum midge, yellow sugarcane aphid, greenbug, and panicle feeding bugs. In Mali, a third year of research on panicle-feeding bugs of sorghum was completed. Methodology for screening sorghums for panicle-feeding bug resistance has been tested. A damage rating scale is being evaluated, and special plastic bags to protect panicles from bugs for comparison to naturally bug infested panicles have been shown to be effective in determining degree of bug susceptibility. These subjective ratings, in conjunction with germination trials, will allow plant breeders to make better selection decisions during progeny selection and line evaluation. This multidisciplinary program has been extremely successful. The principle collaborator, Dr. Y. Doumbia, was recognized by SAFGARD for outstanding research contributions.

Graduate students from Colombia, Mexico, Malawi, and the United States are being trained in entomology. Technology transfer has occurred through publications and exchange visitation. Collaboration with ICRISAT scientists has continued to be very strong.

Objectives, Production and Utilization Constraints

Objectives

Mali sorghum panicle-feeding bug research: In collaboration, with Dr. Y. O. Doumbia, researchers are working to develop practical techniques for screening sorghums for resistance to panicle-feeding bugs; relate resistance to glume, kernel, and grain-texture characteristics; and relate panicle-feeding bug abundance and kernel damage to pathogen infection, grain deterioration and food quality.

Technology development and student training research: The objectives of research conducted in Texas are to provide a mechanism for graduate student training programs, identify and evaluate sorghums resistant to insect pests, determine resistance mechanisms, investigate plant-pest ecological responses and determine economic injury levels. Individual student research program results are reported under the Student Training section of this report.

Constraints

The role that insect pests play as a deterrent to sustainable agriculture is a constraint that must be dealt with in a biologically/ecologically sound manner. The negative impact of aphids, panicle-feeding bugs, sorghum midge, and panicle-infesting caterpillars in traditional farming systems is dramatically increased when improvements in agricultural production are attempted through breeding and changing cultural practices. Also, the public mandate in the U.S.

for safe food, clean water, and wildlife conservation requires insect pest control strategies that are less dependent on insecticides. The species of insect pests that infest sorghum vary geographically in intensity and persistence. Sorghum in different production areas encounter at least one key insect pest species, and several occasional insect pest species. Reducing the severity of these insects requires an integrated approach using several control tactics. The Texas A&M University Sorghum Entomology project focuses on developing insect control technologies applicable to sustainable agriculture systems. The tactics developed and evaluated include plant resistance to insects and manipulation of cultural practices. Each tactic is supported with ancillary insect pest biological and ecological research to ensure their proper use and impact in insect pest management strategies. The project's approach involves on-site collaborative research, complementary U.S. technology development activities, and graduate student training. The collaborative research in Mali focuses on damage assessment and plant resistance to the sorghum panicle-feeding bug complex. Research in the U.S. supports graduate training programs and involves a holistic approach to identifying, evaluating, and deploying sorghum midge resistant sorghums as a component of integrated pest management, and developing and validating sorghum plant and sorghum midge dynamics computer models; and developing and evaluating greenbug and yellow sugarcane aphid resistant sorghums.

Research Approach and Project Output

Mali sorghum panicle-feeding bug (Eurystylus marginatus) research: The following report of research relative to the collaborative sorghum panicle-feeding bug project is from Dr. Y. Doumbia's report to the Regional Technical Committee from Sotuba. The results of four trials are summarized here.

In a preliminary evaluation trial at Sotuba, 51 sorghum lines were assessed for new sources of resistance to damage by panicle feeding bugs under natural infestation conditions. Of these lines, many were progenies of Malisor 84-7 crosses with other genotypes. A Fisher block experimental design with two replications was used with entries planted in two, five meter long rows. Data collected included, panicle form, length of glumes, and kernel color. Panicle-feeding bug abundance was determined from five panicles per plot at the milk stage of kernel development. Bug damage and level of mold infection were rated. Data also were recorded on vitrosity, 1000 kernel weight, germination, and percentage floating kernels. Comparisons of these parameters were made using kernels from panicles that were unprotected from bugs, and those that were protected from infestation. Differences in the level of bug damage occurred among the entries (Table 1). Bug infestation levels ranged from 25 to 382 bugs per five panicles. Of the 51 genotypes, 21 had bug damage ratings of between 1 and 2 and they were: Tx9, Tx1, 90L 19156-91PR 2560, Malisor 84-7, 90-CZ-CS-TX-11, Tx17, Tx25, Tx15, Tx14, Tx5, Tx6, Tx23, 90L 19254 91PR 2573 (op), 90L 19134-91PR 2557 (op), 90L 2000 (Malisor 7*SRN39) F2, Tx19, Tx21, 90L 19225-91PR 2579 (1-5), 90L 19281-91PR 2575, 90L 19282-91PR 2576 (op), 90L 19037-91PR 2565. Most of these were progenies of crosses between Malisor 84-7 and other sorghum lines. These results indicate that the resistance of Malisor 84-7 is transferable. Of the 51 entries in the trial, 32 had mold damage ratings of between 1 and 2, indicating that over half the lines had some resistance to mold infection. The sorghum lines with lower levels of head bug damage usually had less mold damage and higher 1000 kernel weights.

During the 1989 and 1990 seasons, preliminary screening trials were conducted to evaluate 100 sorghum entries for resistance to panicle feeding bugs at Sotuba. These 100 entries contained sorghum lines from the national program, ICRISAT, and Texas A&M University. From these trials, 8 lines, plus Malisor 84-7 were selected based on their performance and lower levels of bug damage and placed in an advanced screening trial. The trial was conducted in a Fisher block design with four replications and 5 m long, single row plots. Two panicles in each plot were caged at panicle exertion and at the milk stage, 20 adult male and female pairs of head bugs were introduced into the cages. Two panicles were protected from infestation using plastic pollinating bags, and the remaining panicles were allowed to be naturally bug infested. Bug abundance was determined on five panicles, and at grain maturity, bug and mold damage was rated, and bugs in cages counted. Bug abundance, bug and mold damage ratings, and 1000 kernel weight for the nine sorghum lines subjected to natural infestation are shown in Table 2. Malisor 84-7 and IS27477 were affected least by head bugs. Malisor 84-7, 87-SB-F4-54-2, B-VAR, and 82-Select grain dur, were damaged the least by head bugs and usually were less mold infected. The differences in 1000 kernel weight of these sorghum lines when panicles were protected versus no protection was also low, indicating a level of resistance. Malisor 84-7, 87-SB-F4-54-2, IS21525, B-VAR1, and 82-Select grain dur again show good resistance when artificially challenged and support the results obtained from natural bug infestations (Table 2).

A significant issue relative to the panicle-feeding bug problem is the relationship of bug damage and mold infection. To assess the relative amount of damage caused to kernels by bugs and by molds and the amount caused by bug and molds in combination, an experiment was conducted using a susceptible variety ICSV1002. A Fisher block experimental design was used with four replications. The treatments compared were application of the fungicide Benomyl for mold control, protection from bug infestation using plastic pollinating bags, protection from mold and bugs with fungicide and bags, and natural infestation. Bug abundance was determined from five panicles 14 days after anthesis. At grain maturity, bug damage and mold infection was rated for sorghum receiving each treatment. After harvest, 1000 kernel weight, kernel vitrosity, percent floating kernels and germination were compared. This experiment was conducted in both 1990 and 1991. In 1991, bugs were

Table 1. Reaction of different sorghum genotypes to bug and mold damage in 1991 at Sotuba.

Entry	# bugs (5 panicles)	Bug damage rating	Mold damage rating	Damages ratings protected	1000 kernel wt. infested	1000 kernel wt. uninfested
90-CZ-CS-TX-13	24.0	2.50	1.50	2.50	19.35	21.63
90-CZ-CS-TX30 (OH/84-7/26/1)	40.0	4.50	3.50	3.0	36.30	39.98
90-CZ-CS-TX15	171.0	1.75	2.50	2.75	17.50	22.20
90-CZ-CS-TX-9	140.50	1.25	1.50	1.25	18.90	21.50
90-CZ-CS-TX-26 (Koro-Kollo)	106.50	3.75	3.50	2.50	22.60	26.02
90-CZ-CS-TX-37 (86-EN-361)	314.0	2.50	2.0	1.25	15.80	21.65
90-CZ-CS-TX-2	161.0	2.50	1.25	2.0	17.97	22.05
90-CZ-CS-TX-7	55.0	3.25	1.50	3.0	15.57	24 88
90-CZ-CS-TX-14	28.50	1.75	1.50	1.25	16.68	18.45
90-CZ-CS-TX-25	37.50	1.50	2.0	1.25	18.30	17.95
90-CZ-CS-TX-17	96.0	1.50	1.25	1.50	14.55	23.75
90-CZ-CS-TX-22	225.0	2.50	1.75	2.50	16.82	21.52
90-CZ-CS-TX-4	143.50	2.75	1.0	1.25	17.80	22.63
90-CZ-CS-TX-10	106.50	2.50	1.25	1.25	17.70	24.48
90-CZ-CS-TX-38	126.50	3.25	1.50	1.0	17.15	27.20
90-CZ-CS-TX-20	70.50	2.50	1.0	1.50	16.03	21.53
90-CZ-CS-TX-36	120.50	3.0	3.25	3.0	22.65	20.25
90-CZ-CS-TX-19	32.0	2.0	1.68	1.0	14.10	11.68
90-CZ-CS-TX-20	88.0	2.0	1.0	1.25	13.62	20.35
90-CZ-CS-TX-24	163.50	2.50	1.75	1.75	16.32	21.75
90-CZ-CS-TX-12	185.50	2.50	1.25	1.75	17.82	22.48
90-CZ-CS-TX-18	67.0	3.0	1.0	1.0	19.25	21.45
90-CZ-CS-TX-3	85.0	2.50	1.0	2.0	16.82	24.30
90-CZ-CS-TX-5	148.0	1.75	1.25	1.0	19.53	24.38
90-CZ-CS-TX-8	249.50	2.75	1.50	2.50	15.43	20.90
90-CZ-CS-TX-11	124.0	1.50	2.0	1.25	22.63	30.35
90-CZ-CS-TX-16	42.0	2.50	2.25	2.25	16.93.	21.90
90-CZ-CS-TX-27	171.50	4.25	4.0	4.0	18.67	26.05
90-CZ-CS-TX-23	116.50	1.75	1.75	1.75	14.70	18.02
90-CZ-CS-TX-6	177.0	1.75	2.0	2.25	17.75	19.90
90-CZ-CS-TX-1	83.0	1.25	1.75	1.50	20.57	21.70
90L 19090-91 PR 2564 (4-7)	125.50	2.25	1.75	1.50	18.60	25.28
90L 19140-91 PR 2566 (2-5) (7-9)	86.0	2.50	3.25	2.50	17.27	19.27
90L 19156-91 PR 2560	218.50	1.25	2.0	2.75	15.47	19.05
90L 19164-91 PR 2562	71.50	2.25	2.25	2.0	15.95	19.18
90L 19225-91 PR 2579 (1-5)	109.50	2.0	2.75	3.0	15.38	18.05
90L 19239-91 PR 2570 (opq)	116.0	2.50	2.0	1.75	16.60	17.90
90L 19254-91 PR 2573 (op)	285.50	1.75	1.25	1.0	16.13	19.05
90L 19281-91 PR 2575	185.50	2.0	3.0	2.75	16.43	21.22
90L 19282-91 PR 2576 (op)	171.50	2.0	2.0	2.0	16.25	20.88
90L 19134-91 PR 2557 (op)	198.50	1.75	2.0	1.50	14.47	24.63
90L 19154-91 PR 2559	252.0	2.75	1.25	1.50	17.63	21.55
90L 19240-91 PR 2571	263.50	4.0	1.75	1.25	22.28	28.13
90L 19232-91 PR 2580 (op)	128.50	3.0	1.50	1.25	18.80	21.73
90L 19037-91 PR 2565	197.50	2.0	1.50	1.75	17.03	24.20
90L 19023-90 L1 9023 (op)	172.50	2.75	1.0	2.0	16.58	23.35
90L 19178-90 L 19178 (op)	382.0	2.50	1.25	1.50	16.93	25.17
(Malisor 84-7*SRN 39)F_2 - 90L 2000	150.0	1.75	1.50	1.75	21.75	23.65
IPS-001	35.0	3.0	1.0	1.0	21.17	27.95
Malisor 84-7	121.50	1.50	1.0	1.0	18.60	19.22
90-CZ-CS-F_5-20(ICSV1063xMalisor84-5)5-2	154.0	3.75	1.0	1.50	18.20	26.22
$\bar{X}$	139.69	2.40HS	1.78HS	1.83S	18HS	22.53HS
SE	10.16	0.09	0.09	0.09	0.38	0.48
CV	68.08%	25.74%	41.76%	42.81%	13.52%	16.40%

Table 2. Evaluation of selected sorghum lines for resistance to bugs and molds using natural infestation.

Varieties	# of bugs (5 heads)	Bug damage rating	Mold damage rating	1000 kernel weight	1000 kernel wt. (protected)
		Natural Infestation			
Malisor 84-7	21.75A	1.0E	1.88ABCD	3.52BC	4.03DE
87-SB-F4-54-2	87.25B	1.88CDE	2.13ABC	3.25BCD	5.02B
IS-16-357	155.0AB	3.88A	1.25D	3.47BC	4.84BC
IS21468	62.0B	2.75BC	2.63A	3.04CD	3.46E
IS21525	61.25B	2.50BCD	1.50CD	3.16B	4.57BCD
IS27477	28.25A	3.25AB	1.63BCD	4.55A	6.63A
R-6078	77.0B	2.50BCD	2.0ABCD	2.89D	4.25CD
B-Var1	68.0B	1.63DE	2.38AB	2.84D	3.54E
82-Select grain dur	67.50B	1.0E	2.50A	3.13BCD	3.51E
P,0.05	HS	HS	HS	HS	HS
CV	88.64%	25.12%	23.61%	9.63%	9.48%
Mean	97.889	2.264	1.986	3.366	4.486
		Artificial Infestation			
Malisor 84-7	51.25B	1.0D(8)	2.13BC	3.46D	
87-SB-F4-54-2	52.25B	2.63BC(8)	2.50AB	4.10BC	
IS-16-357	237.50A	4.50A(20)	2.63AB	3.67BCD	
IS21468	51.0B	3.13B(17)	1.15C	3.21D	
IS21525	146.25B	2.25C(2)	3.25A	4.17AB	
IS27477	226.50A	4.0A(19)	3.0AB	4.67A	
R-6078	62.25B	4.13A(16)	2.38AB	3.60CD	
B-Var1	51.50	2.0C(17)	2.75AB	3.48D	
82-select grain dur	55.75B	1.25D(6)	3.13AB	3.23D	
P,0.05	HS	HS	HS	HS	
CV	63.84%	17.12%	24.83%	9.4%	
Mean	103.206	2.764	2.556	3.733	

Table 3. Bug abundance and bug and mold damage to sorghum protected or unprotected from bugs and molds.

	# of bug (panicles)		Bug damage rating		Mold damage rating		1000 grain weight		Plot weight	
Treatments	1990	1991	1990	1991	1990	1991	1990	1991	1990	1991
Fungicide protected	21.25B	213.0A	2.45B	3.85B	1.85B	2.04B	21.14A	25.74C	2.12	3.35B
Plastic bag protected	24.75B	126.75B	1.0C	1.0C	1.05C	2.05B	22.34A	33.71B	2.75	3.86A
Fungicide/plastic bag protected	47.75A	129.25B	1.0C	1.0C	1.10C	1.95B	22.0A	36.68A	2.57	3.81A
Natural infestation	37.25AB	129.7B	2.90A	4.60A	2.64A	3.45A	20.65A	25.41C	2.40	2.57C
P = 0.05	S	HS	HS	HS	HS	S	HS	HS	HS	HS
CV	37.10%	17.44%	11.22%	5.74%	19.26%	25.04%	16.51%	4.81%	29.76%	5.92%
Mean	32.750	149.68	1.83	2.613	1.66	2.462	21.53	30.38	2.46	3.39

more abundant than in 1990 (Table 3), with a mean infestation level of 150 and 33 bugs per five panicles, respectively. Bug abundance in the treatment plots was about equal, of course there were no bugs on bagged panicles. Panicles that received no protection from bugs or molds were damaged more severely than panicles that were protected from bugs. The application of a fungicide only slightly lowered the level of damage. These data indicate that based on visual damage ratings, bugs cause more damage than mold. Protecting panicles from bugs resulted in kernels with higher kernel weights than those that were not protected from bugs and those protected from molds but not bugs (Table 3). A similar trend was shown for panicle weights. Also, there was a significant correlation between bug damage and mold, and between bug damage, mold incidence, kernel weight, and panicle weight.

A final experiment was conducted to identify a simple screening technique to evaluate resistance/susceptibility to panicle-feeding bugs. The treatments included protecting a few panicles of a susceptible sorghum variety and comparing damage to panicles that were naturally infested. The ICSV variety was used. Methods used to protect panicles from bugs included the application of the insecticide diazinon and protection from bug infestation using constructed cages or plastic pollinating bags. Protection from bugs provided the opportunity to compare damage to panicles from a natural infestation to panicles that were uninfested and undamaged. Bug abundance was determined from five panicles per plot, 14 days after anthesis. At maturity, bug damage was rated. After harvest, 1000 kernel weight, vitrosity, floatation and germination were determined and compared among treatments. The constructed cages and plastic

Table 4. Comparison of the bug and mold damage to grain protected with insecticide cages or bags and grain subjected to natural infestation, 1991.

Treatments	Bug damage rating	Mold damage rating	Panicle weight	1000 kernel weight
Insecticide protected	1.95B	2.05B	4.69A	31.55A
Cage protected	1.00C	2.17B	3.01C	30.68A
Plastic bag protected	1.00C	2.07B	3.61B	30.71A
Natural infestation	4.05A	3.65A	2.90C	31.07A
P = 0.05	HS	HS	HS	HS
CV	9.43%	17.48%	7.79%	8.29%
Mean	2.00	2.48	3.55	31.00

pollinating bags provided the best protection from bug damage (Table 4). Insecticide application reduced the level of damage compared to no protection from bugs but was less than with cages or bags. Mold incidence was about the same on panicles that were protected from bugs by any of the methods used compared to no bug protection. Panicle weight was greatest for panicles protected using insecticides, indicating some level of control of other insect pests not influenced by cages or bags. Weight of 1000 kernels did not differ among the treatments. From these data, it seems practical to use cages or bags over a few panicles to compare with panicles that are naturally infested. Breeders could easily use this procedure to evaluate breeding material.

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

Technology Development

Confirmation of a new greenbug biotype (biotype I) has resulted in an increased effort to identify resistant germplasm. Twelve exotic sorghum lines, from the Soviet Commonwealth, Syria and China, identified by the Nebraska Sorghum Breeding Program as possible biotype I resistant were screened under controlled greenhouse conditions. The experimental lines along with biotype E greenbug resistant and susceptible check lines were grown together in plastic germination flats. Biotype I greenbugs were obtained and cultured on a commercial sorghum hybrid and then transferred onto the plants in the flats at a rate of 6 to 10 per plant. Plant infestation was initiated two days after plant emergence and visual plant injury ratings were made nine days after infestation when both check lines were either dead or exhibiting severe plant necrosis. Based on plant damage ratings, two lines, PI550610 and PI550607, were found to be highly resistant while four others exhibited moderate levels of resistance (Table 5). Back-crosses to elite biotype E resistant parent lines were made and will be screened.

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

Table 5. Biotype I greenbug resistance in sorghums.

Sorghum PI#	Origin	Damage rating $\bar{x}$
550585	Soviet Commonwealth	7.9a
550607	China	1.5ab
550610	Syria	1.0b
550614	Soviet Commonwealth	5.5ab
550615	Soviet Commonwealth	3.8ab
550629	Soviet Commonwealth	4.5ab
550629	Soviet Commonwealth	5.8ab
550631	Soviet Commonwealth	6.3ab
550636	Soviet Commonwealth	6.0ab
550637	Soviet Commonwealth	5.5ab
550640	Soviet Commonwealth	X
550685	Soviet Commonwealth	6.0ab
TX2783 (Biotype E Resistant Line)		9.0a
RTx430 (Biotype E Susceptible Line)		9.0a

Student Training

Bonnie Pendleton, Ph.D. student from the U.S.: Data on the population dynamics of the sorghum midge in relation to the anthesis of sorghum were used to validate and refine a model to simulate sorghum midge development. Greater understanding of, and ability to predict sorghum midge population dynamics in relation to the development and location of sorghum would improve sorghum midge management capabilities. Sorghum hybrid and length of panicle accounted for 47.8% of the variability in the number of spikelets per panicle. Longer panicles required 8 days to complete anthesis. Most spikelets were susceptible to sorghum midge oviposition on days 3-4 of anthesis. Most spikelets in a field were in anthesis on days 7 and 8. A model to simulate sorghum midge population dynamics was formulated by combining a temperature-dependent poikilotherm development model, a temperature-independent distribution of sorghum midge development times, a distribution of abundance of sorghum spikelets in anthesis in a field, and assessments of daily abundance of ovipositing sorghum midges. The model was used to accurately predict sorghum midge emergence and occurrence of generations. Sorghum midge generation time ranged from 15.8-20.5 days. Abundance increased from no, or few, ovipositing sorghum midges in May to a maximum in mid-July. The static economic threshold density of one ovipositing sorghum midge per panicle in anthesis was estimated to be exceeded on 27 June, during the last days of the season's third generation of sorghum midges. Wind was the primary determinant of the direction and probably distance of dispersal of sorghum midges. The prevailing direction of morning winds in the Brazos River Bottom shifted from south southeast in May to south southwest in August. Most sorghum midges trapped during late July and August dispersed toward the northwest, but some dispersed against the prevailing wind direction and toward nearby sorghum. Sorghum midges were trapped 400 m from where they had emerged. The maximum altitude that sorghum midges traversed in passively dispersing between sorghum fields was not determined.

Doug Jost, M.S. student from the U.S.: In cooperation with Temple TAES scientists, research was conducted to validate a sorghum midge component of the sorghum crop growth model, SORKAM. Validation required sampling sorghum midge abundance and distribution, damage and yield loss. Incorporation of the sorghum midge component into SORKAM will allow prediction of the initial emergence of sorghum midges, abundance increases, and sorghum yield loss. Validation required collecting data for two years in Nueces and Hill counties. Nine sorghum fields in each county with three planted early, normal and late were used for data collection. A CR-21 weather station recorded daily precipitation, minimum and maximum temperatures, and solar radiation. Data on field location, previous crop, sowing date, and variety were obtained from participating farmers. Sorghum midge abundance in 1991 was considerably higher than in the previous year and yields were higher largely due to more annual rainfall. Field parameters required to execute SORKAM were incorporated into the model. The observed data were then compared to SORKAM'S predictions. Initial comparisons indicated that further modifications to the model were needed. Data from nine of the 36 fields were selected to refine the model. Modifications of the model included lowering initial johnsongrass densities. The model was then reevaluated and further modifications of SORKAM were made. Although the model still requires refinement, close approximation between observed and predicted values are being recorded. Statistical analysis remains to be conducted.

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

Nora Jimenez, M.S. student from Colombia: Currently, the resistance level of sorghum midge resistant sorghum hybrids is not high enough to prevent damage when sorghum midge abundance is high. The resistance has been categorized as nonpreference for oviposition. An approach similar to using multilines, where sorghum midge resistant and susceptible hybrids were planted in mixture, was used to enhance the nonpreference resistance by providing the insect a choice of a susceptible host. Mixed plantings in different proportions of resistant and susceptible plants of 100% resistant to 100% susceptible in 10% increments were made at College Station and Corpus Christi. Based on mean number of sorghum midges per panicle, kernel damage ratings, and per panicle and combined plot yields, the mixed plantings did not consistently enhance the nonpreference resistance. Per panicle yield of the resistant hybrid in one experiment tended to increase as the composition of susceptible plants in the mixture increased. However, per panicle yield increases of the resistant hybrid were not significantly elevated when grown in mixture with a susceptible hybrid over when it was grown alone. Combined yields of the resistant and susceptible hybrids when grown in mixture were not significantly greater than when the hybrids were grown alone. The results suggested that the resistance was not due to nonpreference. The nature of the resistance to sorghum midge was assessed in field and laboratory experiments at College Station by comparing the time of flowering during the day of the resistant and susceptible hybrids with the abundance of sorghum midges. The date revealed an asynchrony between when the resistant hybrid flowered (2400 to 0600 h) and when sorghum midges were present and ovipositing (0820 to 1400 h). Flowering of the susceptible hybrid coincided with the presence of female sorghum midges. Tracking 103 females on spikelets of the resistant and susceptible hybrids from 0930 to 1500 h in the field showed that ovipositional success was significantly affected by genotype, part of day (morning or early afternoon), and time periods (0930 to 1000 h, 1000 to 1200 h, 1200 to 1400 h, 1400 to 1500 h). There was also a genotype by part of day interaction. Probabilities of ovipositional success due to genotype were 0.35 and 0.55 for the resistant and susceptible hybrid, respectively. Ovipositional success of sorghum midges on the resistant and susceptible hybrids decreased through time (0.39, 0.26, 0.55, and 0.56 during the morning and early afternoon for the resistant and susceptible hybrids, respectively). The frequency of oviposition for sorghum midges on the resistant hybrid declined from 0.50 between 0930 and 1000 h to 0.0 between 1400 and 1500 h, compared to that of sorghum midges on the susceptible hybrid that was 0.57 from 0930 and 1000 h, and 0.41 between 1400 and 1500 h. The resistance appeared to be host evasion (asynchrony of flowering and presence of sorghum midges), and age resistance (ovipositional success declined in time after spikelet flowering).

Anderson Paliani, M.S. student from Malawi: Greenhouse screening trials using visual damage rating of seedling sorghum plants confirmed that PI457709 and PI453951 are moderately resistant to yellow sugarcane aphid when compared to a susceptible standard check, Tx430. These sorghum lines were more resistant to yellow sugarcane aphid in the very early seedling stage (4-10 cm) than at later seedling stage (18-35 cm) when plants were infested with 5 or 10 aphids per plant (Table 6). When early-stage seedling plants were infested with 20 aphids per plant, all plants of the resistant lines were killed within two weeks. Nonpreference was shown not to be a major resistance mechanism of the resistant lines. Based on plant growth, the two resistant lines showed a greater level of tolerance to yellow sugarcane infestation than susceptible standard check sorghum lines and uninfested plants. Antibiosis was shown to exist and is a component of resistance and affects survival and progeny production.

Roger Anderson, Research Associate: An ongoing experiment to determine optimal frequency, interval and times of day for insecticidal applications for remedial integrated pest management of sorghum midge on sorghum was conducted. Insecticide applications begun during the mid (50%) to latter (75%) stages of panicle anthesis resulted in less damage and higher grain yields than when applications were made prior to these anthesis levels. Optimal hourly insecticidal treatments for control of sorghum midge resulted from treatments applied during the early to mid-morning hours (0600-1000). Another experiment was conducted to evaluate the effectiveness of applications of various "oil-only" treatments for control of sorghum midge. Grain yields and kernel damage data indicated that treatments of cottonseed, corn, soybean, peanut, and canola oils resulted in significant increases in yield and reductions in damage when compared to untreated sorghum.

Networking Activities

Research Investigator Exchanges

Ten LDC scientists visited the sorghum entomology program at Texas A&M University. Mrs. Niamoye Diarisso Yaro completed a written report based on the three months during the summer spent at Texas A&M University for short-term training. Her research project was to characterize flowering and grain filling properties of a set of diverse sorghum lines. Mrs. Yaro will return to Texas A&M University for a Ph.D. degree in entomology. George L. Teetes traveled to Mali to review research progress on panicle-feeding bugs. The collaborative research conducted in Mali is reported in a earlier section in this report, and is further described in the Mali Country report. A major effort is needed to publish the Mali panicle-feeding bug research results in a refereed journal.

Germplasm and Research Information Exchange

Seed requests were received from ten LDC scientists, and these were forwarded to Dr. Gary C. Peterson. Publication reprints or copies related to sorghum entomology were sent to 19 LDC scientists. Research supplies and equipment were sent to Mali to support on-site research activities. Material for cages, bags to cover panicles, insect collecting supplies, insect preservation supplies, computer software, and other research related supplies were provided.

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

Publications and Presentations

Publications

Teetes, G. L., M. J. Scully, and G. C. Peterson. 1992. Partial Life tables for corn earworm (Lepidoptera: Noctuidae) on compact- and loose-panicle sorghum hybrids. J. Econ. Entomol. 85: 1393-1401.

Merchant, M. E. & G. L. Teetes. 1992. Evaluation of selected sampling methods for panicle-infesting insect pests of sorghum. J. Econ. Entomol. (In press).

Merchant, M. E. & G. L. Teetes. 1992. Attitudes and perceptions of Texas sorghum producers and pest control advisors concerning IPM and insect sampling. J. Econ. Entomol. (Submitted)

Anderson, R. M. & G. L. Teetes. 1992. Evaluation of insecticide application timing, intervals and frequency for control of sorghum midge in sorghum. Tex. Agric. Exp. Stn. PR-0000. 6pp. (Approved for publication)

Presentations

Teetes, G. L. 1991. Insect Resistance in Sorghums: Successes and Needs for Improved Communication for Development and Deployment. Entomological Society of America Section F Symposium, Interdisciplinary Communication and Cooperation in Plant Resistance to Insects. December 8-12, Reno, NV.

Teetes, G. L. 1992. Insect Resistant Sorghums in IPM. Southwestern Branch of the Entomological Society of America. February 10-12. Tulsa, OK.

Teetes, G. L. 1992. The Role of Plant Resistance in Providing Safe Food/Fiber and a Safer Environment. Plant Resistance to Insects Workshop Symposium. February 23-27, Indianapolis, IN.

Teetes, G. L. 1992. Integrated Pest Management: What is the Next Step? Mississippi State University, Entomology Department Seminar. March 27, Mississippi State, MS.

Table 6. Yellow sugarcane aphid plant resistance evaluation.

Screening Experiment

Sorghum line	$\bar{x}$ damage ratings ± sd
Tx430	7.5 ± 0.99a
PI453951	6.3 ± 1.06b
PI457709	6.5 ± 1.19b
# Aphids	
15	7.1 ± 0.99a
10	6.9 ± 1.11a
5	6.3 ± 1.36b
Plant Height (cm)	
18-35	7.1 ± 1.12a
6-12	6.8 ± 1.30a
2-8	6.3 ± 1.05b

Tolerance

Sorghum line	$\bar{x}$ Plant height (cm)
PI457709	33.8 ± 6.12a
Control	35.9 ± 4.84a
PI453951	29.3 ± 9.26ab
Control	30.4 ± 10.26ab
Tx430	24.3 ± 6.60b
Control	27.4 ± 4.08ab

Preference

	Number of Aphids		
Sorghum line	24h	48h	72h
Tx430	6.9 ± 2.79a	7.4 ± 3.29a	7.9 ± 3.36a
PI457709	5.4 ± 3.16a	5.4 ± 3.07a	6.3 ± 3.11a
PI453951	5.9 ± 2.42a	6.0 ± 2.56a	7.5 ± 2.33a

Antibiosis

Sorghum line	Adult longevity	Nymphipositional period	Fecundity	Mean progeny/day
TX430	33.1 ± 4.23a	20.8 ± 5.25a	15.3 ± 5.23a	0.8 ± 0.37a
PI453951	31.6 ± 5.02a	20.2 ± 4.39a	13.8 ± 4.69a	0.7 ± 0.43a
PI457709	31.3 ± 2.75a	19.9 ± 3.12a	12.6 ± 6.46a	0.6 ± 0.25a

Biological Control Tactics for Sustainable Production of Sorghum

Project TAM-125

Frank E. Gilstrap
Texas A&M University

Part II - A

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Dr. J. Bentley, Anthropologist, Escuela Agricola Panamericana, El Zamorano, Honduras.

Summary

In Honduras, the project identified Mr. Jose Monroy as a prospective graduate student for entomology biological control at Texas A&M University, and conducted a short term training program for Mr. Monroy at Texas A&M University. We also completed program planning for Mr. Monroy's thesis research that will be conducted in Honduras, and will manipulate *Solenopsis* ants and a *Doru* earwig for biological control of fall armyworm. Research on greenbug induced alterations in nonstructural carbohydrates in grain sorghum was an adjunct to biological control research on greenbugs, and focused on greenbug effects at the seedling, vegetative and reproductive growth stages grown in the laboratory, greenhouse and field. These experiments demonstrated that greenbug feeding initially increases the concentration of non structural carbohydrates (NSC) in selected parts of sorghum plants, then creates a nutrient sink near the feeding site that draws NSC from other plant parts.

Research characterized imported and naturally occurring strains of *Aphelinus varipes* and *Diaeretiella rapae*, and dealt with local and exotic strains of each parasite. Within species, these strains are morphologically inseparable but have subtle differences in biology. The work is characterizing nonmorphological traits to separate exotic and indigenous strains. For *A. varipes*, results indicated that host preference alone cannot separate strains. The mating behavior of *A. varipes* strains was identical in all seven *A. varipes* strains, and that pre-zygotic reproductive isolation has not occurred between strains. Examination of reproductive isolation began during the summer of 1992, and should be completed by the end of fall 1992. Mummified host remains of all seven strains were similar. Results of standard, horizontal starch gel electrophoretic techniques suggest that the allele for PGI in the Texas strain of *A. varipes* is fixed, possibly due to an initial geographic isolation. For *D. rapae*, pre- emergence mortality occurred in all parasite strains tested on black-margined pecan aphid, and none of the strains successfully parasitized yellow sugarcane aphid. Only the Syrian strain parasitized the cotton aphid, and only the Jordan and Spain strains parasitized yellow pecan aphid and crepe myrtle aphid, respectively. In isozyme starch gel electrophoresis, four of six gels showed clear dark bands and adequate mobility to effect band separation for the Russian and Washington strains. Dissections of aphid mummies were performed for the seven strains of *D. rapae*. Though significant differences were found in mean numbers of meconial pellets recovered from the Russia and Syria strains, mummy coloration, exit hole shape and location, shape of meconia and location of clusters of meconial pellets showed little value as singular diagnostic characters.

Objectives, Production & Utilization Constraints

Objectives

Honduras fall armyworm research: Objectives of this collaborative work are to assess the efficacy of natural enemies that may be useful for biological control of stem borers, fall armyworms and other pests of sorghum in Central America; and to optimize implementation of effective biological control for pests of sorghum crops.

Technology development and student training research: The objectives of research in Texas are to provide graduate level training programs, develop strategies for implementing biological controls in sorghum and millet, test strategies for implementing biological control in annual crop ecosystems, investigate plant-pest-natural enemy ecology and assess potential of natural enemies as biological control agents for sorghum and millet pests, and optimize integration of effective biological controls with local crop protection and production needs.

Constraints

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

Research Approach and Project Output

Honduras fall armyworm research. My travel in fall 1991 to Honduras identified Mr. Jose Monroy as a prospective graduate student of entomology and biological control at Texas A&M University. During early 1992, we developed a short term training program for Mr. Monroy at Texas A&M University. Mr. Monroy arrived in February 1992, and remained until June 1992. During his stay, Monroy was paid a stipend from TAM-125, received special training in culturing and conducting research on natural enemies, and audited several graduate level courses. Mr. Monroy perfected his fluency in English by working in the project laboratory, and he took the TOEFL before returning to Honduras. Monroy contemplates beginning a Master of Science degree at Texas A&M University in the fall of 1993. In August 1992, I went to Honduras and worked with Mr. Monroy, and Drs. Cave, Andrews and Bentley to complete program planning for Monroy's thesis research. Monroy's research will be conducted in Honduras, and will examine the practical manipulation of *Solenopsis* ants and a *Doru* earwig for biological control of fall armyworm. TAM-125 will pay a graduate research assistantship to Mr. Monroy, and will pay for associated research expenses.

Technology development and student training research. *(a) Greenbug Induced Alterations in Nonstructural Carbohydrates in Grain Sorghum.* The goal of this research was to determine if greenbugs create a nutrient sink at the feeding site that competes with other plant nutrient sinks. This work was an adjunct to biological control research on greenbugs, and focused on greenbug effects at three plant growth stages. Experiments were conducted on plants in the seedling, vegetative and reproductive growth stages grown in the laboratory, greenhouse and field. High performance liquid chromatography was used to measure concentrations of fructose, glucose, sucrose, fructan, and starch in greenbug-infested and uninfested sorghum plant samples. For laboratory grown seedlings, greenbug feeding increased glucose and starch concentrations in the shoots. Also, greenbug infestations reduced shoot length, shoot fresh weight, shoot dry weight, root fresh weight, and root dry weight (df=3, $P \leq 0.05$). Greenbug honeydew consisted of 58% polysaccharides (DP3), 18% fructose, 12% sucrose and 12% glucose; accounted for an 18% reduction in shoot dry weight and represented 78% of the difference in total (NSC) in greenbug-infested versus uninfested plants. Greenbug infested seedlings grown in the field and greenhouse had greater concentrations of NSC in shoots and reduced concentrations in roots. A regression analysis of seedling plants from field studies showed that increasing greenbug density caused sucrose to increase in shoots (slope=5.78 *ug* per greenbug, $P=0.012$, $R^2=0.98$), and starch to decrease in the roots (slope=-7.15 *ug* per greenbug, $P=0.013$, $R^2=0.98$). In vegetative stage plants, greenbugs caused an increase in total concentrations of NSC in roots. Increasing greenbug densities on vegetative stage plants caused deficiencies in the shoots before deficiencies occurred in roots. Vegetative plants responded to greenbug feeding differently than seedling and reproductive plants in that low greenbug feeding pressure caused an increase of NSC concentrations in the roots, away from the feeding sites on the shoots. On reproductive plants, greenbugs were confined to the third leaf below the panicle. Greenbug-infested plants had greater concentrations of total NSC in the infested leaf; whereas, samples of uninfested leaves above and below the infested leaf, peduncles and roots showed reduced concentrations of NSC. Generally, these experiments demonstrated that greenbug feeding initially increases the concentration of NSC in sorghum plants, then creates a nutrient sink near the feeding site that draws NSC from roots of seedling plants and other leaves of reproductive plants. Greenbug feeding depleted NSC in all three growth stages, and may help to explain why greenbug damaged plants often exhibit a delayed recovery after aphids are removed.

(b) Characterizing Imported and Naturally Occurring Strains of Aphelinus varipes and Diaeretiella rapae, Important Parasites of Aphids on Small Grains. The parasites, *Aphelinus varipes* (Hym.: Aphelinidae) and *Diaeretiella rapae* (Hym.: Aphidiidae), have recently been imported for biological control of aphids on small grains. Both species are nearly cosmopolitan in distribution. Exotic strains of *A. varipes* were imported and cultured from Greece, Iraq, Germany, Turkey, and the former U.S.S.R.; and indigenous strains were cultured from Texas and Idaho. Exotic strains of *D. rapae* were imported and cultured from Greece, Jordan, Pakistan, Russia, Spain, and Syria; and an indigenous strain was cultured from Washington. Within a species, these strains are morphologically inseparable. However,

differences in one or more biological traits could support their separation into biotypes or sibling species. This work seeks to find nonmorphological characters that will permit separating exotic and indigenous strains of each species from field samples. Separations are needed to clarify which strain is responsible for biological control of the target aphids. Within species, experiments on the *A. varipes* and *D. rapae* strains are assessing 1) host aphid acceptability and suitability, 2) mating behavior, 3) reproductive isolation using reciprocal crosses between strains within a species, 4) characteristics of host aphid mummified remains after parasite adults exit, and 5) starch gel electrophoresis to identify unique enzyme loci. Reciprocal crossing studies for each are in progress, enzyme electrophoresis studies for each are near completion, and other objectives are complete and analysis is in progress.

Results for *Aphelinus varipes*. Each *A. varipes* strain was exposed to different host aphids including greenbug, corn leaf aphid, bird cherry-oat aphid, English grain aphid, cotton aphid, Russian wheat aphid, yellow sugar cane aphid, green peach aphid, and black-margined pecan aphid. All strains parasitized greenbug, corn leaf aphid, and English grain aphid. The strains from Greece, Texas and Idaho each parasitized only about 10% of available Russian wheat aphids, and strains from U.S.S.R. and Turkey parasitized less than 30% of the bird cherry-oat aphids. All strains parasitized about 10% of the yellow sugarcane aphids, green peach aphids, and cotton aphids. None of the strains parasitized the pecan aphid. Yellow sugarcane aphid and green peach aphid are not previously reported as natural hosts for *A. varipes*. Results (Table 1) indicate that some strains seem better adapted to some host aphids than others, but this preference alone will not correctly separate strains.

Mating behavior of *A. varipes* was characterized and compared between strains. The behavior in all strains consisted of three phases of courtship including precoital, coitus, and postcoital. The mating behavior was identical in all seven *A. varipes* strains, and was typical of Aphelinidae. Results indicate that pre-zygotic reproductive isolation has not occurred between strains (Table 1). Examination of reproductive isolation will begin during the summer of 1992, and should be complete by the end of fall 1992.

Assessments of mummified host aphid remains after adult emergence included characterizing mummy color, exit hole location, form and shape of meconia, and location of meconia. The exit hole for *A. varipes* was typically located on the dorsum of the host remains, and anterior to the host cornicles. Numbers of meconial pellets ranged between three to eight, with a mean of five pellets per cluster. The mummified host remains of all seven strains were similar. Results (Table 1) indicated that differences in host remains are rare among strains of *A. varipes*.

Standard, horizontal starch gel electrophoretic techniques were used to detect isozymic differences among *A. varipes* strains. Different staining techniques were used, but phosphoglucose isomerase (PGI) distinguished only the Texas strain from other strains. The Texas strain showed a faster migrating allele for PGI when compared with the other strains. Results (Table 1) suggest that the allele for PGI in the Texas strain is fixed in this population, possibly due to the beginnings of geographic isolation.

Results for *Diaeretiella rapae*. Host aphid acceptability and suitability tests were performed using isolated mated female parasites of each strain. Parasites were provided access to eleven different aphid species including bird

Table 1. Summary of experiments to separate populations of A. varipes from different geographical sources.

	A. varipes geographical source						
	Texas	Idaho	USSR	Turkey	Iraq	Greece	Germany
Aphid hosts							
D. noxia	a	b	b	b	b	a	a[1]
R. padi	a	b	b	b	b	a	a
S. graminum	a	a	a	a	a	a	a
M. avenae	a	a	a	a	a	a	a
R. maidis	a	a	a	a	a	a	a
S. flava	a	b	b	a	a	a	a
M. persicae	b	a	a	a	a	b	b
M. caryella	a	a	a	a	a	a	a
Courtship	a	a	a	a	a	a	a
Electrophoresis	a	b	b	b	b	b	b
Host remains	a	a	a	a	a	a	a
Summary	a	b	b	b	b	a	a

[1] Same letter means no significant differences between strains.

Table 2. Summary of experiments to separate populations of Diaeretiella rapae from different geographic sources.

	Strains						
	Greece	Jordan	Pakistan	Russia	Spain	Syria	Washington
Host Aphid Acceptability	1	2	1	1	3	4	1
Electrophoresis	1	1	1	2	1	1	?
Mating behavior	1	1	1	1	1	1	1
Host remains	1	1	1	1	1	1	1
Reproductive isolation	■	■	■	■	■	■	■
Summary	A	B	A	C	D	E	?

Strains with the same number or letter (in rows) were not separated with the indicated tactic; ? indicates additional samples needed for clarification of results; ■ indicates data is incomplete at the present time.

cherry-oat aphid, black-margined pecan aphid, corn leaf aphid, cotton aphid, crepe myrtle aphid, English grain aphid, greenbug, green peach aphid, Russian wheat aphid, yellow pecan aphid, and yellow sugarcane aphid. All parasite strains parasitized black-margined pecan aphid, corn leaf aphid, English grain aphid, greenbug, green peach aphid, and Russian wheat aphid. However, pre-emergence mortality occurred in all parasite strains tested on black-margined pecan aphid, and none of the strains successfully parasitized yellow sugarcane aphid. The mean fecundity of the Greece strain on bird cherry-oat aphid was significantly greater than other parasite strains. Parasite strains from Jordan, Syria, and Spain can be separated from other strains by their ability to recognize and parasitize specific host aphids (Table 2). Only the Syrian strain parasitized the cotton aphid, and only the Jordan and Spain strains parasitized yellow pecan aphid and crepe myrtle aphid, respectively.

Standard horizontal techniques of starch gel electrophoresis were used to analyze the *D. rapae* strains. Six buffer recipes used in similar studies elsewhere were tested for detecting differences. Four of the six showed clear dark bands and adequate mobility to effect band separation. Twenty-four enzyme loci were screened to identify loci with fixed genetic differences or 'markers' for separating respective parasite strains. Aldolase (ALD) was the only enzyme locus that showed 'marker' bands. The Russian strain of *D. rapae* showed a consistently slow migrating electromorph for ALD; whereas, the other strains were monomorphic and fast migrating. Phosphoglucose isomerase (PGI) showed allozyme variability for the indigenous Washington strain. The Washington strain showed allele (PGI-1) that was slower in mobility than other strains, and a second allele (PGI-2) that is faster in all other strains. However, the PGI-1 mobility was inconsistent between the four buffering systems. The polymorphisms observed to date suggest that esterase loci might permit separation of the parasite strains. At present, the Russian strain of *D. rapae* can be separated from other tested strains by using the aldolase marker (Table 2). Additional electrophoretic samples may permit further separation of the strains using the PGI and EST loci.

Comparison of courtship and mating behavior in each *D. rapae* strain revealed a sequence of seven behavioral components. These components included wing fanning, mounting and antennation, copulation and antennal drumming, a quiescent stance, and post-copulatory grooming. The quiescent stance of female *D. rapae* has not been previously identified, and is a new component in the braconid behavioral chain. Male antennal drumming during copulation may also be an addition to the chain. Qualitative observations and quantitative analyses of *D. rapae* courtship and mating behaviors failed to identify unique behaviors that could separate the parasite strains.

Dissections of Russian wheat aphid mummies were performed on the seven strains of *D. rapae*. Characteristics of host remains included mummy coloration, exit hole shape, exit hole location, larval meconia shape, meconia location and number of meconia. Mummy coloration, exit hole shape and location, shape of meconia and location of meconia clusters showed little value as diagnostic characters. However, significant differences were found in mean numbers of meconial pellets recovered from the Russia and Syria strains. Unfortunately, these differences are confounded by overlap in numbers of meconia produced by other strains.

Networking Activities

Mr. Monroy worked in the Gilstrap laboratory in College Station during the spring semester, 1992, and is currently preparing for his research program. Monroy is expected to begin graduate studies with Gilstrap in fall 1993, and his thesis topic will be use of *Solenopsis* ants and *Doru* earwigs for biological control of fall armyworm on sorghum and corn. During July 25-30, 1992, Gilstrap made an on-site visit to Zamorano Valley (Escuela Agricola Panamericana) to develop a research plan for Jose Monroy on biological control research. During this time, Gilstrap visited with Drs. Jeffrey Bentley, Robert O'Neil (entomologist, Purdue University), Alfredo Rueda (Subhead of Department of Crop Protection), Juan Rosas (Plant Breeder) and Abelino Pitty (Especialista en Manejo de Malezas). We made visits to several sites in Zamorano where students were conducting research, and we discussed the various ways these activities could be modified to address additional key questions.

Gilstrap was an organizer and participant in a workshop session on biological control of the wheat aphids. Gilstrap presented a paper that examined improved techniques to evaluate the impact of natural enemies of pests on annual crops. The paper pointed out the challenges that are peculiar to estimates of natural enemy efficacy in annual crops versus tactics typically used in perennial crops. Examples for the paper were extracted from current studies by Gilstrap's INTSORMIL program in the sorghum-wheat-wild grass ecosystem.

Publications and Presentations

Publications

Youm, O. & F. E. Gilstrap. 1992. Life-fertility tables of *Bracon hebetor* Say (Hymenoptera: Braconidae) reared on *Heliocheilus albipunctella* De Joannis (Lepidoptera: Noctuidae). Insect Sci. Applic. (Accepted)

Youm, O. & F. E. Gilstrap. 1992. Population dynamics and parasitism of *Haimbachia ignefusalis*, *Sesamia calamistis*, and *Heliocheilus albipunctella* in millet monoculture. Insect Sci. Applic. (Accepted)

González, D. & F. Gilstrap. 1992. Foreign exploration: Assessing and prioritizing natural enemies and consequences of pre-introduction studies. Symp. Proc. E.S.A. 42 ms. pp. + 2 fig. (In Press)

González, D., F. Gilstrap, L. McKinnon, J. Zhang, N. Zareh, G. Zhang, P. Stary, J. Woolley & R. Wang. 1992. Foreign exploration for natural enemies of Russian wheat aphid in Iran, and in the Kunlun, Tian Shan, and Altai Mountain Valleys of the People's Republic of China. Proc. 5th Russian Wheat Aphid Conf., Ft. Worth, Texas, p. 197-209. Jan. 1992.

McKinnon, L., F. Gilstrap, D. González, J. Woolley, P. Stary & R. Wharton. 1992. Importations of natural enemies for biological control of Aphids. Proc. 5th Russian Wheat Aphid Conference, Ft. Worth, Texas. p. 136-145. Jan, 1992.

Gilstrap, F. E., I. Bayoun & G. Michels. 1992. The impact of aphid biological control: Some ideas on evaluating natural enemies in annual crop ecosystems. Proc. 5th Russian Wheat Aphid Conf., Ft. Worth TX, p. 146-151.

Presentations

Gilstrap, F. E. "State and federal agencies in biological control: Roles, influence, domain and harmony." IN: Symposium on "Changing Roles in the Practice of Classical Biological Control. Dec. 10, 1991, Reno NV, ESA meeting.

Gilstrap, F. E. "The current state of biological control of Russian wheat aphid." IN: 5th Russian Wheat Aphid Workshop. Jan. 28, 1992, Ft. Worth TX.

Biological Control Tactics for Sustainable Production of Millet

Project TAM-125

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Part II-B

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Summary

In INTSORMIL Year 13, Gilstrap and Youm developed a proposal and detailed work plan for a training activity to prepare an INRAN scientist for collaboration on identifying and assessing natural enemies of millet head caterpillar (MHC). The trainee's account of this activity was not available from INRAN at the time of this report.

Research was conducted on methodology for evaluating natural enemies of pests in agroecosystems that include annual crops such as millet and sorghum. This project in the U.S. supports concepts for biological control work on insect pests that occur intermittently. Bioassays were conducted in the laboratory on fourteen insecticides that are identified insecticides with differential toxicity to aphids on small grains and their natural enemies. The assays identified insecticides with differential toxicity to greenbugs and to associated parasites and predators. Fourteen insecticides (i.e., malathion, methyl parathion, diazinon, sulprofos, profenofos, acephate, phorate, chlorpyrifos, dimethoate, esfenvalerate, permethrin, deltamethrin, methomyl and amitraz) were tested. Of the 14 insecticides, only two (i.e., malathion and chlorpyrifos) appear to be good candidates for the planned chemical exclusion studies. Because of their high toxicity to the enemies and low systemic action in the plant, they selectively remove enemies without leaving residues that adversely affect the aphid reproduction. This removal of natural enemies permits assessing greenbug population increases in the absence of natural enemies, and in turn helps establish the importance of natural enemies for suppressing the aphid.

Field experiments for this project are in progress near Amarillo, TX. Chemical and mechanical exclusion experiments have been tested on greenbug infested potted plants exposed in the field under open and closed cages. These studies clearly demonstrated the effect of the enemies in suppressing aphid populations both in wheat and sorghum. Host exposure studies were initiated during the spring of 1991, and consisted of potted wheat plants infested with greenbugs that were exposed in wheat, grain sorghum and Conservation Reserve Program (CRP) ecosystems.

Objectives, Production & Utilization Constraints

Objectives

Niger millet biological control research: Objectives of this collaborative work are to assess the efficacy of natural enemies that may be useful for biological control of stalk borers and the millet head caterpillar; and to optimize implementation of effective biological control for pests of millet crops.

Technology development and student training research: Objectives of research in Texas are to provide graduate level training programs, develop strategies for implementing biological controls in sorghum and millet, test strategies for implementing biological control in annual crop ecosystems, investigate plant-pest-natural enemy ecology and assess the potential of natural enemies as biological control agents for sorghum and millet pests, and optimize integration of effective biological controls with local crop protection and production needs.

Constraints

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

Research Approach and Project Output

Niger millet stalk borer and head girdler research

The primary goal of this project is to implement biological controls of the millet pests, enlarging on research conducted by Dr. Ousmane Youm in Niger in 1986-88. Key elements of this project are: (1) cooperative research activities with the Institut National de Recherches Agronomiques du Niger (INRAN), Institute Economie Rural (IER) du Mali, ICRISAT-ISC, and INTSORMIL, (2) graduate training in entomology at Texas A&M University for a citizen of a country in West Africa, and (3) research conducted at the ICRISAT-ISC. This project seeks to build on Dr. Youm's training in entomology and biological control to facilitate training additional NARS scientists for the region.

The dissertation research of Dr. Youm is the basis for extending the millet research and for examining tactics implementing biological control of millet head caterpillar. A primary goal for 1992 was to initiate a new Ph.D. program researching biological control of millet head caterpillar. For a variety of reasons, we were unable to achieve that goal with IER (Mali) or INRAN (Niger) in Project Year 13. However, Gilstrap and Youm submitted a proposal to INRAN to train an INRAN scientist for future collaboration on identifying and assessing natural enemies of millet head caterpillar (MHC). This proposal was accepted in August 1992, by the Director General of INRAN and the local USAID mission. The trainee's account of this activity was not available from INRAN at the time of this report. A secondary goal in Project Year 13 was publication of Dr. Youm's work on biological control of millet head caterpillar and millet stem borers from his Ph.D. research. Five manuscripts were developed, and two are accepted for publication.

Technology development and student training research

Methodology must be developed to evaluate natural enemies of pests in agroecosystems that include annual crops such as millet and sorghum. This project is conducting research in the U.S. that supports methodology and concepts for addressing the ephemeral nature of sorghum, the intermittent occurrence of pest insects, and is focused on greenbug, *Schizaphis graminum*. The U.S. goals of this project are to provide biological control methods and understanding that can be applied to obtaining objectives on millet in West Africa. Specific objectives are (a) select an insecticide that will differentially kill or repel aphids natural enemies and not affect the aphids, (b) develop methodologies for measuring the impact of natural enemies attacking aphids, (c) determine how host (i.e., pest) exposures can contribute to measuring the impact of natural enemies attacking aphids, and (d) compare relative merits of chemical exclusions, mechanical exclusions and host exposures for assessing the impact of natural enemies of aphids in annual crop ecosystems.

Bioassays were conducted in the laboratory on fourteen insecticides seeking differential toxicity to aphids on small grains and their natural enemies. Development of these methods is essential to establishing baseline data about the effectiveness of naturally occurring enemies, and for verifying tactics that measure the impact of natural enemies in biological control. Fourteen insecticides (i.e., malathion, methyl parathion, diazinon, sulprofos, profenofos, acephate, phorate, chlorpyrifos, dimethoate, esfenvalerate, permethrin, deltamethrin, methomyl and amitraz) were tested. Parasites tested included *Aphelinus varipes* (Foerster), *Lysiphlebus testaceipes* (Cresson), and *Diaeretiella rapae* (M'Intosh). Predators tested included four coccinellids: *Hippodamia convergens* (Guerin-Meneville), *H. sinuata* (Mulsant), *Coccinella septempunctata* L., and *H. variegata* (Goeze). Of the 14 insecticides, only malathion and chlorpyrifos showed needed characteristics for the planned chemical exclusion studies. Because of their high toxicity to natural enemies and low systemic action in the plant, these two insecticides will selectively remove enemies without leaving residues that adversely affect aphid reproduction. This removal of natural enemies permits assessing greenbug population increases in the absence of natural enemies, and in turn provides understanding of the importance of natural enemies in slowing aphid population growth.

Field experiments are in progress near Amarillo, TX. Chemical and mechanical exclusion experiments were conducted on greenbug infested potted plants exposed in the field under open and closed cages. The field experimentation seeks to separate the effects of predation and parasitism by adjusting periods of field exposure to natural enemy activity. An exposure period of six days was used to measure predation, and a period of two days was used to measure parasite activity. Predation is being measured indirectly as the difference in aphid numbers in open versus closed cages at the end of the exposure period. Parasite activity, however, is being measured directly by counting numbers of parasitized aphids and calculating percent parasitism.

The clumped distribution of greenbugs complicates sampling and evaluating natural enemies, especially when these experiments depend on naturally occurring aphid populations on noncrop plants. Thus, we are using host exposures to follow and evaluate the activity of aphid natural enemies across different habitats (i.e., sorghum, wheat, and noncultivated host plants) in the ecosystem. This approach is labor intensive, but measures the collective activity of a natural enemy complex in a "constant" environmental setting throughout the year. It enhances measuring natural enemy impact despite the discontinuity of host plants in the ecosystem.

Host exposure studies were initiated during 1991 and 1992. Potted wheat plants infested with greenbugs were exposed in wheat, grain sorghum and Conservation Reserve Program (CRP) habitats. Seedlings infested with a fixed number of greenbugs were placed in a respective habitat in alternate weeks. The activity of the predator complex showed similar patterns in both 1991 and 1992. Predators collected during 1991 consisted of mostly coccinellids, though a few *Orius insidiosus* were collected late in the season. Most coccinellids collected in 1992 were *H. convergens*; whereas, in 1991 most were *H. sinuata*. Other coccinellids collected included *C. septempunctata* and *H. parenthesis*. In 1991, parasites were not detected until July and consisted mostly of *L. testaceipes*. Other species of parasites that were collected included *A. varipes*, *A. asychis* and *D. rapae*. Several of the collected *A. varipes* and *A. asychis* closely resembled strains of exotic parasites imported from Asia. If these individuals are confirmed as exotic, they verify that strains of parasites imported and released for aphid biological control have become established. In 1992, parasites were reared from greenbugs in early March, though parasitism decreased considerably during the summer. The reduced parasitism in the summer may have been due to the heavy rains in the research area during the first several weeks of the summer. Collected parasites consisted mainly of *L. testaceipes*. During the summer of 1992, an increasing number of *A. asychis* individuals were reared out of the exposed aphid materials.

Thus far, the host exposure experiments show clear differences in the aphid populations when the effects of predation are excluded. In insecticide exclusions, malathion excludes parasitism but not predation, and significant reductions in parasitism were observed on exposed plants treated with malathion. Mechanical exclusion studies clearly demonstrated that both parasitism and predation are important for suppressing aphid populations in wheat and sorghum.

These studies are continuing in 1993, and a complete assessment of results will be reported in Mr. Imad Bayoun's Ph.D. dissertation.

Networking Activities

In 1992, Gilstrap and Youm developed a proposal and work plan for a training activity to prepare an INRAN scientist for collaboration on identifying and assessing natural enemies of millet head caterpillar (MHC). The proposal was submitted to the Director General of INRAN for approval. The training objectives were to (1) collect samples of immature stages of MHC and record data to assess MHC population dynamics and rates of MHC parasitism, (2) process samples of immature stages of MHC in the laboratory to emerge parasites and adult moths, (3) prepare and handle diet for holding the immature stages of collected MHC, (4) prepare emerged MHC adults and parasites for shipment to taxonomic authority, and (5) prepare data and a report for end of season accounting on program progress. Participants were to include an INRAN scientist, Ousmane Youm (Principal Scientist, ICRISAT-ISC) and Frank Gilstrap (INTSORMIL Principal Scientist and Professor, Texas A&M University). In an August 1992 meeting that included the Director General and other INRAN administrators, it was agreed that INRAN would participate in the proposed plan during 1992. Mr. John Mitchell (USAID) agreed to provide a portion of the needed funding, and Gilstrap agreed to provide additional funds as needed from TAM-125B.

The trainee's account of this activity was not available from INRAN at the time of this report.

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

Project TAM-128

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Summary

Of 144 isolates of *Fusarium* spp. section Liseola obtained from sorghum grain of nine cultivars grown at one location in Tanzania, 33% were in mating population A, 51% in F, and the remainder are yet unclassified. Genetic relatedness between *Colletotrichum graminicola* isolates from around the world, but predominantly from sorghum, was more correlated with geographical origin than with susceptibility or resistance of the (sorghum) host when evaluated using RAPD (Random Amplified Polymorphic DNA) markers. Several introduced sorghums with known anthracnose resistance at several global locations were also resistant under high incidence of anthracnose at Mansa, Zambia. Many of these anthracnose resistant sorghums were also well adapted agronomically at the Mansa location and at other Zambia and Zimbabwe locations. Significant levels of aflatoxin were produced on grain of all sorghum cultivars regardless of grain mold resistance or susceptibility when heads were doubly-inoculated with *Aspergillus flavus* at the bloom and soft dough stage. The most susceptible cultivars were those most susceptible to grain mold and weathering, like SC120, which developed aflatoxin levels of 2600 ppb. However, aflatoxin levels in noninoculated grain in both this experiment and in sampling across large geographic areas indicate that there is a minimal threat of pre-harvest aflatoxin on grain sorghum. Reports of natural occurrences of aflatoxin above 20 ppb on grain sorghum in the field are rare.

Objectives, Production and Utilization Constraints

Objectives

Characterization of *Macrophomina phaseolina* from diverse hosts in Southern Africa.

Disease development, economic impact, and host:pathogen interaction of *Exserohilum turcicum* on sorghum cultivars with specific and general leaf disease resistance.

Evaluate biological control techniques for sorghum downy mildew of sorghum.

Identify and characterize the *Fusarium* species occurring on pearl millet and sorghum in the SADCC region and assess their role in diseases of each host and their potential for mycotoxin contamination of seed used for human consumption.

Development of a race (pathotype) typing system for isolates of *Colletotrichum graminicola* from sorghum using RAPD biotechnology.

Determine stability and sources of resistance to major foliar pathogens through field screening nurseries at strategic locations.

Development and deployment of standard and disease specific germplasm nurseries throughout the SADCC region to monitor variability and impact of major sorghum pathogens and to identify the best adapted sources of disease resistance.

Research Approach and Project Output

Macrophomina phaseolina

Several isolates (fifty per host) of *M. phaseolina* were obtained from sorghum, maize, and pearl millet grown in a single contiguous field plot area at Corpus Christi in 1991. These isolates are being evaluated, along with the other isolates from Africa, for diversity in culture which may relate to host preference in the same field. However, these U.S. hosts are all gramineous and there are no anticipated differences among them on chlorate-amended media but they may all be culturally different isolates from non-gramineous hosts and they may be otherwise morphologically distinct from African isolates regardless of host source. Additional charcoal rot tissue specimens were collected from a few diverse hosts in the Okavonga delta region near Maun, Botswana.

Sorghum Downy Mildew

I.S. Kunene completed her dissertation research on biocontrol of sorghum downy mildew (SDM) using the chytrid *Gaertnariomyces semiglobiferum*. Her results were summarized in a previous report. She clarified the taxonomy of the previously unclassified species and determined that it may have potential as a biocontrol agent of oospores of *Peronosclerospora sorghi* in field soil.

Fusarium Species on Grain

Mr. Anaclet Mansuetus is conducting research to compare the population structure of *Fusarium* species in section Liseola on sorghum from three locations in Tanzania using mating type and vegetative compatibility markers. One hundred-forty-four isolates of *Fusarium* spp. were obtained from sorghum grain of nine cultivars grown in the 1990/1991 SADCC/ICRISAT grain mold resistant nursery at Ifakara, Ifakara District, Tanzania. These isolates were crossed to A+, A-, F+, and F- that are testers for the mating population A and F which are considered to be different biological species. Of all isolates 33% were in population A, and 51% were in population F. Mating type distribution was 25% A+, 8% A-, 37% F+, and 14% F-. The predominance of mating population F over A suggests that the threat of mycotoxins may be minimal at Ifakara since the mating population F is known to produce low amounts of fumonisin B1 compared to mating population A.

Thirteen isolates that were in mating population F were tested for their vegetative compatibility to determine the potential for asexual genetic exchange within this population. Non-nitrate utilizing mutants could be generated and were used for complementation tests. Two vegetative compatability groups were identified, but each group was comprised of two isolates only. One isolate was self-incompatible, whereas 8 were different based on this test. Isolates in neither the A or F group are being analyzed for their occurrence in mating populations B, C, D, or E. Studies on the diversity of vegetative compatibility are being limited to populations A and F. More studies of this nature are being conducted to characterize all isolates from the other two locations (Ilonga, Kilosa District, and Kachiri, Ngara District) in Tanzania.

Colletotrichum graminicola.

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

The International Sorghum Anthracnose Virulence Nursery (ISAVN), the Extended Anthracnose Virulence Nursery (EAVN), and another nursery, Anthracnose Resistant Germplasm Nursery, ARGN, of diverse sorghums with known resistance to anthracnose (*Colletotrichum graminicola*), and some resistance to leaf blight (*E. turcicum*) were established at three locations (Mt. Makulu, Golden Valley, and Mansa) in Zambia to evaluate anthracnose response, other disease reactions, and overall adaptation. Sorghums were provided in collaboration with TAM-121, TAM-122, and TAM-124. Table 1 shows the most anthracnose resistant and agronomically desirable sorghums of this group at Mansa in 1992. Anthracnose incidence and severity were excellent for screening only at the Mansa location but the most susceptible cultivars were distinguishable at the Golden Valley location. Drought at the Mt. Makulu location reduced and delayed any significant incidence of anthracnose and severe drought precluded establishment of nursery materials planted at the Lusitu location.

A very drought tolerant, local, improved sorghum variety, Kuyuma (WSV387), demonstrated its value in the

Table 1. Anthracnose severity of agronomically desirable sorghums from the Anthracnose Resistant Germplasm Nursery at Mansa, Zambia in 1992.

Entry	Agronomic Rating[1]	Anthracnose[2] Mean % severity
87L3450	1.0	10
R8602	1.5	0
87L3452	1.5	10
86EON361	1.5	20
86EON362	1.5	22
A8618&R8602(Sus)[3]	2.0	0
84EON100	2.0	0
87BH8341	2.0	20
87BH8351	2.0	18
R8505 (RTX 436)	2.0	38
(((SC120*Tx7000)*TX7000)*R6956)	2.5	5
B9006	2.5	0
A8618*R8505(Red)[3]	2.5	0
B8618	2.5	3
SRN39	2.5	5
EBA-7*TX434*C7*T2	2.5	5
86EON374	2.5	15
R8511	2.5	25
TAM428	2.5	38
Dorado	2.5	50
ATxARG-1*R8505[3]	2.5	40

[1] Agronomic rating (adaptation and agronomic type) at Henderson Station, Zimbabwe is from a mean of two replications where 1.0=best; 5.0=worst.

[2] Foliar anthracnose value is mean percent severity of two replications.

[3] Hybrid.

Lusitu and general Southern Zambia region where it produced significant yields when most other local photoperiod-sensitive sorghums and maize had failed. However, this variety is extremely susceptible to anthracnose and there is a risk of yield and quality loss to anthracnose where it is grown in the higher rainfall latitudes North of Lusaka (50-70% loss of leaf area, Mansa '92, and up to 100% leaf loss in previous years). Another improved local sorghum variety, Sima (WSV187) also produced good yields in Southern Zambia and, though not as drought tolerant as Kuyuma, it has moderate resistance to anthracnose (40% loss of leaf area, Mansa '92).

Exserohilum turcicum

The ISAVN, EAVN, and ARGN sorghum nurseries, mentioned previously, were planted at the Henderson Station, North of Harare, Zimbabwe. Extreme drought stress precluded any development of leaf blight but valuable ratings were obtained on agronomic adaptation of the nursery materials. Because the extreme drought conditions are unusual for this area, the ratings may be more indicative of performance in dryer areas of Southern Zimbabwe. The most agronomically-desirable sorghums are listed in Table 2. Some entries previously demonstrated high anthracnose resistance and good adaptation to other SADCC areas in 1990 trials and all had low anthracnose at Mansa, Zambia in 1992.

Table 2. Sorghum entries from the anthracnose resistant germplasm nursery having a good agronomic rating at the Henderson Station, Zimbabwe and low anthracnose at Mansa, Zambia.[1]

Entry or Pedigree	Agronomic Rating
A8618*R8602(Sus)[3]	1.3[2]
A8618*R8602(Red)[3]	1.5
R6956	1.8
Sureno	1.8
R8602	1.8
ATx378*RTx434[3]	1.8
86EON362	1.8
86EON374	1.8
82BDM499	2.0
SC748-5	2.0
(R2241*(R5646*SC326-6))	2.0
ATX631*R8505[3]	2.0
(SC173*SC414)/499	2.3
B8618	2.3
R8505*(R5646*SC326-6)	2.3
(((SC120*Tx7000)*TX7000)*R6956)	2.5
TAM2566	2.5
Sureno*82BDM499	2.5
87BH8341	2.5
87BH8351	2.5
ATx631*R8511[3]	2.5

[1] Foliar anthracnose of all entries was at a mean percent severity of 20% or less at Mansa, Zambia

[2] Agronomic rating (adaptation and agronomic type) at Henderson Station, Zimbabwe is from a mean of two replications where 1.0=best; 5.0=worst

[3] Hybrid.

Standardized Nurseries

Several of the entries from the ARGN having good anthracnose resistance and good agronomic desirability across the Zambia and Zimbabwe locations were selected for further testing in these countries for stability of their disease and agronomic response. Leaf blight reaction is especially needed because of the drought-limited development of leaf blight in the 91-92 season at several locations including the primary leaf blight screening location at Henderson Station in Zimbabwe. Many of these cultivars could be immediately utilized in country breeding programs and some are being selected for incorporation into standardized trials in both country and SADCC-sponsored nurseries.

Other Sorghum Research-Aflatoxin

Aflatoxin does not normally occur on sorghum grain in the field or it very infrequently occurs at levels below 10 ppb; this level is near the detection limits of the aflatoxin antibody immunoassay column techniques routinely used to evaluate aflatoxin content on large numbers of samples. Grain collected by the P.I. from drought-stressed sorghum in South Texas, and from North Texas and Nebraska in 1990 had minimal aflatoxin (6 ppb or below) but had significant numbers of *A. flavus* conidia on their seed surfaces. Under improper storage conditions (e.g. inadequate drying of grain harvested at high moisture) these conidia can germinate, colonize sorghum grain and produce significant levels of aflatoxin (above 20 ppb) within short periods of time.

In 1991, sorghum cultivars with diverse genetic backgrounds, kernel characteristics, and variable grain mold and weathering resistance were grown in South Texas to evaluate the potential for pre-harvest aflatoxin in sorghum. In four replications, plants in one half of each single row plot of 6 m were either nontreated or inoculated with a condial suspension of an aflatoxin producing isolate of *Aspergillus flavus* at both the bloom and soft dough stages. Grain from all *A. flavus* inoculated sorghums developed aflatoxin contamination above 20 ppb, including the highly grain mold resistant SC630 (300 ppb), but the highest levels were produced on those cultivars most susceptible to grain mold like SC 120 (2600 ppb). Grain from plants in most control plots had aflatoxin levels below 20 ppb but these plots were apparently affected by the proximal inoculum of *A. flavus* on inoculated heads because similar noninoculated cultivars only a few meters away had only 3 ppb aflatoxin. These results indicate sorghum may be vulnerable if sufficient inoculum is present but under natural conditions there may rarely or never be sufficient inoculum for significant aflatoxin occurrence even on the grain mold susceptible cultivars. The competition provided by other saprophytic and pathogenic grain mold fungi may also influence the lack of *A. flavus* colonization and aflatoxin contamination.

Networking

The principal investigator collaborated with TAM-121, TAM-122, and TAM-124 to introduce over 150 sorghum cultivars for evaluation in the SADCC region, primarily in Zambia and Zimbabwe. These entries were evaluated for disease resistance (principally anthracnose) and agronomic adaptation and desirability. The best entries will be incorporated into country and regional nurseries for further evaluation and potential use in breeding programs for cultivar improvement.

Publications and Presentations

Publications

Guthrie, P., A. I., C. W. Magill, R. A. Frederiksen and G. N. Odvody. 1991. Random Amplified Polymorphic DNA markers: A system for identifying and differentiating isolates of *Colletotrichum graminicola*. Phytopathology 82:832-835.

Kunene, I.S. 1991. *Gaertneriomyces* species as a potential biological control agent of sorghum downy mildew. Ph.D. Dissertation. Texas A&M University, College Station, Texas. 100 pp.

Odvody, G. N. and S. D. Livingston. 1991. Potential for Pre-Harvest Aflatoxin in Sorghum. p. 25 *In* Proc. of 3rd Annual Texas Plant Protection Conference, December 2-4, 1991 College Station, TX.

Livingston, S. D., C. W. Horne, and G. N. Odvody. 1991. The Occurrence and Effect of Aflatoxin in the South Texas Feed Grain Industry. *In* Proc. of the Southern Association of Agricultural Scientists. February 2-6, 1991, Fort Worth, TX.

Presentations

Frederiksen, R. A., D. T. Rosenow, F. R. Miller and G. N. Odvody. 1992. Disease resistance in sorghum. Abstr. D-9. *In* Proceedings of Durable Resistance, A Symposium on Durability of Disease Resistance. ICA, Wageningen, The Netherlands. February 24-28.

Guthrie, P. 1992. The potential of PCR/RAPD markers to determine differences in variability of *Colletotrichum graminicola* isolates. *Presented at*: Genetics of Host-Parasite Interactions Between Plants and Fungal Pathogens in the Genus *Colletotrichum*. Whitney Marine Lab, University of Florida, Marineland, FL. January 23-26.

Sustainable Production Systems

Modelling Millet and Sorghum Establishment and Growth and Sustainable Crop Production

Project KSU-106

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Summary

Field emergence of the best five sorghum genotypes planted under severe environmental conditions in Zimbabwe showed emergence rates of 45%, more than twice the poorest genotype at 21%. Incorporation of these responses through the controlled environment affects presently being studied, along with the other improvements made in SORKAM, the sorghum growth model achieved this year will make a very useful tool in evaluating agronomic practices, both in the U.S., and in areas of Africa or Asia where stand establishment is a more severe problem.

Objectives, Production and Utilization Constraints

Objectives

Botswana and Mali: Determine suitability of available crop models for use in southern and western Africa.

Zimbabwe: Evaluate the genetic variability for sorghum establishment under conditions of high temperature and moisture stress.

U.S.: Developed replanting guidelines based on long-term historical data, achieved plant population, and time of year.

Constraints

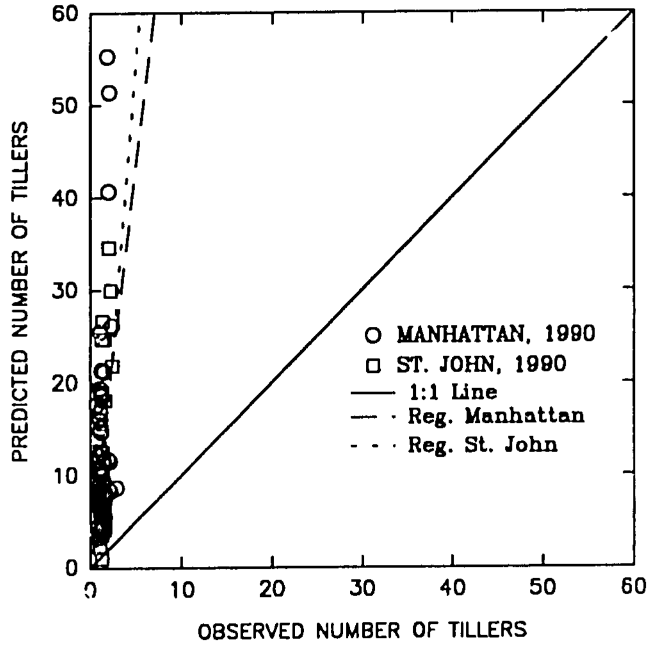
Constraints to productivity include climatic, edaphic, and biological factors. The climate of sorghum and millet producing regions has low and erratic rainfall which has high within- and between-year variability. The solar radiation is high, due to frequent cloudless conditions, and humidity is low resulting in a high potential evapotranspiration (PET) rate. In Botswana the average PET exceeds the average precipitation in every month. The soils are often of low fertility and are prone to crusting, rapid drying, and high soil temperatures which reduce crop establishment. Sorghum and millets are small seeded crops requiring shallow planting. Social and economic constraints add to the difficulties of crop management. Low yields are the norm in these regions and crop failure is common. Farmers may be unable to produce subsistence grain and seed for the following season. Low yields are a function of the harsh environment and the low level of management which often do not enable the farmer to obtain a satisfactory stand.

Research Approach and Project Output

Objective 1. Determine the suitability of available crop models for use in southern and western Africa.

Two aspects of the sorghum growth model SORKAM have previously been identified as requiring improvement. Research by Adama Coulibaly, Mali, included in last years' annual report, showed that tillering of grain sorghum could be related to daily dry matter production with the requirement per growing point, which depends on genotype and is influenced by temperature. A field study was designed to provide a range of tillering responses and serve as validation data for these relationships. Eight cultivars including Segaolane from Botswana and CSM 63 from Mali, two planting dates and three plant populations were planted at Manhattan and St. John, KS. Results from the controlled temperature study reported last year were used to develop tillering coefficients to predict tiller numbers for these field conditions. Comparison of actual and predicted tiller numbers are shown in Figure 1. Obviously, use of tillering coefficients developed under controlled conditions are not adequate to predict tiller numbers under field conditions. Results from this field experiment and other available data will be utilized to design a follow-up study to evaluate the method of tiller prediction, and attempt to develop relationships which are more robust under field conditions. A preliminary modifi-

Figure 1. Comparison of predicted and observed tiller numbers from both plantings at Manhattan and St. John, Kansas, 1990.



cation has been made, and will be discussed under Objective 3.

The second problem of the growth model is predicting grain growth. Considerable improvement in this has been made using data from the experiments partially reported in the last annual report describing individual kernel growth rates, and the factors that determine these rates. Of particular importance is the finding that the relative pollination time within the panicle determines the growth rate with those florets pollinated first having the highest growth rate which is maintained throughout grain filling, irrespective of their position on the panicle. More detail on how results from these experiments were used in modifying the grain growth portion of the model, will be reported under Objective 3.

Results from experiments by two SADCC/ICRISAT/INTSORMIL students, Ruth Madulu, Tanzania, and Etani Lele, Botswana, were designed to provide information on the compensation by yield components of grain sorghum under a range of management and climatic conditions which result in a wide range of grain yields. Segaolane from Botswana and three U.S. hybrids were included to evaluate differences in yield component response and provide validation data for an improved version of the crop growth model. Field experiments were planted at St. John and Manhattan on two dates at populations of 40,000, 80,000; and 160,000 plants/per hectare to cover the range of plant populations likely encountered in both U.S. and LDC fields. Two levels of inputs were applied: low management, consisting of minimum soil preparation, no fertilizer and no chemical or mechanical control; high management, normal soil preparation, recommended fertilizer application, and chemical and mechanical weed control. Yield response to management varied among cultivars and between locations (Table 1). All cultivars yielded significantly more under high management, than low management at both locations.

It is not surprising there were interactions between management, cultivar and locations, since the weed pressures were very different at the two locations, and different between planting dates as shown in Table 2.

Objective 2. Evaluate the genetic variability for sorghum establishment under conditions of high temperature and moisture stress.

Field research was conducted at four locations, Aisleby, Lucydale, Matopos, and Sandveld, Zimbabwe, utilizing 30 sorghum genotypes which had previously been studied at the SADCC/ICRISAT Center at Matopos. Plantings were conducted under dryland conditions at Aisleby, Lucydale and Sandveld, and because of severe drouth, additional plantings were made using small amounts of irrigation to simulate rainfall. Daily emergence counts and an emergence

Table 1. Grain yield as affected by cultivar, date of planting and management level.

Date and cultivar	Location Manhattan Low mgmt.	 High mgmt.	 St. John Low mgmt.	 High mgmt.
	kg/ha			
Date 1				
Segaolane	3114	6717	164	4556
DK 69	4936	7624	291	5245
ATx623xRTx430	4936	8030	461	4295
E57	4817	6760	1037	4042
Date 2				
Segaolane	629	1375	1567	1813
DK 69	605	1930	1400	1010
ATx623xRTx430	1092	2536	4371	3123
E 57	1854	3953	4275	4039

Table 2. Effects of planting date and management on weed dry matter produced.

Treatment	Location: Manhattan	Location: St. John
	kg/ha	kg/ha
Date 1	1007	698
Date 2	866	15
Low management	1873	603
High management	0	110

rate index were computed for each genotype and planting. Planting dates and irrigation or irrigation plus rainfall received during the emergence period are shown in Table 3.

Significant location by genotype interactions were observed on both percent emergence and emergence rate index which were very highly correlated (r = 0.99). Because the objective of these field studies was to select materials which would be studied in more detail, the four best and four poorest genotypes at each location were identified. Table 3 shows the mean emergence percentage for the best and poorest four genotypes in each experiment. In each case, there was good separation between the two groups. The extremely low emergence at Lucydale and Sandveld 1 was because of soil crusting. Considering all plantings, sixteen of the genotypes were in the category of best four in at least one planting, and sixteen genotypes were in the category of poorest four. Four genotypes showed up in both categories. Table 4 shows the genotypes that were in each category in three or more plantings. Mean and maximum daily soil temperatures at seeding depth for Aisleby are shown in Figure 2. Planting depth, soil moistures for the three plantings at Aisleby are shown in Figure 3.

Objective 3. Setting replant guidelines based on long-term historical data, achieve plant population, and time of year.

SORKAM, a sorghum growth model, will be tested and verified using sensitivity analyses and validation studies. Before proceeding with crop simulations we need to confirm that the model is giving accurate, sensible yield responses to changes in plant populations, planting dates, and plant maturities. Changes in tiller number, kernel numbers and kernel weight are the main sources of compensation the plant uses to adjust to changing weather conditions. The model should accurately simulate these yield components at the differing levels of plant populations, planting dates, and maturities that we will be exploring. If problems are discovered which will not allow us to accurately simulate sorghum yields under the conditions listed above, SORKAM will be revised by improving the mathematical relationships responsible for determining the yield components.

Using 33 years of climate data at several Kansas locations, cumulative frequencies for seven planting dates, six plant populations, and three maturity class combinations

Table 3. Planting locations, dates, rainfall or irrigation, and emergence of best and poorest four genotypes for field plantings in Zimbabwe.

Experiment	Planting date	Rainfall, mm	Irrigation, mm	Total, mm	Emergence, %: Highest 4	Emergence, %: Lowest 4
Aisleby 1	1/21/92	86.0	-	86.0	69.7	26.3
Aisleby 2	2/18/92	17.0	32.0	49.0	74.8	22.0
Aisleby 3	2/26/92	37.0	21.2	58.2	91.6	42.6
Lucydale	1/23/92	110.0	-	110.0	7.3	0.5
Matopos 1	2/19/92	17.3	36.4	53.7	37.0	6.1
Matopos 2	2/25/92	17.3	45.7	63.0	47.5	8.2
Sandveld 1	1/22/92	45.4	-	45.4	23.7	2.5
Sandveld 2	2/19/92	6.8	36.9	43.7	60.0	16.7
Sandveld 3	3/13/92	52.5	31.5	84.0	79.6	15.7

Table 4. Frequency of occurrence of best and poorest genotypes and their mean percent emergence.

Category	Genotype	Frequency	Mean % emergence
Highest	8636H	5	46.4
	SDSH159	5	48.4
	SDSH18	4	47.3
	MMSH375	3	42.3
	MMSH1040	3	41.6
Lowest	A603	7	15.6
	Town	5	27.3
	MMSH1413	3	22.3
	MMSH707	3	22.3
	Macia M	3	19.0

Figure 2. Maximum and mean soil temperature at seeding depth for the Aisleby 1 planting.

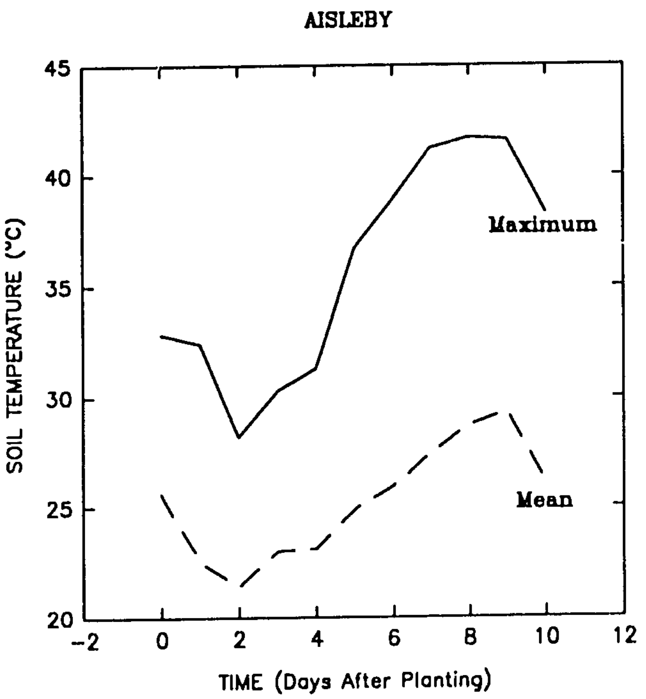
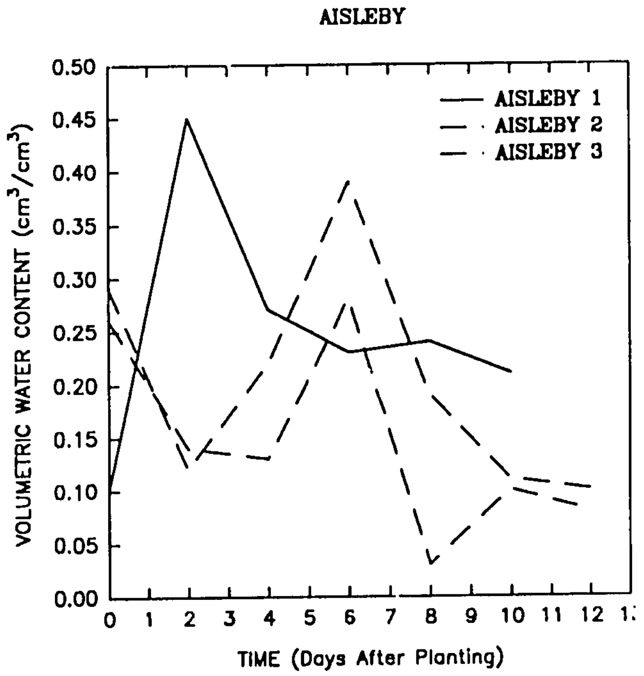


Figure 3. Volumetric water content in the 5.0 to 7.5 cm depth during emergence of the three plantings at Aisleby.



will be developed from the modeled yield data. These will be compared to the weather patterns used in the simulations to determine the relationship between optimum sorghum yields and the weather conditions experienced.

Mathematical relationships will be developed that will allow us to predict original and replant yields based upon the important weather factors experienced to date (precipitation, temperature, etc.), the original stand remaining, and the weather forecast for the remaining growing season.

Yield data from these simulations along with an economic analysis of replanting costs and risk factors will be used in the following objective function to determine when replanting would be an effective management decision.

Economic return to replanting =

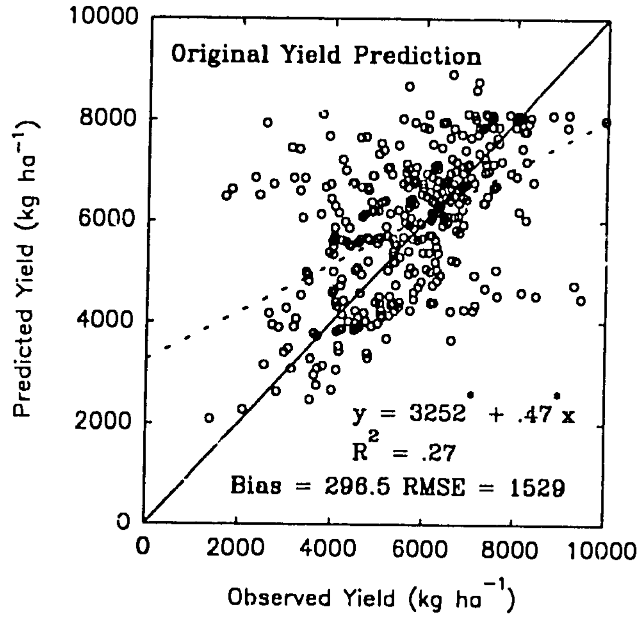
[(Replant yield - Original yield) X Harvest Price] - Replant cost - Risk cost

Using the weather-yield equations determined in conjunction with the objective function, we will develop a computer based decision model for making replant decisions in the field.

A validation study was made for yield, yield components, and phenology using 13 data sets collected at Manhattan and Powhattan, Kansas from 1965 to 1985. These data sets contained plant populations ranging from 20,000 to 300,000 plants ha^{-1}, planting dates ranging from 25 April to 15 July, and hybrids from all three maturity classes (early, medium, and late). Not all data sets contained yield component or phenological data. A sensitivity analysis was done for yield, tiller number, seed number, and seed weight changes in response to changes in plant populations, planting dates, maturity, and yearly changes in weather pattern. Responses were checked at six different plant populations, four different dates, three maturity levels, and four weather patterns. The sensitivity of the model was measured by measuring changes in yield, tiller number, seed number, and seed weight for each population level by date, by maturity, and by weather pattern combination.

Validation studies indicated that SORKAM modeled phenology well but had problems simulating yield (Fig. 3), tiller number and kernel weight. Sensitivity and validation studies indicated that the model was not very sensitive to changes in initial plant population. This was the result of overestimating tiller numbers on some hybrids and a poor simulation of kernel weight. It was clear from these studies

Figure 4. Comparison of predicted and observed sorghum yields using the published SORKAM model.



that improvements needed to be made in how the model represented both tillering and kernel weight.

Recent studies have improved our knowledge of both tillering and kernel weight relationships in the sorghum plant. We used these to develop new relationships in the model or to improve those functions already represented. In the case of kernel weights, we found that the existing functions did not handle translocation from the stalk to the grain realistically. In addition, the pattern of kernel growth did not fit those patterns observed in the field. SORKAM placed too much emphasis on grain growth during the leveling off period when, in reality, there is only a 10% increase in kernel weight during this period. Field studies in 1990 had found a relationship between the grain fill rate and the amount of light intercepted by the sorghum plant and the number of kernels on the plant. We used this study to develop a relationship between grain fill rate and the dry weight produced per kernel by the plant during the linear kernel growth period (Fig. 4). We also divided grain fill into three separate phenological periods (lag period, linear growth period, and leveling off period) using growing degree days (GDD) base 5.7°C. By combining the grain growth function with the new model of grain growth phenology we greatly improved the simulation of kernel weight with the new model accounting for 71% of the variation in kernel weight compared to 40% in the original SORKAM model.

Studies of tillering in 1990 had shown that the relationship between the dry matter requirement per growing point and daily minimum air temperature was not well represented by the linear function currently used in SORKAM. We attempted to improve this relationship by fitting an exponential function to data collected in Kansas and Australia (Fig. 5). Using this function we could account for 44% of the variation in tiller numbers compared to 4% in the original model; however, in both models the slope and intercept of the observed verses predicted values were significantly different from 1 and 0.

With both kernel weight and tiller number improvements in SORKAM, there was a significant improvement in simulated yield (Fig. 6). The revised version now accounts for 72% of the variation in sorghum yield compared to 27% accounted for by the original version. Furthermore, in the new model neither the slope nor the intercept of observed verses predicted values were significantly different from 1 and 0. With these improvements to SORKAM we feel we can now proceed with the simulations for developing the cumulative frequency functions.

Networking activities

Workshops

Invited keynote address at the Second Australian Sorghum Workshop, February 19, 1992, Gatton, Queensland, Australia.

Figure 5. Relationship between individual caryopsis fill rate and plant growth rate per caryopsis.

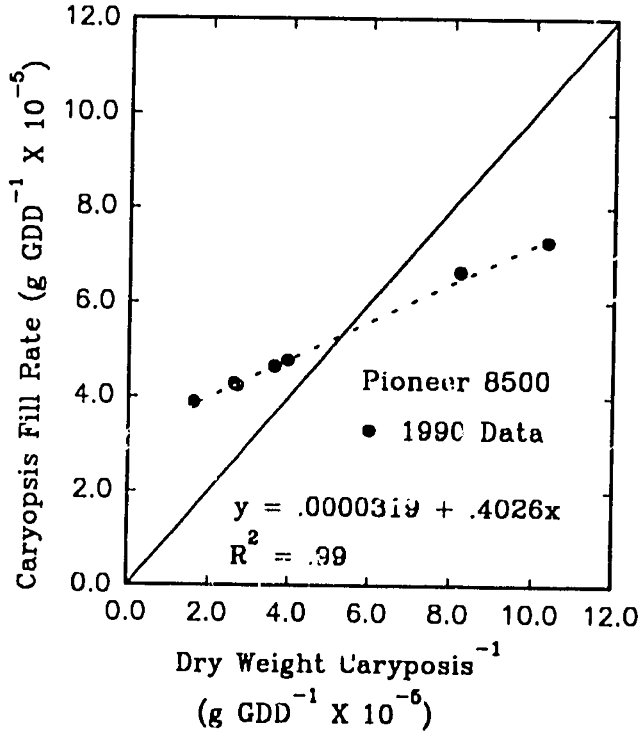


Figure 6. Relationships used to predict tiller number (- - -old —new).

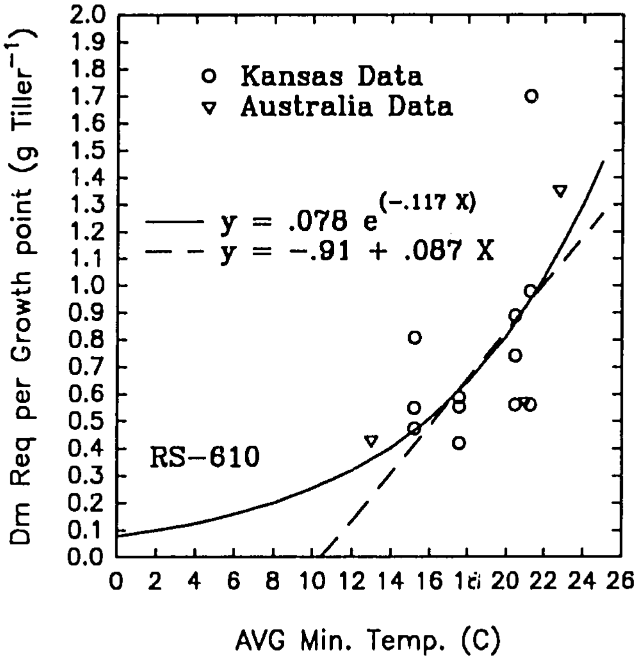
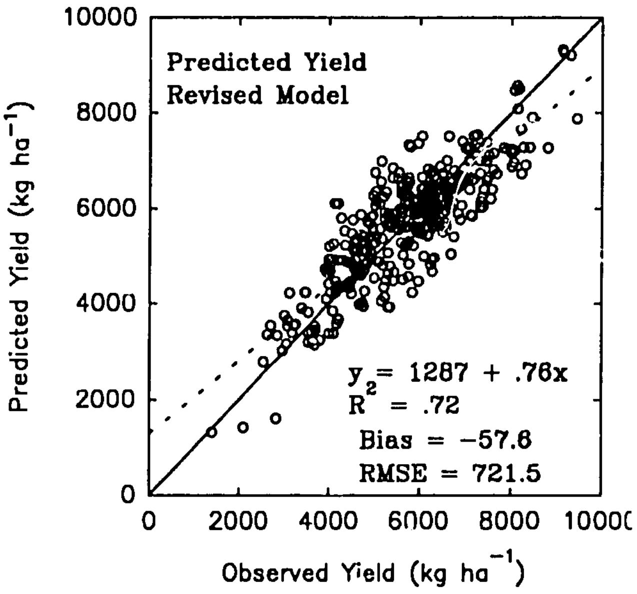


Figure 7. Comparison of predicted and observed sorghum yields with the improvements made in tillering and caryopsis fill rate.



Research investigator exchanges

Discussions were held with Dr. Louis Mazhani, Chief Agricultural Research Officer, regarding future collaboration in the modelling efforts in Botswana. He indicated that Nieso Mokete would be attending a Crop Growth Modelling Workshop sponsored by the Australians, and would be their person primarily involved in such activities. I offered to assist Nieso in any way possible, including having him spend some time during their off season at Kansas State. At this point, no definite plans have been made. Earlier plans for follow-up in Mali have also failed since Adama Coulibaly was not approved to continue on a plant growth modelling project and likely would not be involved with modelling on his return to Mali.

Publications and Presentations

M'Khaitir, Y. O. and R. L. Vanderlip. 1992. Grain sorghum and pearl millet response to date and rate of planting. Agron. J. 84:579-582.

Coulibaly, A., and R. L. Vanderlip. 1991. Relationships between growth rate and tiller number in grain sorghum. Agron. Abst. 83:141.

Heiniger, R. W., R. L. Vanderlip, and K. D. Kofoid. 1991. The influence of pollination pattern upon interpanicle kernel weights in *Sorghum bicolor* (L.) Moench. Agron. Abst. 83:146.

Stegmeier, W. D., R. L. Vanderlip, and D. J. Andrews. 1991. The development of pearl millet as a food and feed grain crop for the central Great Plains. Agron. Abst. 83:161.

Improved and Sustainable Dryland Cereal Production Technology for Smallholder Farmers in Botswana

Project KSU-107
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Collaborating Scientists

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F.A.O. Soil Mapping and Advisory Services: Mr. P. DeWit and Dr. W. Joshua, Ministry of Agriculture, Private Bag 003, Gaborone, Botswana.
Arable Lands Development Program: Mr. G. Chilume, Mr. M. Mapatsi, Mr. A. McPherson; Ministry of Agriculture, Private Bag 003, Gaborone, Botswana.
Palapye Development Trust: Mr. S. Malinga.

Summary

Multilocational on-station and on-farm trials at 15 sites were carried out during Year 13. These trials were aimed at improving tillage and fertilizer practices for dryland sorghum. Results from these trials demonstrated the importance of early primary tillage in achieving better crop stands and yields. Tillage and fertilizer interacted at only one of the sites, indicating that their effects tended to be independent of each other. It was better to apply fertilizer broadcast before planting rather than by banding next to the seed. In general, lower yields were obtained with animal versus tractor draught for tillage operations. However, comparison of the financial benefits from using animal draught versus tractor draught for sorghum production, showed no clear trend. Benefits were quite comparable for the two systems, with lower yields under animal draught being offset by its relatively lower costs.

Results from the fertilizer studies generally showed significant response to P when the initial soil P levels by Bray 2, the standard laboratory method, was less than 10 mg/kg. Production level also must be considered.

Objectives, Production and Utilization Constraints

Objectives

The major purpose of the KSU-107 sorghum/millet activity is to assist Botswana's Department of Agriculture with dryland sorghum/millet research and development. This purpose is achieved by providing research input, technical assistance as requested, and training of Botswana's agricultural research scientists and technicians.

The specific Year 13 objectives covered in this report are:

Continue multilocation, mostly on-farm, trials to evaluate several tillage systems in conjunction with fertilizer applications for their effect on sorghum growth and yield, soil physical properties, soil moisture conservation, and weed control.

Continue multilocational trials to evaluate the effect of P application on hardveld and sandveld soils in Botswana.

Initiate, using data from 1988/89, 89/90, and 90/91 tillage trials, validation of sorghum growth simulation models.

Constraints

Most cereal production in Botswana comes from traditional, small-holder, subsistence-oriented dryland farms. An average of about 4-5 ha are ploughed per farm family, mostly by cattle or donkey teams, although the use of tractors is increasing. Crops are weeded once or not at all. Krall manure, fertilizers, pest control, crop rotations, and crop residues are rarely used.

Most arable soils of Botswana are relatively infertile, sands, loamy sands, or sandy loams. The soils are "hard-setting" i.e they are structureless and become compact, dense, and hard when dry, and have low moisture retention capacity. All assessments of these soils agree that they are marginal for arable farming.

Sites: Selections of these experiments were implemented at 15 sites, which represent a wide range of soil and rainfall conditions in Botswana, as follows:

Site	Site Code	Farmer	Experiment E1	E2	E3	E4	E5	E6	E7	E8
Chanoga	N1	Dipuo	x	x						x
Matsaudi	N2	Station				x				
Shorobe	N3	Station			x	x				x
Pandamatenga	V1	Station				x			x	
Mathangwane 1	F1	Zimundu	x			x				
Mathangwane 2	F2	Mpatane	x	x	x					
Palapye	M5	PDT (NGO)	x	x	x					
Mahalapye 1	M3	Lekone	x	x						
Mahalapye 2	M4	Meleme	x							
Sebele	S1	Station	x	x	x	x	x		x	
Odi	S2	Tau				x				
Goodhope	G1	Station				x			x	
Mushopa	P3	Mosebiwa	x	x	x	x				
Tswidi	P2	Katholelo	x	x	x	x				
Sese	J1	Mabine	x	x	x	x				

All sites in the 1989/90 trials were used in 90/91, and six sites were added, namely N1, N2, N3, V1, S2, and G1.

It is fairly well-established that lack of adequate P in the soil is a major limiting factor for crop growth in Botswana. However, little is currently known about the levels of P and other nutrients that are needed to produce economically optimal yields of specific crops on specific soil types in Botswana. Parallel studies on soil fertility and its management are needed to complement those on soil moisture conservation tillage.

Research Approach and Project Output

INTSORMIL in close collaboration with scientists of the Dept. of Agricultural Research and the Dept. of Field Services in the Ministry of Agriculture helped initiate, develop, and implement a comprehensive program to address the foregoing needs. Program planning activities were appropriately structured to ensure that the program remained relevant and responsive to the needs in the specific areas of research.

Multilocational trials were designed to meet the objectives outlined above. These trials are as follows:

E1: Tillage systems by tractor for sorghum, hardveld & sandveld.

E2: Tillage systems by animal for sorghum, hardveld, sandveld, & fluvisol.

E3: Tillage systems by tractor for maize, hardveld & sandveld.

E4: Fertilizer response for maize and sorghum, hardveld, sandveld, & vertisol.

E5: Weed control methods for deep ripping, hardveld.

E6: Crop residue/phosphorus interaction, hardveld & sandveld.

E7: Tillage systems by tractor for sorghum, vertisol.

E8: Tillage systems by animal for maize, sandveld & molapo fluvisol.

Experiments E1 through E5 were the same as for the 1989/90 trials. Experiments E6, E7, and E8 were additional for 90/91.

Tillage trials E1, E2, E3, E7, E8: For E1, E2, and E3 at all sites a selection of the six tillage treatments as for 1989/90 trials were compared with and without fertilizer. These treatments were as follows:

T1 = Conventional: Single mouldboard ploughing on day of planting. Crop row-planted to obtain 50,000 plants per ha. +/- 10%

T2 = Double ploughing: Early spring mouldboard ploughing with first rains followed by second ploughing on day of planting. Crop row-planted to obtain 50,000 plants/ha. +/- 10%

T3 = Deep Ripping: Deep ripping to 50 cm on 150 cm centres as soon as possible after harvest followed by and shaping and other secondary tillage as appropriate with this system. Crop row planted along riplines to obtain 20,000 plants/ha. +/- 10%

T4 = Ploughing and Cultivation: Early ploughing as in T2 followed by tined cultivation on day of planting. Crop row-planted to obtain 50,000 plants/ha. +/- 10%

T5 = Conventional with Wide Row Spacing: As for T1 but with 150 cm. row spacing as in T3. Crop row planted to obtain 20,000 plants/ha. +/- 10%

T6 = Broadcast Plough/Plant: Broadcast seed at 6 kg/ha followed by single mouldboard ploughing to 10-15 cm. depth. This is the traditional method.

To compare these treatments with and without fertilizer each treatment plot was split lengthwise and commercially available single superphosphate fertilizer applied at 15 kg P per ha to the same half of each plot as for the 1989/90 trials. The fertilizer was applied broadcast at planting, except for T3, the deep ripping treatment, where it was applied at various depths in the riplines at the time of ripping.

For E1 all six core tillage treatments were evaluated. At sites F1, S1, M3, M4, and J1 other treatments were added to meet specific needs and objectives. Treatments were replicated at least twice in a split-plot design with randomized complete blocks at all sites with tillage as the main plot treatment and fertilizer as the subplot treatment. E2 was implemented with treatments T1 through T4 and either T5 or T6, but using animal draught implements. At M3 two treatments T7 and T8 were added. Treatment T3 for E2 was designated as chisel ploughing. The strips were chiselled to a depth of 25-35 cm using a two-furrow animal drawn mouldboard plough fitted with reversible tynes, and the crop planted on these 150 cm spaced strips. Trial E3 was implemented with treatments T1 through T4 using maize as the indicator crop. Table 1 summarizes the rainfall data collected at the thirteen sites.

Tillage Trials

Tractor implemented trial E1 with sorghum: Table 2 presents the results for the effect of the six core tillage treatments on grain yields. The climatic, soil, and management factors at each site are integrated and expressed in the grain yield.

From the results in Table 2 the following are apparent:

The double plough treatment gave the highest overall yield of sorghum grain across all the sites. The yield was close to 33% higher than the conventional and plough + cultivate treatments, about 50% higher than the broadcast/plough treatment, about 80% higher than the conv. + WRS treatment, and about 130% higher than the deep rip treatment. Increased yields from the early mouldboard treatments T2 and T4 were statistically significant at F2, S1, and P3.

In general, there was high variability in yields (and other components of yield) at the sites as indicated by the high coefficients of variation.

Fertilizer interacted with tillage treatment only at site P2. A significant fertilizer response was obtained at only two of the ten sites namely, S1 and M4. Across sites, fertilizer resulted in an overall weak yield response of 13%.

Animal draught tillage trial E2 with sorghum: The results of similar analyses on yield and components of yield done for E1 are presented for E2 in Table 3 which shows:

Overall mean yields across sites tended to be lower with the animal draught compared to those for E1 with tractor draught, but only by about 15%.

A distinct overall yield benefit from the early mouldboard ploughing for treatments T2 and T4. Overall mean yields across the five sites were, respectively, about 48% and 38% higher for these treatments compared to the conventional treatment. In most but not all the sites, this yield benefit appeared to be the result of higher plant populations. At S1, where the plant population was about 50% higher for the broadcast/plough treatment, yields were lower compared to T1, T2, and T4. The optimal plant population may have been exceeded in this case.

Chisel ploughing, T3, performed poorly at all the sites. Yields were about half those for the conventional and broadcast/plough treatments and a third those for the double plough and plough + cultivate treatments. The chisel ploughing treatment had markedly lower plant populations.

Fertilizer application had no marked effect on yields; the response to fertilizer tended to be better at the higher yielding sites.

Fertilizer Trials

Due to the lateness of planting and the unfavorable rainfall distribution, the crops for E4 were much poorer than in the 1989/90 season. A summary of the planting dates, yield at zero P fertilizer which gives an indication of the conditions at each site, and CV are given in Table 4.

Table 1. Rainfall data summarized for thirteen sites used in the 1990-91 tillage and fertilizer trials.

	Site												
	N1	N3	V1	F1	F2	S1	M3	M4	M5	P2	P3	J1	G1
Rainfall	369.3	618.9	453.1	392.9	381.8	562.4	371.9	352.5	407.2	374.0	621.5	351.2	440.9
Raindays	28	48	47	34	35	47	31	31	23	17	27	26	40
No. > 10 mm	10	20	15	11	12	19	15	13	11	11	17	12	15
Mean depth	13.2	12.9	9.6	11.6	10.9	12.0	12.0	11.4	17.7	22.0	23.0	13.5	11.0

Table 2. Sorghum grain yields kg/ha adjusted for already harvested, grazed and immature heads and 10% moisture for E1 at ten sites used in 90-91 tillage trials.

	Site										
Treatment	N1	F1	F2	S1	M3	M4	M5	P2	P3	[1]J1	Mean
Conv.											
+fert	1203	882	1133	293	1229	1906	1536	164	1434		1087
-fert	1402	1255	1895	151	1005	768	579	202	1114		930
Mean	1302	1069	1514	222	1117	1337	1057	183	1274		1008
DP											
+fert	1020	1441	2519	818	1497	1715	872	242	2211		1371
-fert	1546	1338	1872	594	947	1235	1032	46	2476		1232
Mean	1283	1390	2196	706	1222	1475	952	144	2344		1301
Deep rip											
+fert	1023	552	998	108	922	982	625	134	666		668
-fert	458	517	1383	126	600	465	611	26	38		469
Mean	741	535	1190	117	761	724	618	80	352		569
Plough + cult.											
+fert	1096	1276	1571	874	1207	1860	983	313	747		1103
-fert	1245	1168	729	672	1648	1423	833	204	796		969
Mean	1171	1222	1150	773	1427	1641	908	259	772		1036
Conv. + WRS											
+fert	765	549	1566	80	1024	1219	524	9	469		689
-fert	740	872	1556	53	1346	1197	550	95	322		748
Mean	753	710	1561	66	1185	1208	537	52	396		719
B/cast-plough											
+fert	963	m	1056	m	1457	981	776	183	777		885
-fert	1338	m	1054	m	922	850	660	289	400		788
Mean	1150	m	1055	m	1190	915	718	236	589		836
Overall mean											
+fert	1012	940	1474	435	1223	1444	886	174	1051		960
-fert	1122	1030	1415	319	1078	990	711	144	858		852
Tillage	ns	ns	**	**	ns	ns	ns	ns	*		
Fertilizer	ns	ns	ns	*	ns	*	ns	ns	ns		
Tillage x fert. interaction	ns	ns	ns	ns	ns	ns	ns	**	ns		
cv main plot %	62.0	42.1	25.8	86.7	31.8	37.5	57.3	80.7	58.3		
cv subplot	18.8	15.1	34.0	37.1	22.2	33.7	63.9	44.1	39.3		
SED_1	457	294	218	163	259	322	264	74	388		
SED_2	80	67	166	44	104	168	170	23	151		
SED_3	478	312	361	177	315	434	396	84	468		
SED_4	196	149	407	99	255	411	417	57	369		
df for E_a 5	4	10	12	5	5	10	10	5			
df for E_b 6	5	12	15	6	6	12	12	6			

[1]Trial planted but considered a failure, **, * and ns = respectively, highly significant P(>F) < .01, significant P(>F) > .01 and < .05, or not significant.
SED_1 = for comparing tillage teatment means over all fert. levels, SED_2 = for comparing fert. treatment means over all tillage treatments, SED_3 = for comparing tillage teatment means at a given fert. level, SED_4 = for comparing fert. treatment means for a given tillage treatment, m = not implemented or failed or data lost.

As can be seen, the trials that were planted early at Goodhope and Sebele performed much better than the late planted ones. The trials at J1 and N3 failed due to poor germination and no data are presented for these sites. Analysis of variance (AOV) was carried out using the MSTAT computer program and all significance levels were 10%. Regression lines of the form $ax^2 + bx + c$ were fitted to yield averaged over all N treatments against P rate or vice-versa, as appropriate. These equations are given in Table 5.

From the previous two seasons' results, it was expected to find significant responses to applied P up to 5 ppm and responses up to 10 ppm. However, in this year's results, the effect of yield level at zero P also has to be taken into consideration. Responses were expected at Tswidi, Mathangwane and Pandamatenga, however, the expected result was not obtained at Mathangwane. This was because the crop performed very poorly as was seen from the site yield level. The poor performance probably resulted from the very late planting date.

The significant response to P at Goodhope was completely unexpected but can be explained when looking at the high yield that was obtained from this site. Conditions were optimal and management was very good, so even a relatively high level of soil P was not adequate for maximum crop growth. This can be contrasted with the situation at Sebele where, even though yields were high, no response was seen.

Table 3. Sorghum grain yields kg/ha adjusted for already harvested, grazed and immature heads and 10% moisture for E2 at seven sites used in 1990-91 tillage trials.

	Site							
Treatment	[1]F2	S1	M3	M5	P2	P3	[1]J1	Mean
Conv.								
+fert		1327	1001	493	654	415		778
-fert		953	730	548	815	366		682
Mean		1140	866	520	734	391		730
DP								
+fert		1209	1501	424	1077	1095		1061
-fert		1621	1224	502	1269	881		1099
Mean		1415	1362	463	1173	988		1080
Chisel plough								
+fert		325	306	403	156	m		298
-fert		453	439	411	168	m		368
Mean		389	372	407	162	m		333
Plough + cult								
+fert		1590	1392	531	739	628		976
-fert		1579	1638	433	1058	467		1035
Mean		1584	1515	482	898	547		1006
B/cast-plough								
+fert		1090	1137	m	446	m		891
-fert		1033	635	m	537	m		735
Mean		1062	886	m	491	m		813
Overall mean								
+fert		1108	1067	462	614	713		793
-fert		1128	933	473	769	571		775
Tillage		ns	*	ns	ns	ns		
Fertilizer		ns	ns	ns	*	ns		
Tillage x fert. interaction		*	ns	ns	ns	ns		
cv main plot %		62.9	32.5	29.5	61.5	60.7		
cv subplot %		9.6	21.1	16.6	20.6	34.7		
SED_1		497	230	97	301	275		
SED_2		48	94	39	64	129		
SED_3		503	274	112	318	317		
SED_4		108	211	78	143	223		
df for E_a		4	4	3	4	2		
df for E_b		5	5	4	5	3		

[1] Trial planted but considered a failure, **, *, and ns = respectively, highly significant P(>F) < .01, significant P(>F) > .01 and < .05, or not significant. SED_1 = for comparing tillage treatment means over all fert. levels, SED_2 = for comparing fert. treatment means over all tillage treatments, SED_3 = for comparing tillage treatment means at a given fert. level, SED_4 = for comparing fert. treatment means at a given tillage treatment, m = not implemented or failed or data lost.

Table 4. Planting dates, mean site yield at zero P and rainfall at site from 1 September through 30 April, for the 1990/91 fertilizer trials.

Site	Planting date	Yield at 0 P[1] kg/ha	CV	Total rainfall mm
N2, Matsaudi	28.12.91	very variable	62.4	518.0
N3, Shorobe	14.1.91	failed	—	618.9
V1, Pandamatenga	31.12.91	sorghum: 807	17.2	453.1
F1, Mathangwane	6.2.91	sorghum:178	38.9	392.9
S1, Sebele	1.12.90	sorghum:3020	22.5	562.4
S2, Odi	15.12.91	467	39.9	—
G1, Goodhope	12.12.90	2085	15.4	440.9
P2, Tawidi	20.1.91	sorghum: 217	35.4	374.0
P3, Mashupa	23.1.91	very variable	36.2	621.5
J1, Sese	11.1.91	failed	—	351.2

Table 5. Sorghum responses to phosphorus at the eight locations. (Yield = $ax^2 + bx + c$).

Location	a	b	c	R^2
N2	-0.12	9.53	136.05	.75
V1	0.03	2.48	790.46	.85
F1	-0.03	3.34	128.34	.24
S1	0.32	-29.28	280.31	.59
S2	0.23	-7.16	484.80	.72
G1	-1.19	82.13	2180.82	.91
P3	0.01	1.02	244.68	.84

Soil P levels were adequate here to sustain vigorous growth and the applied P was not utilized. Comparing Goodhope with Pandamatenga; the soil test level was lower at Pandamatenga than at Goodhope but the response, although showing an increase, was not significant due to the lower yield obtained.

The foregoing observations show that use of phosphate fertilizers is justified by increased yields on soils that have less than 10 ppm soil P by Bray II and on soils with P levels of up to 20 ppm if a high yield can be predicted from past performance.

Crop Growth Simulation

Because of the press of work on reports related to termination of this project the work with crop simulation was not accomplished.

Because this represents the final report from this project the following "end of tour" report is included.

Program Resume

The main part of this program was based on the consensus that the soil management research work initiated during the final two years of ATIP should be continued for another two years. The main technical objective was to continue, and expand on, the ongoing on-farm and on-station research on tillage and fertilizer practices across various rainfall and soil conditions in Botswana.

A management-by-objectives approach was used to implement the program. A multidisciplinary working group consisting of DAR researchers, ALDEP field managers, the SADCC/ODA Land and Water Management Project, and FAO/UNDP supported Soil Mapping and Advisory Services joint planned and implemented all the field research. Initially, the USAID-sponsored technician chaired and guided the group's activities until a DAR researcher could take over this function in July 1991.

Subsidiary aspects of this program fulfilled the broader objective of the INTSORMIL CRSP to provide technical inputs into DAR programs on genetic improvement of sorghum and millet and control of pests and diseases of these crops.

The program constituted the main portion of the INTSORMIL CRSP's involvement in the SADCC region. During the course of this program, this involvement was coordinated through the Agronomy Department at Kansas State University.

Program Outputs

Including the previous research under ATIP, a total of eight different trials were conducted at 19 on-farm and on-station sites resulting in a total of 115 trial years of data. The number and types of sites and trials increased progressively over the years. They were distributed over all of eastern Botswana and in the Molapo areas around Maun.

The results of this research have been fully documented. They were adequately presented and disseminated locally in Botswana through departmental seminars, and externally to SADCC researchers through the annual regional workshops of the SADCC/ICRISAT/SMIP and the SADCC/ODA Land and Water Management Project. They constitute a comprehensive database on tillage and fertilizer practices in Botswana. From the inception of the program, the field data collection was structured with this end in mind. All the data collected have been computerized and archived in an easily accessible DBASE3 database. Already, the FAO-sponsored LUPSAD project which was launched in late 1991, has made extensive use of these trial data and results to validate their models for dryland crop performance and land use planning. A recent mission from IBSRAM found the reports useful in fulfilling their terms of reference to prepare a comprehensive plan for the Pandamatenga farms. The reports have been requested extensively by BCA students in preparing term papers. Copies were collected by numerous researchers from SADCC countries visiting the DAR. Thus the database and reports are serving a useful purpose for furthering future agricultural research and development in Botswana and in the SADCC region.

With the MBO approach, DAR researchers participated in all aspects of program planning and implementation. The program thus resulted in a self-sustaining group within the DAR, that is experienced and capable in the conduct of a nationwide program of applied research in dryland agriculture. In addition, close working linkages have been forged between the DAR and other departments in the Ministry of Agriculture. Through field days at the trial sites and videos of the program, extension agents have also been brought into closer contact and association with DAR staff.

Other outputs included visits by campus-based INTSORMIL participating researchers from the University of Nebraska at Lincoln, Kansas State University, and Texas A&M University. DAR staff were able to benefit from their expertise in areas of sorghum and millet breeding, dryland agronomy, and pest and disease control.

The program also attempted to further expand external institutional linkages for the DAR. This resulted in visits in late 1990 and in mid 1991 by USDA national program staffers in dryland agriculture, and by a systems modeler from IFDC collaborating on the USAID-funded IBSNAT project. DAR researchers were sponsored to attend several conferences organized by the CRSP in the U.S. and from other countries hosting and participating in the INTSORMIL CRSP.

Publications and Presentations

Persaud, N., A. McPherson, B. Sebolai, S. Beynon, M. Phillips, and N. Mokete. Tillage and Fertilizer Research Programme Report on the 1990/1991 Tillage and Fertilizer Trials. 29 February, 1992.

Persaud, N., W.D. Joshua, N. Mokete, F. Pule, and T.S. Moroke. Tillage and Fertilizer Research Programme Report on the Soils of the Tillage and Fertilizer Trial Sites. 29 March, 1992.

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

Project MSU-111

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Summary

The primary objective of this project is to develop minimum-input technology strategies for the evaluation of Al-tolerant hybrids and varieties grown in tropical savanna soils.

Two sets of 125 Al-tolerant A and B pairs have been distributed to three different NARS (public sector) in South America (IDIAP, Panama; FONAIAP, Venezuela; and ICA, Colombia), and to the private sector (FEDEARROZ, Colombia; CIBA-Geigy, Argentina; ICI, Argentina; and PROSEGRA, Venezuela). Crosses of these sets of lines have been evaluated, using the Al-tolerant lines as females and three different pollinators (TX 430, IA 28, and ICA-Nataima) as males.

ICA is evaluating a new set of advanced materials with better agronomic types than those of the world collection.

Objectives, Production and Utilization Constraints

Objectives

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

To establish a regional program for the development of sorghum and pearl millet germplasm with tolerance of low pH tropical soils with phytotoxic levels of Al.

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

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

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

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

To establish a regional program for the development of sorghum and pearl millet germplasm adapted to tropical environments.

To distribute sorghum and pearl millet germplasm developed from INTSORMIL projects and ICRISAT to national programs in Latin America and Africa.

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

Assist other INTSORMIL PIs in conducting research in Colombia.

Constraints

Most Latin American countries are beginning to open up their markets by freeing imports; international prices will lower domestic prices of some products, especially grains.

Most sorghum in Latin America is grown on valuable lands, making its production unprofitable. An alternative for reducing production costs is to incorporate marginal lands into the production system.

Soil acidity is the most important constraint to increased sorghum and pearl millet production in South America, where the largest acid soil areas in the world are found. These acid soils contain levels of Al, and sometimes Mn, that are toxic enough to inhibit the growth of major cereal crops. This limiting factor can be overcome by using germplasm tolerant of high concentrations of Al in the soil.

A second constraint, possibly more important, is the inadequate management of these highly fragile soils. The ecosystem can be easily destroyed, not only at soil level, but also at the external environment level. Maintaining and, if possible, improving soil structure and nutrient balance are of maximum importance. If the above mentioned savannas could be cultivated under a sustainable agricultural system, the pressure for land on the Amazon Basin would decrease. Agriculture in the savannas can be more easily mechanized and harvested products would be closer to population centers than agriculture in the Amazon region. Crop rotation, new fertilization and soil preparation practices, and integrated pest and disease management must become part of the research tool kit for the future.

The third most important constraint to sorghum and pearl millet production is drought. In many parts of South America, drought, caused by variable rainfall patterns, is an annual problem. Drought tolerance in sorghum needs to be studied.

A fourth constraint to sorghum production is head mold diseases in both acid and nonacid areas. Because sorghum is not produced in the very dry areas of South America, relative humidity is a problem in most production areas. The grain loses its quality and the amount of aflotoxins increases.

Other specific long-term research goals in Colombia are research in pearl millet production and other factors that affect sorghum production such as pathology (other than head diseases) and grain quality.

Research on acid soil constraints would benefit both undeveloped countries and the U.S. in several ways. Al-tolerant germplasm would help increase sorghum production in acid soils in both regions while using fewer inputs. The U.S. would probably receive most benefit through commercial seed companies. By using the proven Al-tolerant germplasm for hybrids in their overseas operations, multinational seed companies would encourage spinoff improvement in U.S. hybrids, especially if a large enough demand develops. Demand for improved varieties and hybrids should be ample in Latin America and Central Africa, both regions deficient in food and feed grains.

Research Approach and Project Output

Adaption of Genotypes to the Environment

The INTSORMIL Program has developed genotypes adapted to the different ecosystems where sorghum has been planted. We must remember that sorghum in Latin America is planted as a second crop and, as such, is not a specialized crop. When we evaluate and select in the experimental field, we must therefore consider HARDINESS as the characteristic that makes sorghum more attractive than other crops. Its HARDINESS is what allows sorghum to be grown as a second crop. If we are to exploit it to our benefit, we need to reduce production costs, thus enabling us to compete in international markets. Sorghum's international price is usually low, especially in countries such as Argentina, which have low production costs and high productivity, or in countries with subsidized prices.

Llanos Orientales (Meta)

For the Llanos Orientales (Eastern Plains) of Colombia, the program has developed genotypes that tolerate as much as 60% Al saturation (level 2). Areas with good road infrastructure, thus facilitating sorghum production, are areas with levels 1 and 2 Al saturation.

Varieties adapted to these ecosystems (levels 1 and 2) would provide an alternative to the commercial hybrids being grown in these regions, especially in the better (vega) soils with Al-saturation levels of less than 30%.

The new genotypes being evaluated must be highly tolerant of head diseases, adapted to soils with low exchange capacity, and resistant to bird damage. Those factors (excluding tannin contents) that influence tolerance of head diseases and bird damage must be studied and evaluated.

Llanos Orientales (Arauca)

The soils of this region have different levels of Al saturation. They range from vega soils (less than 30% Al saturation and an exchange capacity higher than 20%) to soils with Al-saturation levels above 75% and an exchange capacity lower than 10%. Both types of soils are susceptible to flooding.

In this Department, genotypes of the world collection have been evaluated for four years in regional trials and semicommercial fields, to find the best adapted genotypes, especially to flooding, which is highly characteristic of this region.

When rains were heavy during flowering, and soils became waterlogged, INTSORMIL's genotypes resisted flooding, yielding over 2.5 tons of grain/ha in vega soils (level 1). In contrast, in the Arauca Department, if drought occurred during flowering, the genotypes of the first generation yielded less than 500 kg/ha in level 2 soil (between 30% and 60% of Al saturation). THERE IS NO CORRELATION BETWEEN ALUMINUM TOLERANCE AND DROUGHT TOLERANCE.

Breeding and Institutional Building in Colombia

For eight years considerable effort was put into evaluating acid-tolerant lines from the world collection. ICA and the El Alcaraván Foundation, with INTSORMIL's support, have been carefully evaluating the possibility of releasing three lines adapted to Arauca. The lines are IS 8577, IS 6944, and IS 3071. MN 4508 (Sorghica Real 60) and 156-P5 Serere-1 (Sorghica Real 40) were used as commercial checks.

Originally, 30 lines of the world collection were evaluated in the remote region of Arauca where supplies are not easy to get - - an important reason for selecting low-input technology for production and evaluation. INTSORMIL defines low-input technology in Latin America as requiring fertilization levels lower than 60-60-60 of N, P_2O_5, and K_2O, with no fungicides or insecticides.

In Latin America, where rotation with rice is used, sorghum is a second crop. Rice is planted in the rainy season and sorghum in the dry season when lack of water could be a problem. In other regions, rotation is with soy beans or cotton. As a result, INTSORMIL has developed technology that can use residual fertilization from the main crop, and thus efficiently exploit the soil.

Characteristics of the genotypes IS 3071, IS 8577, and IS 6944:

IS 3071

1. The main characteristic, very important in Arauca, is tolerance of flooding. This genotype may be the first to be released for poorly drained savannas (savanna mal-drenada).

2. Yields are better in the rainy season (first semester) than in the dry season (second semester).

3. It is highly tolerant of head diseases.

4. Using low-input technology, it has a yield potential higher than 3.5 tons/ha in vega soils (level 1)—with Al saturation lower than 30%; and a yield potential higher than 2 tons/ha in vegon soils (level 2)—with Al saturation lower than 60%.

5. Plant height in the first semester is about 230 cm. In contrast, plant height in the second semester is about 150 cm.

6. It can be mechanically harvested.

7. The grain's protein content is about 12%.

8. Contents of various polyphenols total less than 1%, according to the Foil and Dennis method.

IS 8577

1. This genotype tolerates high levels of Al saturation, essential in Arauca where 80% of the region's soils are acid. It is considered the most tolerant of genotypes with good yield potential.

2. Yields are better in the rainy season (first semester) than in the dry season (second semester).

3. It is highly tolerant of head diseases.

4. Using low-input technology, it has a yield potential higher than 3.5 tons/ha in vega soils (level 1)—with Al saturation lower than 30%; and a yield potential higher than 2 tons/ha in vegon soils (level 2)—with Al saturation lower than 60%. It can yield more than the economic threshold of 1.7 tons of grain/ha in soils with Al-saturation levels between 60% and 75%.

5. Plant height in the first semester is about 215 cm. In contrast, plant height in the second semester is about 160 cm.

6. It can be mechanically harvested.

7. The grain's protein content is about 12%.

8. Contents of various polyphenols total less than 1%, according to the Foil and Dennis method.

9. Its coefficient of sensitivity is lower than, and statistically different to, 1. It is, therefore, a genotype that yields better in poor soil conditions such as those with high Al saturation.

IS 6944

1. The main characteristic is high yield potential, necessary for vega soils in Arauca. This genotype may be the first to be released for areas with Al-saturation levels lower than 60%.

2. Yields are better in the dry season (second semester) than in the rainy season (first semester).

3. It is highly tolerant of head diseases.

4. Using low-input technology, it has a yield potential higher than 3.5 tons/ha in vega soils (level 1)—with Al saturation lower than 30%; and a yield potential higher than 2 tons/ha in vegon soils (level 2)—with Al saturation lower than 60%.

5. Plant height in the first semester is about 230 cm. In contrast, plant height in the second semester is about 160 cm.

6. It can be mechanically harvested.

7. The grain's protein content is about 12%.

8. Contents of various polyphenols total less than 1%, according to the Foil and Dennis method.

9. This genotype has excellent grain yields. Using low-input technology, it yields between 2 and 6 tons of grain/ha in vega soils, depending on the soil's natural fertility. It is highly efficient in using phosphorus.

New Germplasm

Advanced lines

Since 1990 a new set of lines have been evaluated with the objective of decreasing plant height, keeping resistance or tolerance of head mold and yield potential above 3 tons of grain/ha while using low-input technology at levels 1 and 2 of Al saturation. These lines have been sent from the Arauca Project through ICA-La Libertad - Regional 8. These lines have the same levels of tolerance as the lines of the first generation (lines of the world collection) but their better architectural type is more acceptable to farmers.

Hybrids

National and multinational seed companies in Latin America have a special role in the development and research of the sorghum crop, both 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. INTSORMIL was working on the development of basic or strategic germplasm that will allow the seed industry to be involved in the development of new hybrids or varieties for that ecosystem. INTSORMIL is providing A and B Al-tolerant pairs that can be used by commercial companies as female lines with their own R lines as male lines, thus allowing each company to keep exclusivity for its final product. Such a methodology will have a multiplier effect, because each company would evaluate the basic germplasm according to specific genetic combinations and to the specific markets they are targeting.

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

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

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

Most of this year's research aimed to support ICA in developing the agronomic package for the release of future varieties, in particular to develop minimum-input technologies for the evaluation and production of Al-tolerant lines grown in tropical savanna soils. By using first-generation lines from the world collection, uniform regional yield trials were conducted at sites determined by national programs in Colombia (La Libertad and Arauca), Venezuela, Peru, and Brazil.

Because of quarantine problems with Texan germplasm, the genotypes sent by Dr. Darrell Rosenow in 1991 are being increased at CIAT. In cooperation with other INTSORMIL projects, drought-tolerant sorghum germplasm (Project TAM-122) was evaluated in Motilonia (in collaboration with FENALCE), on the Colombian Atlantic Coast, and at Nataima. Pearl millet germplasm (UNL-118 and KSU-101) was evaluated at ICA-La Libertad. Future phosphorus-efficiency research will be conducted with UNL-114. Studies on use of sorghum in food products involve direct consultation between ICA and INTSORMIL's food quality projects. With the El Alcaraván Foundation, two projects were conducted on the use of sorghum. One project chemically characterized and analyzed the digestibility of sorghum for monogastrics. High levels of both protein (12%) and digestibility were found in sorghum grown at 10% Al saturation in lines MN 4508, 156-P5 Serere-1, and IS 8577. In a cooperative experiment between the National University of

Palmira, CIAT's Cassava Program, and INTSORMIL, sorghum was compared with cassava for feeding rabbits. Sorghum (PPQ-2) was found to be a more effective diet than cassava.

Breeding material was generated from crosses among Al-tolerant sources, agronomically elite lines, and new sources of tolerance. Different sets of segregating material were sent from MSU-104 to be screened at Colombia. Dr. George Teetes's sets have been increased at CIAT and tested under different levels of Al saturation with good results. They were further screened for plant height and tolerance of head mold diseases. Because the first-generation lines from the world collection are tall and late maturing, we aimed to reduce height and maturing time while keeping tolerance of head mold diseases. The world collection lines were grouped according to Al tolerance. Yield trials of the agronomically best performing and Al-tolerant lines were conducted by ICA and El Alcavarán at different levels of Al saturation. In an evaluation of the stability of these lines, Osorio found that IS 8931 was the most stable, according to the Digby (1979) method modified by Granados.

All research conducted for INTSORMIL Project MSU-111 follows the low-input technology approach. Dolomitic limestone (300 kg/ha) is used more as a source of calcium and magnesium than for correcting the acidity of the soil. Only 60-60-60 of N, P_2O_5, and K_2O is used.

Concept of Al-saturation Levels

Since the concept of Al-saturation levels was first developed, different nurseries for each level have been maintained independently. Studies show that lines from F_2 or F_3 populations selected for nonacid soils would lose their tolerance of Al toxicity if only one parent were Al tolerant.

Original classification

Three classes of Al saturation have been selected according to the performance of genetic material in yield trials and other related research. Acid-soil savannas were grouped into classes and subclasses, according to the levels of Al saturation in the soil.

Class 1	0%-35%	Subclasses	0%-20%
			21%-35%
Class 2	36%-60%		36%-45%
			46%-60%
Class 3	61%-90%		61%-75%
			76%-90%

New approaches

Scientists from ICA and FENALCE in Colombia, and EMBRAPA in Brazil, suggested changes in the original classification developed by INTSORMIL to include aspects not considered in the first classification, such as P content, organic matter, exchange capacity, and origin of soil.

This new approach is very significant in that it indicates not only the level of Al saturation at which a variety can produce economic grain yields, but also the agronomic management suitable for that line at a particular level of Al saturation. Varietal response to the different agronomic practices has been found to be directly related to the Al-saturation level of the soil in which the variety is growing. The basis for the new classification is:

Low stress

Soils with pH between 4.5 and 6.5
Origin: alluvial

		P_2O_5	CEC	OM
Class A	0%-20% Al sat.	+ 10	+ 20	+ 4
		- 10	+ 20	+ 4
Class B	21%-30% Al sat.	+ 10	+ 20	+ 4
		- 10	+ 20	+ 4
Class C	0%-30% Al sat.	+ 10	+ 30	- 4
		- 10	+ 20	- 4
Class D	0%-30% Al sat.	- 10	+ 20	+ 4
		- 10	- 20	- 4

Origin: nonalluvial
Soils improved through lime applications or management through time.

		P_2O_5	CEC	OM
Class A	0%-20% Al sat.	+ 10	+ 20	+ 4
		- 10	+ 20	+ 4
Class B	21%-30% Al sat.	+ 10	+20	+ 4
		- 10	+ 20	+ 4
Class C	0%-30% Al sat.	+ 10	+ 30	- 4
		- 10	+ 20	- 4
Class D	0%-30% Al sat.	- 10	+ 20	+ 4
		- 10	- 20	- 4

Medium stress

Soils with pH between 4.5 and 6.5
Origin: alluvial

		P_2O_5	CEC	OM
Class A	30%-45% Al sat.	+ 10	+ 20	+ 4
		- 10	+ 20	+ 4
Class B	30%-45% Al sat.	+ 10	+ 20	+ 4
		- 10	+ 20	+ 4
Class C	46%-60% Al sat.	+ 10	+ 30	- 4
		- 10	+ 20	- 4
Class D	46%-60% Al sat.	- 10	+ 20	+ 4
		- 10	- 20	- 4

Origin: nonalluvial
Soils improved through lime applications or management through time.

		P_2O_5	CEC	OM
Class A	30%-45% Al sat.	+ 10	+ 20	+ 4
		- 10	+ 20	+ 4
Class B	30%-45% Al sat.	+ 10	+ 20	+ 4
		- 10	+ 20	+ 4
Class C	46%-60% Al sat.	+ 10	+ 30	- 4
		- 10	+ 20	- 4
Class D	46%-60% Al sat.	- 10	+ 20	+ 4
		- 10	- 20	- 4

High stress

Soils with pH between 4.5 and 6.5
Origin: alluvial

		P_2O_5	CEC	OM
Class A	61%-75% Al sat.	+ 10	+ 20	+ 4
		- 10	+ 20	+ 4
Class B	61%-75% Al sat.	+ 10	+ 20	+ 4
		- 10	+ 20	+ 4
Class C	76%-90% Al sat.	+ 10	+ 30	- 4
		- 10	+ 20	- 4
Class D	76%-90% Al sat.	- 10	+ 20	+ 4
		- 10	- 20	- 4

Origin: nonalluvial
Soils improved through lime applications or management through time.

		P_2O_5	CE	COM
Class A	61%-75% Al sat.	+ 10	+ 20	+ 4
		- 10	+ 20	+ 4
Class B	61%-75% Al sat.	+ 10	+ 20	+ 4
		- 10	+ 20	+ 4
Class C	76%-90% Al sat.	+ 10	+ 30	- 4
		- 10	+ 20	4
Class D	76%-90% Al sat.	- 10	+ 20	+ 4
		- 10	- 20	- 4

Level 1

Class 1, 0%-35%—Low stress; Subclass 0%-20%, Vega. All susceptible genotypes can perform well under these conditions. The susceptible commercial hybrids and varieties have the potential to produce a grain yield of over 3.5 t/ha. INTSORMIL material is tall under these conditions but with a grain yield of 4 t/ha.

Subclass 21%-25%. In this class, Al saturation affects highly susceptible germplasm and most commercial hybrids have reduced grain yield. Only the most Al-tolerant hybrid will produce reasonably well under these conditions. First-generation lines from INTSORMIL do not suffer effects from these levels of Al saturation.

Class 2, 30%-60%—Medium stress; Subclass 30%-45%, Vega. No susceptible commercial variety or hybrid will produce economically under these conditions. First-generation line from INTSORMIL, 156-P5 Serere-1, is being planned for release for this Al-saturation level. Grain yields expected to be about 3 t/ha, according to Walter Rendón (1988). The economic threshold for the Llanos Orientales, giving 15% profit, is 1.7 t/ha. 156-P5 Serere-1 is one of the shortest of the first-generation lines and has excellent agronomic characteristics for these conditions.

Subclass 46%-60%. Lines such as MN 4508 and IS 9084 performed well under these conditions, although more Al tolerance is necessary for these conditions. In this subclass, the height of first-generation lines reduces to under 170 cm and grain yields are about 2.5 t/ha.

Class 4, 61%-90%; Savanna—High stress; Subclass 61%-75%. Only one first-generation line, IS 8577, will have economic grain yields under these conditions. Height is heavily reduced and drastic stress is evident in most first-generation lines. IS 8577 yields about 2 t/ha in this subclass.

Subclass 75% and above. No germplasm now available yields economically in this subclass. An intensive selection of the most tolerant lines both for varieties and hybrids is in process. Hybridization may be the most appropriate genetic approach to solve this limitation.

Collaborative Sorghum Research

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

Because three varieties may be released in 1993, considerable effort was placed in semicommercial fields consistent with the specific levels of Al saturation where each variety may be released. FENALCE, ICA, CRECED, and the El Alcaraván Foundation have been and will continue to be in charge of these semicommercial fields. In collaboration with CIAT, INTSORMIL will increase basic seed for ICA. INTSORMIL and CIAT will use the profits obtained from basic seed production to support ICA's program.

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

Collaboration with ICA and the El Alcaraván Foundation

La Libertad, Colombia

Over the last three years, regional trials formed the Project MSU-111's main approach for acid soils in Colombia. Because ICA also has a scientist assigned to this region (Mr. Walter Rendón), all work done in El Alcaraván is replicated in full in ICA-Arauca, with the cooperation of ICA and the El Alcavarán Foundation. The El Alcaraván provided support for the evaluation of new segregating materials and hybrids. Joint evaluation of these new lines will strengthen cooperation and result in better defined goals and objectives among El Alcaraván, ICA, and INTSORMIL.

La Libertad has a well-drained savanna ecosystem, whereas Arauca has a poorly drained savanna ecosystem. Twenty-five Al-tolerant lines were tested in these regional trials. As a result of the trials and additional related research, these acid-soil savannas were classified according to the levels of Al saturation in their soils. La Libertad continues to be the main site for evaluating and selecting materials adapted to acid-soil conditions in well-drained savannas.

Department of Arauca, Colombia

Since 1988, sorghum research has been conducted in Arauca in collaboration with the El Alcaraván Foundation, which provided the funds for the experiments. Arauca, typified by poorly drained savannas, was a new research area in Colombia for INTSORMIL and both normal and acid soil sites were used to evaluate sorghum and pearl millet, enabling the project to test selected advanced materials in acid and nonacid soils. Regional trials have been conducted with first-generation lines and resulting progeny was tested in semicommercial fields. In Arauca, research was carried out at three sites with high levels of Al saturation, and five sites with nonacid soils, according to the classification of Al-saturation levels.

The El Alcaraván Foundation supported the B.Sc. thesis by Adolfo Gasca, entitled "Evaluation of General and Specific Combining Abilities of Al-tolerant Lines in Arauca." A second thesis aims to determine the stability of 29 sorghum genotypes, including the first-generation lines in Arauca.

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

The INTSORMIL Sorghum and Millet Collaborative Program, which is headquartered at CIAT, has promoted and established a Latin American network that involves both public and private sectors at the national and international levels in the introduction, interchange, storage, increase, and distribution of germplasm. The network will be located at CIAT and will maintain the most advanced sources of genetic resistance and variability available in advanced research institutions around the world for those Latin American research institutions who work on sorghum and pearl millet.

The companies who will receive the most benefit will be the small national companies which will then be able to get germplasm sources for developing the new lines available in the main research centers but which, for different reasons, are not available to the small Latin American research institutions.

With few resources, this network can have great impact in Latin America.

Networking Activities

Annually, a workshop is organized by ICA, the El Alcaraván Foundation, FENALCE, and the universities. The idea is to share <u>all</u> research results of experiments done in Colombia. The El Alcaraván has been supporting the annual publication of this proceedings.

The meeting is significant, being the only opportunity where a full updating is carried out and a work plan implemented with the participation of all institutions involved in Colombian sorghum research. In 1990, the private sector became involved and future results are expected to be better.

An international meeting, emphasizing crop protection, is to be held at ICA-Tibaitatá, Colombia, with the participation of all Latin American countries. This meeting may provide the basis for a Latin American Sorghum Network. INTSORMIL is playing a major role in the realization of this event, to be held during the last week of January, 1993. The meeting is expected to bring INTSORMIL scientists and Latin American scientists closer, thus strengthening the possibilities of improved research in crop protection.

Publications

Calderón, M. A. 1990. Determinación de la digestibilidad *in situ* y composición química del forraje de diferentes genotipos de sorgo (*Sorghum bicolor*) y millo (*Panicum miliaceum*) en diferentes etapas de crecimiento. Tesis zootecnia. Facultad de Ciencias Agropecuarias, Universidad Nacional de Colombia, Palmira, Colombia. 187 p.

Fundación El Alcaraván/INTSORMIL/CIAT. 1991. Informe de las actividades de investigaciones realizadas en Colombia en el Cultivo de Sorgo. Bogotá, Colombia. 300 p.

Muñoz-Aguedas, G. 1991. Seminario sobre el gusano cogollero *Spodoptera frugiperda*. Comité Interinstitucional de Sorgo (CIS) and CIAT, Cali, Colombia. 122 p.

Sánchez-Cortés, L. 1990. Caracterización química y determinación de la digestibilidad *in vivo* de diferentes genotipos de sorgo (*Sorghum bicolor*). Tesis zootecnia. Facultad de Ciencias Agropecuarias, Universidad Nacional de Colombia, Palmira, Colombia. 206 p.

Table 1. **Nutritive value[a] (in percentage) of different sorghum varieties included in the INTSORMIL collection and in commercial materials harvested in Arauca.**

Variety[b]	DM	CP	SP	NFE	SC	T	IVDMD	IVDMD[c]	Ca	P	GE (Cal/g)	DE (Mcal/kg)
IS 2765	85.02	8.42	50.50	81.07	1.60	0.80	97.20		0.017	0.37	4538	
IS 3522	85.60	9.12	31.92	79.72	1.59	1.29	92.29		0.012	0.38	4610	
IS 6944	85.23	9.64	56.20	76.30	1.74	0.80	91.36		0.018	0.50	4570	
IS 7151	85.41	9.62	41.79	77.99	1.64	1.28	84.48		0.017	0.53	4634	
IS 8577	86.23	11.35	45.00	78.42	1.45	0.82	78.32	88.40	0.016	0.35	4547	4.000
IS 8931	84.56	10.40	44.99	76.68	1.63	0.91	88.15		0.018	0.48	4558	
IS 8996	85.68	9.02	43.51	78.78	1.93	0.92	85.26		0.021	0.43	4588	
IS 9084	86.17	9.93	48.51	78.63	1.85	0.76	87.04		0.018	0.47	4609	
IS 9938	86.29	10.56	42.99	80.00	1.49	1.29	85.54		0.019	0.53	4654	
IS 9945	86.38	10.84	49.24	78.56	1.49	1.15	82.62		0.014	0.39	4506	
IS 12152	86.95	11.06	45.69	78.68	1.52	1.25	79.92		0.017	0.37	4627	
MN 4508	86.63	10.44	44.92	79.66	1.52	1.27	85.68	89.70	0.016	0.41	4528	4.035
PPQ 2	86.81	9.08	42.25	80.19	1.56	0.91	83.69		0.020	0.43	4516	
Serere-1	84.87	11.87	50.87	78.18	1.34	0.65	82.30	88.04	0.015	0.35	4558	3.977
Icaima	87.23	8.78	35.80	83.24	1.30	0.87	77.07		0.013	0.29	4477	
ICA-Nataima	86.66	11.00	55.74	81.03	1.05	0.65	70.37		0.03	0.30	4436	

[a] DM=Dry matter; CP=Crude protein; SP=Soluble protein; NFE=Nitrogen-free extract; SC=Soluble carbohydrates; T=Tannins; IVDMD=In vitro dry matter digestibility.

[b] Sorghum varieties cultivated in savannas.

[c] In vivo dry matter digestibility; Ca=Calcium; P=Phosphorus; GE=Gross energy (Cal/g); DE=Digestibility energy (Mcal/kg).

Source: Sánchez-Cortés, 1990.

Table 2. **Environment index for five lines evaluated in Arauca through 21 locations between 1986 and 1991.**

Environmental Index	IS 8931 (pr=0.98)	Serere-1 (pr=1.12)	MN 4508 (pr=1.09)	Icaima (pr=1.26)	IS 8959 (pr=1.38)
- 1537.1	1075.7	619.7	1007.3		564.4
- 1506.7	1105.4	653.7	1040.5		706.5
- 1470.2	1141.1	694.5	1080.3	689.9	756.9
- 1079.0	1523.5	1131.5	1507.2	1181.4	1297.6
- 842.6	1754.6	1395.6	1765.1		1624.3
- 704.0	1890.1	1550.5	1916.4		1815.8
- 646.3	1046.5	1615.0	1979.4		1895.8
- 559.3	2031.5	1712.1	2074.3	1934.3	2015.9
- 347.0	2239.0	1949.3	2305.9		2309.3
- 134.4	2446.9	2186.9	2537.9		2603.3
- 63.8	2515.9	2265.7	2615.0		2700.9
222.4	2795.7	2585.4	2927.2		3096.4
359.8	2930.0	2739.0	3077.2	2989.0	3286.3
425.5	2994.2	2812.3	3148.8	3071.4	3377.1
506.5	3073.4	2902.9	3237.2		3489.1
980.9	3537.1	3432.8	3754.8	3769.2	4144.8
1113.0	3666.2	3580.4	3899.0		4237.4
1132.1	3684.9	3601.7	3919.8	3959.1	4353.8
1301.0	3850.0	3790.4	4104.1	4171.3	4587.3
1335.9	3884.1	3829.4	4104.2	4215.2	4635.5
1513.4	4057.6	4027.9	4335.9		4880.8

Table 3. Hybrid evaluation of A and B pairs at the El Alcaraván Nueva Sede, Arauca, 1991 B.

Number	Pedigree	Yield	Plant height
1	MS (AT2)- 3-6-1-1-1 X IA28	511.25	125
2	MS (AT1)- 26-1-1-1-1 X IA28	4510.90	142
3	MS (AT1)- 3-2-2-1-1 X TX430	4449.85	114
4	MS TX623 X (TX430 X IS 8577)-26-1-2-1	4353.00	225
5	MS TX623 X IA28	4310.10	153
6	MS (AT1)-24-5-2-1-2 X TX430	4201.80	143
7	MS TX623 X (TX430 X MN4508)-14-1-1-1	4190.80	128
8	MS TX623 X TX430	4102.35	169
9	MS (AT1)-24-5-2-1-1 X IA28	4087.20	126
10	MS (AT2)-7-5-1-2-2 X IA28	4056.35	136
11	MS (AT1)-26-1-2-2-2 X TX430	4002.80	138
12	MS TX623 X (NB9040 X IS 8577)-9-2-1-1	3984.00	127
13	MS TX623 X (TX430 X IS 6944)-12-2-1-1	3963.80	170
14	MS (AT2)-3-3-1-1-2 X IA28	3954.55	127
15	MS (AT1)-24-5-2-1-2 X IA28	3897.70	144
16	MS (AT2)-27-1-1-2-1 X IA28	3889.10	110
17	MS (AT2)-10-6-1-2-2 X IA28	3878.00	120
18	MS (AT2)-10-6-1-2-2 X IA28	3872.60	133
19	MS (AT2)-7-5-1-2-1 X IA28	3755.25	133
20	MS (AT1)-27-2-1-1-1 X IA28	3708.70	126
21	MS (AT2)-9-3-1-2-1 X IA28	3689.55	137
22	MS (AT1)-36-4-2-2-1 X IA28	3684.60	135
23	MS (AT1)-48-2-2-2-2 X IA28	3684.50	131
24	MS (AT1) 27-2-1-1-2 X IA28	3674.85	132
25	MS TX623 X (TX430 X IS 9084)-2-1-1-1	3661.10	163
26	MS (AT1)-26-1-2-2-1 X TX430	3623.20	130
27	MS (AT1)-45-1-2-1-1 X IA28	3621.05	112
28	MS (AT1)-25-6-1-2-1 X IA28	3606.10	138
29	MS (AT2)-14-1-1-1-1 X IA28	3582.70	122
30	MS Wheatland X (TX430 X IS6944)-18-1-2-1	3579.40	140
31	MS (AT2)-3-6-1-1-2 X TX 430	3576.90	145
32	MS (AT1)-48-2-2-2-2 X IA28	3568.05	107
33	MS (AT1)-52-2-1-3-2 X IA28	3566.70	128
34	MS (AT1)-24-5-2-1-2 X TX430	3556.00	113
35	MS (AT2)-7-3-1-1-1 X IA28	3553.85	146
36	MS Wheatland X (TX430 X F Gunk)-6-1-2-1	3536.55	140
37	MS TX 623 X (NB9040 X IS 8577)-37-1-2-1	3535.30	132
38	MS TX623 X (NB9040 X IS8577)-26-2-2-1	3529.90	172
39	MS TX623 X (NB9040 X IS 9084)-8-1-1-1-1	3519.80	115
40	MS Wheatland X (TX430 X IS6944)-12-2-1-1	3499.70	113
41	MS (AT2)-25-1-1-2-1 X TX 430	3486.15	141
42	MS (AT1)-27-2-1-1-2 X IA28	3474.85	117
43	MS (AT1)-36-4-2-2-2 X IA28	3465.90	110
44	MS (AT1)-55-1-1-2-1 X IA28	3463.90	137
45	MS (AT1)-48-2-2-2-1 X IA28	3457.85	162
46	MS TX623 X (TX430 X F Gunk)-5-2-1-1	3417.25	122
47	MS (AT1)- 26-1-2-2-2 X IA28	3396.65	145
48	MS (AT1)-24-5-2-1-1 X TX430	3386.95	

Table 4. Plant height and yield of Sorghica Real 60 and Sorghica Real 40, compared with three other genotypes planted in acid soils with Al-saturation levels between 40% and 60%. Average data for 12 sites in the Department of Meta, Colombia.

Genotype	Plant height (cm)	Yield (kg/ha) Semester A	Semester B	Average
Sorghica Real 60	182	3224	2994	3109
Sorghica Real 40	162	3283	2793	3038
IS 3071	190	2839	2421	2630
IS 8577	187	3312	2795	3053
IS 6944	189	2609	2283	2446

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

Project PRF-105

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Summary

In the Sudan by the end of the '80s, there was an increasing introduction of Hageen Dura-1 (HD-1) in the Gezira in spite of an initial large price differential with local sorghums and complaints about taste and "kisra" quality differences when introduced in the mid-'80s. This continuing diffusion indicates the nature of consumer preferences when a sorghum substantially outyields local cultivars. Within some range, food preferences appear to be a function of economic factors. The appropriate analysis of consumer taste constraints is dynamic, i.e., how do preferences change? With HD-1 introduction, taste preferences apparently evolved over time as reflected in the elimination of the price differential between sorghum types.

The more difficult Sahelo-Sudanian agro-climatic zone contains most of the crop area of Niger. With scarcer rainfall and sandier, often low-fertility soils, agricultural production is difficult. As the fallow period is reduced and eliminated with increasing population pressures, alternative methods of raising soil fertility, such as chemical fertilizer, become increasingly important. Modeling is utilized to indicate those regions where, with changes in policy or specific technical adaptations, chemical fertilizer can become a viable activity and would be adopted. A research resource-allocation strategy could utilize these differences to define priority crop production regions.

In Burkina Faso and Honduras, the programming analysis indicated the potential for yield-increasing technologies including water-retention or soil-conservation improvements. These should not only increase yields but also make the agricultural systems more sustainable. The water-retention/soil-conservation measures made other technologies, including chemical fertilizer and, in Honduras, new sorghum cultivars more profitable. Policy changes to moderate the sorghum price collapses of good rainfall years in Honduras and to reduce the real costs of inputs, as with infrastructure improvements in Burkina Faso, both had substantial effects on new technology adoption. Supporting evidence for model predictions was also observed in recent fieldwork in both countries.

Objectives, Production and Utilization Constraints

Objectives

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

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

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

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

Evaluate the impact of performance of input and product markets in affecting technology introduction.

Constraints

Sudan

Taste and preparation differences between a new cultivar and traditional cultivars have frequently been considered as critical factors constraining adoption. This constraint is evaluated over time with data on price differentials between sorghum cultivars. Sudan is known for pervasive governmental intervention in the economy. The impact of these distortions on the main staple, sorghum, specifically on the returns to new technology adoption is evaluated here.

Niger

As the fallow system disappears with higher population pressures, soil-fertility maintenance and improvement will become increasingly important research and farmer objectives. The simplest way to resolve soil-fertility problems is to use chemical fertilization. However, fertilization often is not profitable or there are other farm-level barriers to its introduction. Programming models were employed to evaluate the farm-level constraints and the potential for fertilizer introduction.

Burkina Faso

One of the puzzles of the development process in the Sahel is when the shift will occur from the introduction of extensive or area-increasing technology, such as animal traction, to intensive or yield-increasing technology including new cultivars and agricultural chemicals. Many possible constraints have been suggested for failures to adopt intensive technologies. Two will be evaluated in this report. First, as long as there is abundant, low-cost bush-fallow land, there is little economic incentive to substitute for land with these new inputs. Secondly, if cereal production is not very profitable, there is little incentive to use new inputs, especially those associated with high labor requirements, such as water-retention technologies.

Honduras

The farmers of southern Honduras face three major constraints. With soil degradation especially on the hillsides, maize and sorghum yields have been declining over time. Labor-intensive conservation devices are required to stabilize the hillsides and prevent the farms from being eroded into the valley. Moreover, these conservation techniques will provide increased water availability, reducing one of the main yield risks in the system. The intercropping of local tall sorghums (maicillos) with maize stabilizes cereal availability to the households for different rainfall regimes. Secondly, with high yield and price risks, few inputs are used in these production systems. New cultivars respond well to increased input use, especially chemical fertilizer. Third, in normal to good rainfall years, the prices of sorghum and maize collapse. The combination of yield collapse in poor-rainfall years and price collapse in good-rainfall years stabilizes expected farm incomes at low levels.

Research Approach and Project Output

Sudan

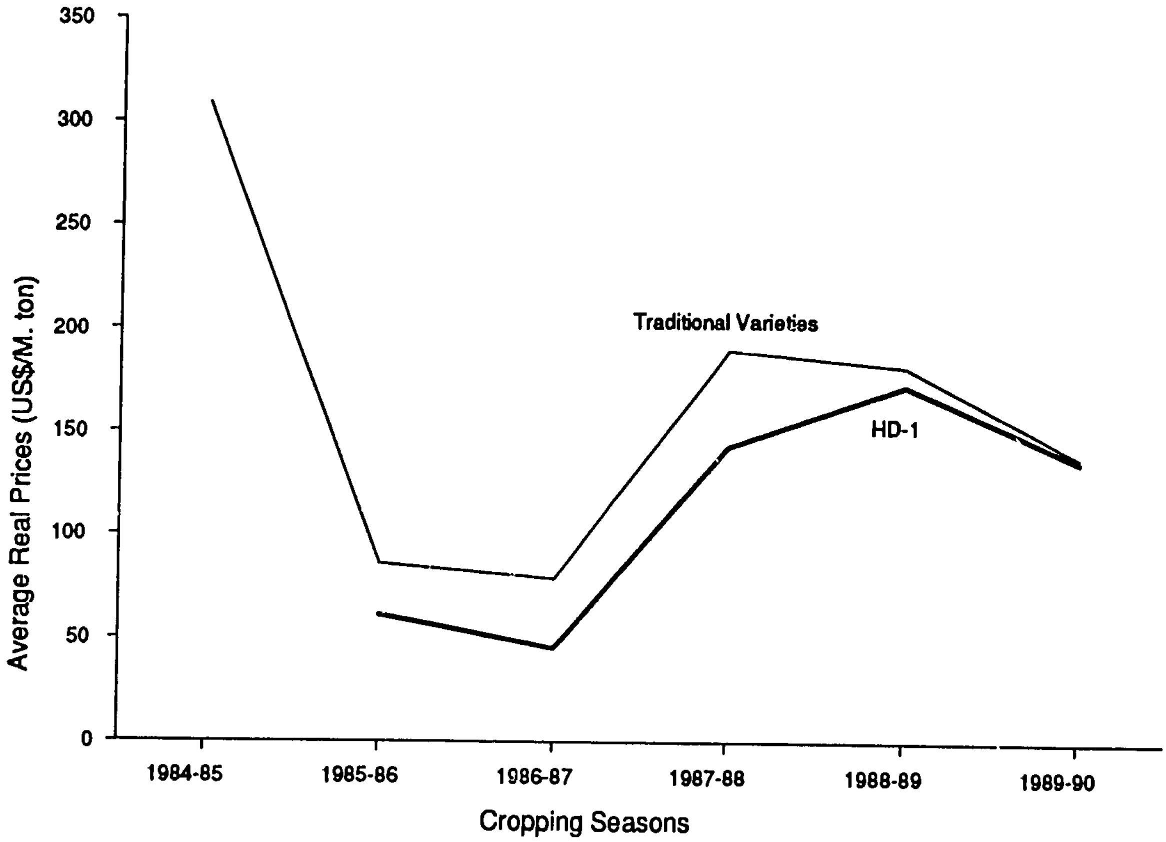
With the high sorghum prices of the drought year (1984-85), crop area increased in the next year from 2.1 million ha to 3.7 million ha on the mechanized vertisols and from 3.4 million ha to 5.5 million ha in the country. Not surprisingly, sorghum prices collapsed (Fig. 1). One important public agency abruptly stopped buying a new sorghum hybrid, Hageen Dura-1 (HD-1) and the price fell even lower for this new hybrid. At this point with large sorghum supplies and low prices, farmers and consumers noted differences in seed size, milling hardness, and poorer "kisra" quality of HD-1.

However, in the Gezira, fertilizer use with irrigation water is profitable and HD-1 responds better to fertilization than traditional sorghums do. Even with low levels of chemical fertilizer, there is a yield advantage to HD-1 of 0.6 t/ha. With moderate fertilization, HD-1 gave over 3 t/ha, a substantial advantage over the traditional cultivar yields of 1 to 1.5 t/ha. These yield differences were on farmers' fields with farmers' practices (Ahmed and Sanders, 1992, p. 22). The price differentials between HD-1 and other sorghums disappeared by the end of the '80s (Fig. 1). In field surveys in the Gezira in the summer of 1990, 90% of the 56 farmers interviewed asserted that the "kisra" from HD-1 was as good or better than that from other cultivated sorghums.

Taste preferences are evaluated at a given point of time. The observed convergence of these price differences indicates an evolution of tastes. The substantial yield differences make the new cultivar much more profitable under high-input conditions than the traditional sorghums. These economic factors are hypothesized to influence consumer preferences over time. Technology introduction and consumer preferences need to be analyzed dynamically over time as economic factors are expected to influence both with some lags.

In the 1991 annual report, the importance of price and exchange-rate distortions on the profitability of Sudanese agricultural activities has been emphasized. Except for favorable rainfall years, the world sorghum price has been substantially below the Sudanese sorghum price at official exchange rates. However, eliminating the overvalued ex-

Figure 1. The price differential of HD-1 relative to traditional sorghum varieties, 1985-90. Source: Ahmed and Sanders, 1992.



change rates removes much of this price distortion. Hence, there is no systematic public policy either reducing or increasing the profitability of sorghum production. Eliminating all these distortions does moderately reduce the profitability of sorghum. However, the effect is much less than on the export crops such as cotton. Moreover, the rate of return from research on HD-1, although slightly reduced, still remains favorable, indicating a profitable social investment (Ahmed and Sanders, 1992, p. 27).

Niger

After intensive fieldwork over 16 months in Niger, farm models were constructed for two regions. These models were utilized to predict adoption of actual and potential technologies. Farmers observed practices of adapting their production decisions to the rainfall patterns at the beginning of the production season were incorporated into the modeling. The models correctly predicted the adoption of early cultivars of millet and cowpeas (Table 1). This diffusion has been observed in Niger recently. The models also predicted higher densities for cowpeas and there are differences in reported field results on this practice.

Chemical fertilizer was not introduced, according to model results. Since chemical fertilizer would be necessary to make these production systems sustainable and to prevent soil mining, various policy and technical changes were simulated to evaluate how to get chemical fertilizer into the cropping system. Most policy changes did not affect fertilizer use because there were alternative investment opportunities with higher returns available to these farmers (Shapiro et al., 1992).

However, the availability of longer-season cultivars with the ability to take advantage of early rains and fertilization did result in their introduction in the model for years with adequate early rainfall (Table 1). The period 1968-85 included several major droughts and rainfall one standard deviation below the long-term normal. Farmers' and breeders' natural response to increased weather stress was to select for earliness. However, as this low-rainfall period becomes history, longer-season-length cultivars will also be demanded by farmers. These cultivars have more potential to respond to higher rainfall conditions and to chemical fertilizer. Breeding and other agricultural scientific development are long-term processes, so diversified strategies and evaluation of the long-term trends are necessary.

Table 1. Model Results of Crop Mix of Expected Incomes[a] for Libore, Niger: Present Technology versus New Technologies.

	Income		Change in total
	Present technology only	New technologies available	income (%)
Expected profit-millet/cowpeas	US $ 466	US $ 624	+34
Expected profit-livestock	$ 116	$ 71	- 39
Wages-agricultural labor	$ 30	$ 29	- 3
Expected profit - rice	$ 220	$ 220	0
Expected total income	$ 832	$ 944	+ 13

Technologies[b]	Farm plan (ha)			Farm plan (ha)		
	States-of Nature before planting			States-of-Nature before planting		
	Early	Normal	Late	Early	Normal	Late
Traditional millet w/cowpeas	3.9	3.9	3.9	2.4	0	0
Improved millet (S.C.) w/cowpeas (S.C.) (high density), P fert. only	n.a	n.a	n.a	0	1.5	1.5
Improved millet (S.C.) w/cowpeas (S.C.) (medium density)	n.a	n.a	n.a	0	2.4	0
Improved millet (S.C.) w/cowpeas (S.C.) (high density)	n.a	n.a	n.a	0	0	2.4
Improved longer cycle millet w/cowpeas (S.C.)(high density) P & N fert.	n.a	n.a	n.a	1.5	0	0

[a] The exchange rate was 298 FCFA/US$.

[b] New technologies: Improved longer-cycle and shorter-cycle (S.C.) millet, improved shorter-cycle cowpeas, fertilizer P and N at planting or P alone at planting, and low and high density shorter-cycle cowpeas.

Source: Model results adapted from Shapiro et al., 1992, p.25.

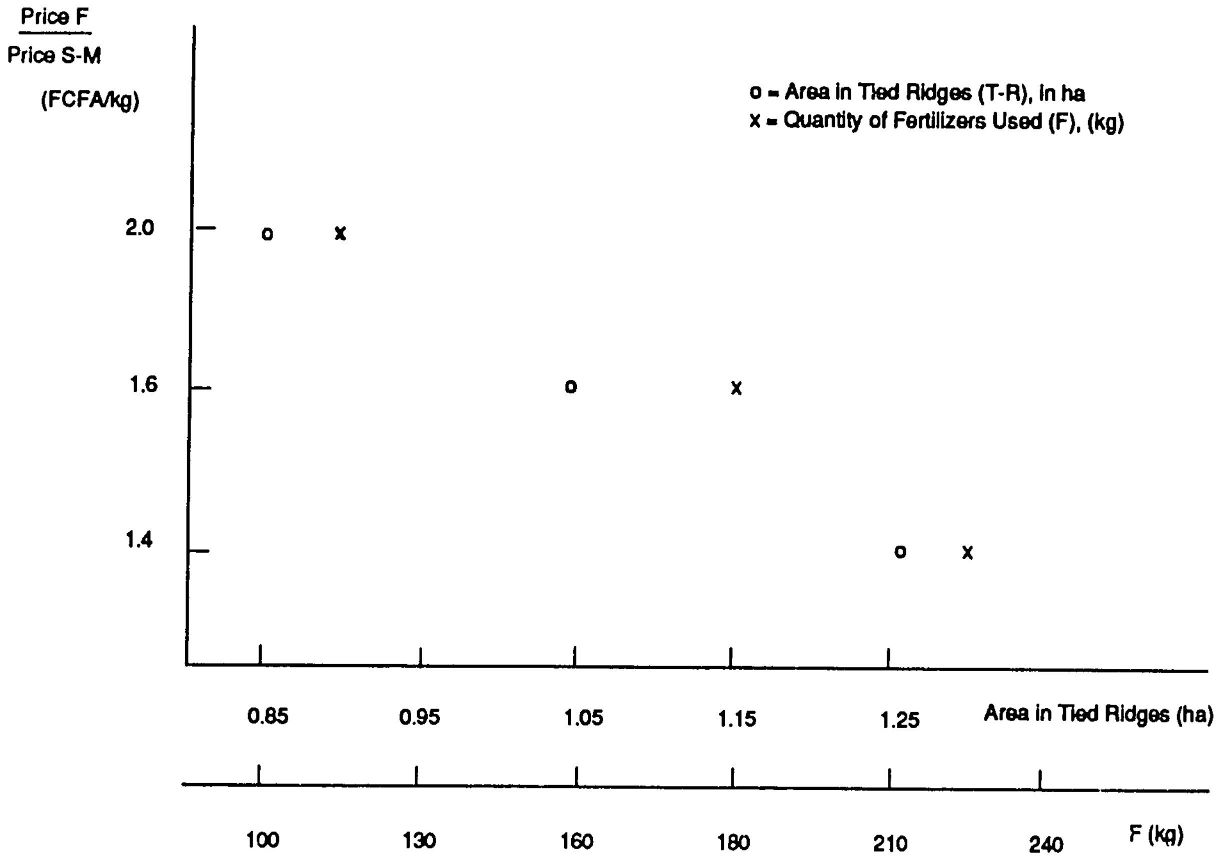
Burkina Faso

Farm-programming models were constructed for the Central Plateau of Burkina Faso. Here high population densities have reduced or eliminated the bush-fallow rotation systems. In the model results, decreasing availability of bush-fallow land results in increasing utilization of more intensive technologies. These model results are consistent with many of the technologies being introduced into the region including contour dikes with manure, increased fertilization, and off-season vegetable production (Ramaswamy and Sanders, 1992, pp. 9, 10, 20-22). Hence, both model and field results show that the shift to intensive technologies is proceeding in this high-population-density region. Unfortunately, income levels are still low, absolutely even with the 36% income increases with new technologies. Moreover, the new technologies are introduced only on a large scale when there is land scarcity and soil degradation. A preferable technology-development strategy would include incentives to introduce yield-increasing technologies before land scarcity and soil degradation. To accomplish this, population growth would need to be slowed and cereal production become more profitable.

When the relative costs of inputs decrease, as with higher output prices, agriculture becomes more profitable and diffusion of new technologies accelerates (Fig. 2). Both of the intensive technologies evaluated here, tied ridges and chemical fertilizer, are increasingly adopted in the model as the relative costs of inputs decreases. To reduce real input costs, governments can take policy measures, such as investments in improved infrastructure (roads) and market information. These investments would help both the incipient input industries (seed firms, chemical fertilizer distribution firms) and the product markets. Another public-policy measure to increase expected profits would be investments to facilitate livestock fattening (sheep and goats) in excellent rainfall years when the price of cereals collapses. All of the above measures would help make cereal production more profitable and encourage diffusion of new intensive technologies. Moreover, governments can influence this process immediately rather than wait for the more negative pressures of population growth and soil degradation to encourage intensive technology introduction.

In previous annual reports (1990 and 1991), women have been shown to be better off with the introduction of new agricultural technologies to the household head rather than with a series of policies directing the agricultural technologies to them and to the land under their control. This result assumes that household decisions are made in a bargaining framework. There is evidence from Burkina and elsewhere that African households make decisions in this way (Sanders and Ramaswamy, 1992, pp. 14-16). Nevertheless, more fieldwork on family decision-making processes and how they change in the process of rapid technological change is very important to complement these studies. Meanwhile, the evaluation of measures to increase family and female welfare has been extended to include household technologies. Measures to increase the efficiency and to reduce the drudgery of female labor are an important aspect of African family welfare. A series of household technologies have been

Figure 2. Effects of improved economic environment on utilization of intensive technologies on the Central Plateau of Burkina Faso.



Notes:

The weighted price of fertilizer (Price F) is constant, with Urea at $0.26/kg and compound fertilizer at $0.36/kg (1988 prices). The average prices of sorghum and millet (Price S-M) were $0.16/kg and increased to $0.20/kg and $0.24/kg, respectively. The prices of other crops were increased proportionally.

Tied ridges and fertilizer are used as complementary inputs on the higher-quality sorghum land. On the compound are (or maize land), only tied ridges are used. Animal traction was utilized to make the ridges.

Exchange rate in 1990 was 273 FCFA/$1U.S. (IMF, 1990).

Source: Ramaswamy and Sanders, 1992.

researched and some promoted in Sub-Saharan Africa. One important set of household technologies includes methods to reduce food-processing time and/or increase food quality, including "sori," a parboiled sorghum technique transforming sorghum into a rice-like product developed by Dr. Lloyd Rooney. Also considered are methods to reduce time of carrying water and collecting firewood. A methodology is developed to economically evaluate these technologies and to compare their effects on households and females with agricultural technologies and off-farm labor. This study, in progress and supported by INTSORMIL, is being undertaken by Ms. Pareena Gupta as part of her Ph.D. dissertation in Economics at Purdue.

Honduras

In previous annual reports (1990 and 1991), the returns to various new technologies have been reported for the low input, hillside systems of southern Honduras. First, soil-conservation techniques reduce runoff and assure an increased water supply. Then new, improved sorghum cultivars (Sureño and Catracho) can be introduced into either the first or second season (Table 2). Finally, the addition of moderate levels of chemical fertilizer, 60 kg of N, further increases yields by another 0.5 to 1 t/ha (Lopez-Pereira and Sanders, 1992b, p. 15). Combining input changes is a difficult process for researchers and farmers. But only with a combined change will there be sufficient

Table 2. Yields of present and new sorghum cultivars without and with soil-conservation technologies in southern Honduras.

		Yields (kg/ha)	
Without Soil-Conservation Technologies		First Season	Second Season
Maicillo (Traditional Sorghum)		780	—
Mixed Crops: Maize/Maicillo	Maize	423	—
	Maicillo	—	553
New Sorghum Cultivars	Sureño	1025	1076
	Catracho	1230	1292
With Soil-Conservation Technologies			
Maicillo		936	—
Mixed Crops: Maize/Maicillo	Maize	508	—
	Maicillo	—	664
New Sorghum Cultivars	Sureño	1179	1238
	Catracho	1415	1486

Note:
The traditional activity yields were collected in a farm survey of 67 farmers on the hillsides of southern Honduras in summer 1989. Traditional activities are long season, allowing only one crop a year. The new cultivars, Sureño and Catracho, can be produced in either the first or second season. Their yields are from experimental data on farmers' fields, provided by Dr. Francisco Gomez and Dr. Dan Meckenstock.

Source: Lopez-Pereira and Sanders, 1992b, p. 14.

returns to get small farmers to adopt new technologies (Lopez-Pereira and Sanders, 1992a). Even with all these changes, agricultural policy is still necessary to avoid the price collapse of good-rainfall years. This policy measure raises expected income from a 16% increase with new technologies alone to a 60% increase (Lopez-Pereira and Sanders, 1992b).

Networking Activities

Workshops and Committees

Sanders was on the organization committee and presented a paper at the Workshop on Social Science Research and the Collaborative Research Support Programs, held at the University of Kentucky, Lexington, June 10-12, 1992. There was a large attendance of social scientists and CRSP agricultural scientists.

An Impact Committee was recruited from a wide range of disciplines and institutions within INTSORMIL. The objective of this unit was to provide input into the ongoing economic evaluation of technology impacts and to make suggestions for future evaluation. The purpose was to draw tighter links between the technical development and the economic and sustainability analysis of those technologies. The committee included:

David Andrews, Breeding, Nebraska
Larry Butler, Biochemistry, Purdue
Larry Claflin, Pathology, Kansas State
Frank Gilstrap, Entomology, Texas A&M
Lloyd Rooney, Food Quality, Texas A&M
Tim Schilling, Management Entity, Nebraska

The committee reviewed Tennassie Nichola's proposed fieldwork in the Sudan to analyze the diffusion of HD-1 and other new technologies. The committee will also be reviewing the research of Pareena Gupta on the impacts of household technologies on female and family incomes. This analysis will include "sori," the parboiled sorghum being developed by Dr. Rooney.

S. Ramaswamy was the coordinator of the 14th annual Middlebury College Conference on Economic Issues, Middlebury, VT, April 3-4, on "Women in Development: Contributions to an Ongoing Agenda." He also was a discussant for the panel on "Women and Structural Transformation." This conference was a continuation for Ramaswamy of his Ph.D. thesis work supported by INTSORMIL. One objective of his Ph.D. dissertation was to evaluate the potential impact of new agricultural technologies and public policy on female farmers in Burkina Faso.

Research Investigator Exchanges

Campus discussions with various scientists directly or indirectly involved with our research program or associated activities included:

Dr. Jerry W. Maranville, Physiologist, University of Nebraska
Dr. Jerry D. Eastin, Physiologist, University of Nebraska
Dr. Abdelmoneim Taha Ahmed, Economist, Agricultural Research Corp., Sudan
Dr. El Hilu Omer, Pathologist, Agricultural Research Corp., Sudan

Collaboration continued with scientists inside and outside of INTSORMIL on the manuscript, "The Economics of Agricultural Technology Development in Sub-Saharan Africa."

Publications and Presentations

Publications

Ramaswamy, S., and John H. Sanders, 1992. "Population Pressure, Land Degradation, and Sustainable Agricultural Technology in the Sahel," Agricultural Systems, forthcoming.

Shapiro, B.I., J.H. Sanders, K.C. Reddy, and T.G. Baker, 1992. "Evaluating and Adapting New Technologies in a High-Risk Agricultural System — Niger," Agricultural Systems, forthcoming.

___, Ousmane Coulibaly, and John H. Sanders, 1992. "Farm-Level Potential of Sorghum/Millet Research in Semi-Arid West Africa," in T. Schilling and D. Stoner (eds.), Proceedings, International Sorghum and Millet CRSP Conference, July 8-12, Corpus Christi, TX. Lincoln, NE: INTSORMIL Management Entity Office, University of Nebraska, Publication No. 92-1, pp. 61-72.

Lopez-Pereira, M.A., and J.H. Sanders, 1992a. "Market Factors, Government Policies, and Adoption of New Technology by Small Honduran Farmers: A Stochastic Programming Application," Quarterly Journal of International Agriculture 31(1):55-73.

___, David Gonzalez-Rey, and John H. Sanders, 1992. "The Impacts of New Sorghum Cultivars and Other Associated Technologies in Honduras," in T. Schilling and D. Stoner (eds.), Proceedings, International Sorghum and Millet CRSP Conference, July 8-12, Corpus Christi, TX. Lincoln, NE: INTSORMIL Management Entity Office, University of Nebraska, Publication No. 92-1, pp. 85-96.

Ahmed, Mohamed M., and John H. Sanders, 1992. "The Economic Impacts of Hageen Dura-1 in the Gezira Scheme, Sudan," in T. Schilling and D. Stoner (eds.), Proceedings, International Sorghum and Millet CRSP Conference, July 8-12, Corpus Christi, TX. Lincoln, NE: INTSORMIL Management Entity Office, University of Nebraska, Publication No. 92-1, pp. 73-84.

Presentations

Ramaswamy, S., 1991. "Are Women Getting Worse Off With Economic Development — Evidence From the Sahel," paper presented at 34th annual African Studies Association meetings, St. Louis, Nov. 24-26.

Sanders, J.H., 1992. "Technology Development of Sorghum and Millet in Semi-Arid West Africa," presented at ICRISAT, Hyderabad, India, Mar., 28 pp.

Sanders, J.H., and S. Ramaswamy, 1992. "Impacts of New Technologies in Burkina Faso and the Sudan and Implications for Future Technology Design," presented at Workshop on Social Science Research Support Programs, University of Kentucky, Lexington, KY, June, 37 pp.

Lopez-Pereira, M.A., and J.H. Sanders, 1992b. "Impacts of Erosion Control and Seed Fertilizer Technologies on Small-Scale Hillside Farmers in Southern Honduras," selected paper, annual meetings of Soil and Water Conservation Society, Baltimore, MD, Aug., 20 pp.

Ramaswamy, S., and J.H. Sanders, 1992. "Population Pressure, Land Degradation, and Sustainable Development," paper presented at third International Association for the Study of Common Property Resources conference, Washington, DC, Sept. 18-20.

Ahmed, M., and J.H. Sanders, 1992. "A New Sorghum Hybrid in Low-Input and High-Input Environments: The Mechanized Rainfed and the Gezira of Sudan," paper presented at USAID Symposium on Impact of Technology on Agricultural Transformation in Africa, Washington, DC, Oct., 31 pp.

Resource Efficient Crop Production Systems

Project UNL-113

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University of Nebraska

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Mr. Minamba Bagayoko, IER, Mali
Mr. Samba Traore, IER, Mali
Mr. Mirghani Mohamed, INTSORMIL/ARC, Sudan
Dr. Saeed Farah, ARC, Sudan
Dr. Francisco Gomez, Sorghum Program, Honduras
Dr. Daniel Meckenstock, INTSORMIL/Honduras
Mr. Patricio Gutiérrez, INTSORMIL, Honduras/USA.
Dr. Jerry Eastin, Professor, University of Nebraska, Lincoln, Nebraska
Dr. Richard Vanderlip, Professor, Kansas State University, Manhattan, Kansas

Summary

Results of the yield of soybeans following sorghum over a long period showed a consistent yield increase as compared to continuously grown soybean.

The greatest increases were when either 0 or 171 kg ha^{-1} N had been applied.

Nitrogen fertilizer and/or the previous legumes greatly influenced growth. Growth data were successfully described by joint polynomial functions to account for leaf senescence. Nitrogen was satisfactory accounted for by exponential functions. The general function fitted to yield and leaf nitrogen was quadratic with no intercept.

Two similar long-term legume-cereal and applied cropping system studies were established in 1990. At the higher rainfall site at Samanko, cropping systems were grain sorghum-peanut based, while at the lower rainfall site at Cinzana, pearl millet-cowpea based systems were used. In both 1990 and 1991 no interaction between cropping systems and N rates occurred for either of two long-term cropping system studies established in Mali. Application of 80 kg ha^{-1} N greatly increased the yield of sorghum grain and sorghum, while pearl millet responded to only 20 kg ha^{-1}. The rotation of grain sorghum with peanut and pearl millet with cowpea increased both grain and stover yield. When sorghum-peanut intercrop was the previous crop, sorghum grain and stover yield was increased over that of continuous grain sorghum, but less than following a peanut sole crop. The previous millet - cowpea intercrop resulted in no improvement of either the succeeding pearl millet grain or stover yield. Grain sorghum showed a greater response than pearl millet to N application and the previous legume or cereal-legume intercrop than did pearl millet. Sole-cropped sorghum following peanut produced a yield equivalent to continuous sorghum with 80 kg ha^{-1} N application. Sole-cropped millet produced a yield equivalent to 40 kg ha^{-1} N application.

Piston displacement in the *in vitro* screening technique for emergence in crusted soils was affected only by the genotype. These large differences in piston displacement among the 8 grain sorghum genotypes studied indicating that variability in the ability to emerge through crusted soils exists in grain sorghum germplasm. The lack of a positive association between percent potential germination and coleoptile length with ability of sorghum to emerge through an *in vitro* simulated soil crust indicated that these parameters would be of little use in breeding programs to indirectly select for improved emergence in crusted soils. Coleoptile diameter was highly correlated with ability of sorghum to emerge through a soil crust (0.84 to 0.87), but seed production year X genotype interactions occurred. Coleoptile diameter in germination paper may be an effective initial screening technique, but confirmation of results using the piston displacement screening technique is recommended. The genotype IA9 was superior to all other genotypes studied, and could be useful in breeding programs to improve the ability of grain sorghum to emerge through crusted soils.

Weeds are very competitive with crops for water and nutrients. For Segaolane and two hybrids in Nebraska, water

use efficiency was reduced if weed were allowed to grow. On the average, water use was increased 133% with partial weed control and 226% with complete weed control. This suggests farmers could significantly increase yields if they did not let weeds consume the water that could be available for the desired crop.

The maicillos criollos are a group of landrace sorghum populations used by subsistence farmers in Central America. The maicillos are intercropped with maize and initially exist under low light. No differences in photosynthesis (PS) were found between the maicillos Casho de chivo and San Bernardo III compared to the temperate variety TAM428 when planted in pure stand. PS reached averaged values of CO_2 evolution of 90 μmol m^{-2} s^{-1} at a light intensity of 1700 μE m^{-2} s^{-1}. Thus, the potential photosynthetic capacity of the maicillos is similar to that of temperate sorghum. Both maicillos had higher photosynthetic rates at light intensities less than 700 μE m^{-2} s^{-1}. In Aporque, San Bernardo III reached PS values of 55 μmol CO_2 m^{-2} s^{-1} at 200 μE m^{-2} s^{-1} whereas TAM418 reached PS values of 35 μmol CO_2 m^{-2} s^{-1} at the same light intensity. A similar response was observed in Casado (data not shown). This tolerance of maicillo to shade will open a wide range of opportunities to increase productivity in mixed cropping systems. It will be particularly useful for use in agroforestry systems such as alley cropping with fast growing leguminous trees.

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 moisture relationships.

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

Long-term studies to determine sorghum genotype (tall, intermediate, short) by residue management interaction effects will be continued in Mali.

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

Constraints

There are many constraints involved with cropping systems studies. First, they are long term investments. For instance, once a rotation or intercropping system is started it takes time to stabilize. These systems cannot be stopped and restarted. Second, a host scientist must be genuinely interested in these long term projects and they will need added funding. 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 next most influential environmental factor affecting plant growth and yield is often adequate nitrogen and/or phosphorus. The importance of these elements is becoming even greater with more intensive cropping practices used when availability of new land is limited. Legumes become a viable means for improving soil fertility (especially nitrogen status and maybe phosphorus) as monetary constraints for purchasing fertilizer occurs in many developing countries. Improved fertility also improves water use efficiency of grain crops.

Rotations

Grain sorghum-soybean rotation

Research Methods

Sorghum and soybean can be grown in rotation, a sustainable agricultural system. Although cereal yields are improved, little information is available on the affect of the rotation on the legume. The experiment is planted in a randomized complete block design with four replications. Plots are thinned to a uniform stand about two weeks after emergence and 0, 57, 114, and 171 kg N ha^{-1} was applied as ammonium nitrate to the designated sorghum plots. Yield and yield components and agronomic data is taken from the two middle rows of six row plots.

Research Results

Results of the yield of soybeans following sorghum over a long period are shown in Table 1. There is a consistent yield increase of soybean when grown after sorghum. However, there is a greater increase where either 0 or 171 kg ha^{-1}

Table 1. Seed yield of soybean following grain sorghum over a ten year period as compared to continuously grown soybean. (1975 and 1977-1986.

Treatment	Yield	Increase over the control
	- - kg ha^{-1} - -	- - % - -
Cont. soybean (0 N)	2335	- -
Soybean (0 N)*	2520	7.9
Soybean (57 N)	2432	4.1
Soybean (114 N)	2440	4.5
Soybean (171 N)	2552	9.3

[*] Nitogen was applied to the previous sorghum crop.

N has been applied. Speculatively, this advantage may be due to a reduction of mildly infectious soil borne organisms and residual soil N.

Bionitrogen availability and water use efficiency of grain sorghum grown in rotation with legumes in Sudan.

Mirghani S. Mohamed

Research Methods

SRN-39 is a sorghum cultivar that shows *Striga* resistance. Since it is a relatively new cultivar in Sudan, little information about its growth, N partitioning patterns, and its yield is available.

A rotation experiment was established at Wad Medani in 1988. Sorghum (*Sorghum bicolor* [L.] Moench) variety HD-1 was used. Since *Striga* was a problem, the sorghum cultivar "SRN-39" was used the next two seasons as it shows *Striga* resistance. The legumes used were clitoria (*Clitoria ternata* L.) and phillipesara (*Phasulus trilobus* Ait). The design was a randomized complete block with five replications. Treatments were continuous sorghum at three nitrogen fertilizer rates (0, 40, and 80 kg ha^{-1}) and sorghum rotated with clitoria, phillipesara and fallow. Leaf area and plant weight were sampled at nine growth stages according to R. Vanderlip's criteria.

This part of the study was designed to model growth and N concentration in the vegetative parts.

Research Results

Nitrogen fertilizer and/or the previous legumes greatly influenced growth. Growth data were successfully described by joint polynomial functions. The equations for growth are:

a. plant weight: $\ln W = \alpha + \beta X + \gamma X^2 + \delta X^3$

b. leaf area: $\ln A = \alpha + \gamma^{\sim}(X - X_o)^2$ when $X < X_o$

$\ln A = \alpha + \gamma'(X - X_o)^2 + \delta'(X - X_o)$ when $X > X_o$

where X is the cumulative growing degree units (with base temperature = 15°C), X_o is X when the slope is equal to zero. The use of the second equation allows for leaf senescence. Regression showed that the models accounted for 95% of the variability.

Nitrogen was satisfactory accounted for by exponential functions. The equations are:

c. leaf N concentration: $\eta_l = \alpha + \beta(e^{-\gamma x})$

d. stem N concentration: $\eta_s = \alpha(e^{-\gamma x})$

where η_l,s is the estimated N concentration of leaf and stem respectively. α, β and γ are exponential constants with some biological meanings.

The general function fitted to yield and η_l was quadratic with no intercept. The equation is:

e. Yield: $\hat{Y} = \beta \eta_i - \gamma \eta^2_i$

Where $\hat{Y}$ is the estimated yield, η_i is the leaf N concentration which can be predicted from previous η_l at i^{th} growth stage

Cropping Systems Research in Mali

Minamba Bagayoko

Research Methods

Two similar long-term cropping system studies were established in 1990. At the higher rainfall site at Samanko, cropping systems were grain sorghum-peanut based, while at the lower rainfall site at Cinzana, pearl millet-cowpea based systems were used. Randomized complete block designed experiments with split plot treatment arrangement and 4 replications were used. Continuous sole crop, continuous intercrop, and rotational systems were included as whole plot treatments, with N fertilizer rates as subplots. Data collected included grain yield and yield components, and stover yield.

Research Results

In both 1990 and 1991 no interaction between cropping systems and N rates occurred for either study. Application of 80 kg ha^{-1} N greatly increased the yield of sorghum grain and sorghum, while pearl millet responded to only 20 kg ha^{-1} (Table 2).

Table 2. Influence of N rate on grain and stover yields of sorghum and pearl millet in 1991.

	Sorghum yield			Pearl Millet yield	
N rate	Grain	Stover	N rate	Grain	Stover
			kg ha^{-1}		
0	1195 a	3161 a	0	970 a	2545 a
40	1488 b	3819 b	20	1144 b	3380 b
80	1724 c	4544 c	40	1048 b	3528 b

Means within each column followed with the same letter are not significantly different at $P<0.05$.

The rotation of grain sorghum with peanut and pearl millet with cowpea increased both grain and stover yield (Table 3). When sorghum - peanut intercrop was the previous crop, sorghum grain and stover yield was increased over that of continuous grain sorghum, but not as much as following a peanut sole crop. In contrast, the previous millet - cowpea intercrop resulted in no improvement of either the

Table 3. Influence of previous crop on grain and stover yield of grain sorghum and pearl millet in 1991.

Previous crop	Present crop	Grain yield	Stover yield
		------- kg ha^{-1} -------	
		Samanko	
Grain sorghum	Grain sorghum	1393 a	3138 a
Grain sorghum-Peanut intercrop	Grain sorghum	1961 b	4837 b
Peanut	Grain sorghum	2435 c	6865 c
		Cinzana	
Pearl millet	Pearl millet	1131 a	3657 a
Pearl millet Cowpea intercrop	Pearl millet	1144 a	3175 a
Cowpea	Pearl millet	1350 b	4422 b

Means with identical letters have no significant differences among them at $P<0.05$. Mean separations done within each experiment.

succeeding pearl millet grain or stover yield. Grain sorghum showed a greater response than pearl millet to N application and the previous legume or cereal - legume intercrop than did pearl millet. Sole-cropped sorghum following peanut produced a yield equivalent to continuous sorghum with 80 kg ha^{-1} N application, while sole-cropped millet produced yield equivalent to 40 kg ha^{-1} N application. Analysis of intercropping efficiency using Land Equivalent Ratios (LER) indicated that the pearl millet - cowpea system was superior to the grain sorghum - peanut system (LER of 1.50 versus 1.15).

Grain Sorghum Emergence In Crusted Soils

Research Procedures

Studies were conducted from Dec. 1991 through May 1992 using grain sorghum kernels of the genotypes IA9, IA17, IA33, KS3, KS22, KS24, KS33, and N4692 produced during the 1988, 1989 and 1991 growing seasons. All studies were conducted using a completely randomized experimental design with split-plot treatment arrangement. Years were whole plots, and genotypes sub-plots.

Estimates of genotypes ability to emerge in crusted soils were determined using an *in vitro* screening technique. Kernels were pregerminated at 25° for 32 hours, transferred into growth tubes and 3.7 + 0.1 g piston assemblies placed over the kernels. Ability to emerge was estimated by measuring the distance between the growth tube cap and the tip of the protruding piston shaft immediately after transfer to the growth tubes and 120 hours later. Three replications of 10 growth tube samples were used.

Coleoptile diameter was determined in growth tubes with piston assemblies, and in germination paper. Coleoptile diameters were measured 1 cm from the top and bottom of coleoptiles, and in the middle using a micrometer. Data are presented as the average of the 3 measurements. Coleoptile length and curling, kernel weights and percent potential germination at 32 and 128 hours were also determined.

Analysis of variance procedures were used for data analysis, and L.S.D.s at P = 0.05 were used for mean separation. Correlation of treatment means across years was used to determine the interrelationship among piston displacement, coleoptile length and diameter, kernel weight, and percent potential germination.

Research Results

Piston displacement in the *in vitro* screening technique was affected only by the genotype, while year of seed production and year X genotype interaction effects were not significant. There were large differences in piston displacement among the 8 grain sorghum genotypes studied (Table 4) indicating that considerable variability in the ability to emerge through crusted soils exists in grain sorghum germplasm. Piston displacement by genotypes in this *in vitro* screening technique was relatively stable across years and apparently was not greatly influenced by the seed production environment.

Table 4. Piston displacement in an in vitro screening technique for emergence through a crusted soil, and coleoptile diameter for kernels of grain sorghum genotypes produced in 1988, 1989 and 1991.

Genotype	Piston displacement (Average across years)[1]	Coleoptile diameter					
		Growth tubes - with piston			Germination paper		
		1988	1989	1991	1988	1989	1991
		------------	------------	mm	------------	------------	
IA9	28	1.48	1.60	1.51	0.77	0.83	0.80
KS3	17	1.35	1.26	1.37	0.60	0.69	0.70
IA33	17	1.27	1.30	1.26	0.61	0.67	0.64
IA17	16	1.17	1.22	1.15	0.57	0.70	0.62
N4692	14	1.25	1.10	1.12	0.61	0.60	0.58
KS24	14	1.19	1.15	1.16	0.45	0.55	0.45
KS22	9	1.10	1.16	1.09	0.57	0.60	0.58
KS33	8	1.04	0.86	0.89	0.44	0.48	0.43
L.S.D.(0.05)	2.5	0.103	0.111	0.138	0.065	0.053	0.056
C.V. (%)	17	9	10	13	13	9	10

[1] Year X Genotype interaction was not significant.

Coleoptile diameters were greater in piston containing growth tubes than in germination paper (Table 4). Large differences in coleoptile diameter were found among genotypes. Year of seed production X genotype interactions were present for all methods used. However, in all three years and for both methods of measurement, the genotype IA9 had the greatest coleoptile diameter, while KS33 had the smallest. These results suggested that genetic differences among genotypes for coleoptile diameter exist, and that these differences are magnified when growth is physically impeded.

Piston displacement by grain sorghum genotypes in the *in vitro* screening technique was positively correlated with coleptile diameter and kernel weight, and negatively correlated with percent potential germination at 32 hours and degree of coleoptile curling (Table 5). The magnitude of correlation coefficients between piston displacement and coleoptile diameter (0.84 to 0.87) indicated that coleoptile diameter is a key morphological characteristic associated with capability to emerge through a crusted soil while coleoptile length is of limited importance. Speed of germination is often used as a measure of seed vigor, but in this study, percent potential germination at 32 hours was negatively correlated with ability to emerge through crusted soils.

The lack of a positive association between percent potential germination and coleoptile length with ability of sorghum to emerge through an *in vitro* simulated soil crust indicated that those parameters would be of little use in breeding programs to indirectly select for improved emergence in crusted soils. Coleoptile diameter was highly correlated with ability of sorghum to emerge through a soil crust, but seed production year X genotype interactions occurred. Coleoptile diameter in germination paper may be an effective initial screening technique for ability to emerge in crusted soils, but confirmation of results using the piston displacement screening technique is recommended. The genotype IA9 was superior to all other genotypes studied, and could be useful in breeding programs to improve the ability of grain sorghum to emerge through crusted soils.

Weeds

Sorghum grown at three levels of nitrogen fertility and three levels of weed control

Charles Maliro

Research Methods

An experiment was established to determine the partitioning of weeds/grain/ stover cropped plots with different levels of weed control and nitrogen. Weed treatments consisted of no weed control, 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 sub-plots were nitrogen levels. Three replications were used. Samples were harvested from the middle two rows of six row plots.

Table 5. Correlation coefficients and probability levels for piston displacement, coleoptile diameter and length, kernel weight and percent potential germination.

	Coleoptile diameter		Coleoptile			% Potential germination	
	Growth tube with piston	Germination paper	Length	Curl	Kernel weight	32 hours	128 hours
Piston displacement	0.87	0.84	-0.25	-0.62	0.46	-0.43	-0.14
	<0.01	<0.01	NS	<0.01	0.03	0.04	NS
Coleoptile diameter:		0.85	-0.46	-0.71	0.43	-0.31	-0.03
Growth tube with piston		<0.01	0.02	<0.01	0.04	NS	NS
Germination paper			-0.46	-0.61	0.59	-0.34	-0.21
			0.02	<0.01	<0.01	NS	NS
Coleoptile length				0.65	-0.37	-0.08	-0.15
				<0.01	NS	NS	NS
Coleoptile curl					-0.40	-0.01	-0.05
					NS	NS	NS
Kernel weight						-0.21	-0.14
						NS	NS
% potential germination: 32 hours							0.69
							<0.01

Results

Weeds are very competitive with crops for water and nutrients. Their competitive effect is even more detrimental if these resources are not readily available. This is shown in Table 6. For Segaolane and two hybrids in Nebraska, water use efficiency was reduced if weeds were allowed to grow. On the average, water use was increased 133% with partial weed control and 226% with complete weed control. This suggests farmers could significantly increase yields if they did not let weeds consume the water that could be available for the desired crop.

Table 6. Grain water use efficiency* of sorghum with different levels of weed control.

Genotype	No-weeding	Cultivation after 3 wks	Complete weed control
	----------	$g\ m^{-2}\ cm^{-1}$	----------
Segaolane	4.42	8.75	10.82
Dk 48	5.09	12.09	14.89
Dk 39y	3.75	10.12	17.61
Mean	4.42	10.32	14.44

*grams grain per square meter per centimeter water.

Intercropping

Physiologic response of landrace sorghum to light intensity and intercropping

Patricio Gutiérrez

Research Methods

The maicillos criollos are a group of landrace sorghum populations used by subsistence farmers in Central America. Traditionally, maicillos are planted intercropped with maize to hedge against drought spells that severely reduce the grain yield of maize. To evaluate the effect of intercropping and the tolerance to shade of maicillo, 12 sorghum cultivars (three maicillo populations, three temperate varieties and six enhanced maicillo cultivars) were evaluated using three cropping systems, pure stand, casado and aporque. Casado means married in Spanish, and its name comes from maize and maicillo being planted together in the same row, whereas Aporque derives its name from the practice of planting maicillo between the rows of maize at the time of its cultivation. JX3, a short season maize variety, was used to provide natural canopy shade.

The experiment planted at Mead, NE had a randomized complete block design arranged as a split-plot with three replications. Cropping systems comprised the main plots and sorghum genotype was the split plot effect. Since maicillo won't flower in Nebraska due to its sensitivity to photoperiod and seasonal requirements, a similar experiment was planted in Honduras with the aid of Dr. Dan Meckenstock (TAM-131), therefore starting a collaborative effort to improve sustainable production systems in Honduras.

Research Results

No significant differences in photosynthesis (PS) were found between the maicillos Casho de chivo and San Bernardo III compared to the temperate variety TAM428 when planted in pure stand (Fig. 1). PS reached averaged values of CO_2 evolution of 90 $\mu mol\ m^{-2}\ s^{-1}$ at a light intensity of 1700 $\mu E\ m^{-2}\ s^{-1}$. Since conditions for PS are non-limiting in pure stand, this result show that the potential photosynthetic capacity of the maicillos is similar to that of temperate sorghum. When radiation is intercepted from the canopy of maize, and light becomes a limiting factor, both maicillos had higher photosynthetic rates at light intensities less than 700 $\mu E\ m^{-2}\ s^{-1}$. In Aporque, San Bernardo III reached PS values of 55 $\mu mol\ CO_2\ m^{-2}\ s^{-1}$ at 200 $\mu E\ m^{-2}\ s^{-1}$ whereas TAM418 reached PS values of 35 $\mu mol\ CO_2\ m^{-2}\ s^{-1}$ at the same light intensity (Fig. 2). A similar response was observed in Casado (data not shown).

This tolerance of maicillo to shade will open a wide range of opportunities to increase productivity in mixed cropping systems. It will be particularly useful for use in agroforestry systems such as alley cropping with fast growing leguminous trees.

Ongoing Research

Greenhouse and growth chamber experiments are being conducted to determine differences in respiratory rates of maicillo and to determine if there are differences in CO_2 compensation point between maicillo and temperate sorghum. Also, temperature-response curves with low light intensities are being developed for maicillo.

Networking Activities

<u>Internship</u>: African Internship, Rockefeller Foundation (Mirghani Mohamed, completing his dissertation).

<u>Faculty Development Leave</u>: Dr. Steve Mason completed a year studying mechanisms influencing emergence in crusted soils.

<u>SICNA Tour</u>: Max Clegg organized and coordinated a SICNA sorghum tour with Nebraska and Kansas, September 10-11, 1992.

Assistance Given

Pass through of $7000 to IER, Mali for Cropping Systems Research.

Partial funding ($250) for Dr. Louis Mazhani to attend International Crop Science Congress, 14-22 July 1992, at Iowa State University, Ames, Iowa.

Publication and Presentations

Publications/Abstracts

Bagayoko, M., S.C. Mason, and R.J. Sabata. 1992. Effects of previous cropping systems on soil nitrogen and grain sorghum yield. Agronomy Journal 84: 862 - 868.

Clegg, M.D. 1992. Predictability of grain sorghum and maize yield grown after soybean over a range of environments. Agric. Systems. 39:25-31.

Maliro, C.E., and M.D. Clegg. 1992. The influence of nitrogen fertilizer and weed control on partitioning of total biomass into sorghum grain, stover and weeds. Agron. Abst. p.69.

Mason, S.C., J. Lasschuit, and J.M. Lasa. 1992. Sorghum genotype emergence using an *in vitro* soil crust technique. Agron. Abst. p. 150.

Mason, S.C., J.M. Lasa, J. Lasschuit, and A. Garcia. 1992. Heritability of sorghum emergence using an *in vitro* crusted soil technique. Agron. Abst. p. 106.

Youngquist, J.B., D.C. Carter, W.C. Youngquist, and M.D. Clegg. 1990. Phenotypic and agronomic characteristics associated with yield and yield stability of grain sorghum in low rainfall environments. Bull. of Agr. Res. in Botswana 8:21-33.

Presentations

Mason, S.C. Nov. 1991. Crop production research in Nebraska. Seminar presented to staff, Estacion Experimental de Aula Dei, Consejo Superior de Investigaciones Cientificas.

Dr. Max D. Clegg gave a presentation "Sorghum production" at the AgriPro farmer workshop, March 3, 1992, Crete, NE

Mason, S.C. June, 1992. Emergence of grain sorghum in crusted soils. Seminar presented to agricultural faculty, University of Hohenheim, Stuttgart, Germany.

Figure 1. Sorghum photosynthesis during vegetative growth in pure stand at Mead, NE. 1992.

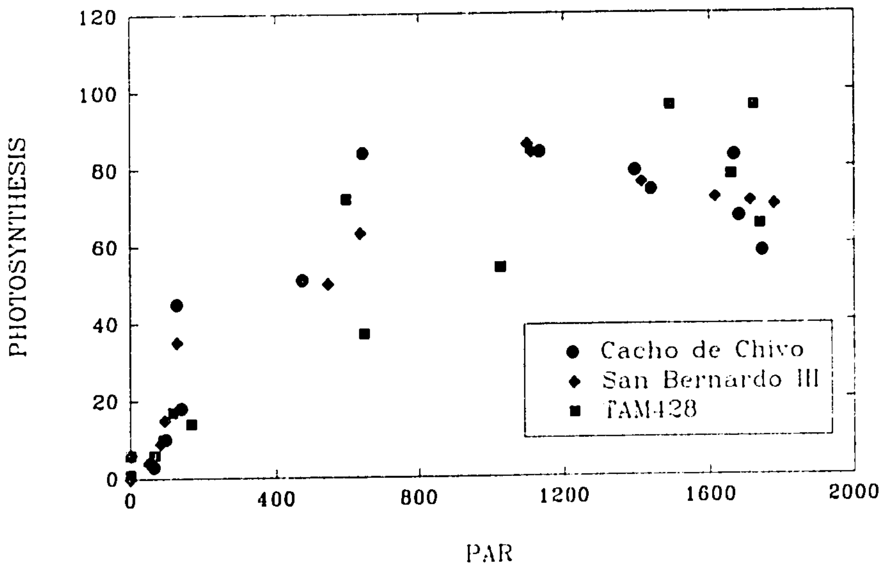
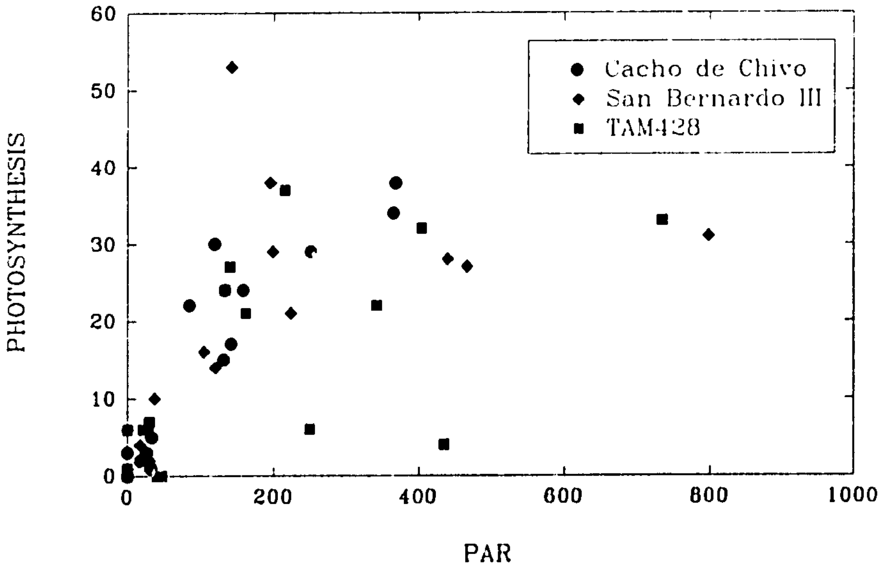


Figure 2. Sorghum photosynthesis during vegetative growth in aporque at Mead, NE. 1992.



Nutrient Use Efficiency in Sorghum and Pearl Millet

Project UNL-114

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Summary

Experiments were conducted in the field on pearl millet at Mead, Nebraska to determine nitrogen (N) effects on pearl millet growth and N use efficiency. The results of these studies showed that pearl millet response to N was limited when residual soil N is high. The crop was most responsive to time of N application when higher rates were used. Genotypes differed in response to time, rate and splitting of applied N. Pearl millet also does not respond well to supplemental water if seasonal rainfall is adequate for good crop growth. Some genotypes may even produce less grain if moisture content is in excess. Genotypes differed for N use efficiency with the improved types being superior in N use efficiency for grain production.

Another set of experiments was conducted at several locations in Mali on grain sorghum response to applied N. These results showed that sorghum responds well to applied N in areas of better soils and sufficient rainfall, but do not respond in drought prone areas where sandy soils are prevalent unless good seasonal precipitation is received. Improved genotypes respond better to good management than the unimproved local types if disease or other environmental hazards which may affect stands and early growth are kept under control. It is obvious that improvement in genetic packages and good management options must go hand in hand.

Objectives and 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 to Reaching Technical Objectives

The work in Mali appears to be on track. This project has provided equipment to facilitate the N efficiency research which should allow quicker turnover of results. The largest constraint to this collaboration appears to be the cost of N analyses in the Mali lab. Comparing their cost to what we can process samples for here at UNL, we found that Mali is about three times higher which reduces the amount of material which we can process and effectively reduces the number of experiments we can conduct in this area. This constraint has not been addressed satisfactorily at this point.

Abdoul Toure has just returned to Mali and it is not certain whether he will take over the UNL-114 effort. With the departure of Abdoulaye Traore to Nebraska for Ph.D. studies, a potential restraint to activities may exist until Toure gets reincorporated into the system, or until a new collaborator is assigned. Currently, Minamba Bagayoko is assisting in keeping the UNL-114 collaboration going.

Work in Niger has been on hold until Mr. Seyni Sirifi completes his degree and returns.

Research Approach and Project Output

Domestic

Study 1 (Abdoul Toure, Mali)

The second year's field work was conducted to complete requirements for the M.S. Thesis. The experimental design and treatment combinations were the same as those previously reported (see INTSORMIL 1990 Annual Report, pp. 27-34). Briefly, four levels of N (0, 28, 56 and 112 kg ha^{-1}) were applied to two pearl millet genotypes (ICTP-8203 and 68A x MLS) at emergence, 25 and 50 days after emergence (DAE). This report will show results of the combined 1989-90 seasons.

Grain yield data are presented in Table 1 and show significant differences existed between the genotypes averaged over all rates and N split treatments. Genotype 68A x MLS was the best in terms of grain yield, and was the shorter, improved genotype. Increasing N rates tended to increase yields up to 112 kg ha^{-1} when applied at emergence (0 DAE), or one half at emergence and the remainder at 25 DAE. There was little advantage to splitting N application as late as 50 DAE for these genotypes.

Total stover yield (Table 1) showed that genotype ICTP-8203 was significantly better for this parameter. The response of this taller, less improved genotype in producing large amounts of stover in comparison to grain is typical of the "local" adapted variety response in the West African region. Nitrogen application did not improve stover yields of either genotype and tended to have a depressive effect at the very high rate regardless of when the N was applied. The notable exception was for ICTP-8203 when N was split at O DAE and 25 DAE where the response to increasing rate was linear.

Total N uptake (data not shown) was increased significantly by N fertilizer as would be expected, and the genotype 68A x MLS had greater uptake and accumulation in its biomass than ICTP-8203. Splitting the N application also tended to increase N uptake and accumulation in the biomass. However, genotype ICTP-8203 was significantly better for N use efficiency (NE$_1$) for total biomass production (Table 2). The control or zero N rate resulted in each

Table 1. Grain and stover yield of two pearl millet genotypes as influenced by N rate and times of N application where 0 DAE = application at emergence, 25 DAE = application at 25 days after emergence and 50 DAE = application at 50 days after emergence. SD = standard deviation. Combined results of the 1989-90 growing season.

N rate	ICTP-8203		68A x MLS		Average	
kg/ha	Grain	Stover	Grain	Stover	Grain	Stover
				kg/ha		
				0 DAE		
0	1055	3342	2254	3345	1655	3344
28	1567	5243	1777	3219	1672	4231
56	1484	3624	1952	2577	1718	3100
112	1109	2903	2606	3089	1858	2996
Mean	1304	3778	2147	3058	1726	3418
				25 DAE		
0*	1055	3342	2254	3345	1655	3344
28*	—	—	—	—	—	—
56	1128	3799	2316	3061	1722	3430
112	2193	5427	2584	2735	2389	4081
Mean	1459	4189	2385	3047	1922	3618
				50 DAE		
0*	1055	3342	2254	3345	1655	3344
28*	—	—	—	—	—	—
56	1406	3666	1983	3238	1695	3452
112	1248	3492	2145	2649	1697	3070
Mean	1236	3500	2127	3077	1682	3289

*The 0 N and 28 N rate treatments were not split but only the 56 and 112 kg/ha N rates. The 0 N data are shown in the 25 DAE and 50 DAE sections for comparative purposes only.

Table 2. NE_1 and NE_2 of two pearl millet genotypes as influenced by N rate and times of N application where 0 DAE = application at emergence, 25 DAE = application at 25 days after emergence, and 50 DAE = application at 50 days after emergence. SD = standard deviation. Combined results of the 1989-90 growing season.

N rate kg/ha	ICTP-8203		68A x MLS		Average	
	NE_1	NE_2	NE_1	NE_2	NE_1	NE_2
			g/g			
			0 DAE			
0	161	51	104	47	133	49
28	159	48	103	55	131	51
56	118	50	87	51	115	51
112	128	51	101	44	103	47
Mean	142	50	99	49	121	50
			25 DAE			
0*	161	51	104	47	133	49
28*	—	—	—	—	—	—
56	134	51	87	49	111	50
112	140	42	81	41	111	42
Mean	145	48	91	46	118	47
			50 DAE			
0*	161	51	104	47	133	49
28*	—	—	—	—	—	—
56	116	40	88	42	102	42
112	97	47	73	36	85	42
Mean	125	46	88	42	107	44

*The 0 N and 28 N rate treatments were not split but only the 56 and 112 kg/ha N rates. The 0 N data are shown in the 25 DAE and 50 DAE sections for comparative purposes only.

genotype having a higher N use efficiency for total biomass production than where N was applied which is a common observation across many crops. Genotype 68A x MLS was more efficient for grain production (NE_2) relative to N (Table 2), and there was a tendency for both genotypes to have greater N efficiencies at the zero N level.

The conclusions of the thesis study were:

1. Pearl millet response to N rate was limited in the field, although obvious in the greenhouse, due to the environmental conditions of this study (soil N availability, pH, temperature).

2. Pearl millet was most responsive to time of N application at the higher N rates applied in terms of grain and biomass production.

3. Pearl millet response to N rate, N timing, and splitting of applied N appeared to be influenced by genotypes although this influence was not always obvious. The present study was very limited in the range of genotypes used to give evidence of this influence.

4. Any improvement of pearl millet response to N should take into account plant parameters such as root density, root length, and soil parameters such as soil organic matter, soil pH, and available soil N content.

5. Root absorbing power would be useful to investigate in pearl millet as long as it can be established that the parameter is under genetic control.

Study 2 (Seyni Sirifi, Niger)

A field experiment was conducted to study the interaction of applied N, soil moisture and genotype on growth, N uptake and utilization of pearl millet. This experiment was part of Mr. Seyni Sirifi's M.S. Thesis research. The N levels were 0, 50, 100 and 150 kg ha^{-1} applied post emergence as ammonium nitrate to genotypes 68A x MLS, MLS, ICTP 8203, HMP 559 and Dwarf PI 185642. Different water regimes were created by using a non replicated irrigated or dryland site adjacent to each other. Plots were of 4 rows in 75 cm spacing and 6 m in length. The experimental design was a complete randomized block with four replications. Plots were overseeded and thinned to 10 cm between plants within a row (55,500 plants ha^{-1}). Although several physiological and morphological measurements were made, only grain yield, N uptake, N use efficiency (NE_1) as total biomass per unit plant N and N use efficiency (NE_2) total grain per unit plant N are presented in this report.

Stands were generally not as good as desirable leading to high C.V.'s for most measurements. Genotypes tended to respond to N application for grain production (Table 3), although there was no difference between the environments. The season was adequate for precipitation and pearl millet apparently could not take advantage of any additional moisture. The MLS genotype was a consistently high yielder in

Table 3. Mean of grain yields for irrigated and nonirrigated tests of applied N on five genotypes of pearl millet. Coefficients of variability are presented in parentheses for each mean in percent.

			Irrigated N levels		
Genotype	0	50	100	150	Mean
			kg ha^{-1}		
68A x MLS	3001 (34)	2807 (31)	2624 (88)	3654 (70)	3022
MLS	4647 (31)	3284 (40)	2842 (48)	4634 (35)	3852
ICTP 8203	3182 (60)	3280 (27)	3309 (28)	5076 (25)	3712
HMP 559	2280 (37)	2328 (51)	3855 (40)	3334 (54)	2949
PI 185642	3123 (19)	3705 (28)	2855 (30)	3424 (11)	3227
Mean	3278	2925	3158	4175	3352
			Non-irrigated		
68A x MLS	2997 (55)	2666 (71)	2865 (43)	5565 (65)	3523
MLS	4931 (10)	4198 (44)	5143 (31)	3141 (31)	4353
ICTP 8203	2216 (61)	3598 (40)	2859 (64)	3007 (87)	2920
HMP 559	3369 (26)	5090 (45)	5562 (64)	3630 (29)	4412
PI 185642	3333 (27)	2596 (51)	2864 (42)	3847 (40)	3160
Mean	3369	3630	3859	3838	3674

these trials, but inconsistent in its response to applied N. There was no significant genotype x N interaction.

Genotype ranked similar to that for grain yield relative to total N uptake in the irrigated test (data not shown); however, a different ranking occurred in the nonirrigated environment. Genotype ICTP 8203 which was a low grain yielder had near the highest total N accumulation. This genotype is a tall, land race type which produces a lot of stover in relation to grain. The N accumulated in its biomass was a function of its ability to produce a lot of total biomass most of which is stover.

Although there appeared to be a tendency for genotypes to accumulate more N with higher fertilizer rates, this trend was inconsistent and was genotype dependent. Genotype 68A x MLS had a linear response to N application in both environments, while other genotypes were varied.

Results for N efficiency for total biomass production (NE_1) were surprising in that the values did not decrease with higher soil N levels in the irrigated test (Table 4). Generally, the more N available to a crop, the less efficiently it uses it to produce grain or stover. However, the nonirrigated test showed that this trend occurred as expected although the magnitude of differences were not great. Genotype HMP 559 clearly was superior for NE_1 compared to other genotypes. There was no genotype x N interaction.

Nitrogen use efficiency for grain production (NE_2) was somewhat reversed from the NE_1 results in that the trend to have decreased values with higher N rates occurred in the irrigated rather than the nonirrigated test (data not shown). There was also very little difference among genotypes although MLS was consistently high reflecting its comparatively high grain yield. There was no difference between water regimes, nor was there genotype x N interaction.

The results of these tests show that when N supplying power of soils is high such as would be found at the Mead, Nebraska location, the pearl millet crops may not respond consistently to applied N as it would in the poorer, sandy soils of the Sahel region of West Africa. Also, when rainfall is sufficient, the crop will not respond to supplemental moisture. Since the crop has never been improved for response to supplemental moisture, but rather for drought resistance, it is not surprising that the genotypes in this test can not take advantage of irrigation, and it may even be a detriment to grain production.

International

Two experiments were conducted in Mali by Mr. Abdoulaye Traore similar to those conducted in the past relative to N management and genetic N use efficiency.

Study 1 (Abdoulaye Traore, Mali)

The first study was a repeat of a previous study which investigated the effects of split N application on growth and yield of sorghum. Two locations of highly contrasting precipitation averages were used. The Samanko location is characterized by a loamy-clay soil type and expected precipitation of about 900 mm while the Bema location is sandy soils with expected precipitation of 350-400 mm. Three rates of N (0, 50 and 100 kg ha^{-1}) were applied either at the 10-leaf stage or the boot growth stage to two sorghum genotypes at each location. At the Samanko location, the local variety Lakahiri was compared to the improved Malisor 7 while at Bema, the local Sakoika was compared to the improved S34.

Table 4 **Means of N efficiency for biomass production (NE_1) for irrigated and nonirrigated tests of applied N on five genotypes of pearl millet. Coefficients of variability are presented in parentheses for each mean in percent.**

Genotype	0	50	Irrigated N levels 100	150	Mean
			$g\ g^{-1}$		
68A x MLS	78.7 (13)	69.4 (13)	112.8 (13)	136.2 (20)	99.3
MLS	75.8 (12)	70.3 (9)	64.6 (18)	68.6 (12)	69.8
ICTP 8203	107.1 (15)	103.9 (22)	88.1 (5)	87.7 (10)	96.7
HMP 559	123.4 (9)	133.6 (10)	117.6 (20)	122.3 (14)	124.2
PI 185642	66.4 (6)	63.1 (8)	61.8 (14)	50.9 (5)	60.6
Mean	90.3	88.1	89.1	93.1	90.2
			Non-irrigated		
68A x MLS	78.8 (13)	65.0 (13)	66.1 (17)	65.9 (15)	69.0
MLS	69.6 (10)	68.4 (16)	64.1 (13)	64.2 (23)	66.6
ICTP 8203	86.5 (18)	85.1 (19)	79.1 (20)	70.1 (11)	80.2
HMP 559	127.3 (7)	111.1 (18)	110.1 (13)	88.5 (9)	109.3
PI 185642	58.9 (9)	57.9 (18)	54.0 (10)	61.0 (13)	58.0
Mean	84.2	77.5	74.7	69.9	76.6

There were no significant differences detected at the Bema location due to a severe post flowering drought. Grain yields were only in the 140-160 kg ha^{-1} range although stover yields were around 4T. There was a tendency for the improved genotype to respond to N application in terms of stover yield, but the difference was not statistically significant.

At the Samanko location where rainfall was near normal, both varieties responded significantly to applied N. The local variety reached a maximum grain and stover yield at the 50 kg ha^{-1} N rate as a general rule while the improved Malisor 7 had increased grain and stover yields up to the 100 kg ha^{-1} N rate. The yields of the improved variety were about double that of the local at this location. Applying N later than the 10 leaf stage did not significantly alter grain yield, but appeared to depress the yield of stover. The results of the N analyses are pending so that some interpretation can be made relative to effects on N uptake and N use efficiency.

The results of this experiment show that sorghum responded significantly to N in the more favorable environments, and that the improved genotypes took the greatest advantage of good management. Any improvement in yield due to genotype or management at the environments only marginal for crop production will be determined largely by those schemes related to efficient water conservation and use.

Study 2 (Abdoulaye Traore, Mali)

A study was conducted at three locations to determine the comparative responsiveness of local versus improved varieties to applied N. However, results from only two locations will be reported. The Sotuba location is characterized by an annual precipitation of 900 mm compared to 700 mm at the N'Tarla location. Sotuba has a loamy-sand soil type and the plot site has been under continuous cultivation for at least 15 years. At N'Tarla, the soil is a sandy-loam and the plot site was a newly opened area which had been in fallow for the past 11 years. It was regenerated with 10 T ha^{-1} manure and 300 kg ha^{-1} of major nutrients. The local varieties chosen for the study were CSM 388 and Tiemarifing while the improved types were S34 and Malisor 7.

The response curves of each variety to increasing N rate at the two locations are shown in Figures 1-4. The local varieties clearly yielded higher than the improved varieties for both grain and stover at each location. This can be explained by the fact that the improved varieties generally have poorer seed quality and when early season conditions are less favorable, these types are often characterized by having poor seedling emergence. In the 1991 season, the time immediately following seeding was unseasonably wet and this resulted in the improved varieties having poor stands. This was most likely the primary factor in the yield reductions. However, local varieties are also favored in this West African region when the season is long. During 1991, the rains persisted late into the season and this favored the local types this year. Very often the improved varieties are subject to fungi attack when wet weather persists. Thus, a combination of poor stands and a long season resulted in locals outproducing the improved varieties in the 1991 season.

Generally, both the local and improved varieties responded to N for both grain and stover production. At the Sotuba location, the highest yields occurred at the 120 kg ha^{-1} rate with S34 being somewhat of an exception (Figures 1 and 2). At N'Tarla, there was a yield increase through the 160 kg ha^{-1} rate for grain and stover for all genotypes tested (Figures 3 and 4). The decline in stover yields at this location

Figure 1. **Grain yield of four sorghum genotypes grown at the Sotuba, Mali location in response to increasing levels of applied N.**

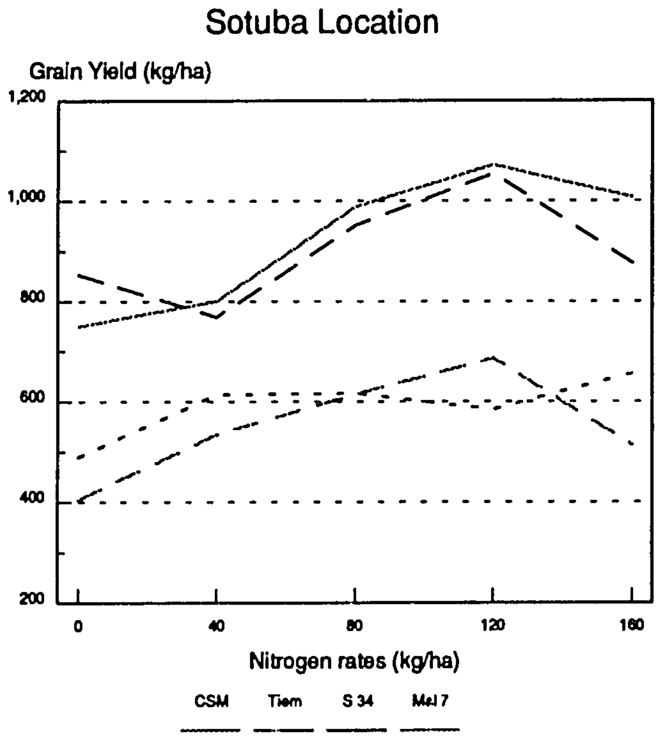


Figure 2. **Stover yield of four sorghum genotypes grown at the Sotuba, Mali location in response to increasing levels of applied N.**

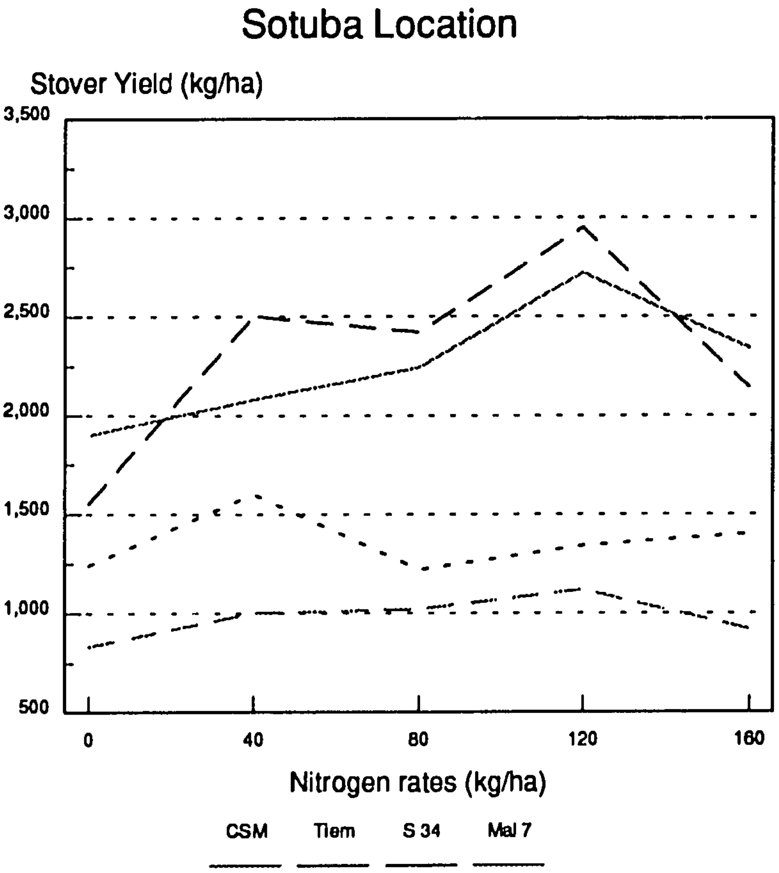


Figure 3. **Grainyield of four sorghum genotypes grown at the N'Tarla, Mali location in response to increasing levels of applied N.**

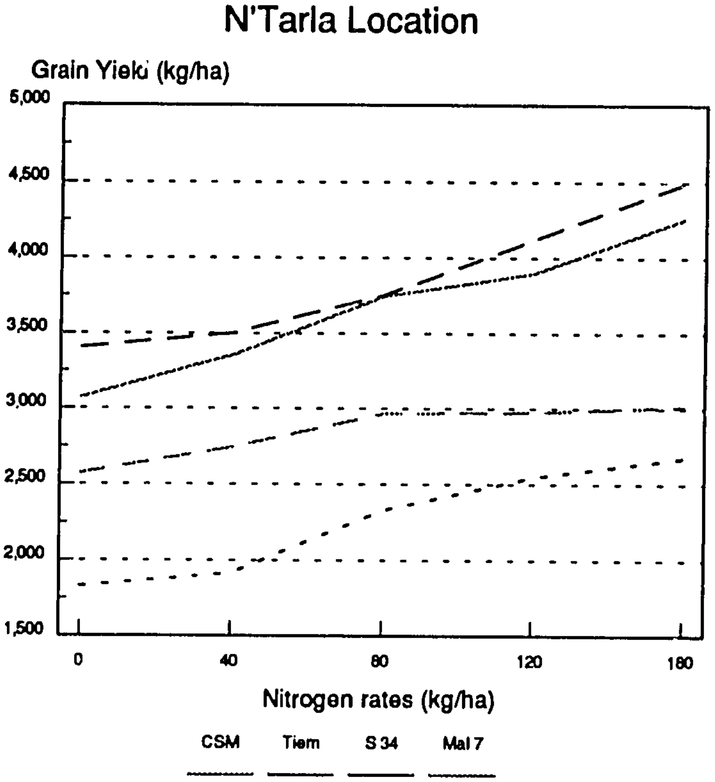
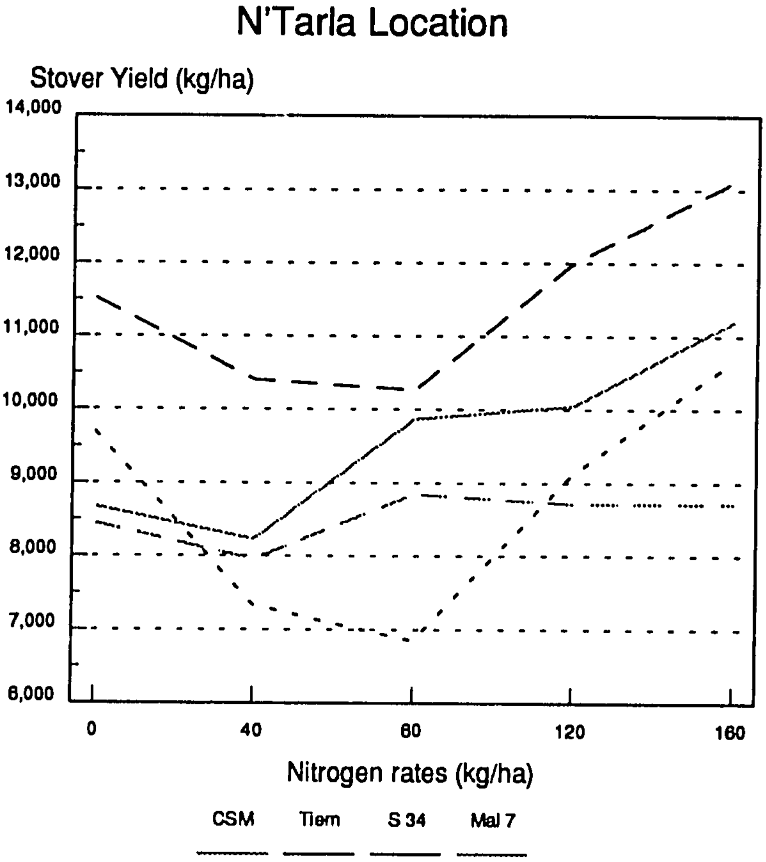


Figure 4. **Stover yield of four sorghum genotypes grown at the N'Tarla, Mali location in response to increasing**



at lower N rates cannot be fully interpreted. Both grain and stover yields were significantly greater at the N'Tarla location this year.

It can be suggested from this preliminary work, that genetic improvement for seed quality relative to germination and emergence potential would significantly improve a new varieties' ability to yield when the early season is excessively wet. Some improvement in disease resistance would add to the ability to sustain yields when wet conditions persist late in the season. It is not clear at this point whether the yield increases obtained by N application offset the additional cost.

Networking Activities

UNL-114 supplied $9000 to Mali for collaborative research in nitrogen agronomy and physiology. In addition, this project furnished a plant tissue grinder and extra blades ($6400), a portable plant tissue chopper ($600) and a portable balance ($400) for use in the collaborative research.

Publications and Presentations

Publications

Youngquist, J.B. and J.W. Maranville. 1992. Patterns of N mobilization in grain sorghum hybrids and the relationship to grain and dry matter production. J. Plant Nut. 15:445-456.

Maranville, J.W. 1991. Strategies of N use efficiency in C_4 grain crops. pp. 71-74. *In* Proc. 17th Bienn. Grain Sorghum Res. Utiliz. Conf. February 17-20. Lubbock, TX.

Toure, A.W. Effect of rate and time of application on pearl millet response to nitrogen. M.S. Thesis. University of Nebraska, Lincoln, NE. 142 p.

Presentation

Made a presentation to the SICNA group during their summer tour at Lincoln, NE on N uptake and use research in sorghum and pearl millet.

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

Project UNL-116
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Professor David Andrews, Breeder, University of Nebraska., Lincoln, NE
Dr. Max D. Clegg, Physiologist, University of Nebraska, Lincoln, NE
Dr. Jerry Maranville, Physiologist, University of Nebraska, Lincoln, NE
Dr. Osman El Nagouly, Sorghum Breeder and Sorghum Research Coordinator, Agricultural Research Center, Giza, Egypt

Summary

Our midseason stress resistance screening model testing continued through 1992 and exposed some genotypes with excellent stalk strength.

Investigations to date suggest that length of grain fill relates positively to seed size. Therefore, the length of grain fill in relation to seed size and metabolic pace or respiration pace (as a possible length of grain fill indicator or controller) is being evaluated. A substantial experiment was initiated to (1) determine the genetic variability for metabolic pace (respiration rate) in 153 fertile S_1 panicles from a tan plant population and (2) determine segregation patterns for respiration rate and grain fill length in subsequent generations. Initial respiration rate measurements suggest two to four fold differences in respiration rates amongst heads which bloomed the same day indicating excellent genetic variability for metabolic pace. The segregation pattern research on respiration rate and grain fill length will be conducted in 1993.

Heat shock protein (HSP) research demonstrated that HSP production is tissue specific amongst roots, leaves and panicles. Specific panicle results clearly show that the hybrid DK46 resistant to high temperature stress, synthesized more HSP and in larger amounts compared to RS671, the sensitive hybrid. Secondly, most of the HSP were present in significant amounts at 40°C in the resistant hybrid. In case of the sensitive genotype, most of the HSP appeared in significant amounts only at 45°C. This differential threshold temperature requirement of the two genotypes appears to be related to the differences in the sensitivity of these two genotypes to high temperature stress in the field. Our speculation is that differences among genotypes in the threshold temperature requirement for HSP synthesis may be very critical to their ability to survive high temperature stress. Physiological roles of these low molecular HSP must be established to further our understanding about their possible mechanistic roles in thermotolerance or other types of stress tolerance.

Objectives, Production and Utilization Constraints

Objectives

The utility of mission oriented physiological research is primarily, if not completely, to (1) devise improvements in cultural practices and (2) to devise or improve genetic manipulation screening techniques.

Therefore, the first general objective includes cultural research investigations relating to water use efficiency (WUE) and nutrient use efficiency (NUE) needs.

A second general objective is investigation of water and temperature stress resistance mechanisms as they relate to (1) developing stress screening techniques and (2) genetic manipulation of stress resistance mechanisms with emphases at both the field and gene levels. Quite obviously gains in these research areas of the second general objective have the net effect of improving WUE in the first objective because of yield improvement (see the seasonal WUE equation below).

Since water is the primary limiting crop production resource in most of the world's sorghum growing regions, a brief review of WUE components and how to maximize WUE follows. By definition:

Seasonal WUE = yield (grain or biomass)/evapotranspiration (ET)

IWUE = CO_2 uptake/transpiration (Sinclair et al., 1984; Tanner and Sinclair, 1983)

Any genetic or cultural factor which increases yield without increasing ET or increases yield faster than ET will improve WUE. Also factors which reduce E and/or T while holding yield constant or decrease yield at a slower rate than E and T decline, will increase WUE (Gandoul et al., 1990; Stewart and Steiner, 1990).

Instantaneous WUE equals CO_2 uptake/transpiration (Sinclair et al., 1984). Newer more sensitive techniques for measuring E, T and CO_2 exchange rates in canopies permit more detailed analyses of selected factors which influence both the numerator and denominator of the IWUE equation. Such measurements at sensitive growth stages (when seed number potential and essential yield potential are being set), may be useful in differentiating between high and low WUE plants. Crops of interest are primarily sorghum, millet and legumes in sorghum/millet based cropping systems. The legume interest stems from the reality of low N soils and high fertilizer N costs in lesser developed target countries.

Evaporation and transpiration measurements may also be useful in determining how comparative cultural practices influence WUE components. Seasonal and instantaneous WUE analyses should provide greater insights into which cultural factors maximize retention of water and which physiological properties should be manipulated genetically to increase WUE.

As alluded to above, any factor having a major impact on yield influences seasonal WUE and usually merits research (examples are species, improved genotype, fertility level, water level, etc.). Evapotranspiration is also influenced by a host of factors including soil type, fertility level, water storage level, root system extent and activity (water rationing over the entire season), tillage and residue effects, climate, micro-climate, canopy architecture, etc. Some factors influence the magnitude of both the numerator and denominator of both the seasonal WUE and IWUE equations. Research in this project is designed and conducted within this general context.

Investigations pertaining to both general objectives stated above include field canopy measurements on photosynthesis, transpiration and soil water content to determine both instantaneous and seasonal water use efficiencies in stress resistant and stress susceptible sorghums, legumes and other crops in sorghum/millet based cropping systems. Legume performance is especially critical in developing countries because of nitrogen deficiencies and the high cost of commercial fertilizers.

Constraints

Niger: Resume development of (1) both rotation and intercropping systems to optimize nitrogen fixation and improve millet yields and (2) continue crop residue management research and add animal manures to reduce soil erosion, improve seedling establishment, maximize water infiltration, and enhance soil nutrient status to improve millet and legume yields.

Sudan: The effort here relates closely to soil nutrient enhancement problems alluded to in the Niger statement. The heaviest effort is preparing Mr. G. I. Gandoul (through a Ph.D. here) to return and evaluate the best legumes primarily for N fixation and oil production to put in their sorghum based Gedarif area cropping systems where soil N status is low from essentially continuous sorghum cropping over the past 50 years.

Egypt: Define water and nutrient level effects on both water and nutrient use efficiencies in sorghum. Cooperate on water and salt stress screenings.

Zimbabwe: Student training research on sorghum emergence problems.

Mexico: Cooperative location testing (University of Nuevo Leon, Monterrey, MEXICO) on control of seed weight in conjunction with post anthesis stress screening.

Botswana (also Senegal, Sudan and others): Supply stress resistant germplasm.

U.S.A.: (1) Cooperate on stress tolerant germplasm screening with Mexico scientists as outlined above particularly on post anthesis stresses and continue stress mechanism research.

References

Gandoul, G.I., J.D. Eastin, M.D. Clegg, and M. Mirghani. Factors influencing water use efficiency. *In* Gebisa Ejeta (ed.) ARC/INTSORMIL Sudan Sorghum and Millet Workshop in November 1989. In Press.

Sinclair, T.R., C.B. Tanner and J.M. Bennett. 1984. Water use efficiency in crop production. Bioscience 34:36-40.

Stewart, B.A., and J.L. Steiner. 1990. Water-Use Efficiency. pp. 151-173. *In* R.P. Singh, J.E. Parr and B.A. Stewart (eds.) Advance in Soil Science, Vol. 13, Dryland Agriculture. Springer Verlag.

Tanner, C.B. and T.R. Sinclair. 1983. Efficient water use in crop production. Researcher ReSearch. *In* H.M. Taylor, W.R. Jordan and T.R. Sinclair (eds). Limitations to Efficient Water Use in Crop Production. American Society of Agronomy, CropScience Society of America, Soil Science Society of America. Madison, WI. USA.

Research Approach and Project Output

Niger: The millet/cowpea rotation plus WUE work was put on hold until 1993 since Mr. Mamane Nouri was in France on short term training during the growing season.

Sudan: Mr. G. I. Gandoul's Ph.D. dissertation research is continuing on how to maximize photosynthesis and minimize transpiration in legumes to increase N fixation in limited water environments. The criticalness of this research relates to large areas where monocropped sorghum over the past 50 years has depleted soil N and N fertilizer is very expensive, dictating the need for high legume N fixation in sorghum based cropping systems. Currently he is involved in greenhouse barrel (200 l volume) stress screening experiments to determine the relative responses of different legumes under stress.

Egypt: Sorghum water x nutrient level interaction experiments are being readied for 1993. One of their biggest experimental problems is quantifying the amount of water applied in the field. Therefore, a water metering system was designed for WUE experiments but was not used in 1992. Some refinements will be made in March, 1993. Over 600 tan plant population selections by Drs. Osman El Nagouly, Dr. M.F. Saba and others were sent as per request plus two random mating populations and four A/B pairs. The A/B pairs arrived too late for planting but the other growouts proceeded as planned. Crossing of Egyptian adapted lines (the Gizas in particular) to stress resistant population steriles to begin an adapted Egyptian population was not achieved. Mr. Mohamed Hovny from Assuit University is conducting his Ph.D. dissertation research at Nebraska on water response and stress screening in sorghum. Essentially all of the cooperative Egypt program is funded by USAID Egypt.

Zimbabwe: Mr. Ermson Nyakatawa's M.Sc. thesis research on genotype emergence responses to different levels of soil crusting, a common Southern Africa problem, is well along. His M.Sc. research will be detailed in the 1993 Annual Report.

Mexico: The first post anthesis stress/seed size screening trials will probably be initiated in March 1993 in cooperation with Dr. Francisco Zavala-Garcia. He is a former UNL student and post doctorate and in contributing post anthesis stress screening unavailable in the U.S.

USA: (1) Continue stress resistance mechanism investigations which involve canopy photosynthesis, transpiration and respiration measurements, root activity research, metabolic efficiency and stress shock protein synthesis, (2) conopy gas exchange measurements were made but stress was minor. Results will not be included. Stress shock protein research rationale and selected results from a paper submitted by P. K. Verma, J.D. Eastin and J.E. Partridge follow.

Heat shock proteins (HSP), a group of proteins synthesized in response to temperature stress, have been associated with thermotolerance in plant tissue. Genetic diversity among these proteins has been related to the differential genotypic responses under stress in crop plants. In most studies, however, the seedling tissue has been used. The objective of this study was to study the heat shock response in two sorghum genotypes contrasting in their sensitivity to stress to answer the following questions (1) do the seedlings and mature plants respond differently to heat shock? and (2) do two contrasting sorghum hybrids have a differential heat shock response especially with respect to the extent of expression of HSP and the temperature at which they are induced?

Sorghum hybrids used in the study were RS671 and DK46. RS671 is a public hybrid sensitive to temperature stress while DK46 is a stress resistant commercial grain sorghum hybrid. Different tissue types studied were as follows: roots and shoots of three day old etiolated seedlings, meristematic and expanded leaf from plants during panicle development, and the developing panicle at FD (floret differentiation) and FD+7 stages. Test tissue was preincubated 2.5 hours at 30C, transferred to test temperatures of 30, 35, 40 and 45C for 10 minutes before adding (^{35}S) methionine and incubated for two hours. The tissue was then extracted and subjected to two-dimensional electrophoresis. Gels were treated with ENHANCE for fluorography analyses with a Visage 110 (BioImage) image analyzer.

Thirty degrees celsius was used as a control and 35, 40 and 45°C were used as heat shock temperatures. However, there was no difference between the protein patterns at 30° and 35°C. The heat shock genes in the two hybrids used must require a temperature higher than 35° for activation. Therefore, for the purposes of this paper, 35° treatment will be considered as control and will be compared with 40 and 45°C treatments to detect a HS response.

Proteins were identified following the schematic diagram given in Figure 1. All comparisons are made using data in Table 1a and b. A total of 29 HSP were detected in shoots (Table 1a) compared to a total of 30 HSP in the root tissue (Table 1b). Most of these HSP were low molecular weight proteins ranging between 15 and 30 kD. However, 65, 70 and 85 kD HSP were present in relatively larger amounts. Over 30 HSP, most of which are low molecular weight proteins, have been reported in plant systems (Kimpel and Key, 1985b; Krishnan et al., 1989; Vierling and Nguyen, 1990). Most plant HSP are present between 15 and 18 kD (Mansfield and Key, 1987). These are also the HSP which are unique to plant systems (Sachs and Ho, 1986). Other low molecular weight HSP in plants range from 20 to 30 kD. High molecular weight HSP are usually abundant in mammalian, insect and yeast systems (Kimpel and Key, 1985b).

The amount of HSP generally increased with temperature as expected, but there were a few exceptions. The synthesis of some HSP which were present at 40°C either slowed down or ceased at 45°C. Fourteen HSP in RS671 were

Figure 1. Diagrammatic pattern of heat shock proteins (HSP) observed in the etiolated seedlings and mature plants at 45 days after planting in two sorghum hybrids following 2-d electrophoresis. Proteins were numbered using a 2-way classification - molecular weights on the vertical axis and arbitrary lane divisions on the horizontal axis.

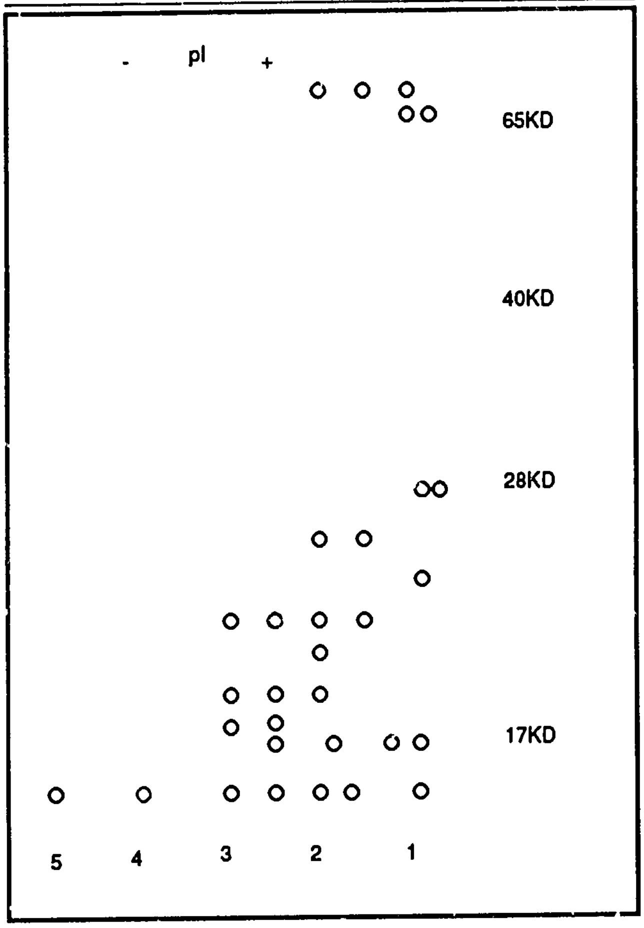
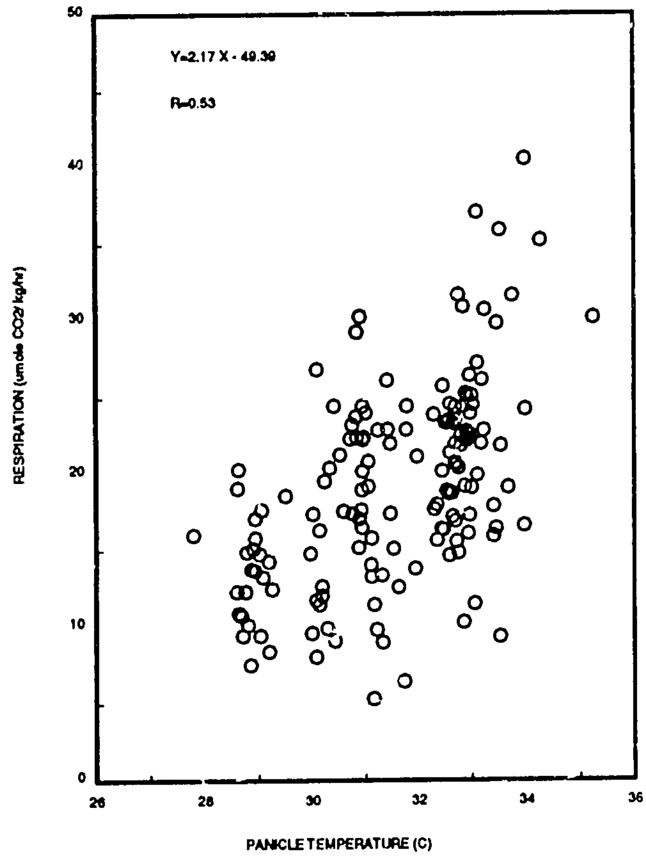


Figure 2. Respiration rates (µmole CO_2/kg/hr) of 153 random mated population S_1 fertile heads taken over two days in the field. Each value is the mean of three measurements.



present in constitutive amounts (at 35°C) in the shoot tissue (Table 1a) and five of these (HSP25-1.5, HSP23-1.5, HSP17-1, 1.5, 2) actually decreased or did not change with increasing temperature. It is interesting to note that four out of these five proteins increased with temperature in DK46 thus showing a normal HS response. The exception (HSP17-2) had a normal HS response in the root tissue of both hybrids. While most of the shoot tissue HSP were common to both genotypes, five HSP were specific to DK46 and two were specific to RS671. Low molecular weight HSP are believed to play a more important role in rendering thermotolerance to plant tissue (Kimpel and Key, 1985b). The most abundant low molecular weight HSP in RS671 shoot were at 28 and 16 kD compared to 28, 17 and 16 kD in DK46.

Fewer HSP were present in RS671 roots compared to the shoots. In DK46 roots had the same number of HSP as shoots (Data will not be detailed in table form here). Also, 26 out of 27 HSP were the same in both tissue types. As in the shoot, the high molecular weight HSP, though fewer in number, were generally present in larger amounts. Five HSP in RS671 and four HSP in DK46 roots which were present in constitutive levels either did not increase with temperature or actually decreased at higher temperatures. In the roots, eight HSP were unique to DK46 while only one was unique to RS671. Of these 8 HSP, HSP28-1, HSP24 and HSP23-2 were not only present in DK46 shoots but were also unique to DK46 shoots. HSP15-2 was present in the shoots of DK46 only. Likewise, HSP85 was present in DK46 root only and HSP19-3 was unique to RS671 root. It is interesting to note that HSP19-3 was present only at 40°C and not at 45°C.

A comparison of the root and shoot HS responses indicated that there were qualitative as well quantitative differences between tissue types and between genotypes. While all of these differences could not be detected without the quantification of fluorographs, a lot of them were evident visually.

The differences between genotypes and among temperature treatments within a genotype were very pronounced in the mature plant. The synthesis of normal proteins, which is interrupted in response to heat shock in plants (Key et al.,

Table 1a. Optical density of heat shock proteins (HSP) in the shoot tissue of etiolated seedlings of two sorghum hybrids.

HSP	RS671			DK46		
	35°C	40°C	45°C	35°C	40°C	45°C
HSP85						
HSP70-3	9.21	9.54	17.10	6.86	9.32	8.18
HSP70-2	7.24	11.29	7.06	4.57	7.37	7.44
HSP70-1		7.32	13.36	5.18	8.01	6.61
HSP65-2		5.40	14.65		6.68	8.09
HSP65	7.77	7.11	10.38	9.95	9.06	10.70
HSP28-2	2.16	2.16	5.94	0.88		3.94
HSP28-1				0.59	2.04	5.59
HSP25-2	1.39	1.34	2.34	0.41	0.80	1.27
HSP25-1.5	0.89	0.78	0.83	0.22	0.39	0.43
HSP24				0.86	1.39	1.81
HSP23-3		0.69	0.23		0.51	1.22
HSP23-2.5	0.71	0.93	0.45	0.26	0.51	0.33
HSP23-2				0.23	0.83	0.99
HSP23-1.5	0.74	0.73	0.59	0.58	0.80	0.63
HSP21-2		0.35	0.70			0.76
HSP19-3						
HSP19-2.5				0.10	0.80	1.77
HSP19-2	0.97	1.41	0.60	0.13	0.29	0.55
HSP18-3		0.95	0.33		0.31	0.94
HSP18-2.5		0.71				
HSP17-2.5		0.47				
HSP17-2	10.11	7.66	6.78	3.60	2.08	2.59
HSP17-1.5	5.94	2.93	2.41	1.92		2.42
HSP17-1	11.13	8.17	5.24	8.39	12.08	10.11
HSP16-5	2.54	3.02	3.37	0.22	0.40	1.71
HSP16-4		1.06	1.05		0.25	0.28
HSP16-3		0.77	0.95	0.24	0.64	0.72
HSP16-2	1.52	2.79	6.84	1.57	3.42	4.60
HSP16-1.5		0.79	3.87		0.86	3.89
HSP15-2						1.50

1985; Burdon, 1986; Lindquist, 1986; Brodl, 1989), was drastically reduced or almost completely inhibited in the mature plant tissue. This reduction was significantly less in the seedling tissue (Figure 2). A total of 27 HSP were present in the expanded and the meristematic part of the leaf of which 24 ranged in size from 15 to 25kD. Only one high molecular weight HSP (65kD) was present. The qualitative as well as the quantitative differences between the two genotypes were greater in the expanded leaf compared to the expanding leaf. The expanded leaf of DK46 synthesized 21 HSP at 45°C compared to 14 in RS671. RS671 is extremely sensitive to stress in the field (Verma, 1987) and shows profuse leaf firing when exposed to even a few days with maximum temperatures higher than 35°C. Like in the seedling tissue, some proteins present in constitutive amounts at control temperature did not increase or actually decreased in amount at higher temperatures; and again this response was usually tissue and/or genotype specific for any one protein. Of the low molecular weight proteins in the expanded leaf, HSP17-1, HSP17-2 and HSP17-3 were present in highest amounts in both hybrids. Groups of HSP most prominently missing in the mature plant compared to seedlings were at 16, 18, 28, 70 and 85kD. It is difficult to say whether the 23kD HSP in seedlings are any different from the 22kD HSP in mature plant even though the image analyzer consistently (over several gels) identified them to be of different molecular weights. At the very least they represent very closely related gene families.

Seven HSP were unique to DK46 and one unique to RS671 in the expanded leaf. DK46 not only had more HSP present in constitutive amounts at 35°C, it also had a greater heat shock response both at 40 and 45°C. All six HSP which appeared at 45°C in RS671 were present at 40°C in DK46. Three of these were even present at 35° in DK46. This clearly indicates a differential temperature threshold required to induce the synthesis of a few HSP in the two hybrids. Similar response was observed in the expanding leaf also. There were only 14 HSP in RS671 compared to 20 in DK46 expanding leaf tissue at 40°C while both hybrids had a total of 22 HSP at 45°C. Clearly some of the HSP were turning on at a relatively lower temperature in DK46 compared to RS671. Two HSP (HSP19-2 and HSP15-1.5) were present only in expanded leaf of DK46 where as HSP20-3 and HSP17-3.5 were unique to expanding leaf in DK46. HSP22-1 was unique to the expanding leaf tissue in both

Table 1b. Optical density of heat shock proteins (HSP) in the root tissue of etiolated seedlings of two sorghum hybrids.

	RS671			DK46		
HSP	35°C	40°C	45°C	35°C	40°C	45°C
HSP85					5.14	3.76
HSP70-3		4.16	3.48	2.91	5.01	9.56
HSP70-2	4.81	5.36	4.07	12.65	8.53	8.72
HSP70-1	4.27	4.09	3.01		7.72	8.63
HSP65-2		2.97	3.29		8.23	9.01
HSP65	2.71	3.54	6.42	4.51	7.63	11.06
HSP28-2	.65	1.79	2.66	0.53	1.65	1.47
HSP28-1					1.23	3.06
HSP25-2	0.73		0.40		1.51	0.60
HSP25-1.5	0.34		0.26	0.62	0.55	0.57
HSP24						1.89
HSP23-3	0.84	1.22	0.21	0.19	0.75	0.59
HSP23-2.5		0.32	0.17	0.39	0.43	0.42
HSP23-2				0.73	0.57	0.86
HSP23-1.5		0.59		0.97	0.95	1.01
HSP21-2				0.56	0.65	0.64
HSP19-3		0.61				
HSP19-2.5	0.26	0.15	0.20		0.44	1.40
HSP19-2		0.33		0.60	0.70	0.85
HSP18-3	0.19	0.61	0.23		1.89	1.15
HSP18-2.5					0.75	
HSP17-2.5		0.07	0.46		0.28	
HSP17-2	1.09	2.28	2.32		3.62	2.51
HSP17-1.5	2.30		1.03		1.99	2.73
HSP17-1		3.65	4.67	7.47	5.79	7.41
HSP16-5		0.74	0.93	0.35	2.01	1.61
HSP16-4					0.43	1.02
HSP16-3					0.58	0.95
HSP16-2	0.54	0.38	4.02	0.67	3.14	6.39
HSP16-1.5		1.50	1.83		0.96	2.89
HSP15-2						1.50

hybrids. As in the expanded leaf, the most abundant low molecular weight HSP in the expanding tissue of hybrids were HSP17-1, HSP17-2 and HSP17-3.

Relatively abundant amounts of HSP with molecular weights higher than 65kD has been reported in sorghum (Howarth, 1989). Differences between expanded and expanding leaves observed here are similar to the tissue specificity reported earlier (Altschuler and Mascarenhas, 1983; Cooper et al., 1984; Ougham and Stoddart, 1986; Howarth, 1989). These should more specifically be interpreted as developmental stage specific differential heat shock responses. The differences between the general pattern of heat shock response among roots, shoots and leaves of mature plant observed in this study are real tissue specific effects.

Differential heat shock responses have been associated with differences among genotypes for thermotolerance. Ougham and Stoddart (1986) compared CK60A, a temperature resistant line and IS84, a stress sensitive line of sorghum. The synthesis of HSP initiated much earlier in the resistant line compared to the sensitive line in seedlings following imbibition. These differences were especially pronounced for high molecular weight HSP. High molecular weight proteins were observed in significantly larger amounts in the seedlings of the two hybrids in this study and may be more critically associated with thermotolerance in the seedling tissue than generally believed in plant systems. Genotypic HSP differences associated with differential stress responses have also been reported in two other studies (Howarth, 1989; Sivaramakrishnan et al., 1990) which used sorghum and pearl millet seedlings. Howarth (1989) observed a non-coordinate control of HSP synthesis during germination and the thermotolerant sorghum line was able to synthesize HSP at an earlier stage of germination compared to the sensitive line. A differential induction of high and low molecular weight HSP, and considerable synthesis of normal proteins during heat shock was also observed. Sivaramakrishnan et al. (1990) observed a greater heat shock response in millet compared to sorghum under identical conditions. Millet can, in general, survive higher temperatures better than sorghum since, over the years, it has evolved into a more drought resistant species than sorghum. The lines used in all three studies discussed above were identified based on their emergence and/or seedling survival under high temperature typical of the semiarid regions of the world where sorghum and millet are commonly grown and where seedling establishment is perhaps the most limiting factor to productivity.

The general pattern of synthesis of HSP in the panicle tissue was the same as in the leaves from mature plants. Since there were few differences between leaf and panicle HS responses, a separate diagrammatic pattern and a detailed table of HSP in the panicle tissue are not presented. At FD, only 12 HSP were present at 40°C in RS671 compared to 21 in DK46. A more obvious difference between the two genotypes at 40°C was in the amounts of HSP synthesized. DK46 had significantly higher rates of syntheses of HSP compared to RS671. At 45°C, there were little differences between DK46 and RS671 (a total of 22 and 19 HSP, respectively) both qualitatively and quantitatively. Clearly, several HSP in RS671 required a threshold temperature higher than 40°C to be expressed, and most had a lower rate of synthesis at 40°C when compared to DK46 at the same temperature. The most abundant HSP in DK46 were HSP25, HSP17-1, HSP17-2 and HSP17-3, with HSP17-1 being present in the largest amount. In RS671, while it was the same four proteins, their relative proportions were different. HSP17-2, and not HSP17-1, was the most abundant of the four HSP. HSP22-2, HSP22-2.5, HSP17-4 and HSP15-4 were present in significantly larger amounts in RS671 compared to DK46 at 45°C.

At FD+7, there was a slight increase in the HS response of DK46. RS671, on the other hand, showed a significantly reduced HS response at FD+7 compared to FD stage even at 45°C. The pattern of the four most abundant HSP at FD+7 was similar to the one observed at FD stage in both genotypes. There was a significant reduction in the rates of syntheses of HSP, or groups of HSP, with the molecular weights of 15, 20 and 22 kD in RS671 at 45°C, at FD+7 compared to FD. On the other hand, these HSP as well as HSP25 and HSP17-4 were synthesized in visibly larger amounts at FD+7 compared to FD in DK46. Clearly, there was a differential developmental regulation of several HSP in the two genotypes. It is interesting to note the reduced HS response in RS671 at FD+7 stage since this hybrid is extremely sensitive to high temperature stress at this stage in the field (Eastin et al. 1983; Gonzalez-Hernandez, 1982; Verma, 1987). Even two hot days in the field during this stage of development can cause the panicle to emerge (later) from the whorl with white band(s) of aborted florets.

The results clearly show that the grain sorghum hybrid DK46, resistant to high temperature stress, synthesized more HSP and in larger amounts compared to RS671, the sensitive hybrid. Secondly, most of the HSP were present in significant amounts at 40°C in the resistant hybrid. In case of the sensitive genotype, most of the HSP appeared in significant amounts only at 45°C and only at FD stage. At the FD+7 stage of development, there was very little increase in the HS response of the sensitive hybrid at 45°C compared to 40°C. It appears that the differential threshold temperature requirement of the two genotypes observed also in the vegetative tissue of these genotypes, is related to the differences in the sensitivity of these two genotypes to high temperature stress in the field. Howarth (1991) noted that a gradual increase in temperature, as would occur in the field, induces the synthesis of HSP. However, even though HSP accumulated in the tissue, their de novo synthesis when high temperatures are encountered, is essential for thermotolerance. A return to normal temperature for 24 hours caused the HSP to lose their protective roles in thermotolerance in sorghum (Howarth, 1991). Thus, there is a time as well as a temperature component in the development of thermotolerance. These observations lend support to our speculation that differences among genotypes in the threshold temperature requirement for HSP synthesis may be very critical to their ability to survive high temperature stress. If the HSP are synthesized at a temperature very near the lethal temperature, they would essentially not be present in the tissue prior to exposure to such severely damaging (but not lethal) temperature to contribute to any protective mechanism, and would be ineffective for protection during the next cycle of stress which may occur the next day. Conversely, if the HSP are synthesized at a relatively lower temperature, they would be in place and (still) be active to protect against highly stressful, but not lethal, temperatures when they do occur later in the day.

Physiological roles of these low molecular HSP must be established to further our understanding about possible mechanisms in thermotolerance. The HSP must also be studied in tissues and during developmental stages which are most critically involved in determining the final economic yield.

A second component of USA Objective 1 involves panicle respiration rate evaluation. Panicle respiration rate information is of interest because plant metabolic pace (as judged by respiration rate) appears to correlate inversely with grain fill length within a genotype. Since grain fill length correlates positively with the seed size component of yield, a good adaptation factor for a given area appears to be through a sufficiently slow metabolic pace to stretch grain fill length to match either the available water supply or the length of the prevailing frost free time period in order to optimize seed size and grain yield. This raises two questions. The first question is how close is the association between panicle respiration rate (estimate of metabolic pace) and grain fill length? The second question is what is the genetic variability for panicle respiration rate? To begin addressing both of these questions a survey of random mating (RM) population fertile S_1 heads was conducted by Ms. Rachel Ngulube (undergraduate from Zambia) with assistance from G. I. Gandoul (Sudan), Mohamed R. A. Hovny (Egypt) and myself. The interest in such a survey stems from the fact that eight years ago Thomas Gerik conducted such a survey on a population here and found three to four fold differences in respiration rates amongst 50 S_1 population plants. Ms. Ngulube surveyed 153 fertile S_1 panicles from a tan plant RM population. Results (Figure 2) on measurements over a range of 29 to 35C (with the bulk of the data from 30-34) illustrate great variability. Most values in Figure 2 are means of three measurements taken at three different temperatures (times of the day). The mean values are plotted against the mean temperature of the three sets of measurements.

Consider the set of genotypes which have a mean respiration rate of 31 ± 1 μmole CO_2/kg/hr. Two genotypes achieve that metabolic pace at 31C while another group achieves that rate at about 33C and one genotype requires 35C to achieve that rate. Based on other measurements we have made, we would speculate that the 35C genotype would fit a higher temperature tropical environment while the 31C genotype set would fit a cooler temperate or higher elevation cooler tropical climate. The difference between 31C and 35C is quite significant because respiration rate (metabolic pace) increases about 15%/°C in sorghum. A 5C increase in night temperature above optimum for a genotype decreased grain fill length 20 to 25% in our tests.

Ms. Ngulube's destructive respiration measurements were taken on the upper 25% of the panicle leaving the rest of the panicle for harvest. The remaining seed was sent to Dr. Francisco Zavala-Garcia in Mexico to advance a generation in a winter nursery. The S_2 progeny will be planted with the S_1's in 1993 to determine segregation patterns for respiration rate and grain fill length. Contrasting respiration types will then be recombined for testing in cool and warm climates to determine whether or not respiration rate screening is likely to be a viable breeder field screening tool. We anticipate this research will be part of Ms. Ngulube's M.Sc. thesis and hope it will lead to Ph.D. research in Zambia.

USA: (2) Objective 2 on determining correlations between grain fill length, head respiration rate, seed weight and yield was addressed in a parent/hybrid test but is not yet fully analyzed. Philosophically it relates closely to the research initiated by Ms. Ngulube just described.

Networking

Workshops

Eastin, J.D. et al. 1992. The response of crops to temperature, water and light stresses. Invited presentation at the EMBRAPA First International Symposium on Environmental Stress: Corn in Perspective. Sponsored by EMBRAPA (Brazilian Agricultural Research Agency/Maize and Sorghum Improvement Center) and CIMMYT, March 1992.

Participated in a mid-term review (five year project) in Hyderabad, India of the Indo-US Subcommission on Dryland Agriculture and Chaired a Program Session On Emerging Public/Private Agricultural Research in India. Dr. P. K. Verma organized the session. The review served as a mid-term goal correction based on achievements to date. My responsibility is to serve as cooperating scientist for USDA, OICD on five projects as follows: The main title is Germplasm Enhancement for Drought Tolerance and Reclamation of Wastelands. Subprojects are:

Screening and breeding rabi sorghum for drought tolerance; Moisture storage and fertilizer management to improve production over M.35-1 (Solapur Center and Bijapur -two projects with about 10 scientists). A post anthesis stress screening scheme was put on trial in 1988 and appears to be working quite well but will require longer term testing. An M.35-1 based line breeding scheme was also initiated in 1989 to improve production over M.35-1 which has been the premiere rabi (grown on stored soil water) sorghum for 50 years in an area supporting several million people. Results at the F_3 level appear very encouraging with a significant number of F_3's showing superiority over M.35-1 in grain yield in both Bijapur and Solapur and in seed size in some of the Solapur lines. The methodology seems to be working quite well. F_5 testing in 1993 rabi will be much more definitive. A longer range population program has also been initiated. There is little doubt that some valuable germplasm for the semiarid tropics and the US will be released from these two programs in the near future.

The Solapur and Bijapur stations are doing excellent research on both WUE and NUE (especially P and N) in both rotation and intercropping systems involving Lucaena - cowpea - sorghum; black gram and green gram and sorghum. The Hyderabad station is doing premiere work on maximizing N fixation under limited water in sorghum/millet based cropping systems plus a castor bean program. Research at Jhodpur includes millet, moth bean and mustard. Sensitive growth stages have been determined. Stress resistance mechanisms related to N nutrition will be addressed over the next two years.

Research Investigator Exchanges

Mohamed R. Hovny from Egypt is doing stress screening/WUE research here for a Ph.D. dissertation through Assuit University.

Several Egyptian scientists have visited for one to two week stays.

Dr. A. N. Lahiri and Dr. S. Venkateswarlu visited from India for 1 week.

Germplasm and research information exchange

Germplasm conservation

(a) Twenty-two stress tolerant rabi sorghum lines are being imported from India.

(b) International exchanges (1991-93): Over 600 population derived R lines sent to Egypt. About 40 R lines to Texas A&M. A stress resistant population was sent to Senegal and ICRISAT, India. Three A/B pairs and 10 R lines to Spain. A/B pair to Senegal.

Seed production

(a) Over 1000 lines plus 4 A/B pairs to India

(b) 169 large seeded accessions acquired for post anthesis stress work in 1992. Most are over 6-12' tall and were crossed to adapted tan plant population steriles in 1992.

(c) Random mating population requests from Brazil

CRSP Produced Technology

CRSP produced technology on legume/millet intercropping is being used by farmers in Niger but the impact has not been quantified.

Assistance Given

Assistance given to collaborating scientists with research equipment, supplies and other support. Valves and miscellaneous irrigation water control equipment developed for Egyptian WUE research plus assembly in Egypt. Canopy gas exchange equipment constructed and carried to Egypt. Those two projects involved about $1000 plus two weeks on site fabrication and testing time.

Appendix Heat Shock Protein References

Altschuler, M. and J.P. Mascarenhas. 1982. The synthesis of heat-shock and normal proteins at high temperatures in plants and their possible roles in survival under heat stress. p. 321-327. *In* Schlesinger, M.J., M. Ashburner and A. Tissieres (ed.) Heat shock from bacteria to man, Cold Spring Harbor Laboratory, Cold Spring Harbor, NY.

Brodl, M.R. 1989. Regulation of the synthesis of normal cellular proteins during heat shock. Physiologia Plantarum. 75:439-443.

Burdon, H. 1986. Heat shock and the heat shock proteins. Biochem. J. 240:313-324.

Cooper, P. and T.D. Ho. 1983. Heat shock proteins in maize. Plant Physiol. 71:215-222.

Cooper, P., T.D. Ho and R.M. Hauptman. 1984. Tissue specificity of heat shock response in maize. Plant Physiol. 75:431-441.

Eastin, J.D., R.M. Castleberry, T.J. Gerik, J.H. Hultquist, V. Mahalakshmi, V.B. Ogunlela and J.R. Rice. 1983. Physiological aspects of high temperature and water stress. p. 91-112. *In* C.D. Raper, Jr. and P.J. Kramer (ed.) Crop reactions to water and temperature stresses in humid, temperate climates. Westview Press, Boulder, CO.

Howarth, C. 1989. Heat shock proteins in Sorghum bicolor and Pennisetum americanum I. Genotypic and developmental variation during seed germination. Plant Cell Environ. 12:471-477.

Howarth, C. 1991. Molecular responses of plants to an increased incidence of heat shock. Plant, Cell and Environ. 14:831-841.

Key, J.L., J. Kimpel, E. Vierling, C-Y. Lin, R.T. Nagao, E. Czarnecka and F. Schoffl. 1985. Physiological and molecular analyses of the heat shock response in plants. p. 327-347. *In* B.G. Atkinson and D.B. Walden (ed.) Changes in Eukaryotic Gene Expression in Response to Environmental Stress, Academic Press, London.

Kimpel, J.A. and J.L. Key. 1985a. Heat shock in plants. TIBS. 353-357.

Kimpel, J.A. and J.L. Key. 1985b. Presence of heat shock mRNAs in field grown soybeans. Plant Physiol. 79:672-678.

Krishnan, M., H.T. Nguyen and J.J. Burke. 1989. Heat shock protein synthesis and thermal tolerance in wheat. Plant Physiol. 90:140-145.

Lindquist, S. 1986. The heat shock response. Ann. Rev. Biochem. 55:1151-1191.

Mansfield, M.A. and J.L. Key. 1987. Synthesis of low molecular weight heat shock proteins in plants. Plant Physiol. 84:1007-1017.

Ougham, H.L. and J.L. Stoddart. 1986. Synthesis of heat-shock protein and acquisition of thermotolerance in high-temperature tolerant and high-temperature susceptible lines of sorghum. Plant Sci. 44:163-167.

Sachs, M.M. and T.D. Ho. 1986. Alteration of gene expression during environmental stress in plants. Ann. Rev. Plant Physiol. 37:363-376.

Sivaramakrishnan, S., V.Z. Patell and P. Soman. 1990. Heat shock proteins of sorghum and pearl millet cultivars with differing heat tolerance at seedling establishment stage. J. Exp. Botany. 41:249-254.

Verma, P.K. 1987. Physiological responses of sorghum genotypes to environmental stress. Ph.D. Diss., University of Nebraska, Lincoln, NE.

Vierling, R.A. and H.T. Nguyen. 1990. Heat shock protein synthesis and accumulation in diploid wheat. Crop Sci. 30:1337-1342.

Publications and Presentations

Journal Articles

Rajewski, J. F., C. A. Francis, and J. D. Eastin. 1991. Differential responses to defoliation of grain sorghum yield components and yield-related traits. Crop Sci. 31:561-66.

Zavala-Garcia, F., P.J. Bramel-Cox, J.D. Eastin, M.D. Witt and D.J. Andrews. 1992. Increasing the efficiency of the crop selection for unpredictable environments. Crop. Sci. 32:51-57.

Zavala-Garcia, F., Bramel-Cox, P.J., Eastin, J.D. 1992. Potential gain from selection for yield stability in two grain sorghum populations. Theor. Appl. Genet. 85:112-129.

Journal Abstracts

Zavala-Garcia, F., O. Marinesco, P.J. Bramel-Cox, J.D. Eastin, and M.D. Witt. 1991. Choosing selection environments in sorghum for high variable target areas. Agronomy Abstracts, p. 122. Verbal presentation.

Verma, P.K., J.D. Eastin, and M.D. Witt. 1991. Leaf extension rate and leaf growth index to differentiate sorghum genotype growth responses under stress. Agronomy Abstracts, p. 135. Verbal presentation.

Zavala-Garcia, F., J.D. Eastin, P.K. Verma, and M.D. Witt. 1992. Sorghum genotypic sensitivity in CO_2 gas exchange to non optimal growing conditions. Agronomy Abstracts, Minneapolis, MN. p. 135.

Presentations

Eastin, J.D. 1991. The influence of environmental stresses on production and water use efficiency. Invited presentation at a January 8-12, 1991 Symposium on the Impact of Global Climate's Changes on Photosynthesis and Plant Productivity in New Delhi, India. Symposium Sponsors: Indian Council of Agricultural Research and the Far Eastern Regional Research Office of the United States Department of Agriculture.

Eastin, J.D. et al. 1992. The response of crops to temperature, water and light stresses. Invited presentation at the EMBRAPA First International Symposium on Environmental Stress: Corn in Perspective. Sponsored by EMBRAPA (Brazilian Agricultural Research Agency/Maize and Sorghum Improvement Center) and CIMMYT. March 1992.

Kubik, K.K., J.D. Eastin, J.A. Eastin. 1991. The effect of solid matrix priming on the germination characteristics of field corn. Agronomy Abstracts, p. 169. Poster presentation.

Kubik, K.K., J.A. Eastin, J.D. Eastin, and M.D. Clegg. 1992. Large scale seed inoculation with beneficial microorganisms using solid matrix priming (SMP) seed enhancement techniques. Agron. Abstracts, Minneapolis, MN. pp. 162, Nov. 1-6, 1992.

Kubik, K.K., J.A. Eastin, J.D. Eastin, and M.D. Clegg. 1992. Supersweet sweet corn: Combining solid matrix priming (SMP), with Microbial seed inoculation. Proc. Nat. Sym. Stand Estab. Hortic. Crops, Fort Myers, FL. pp. 139-145, Nov. 16-20, 1992.

Zavala-Garcia, F., P.J. Bramel-Cox, D. Marinesco and J.D. Eastin. 1992. Effect of the selection environment on genotypic responses to a wide range of environments. Agronomy Abstracts, Minneapolis, MN. p. 120.

Mechanisms of Environmental Stress Resistance in Sorghum and Pearl Millet Relative to Sustainable Production Systems

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Summary

The role of abscisic acid (ABA) in drought and heat tolerance was further investigated. It was previously found that plants grown from seed treated with ABA had greater desiccation tolerance. It was also shown that plants grown from seed produced in a stressful area (Bema, Mali) was more drought tolerant than plants grown from seed produced in a less stressful area (Cinzana, Mali). Seed from these sources was analyzed for free and conjugated-ABA concentrations. It was found that seed produced at Bema had on the average greater concentrations of conjugated-ABA than that in seed produced in Cinzana. There were no differences between the locations in free ABA. It was suggested that the conjugated form is converted to free ABA after the seed germinates.

Several sorghum genotypes were screened for germination and stress tolerance by growing seedlings in charcoal pits at Cinzana, Mali. Sorghums CSM 228, CSM 388, CE-90, and ICSV 1079 had the highest survival when drought and high temperature stressed in the seedling stage.

In continued studies on proline accumulation in stressed sorghums, it was found that significant differences between genotypes in quantities of proline accumulation occurred, even though the plants were stressed the same under controlled conditions. The Malian sorghums CSM 228 and CSM 219 accumulated greater amounts of proline than U.S. genotypes, particularly in their leaves and stems. The Malian sorghums were also higher in both heat and desiccation tolerance. The results indicate that proline accumulation is an adaptive mechanism for increased stress tolerance.

Objectives, Production and Utilization Constraints

Objectives

Define plant physiological and biochemical mechanisms involved in drought and high temperature stress resistance and identify those which may be selected or managed for improved resistance.

Develop and implement practical selection techniques for genotypes with desirable physiological responses, and identify cultural methods which will improve yield or yield stability in stressful situations.

Constraints

Environmental stress is a primary constraint, particularly drought and high temperatures. Germination, seedling emergence, stand establishment and drought, often accompanied by high temperatures, are major problems in Mali. This project is aimed at investigating some of the physiological mechanisms associated with performance under stressful conditions.

Research Approach and Project Output

Research Methods

Role of Abscisic Acid

Abscisic acid (ABA) has an apparent role in plant resistance to stress, including drought, temperature, and mineral. In the ABA experiments, ten genotypes were selected for the study. These included Gadiaba, CSM 219, CSM 228, Malisor-5, Malisor-7, CE-90, CE-151, E35-1 and Sureno. These genotypes were grown from the same seed source at the Bema Research Station and the Cinzana Research Station. Grain was collected at maturity and sent to Nebraska for ABA analysis. Seeds were homogenized and ABA extracted and quantitatively determined, utilizing an ELISA method with a commercially obtained monoclonal antibody (PHYTODETEK, from Ideatek, Inc., San Bruno, CA). Conjugated ABA was determined by digesting the extract at 80°C after alkalizing to pH 12.

Seedling Stress Resistance

In another experiment, testing for seedling resistance to drought and high temperatures was done at Cinzana by utilizing the charcoal pits. The experimental design was randomized blocks with 4 replications. Each block was composed of 20 rows planted with 20 seeds of each genotype, spaced 1 cm apart. Fine charcoal was spread on the surface of the plots in order to increase soil temperature and induce drought. Seedling emergence was evaluated on the 3rd and 7th days after seeding, and plants surviving the stress were counted on the 15th day after seeding.

Proline Accumulation and Stress Tolerance

Proline is known to accumulate in plant tissues when they are exposed to drought and temperature stresses. These studies were a continuation of previous research (INTSORMIL Annual Reports 1988-1991) on proline accumulation. Plants were grown in growth chambers with full nutrient solutions, and at about 4 weeks of age, drought stress was slowly imposed over a period of about a week by adding increments of polyethylene glycol (PEG-8000) which decreased the osmotic potential of the solutions to -3.0 bars. After 7 days of stress, plants were harvested, the tissues divided into leaves, stems, and roots and immediately frozen. Proline concentrations were then determined by the method previously described (INTSORMIL Annual Report, 1988).

Heat and desiccation tolerance tests were performed on leaf disks taken from extra plants grown together in the same media with those grown for the proline studies. They were sampled for stress testing the day after the plants were harvested for proline determinations. The conductivity method was used for evaluation of stress tolerance as previously described by Sullivan and Ross (1979, Stress Physiology in Crop Plants, Wiley Interscience, pp. 263-281.).

Research Findings

Role of Abscisic Acid

We previously found that seedlings grown from seed pre-treated with ABA generally had greater drought tolerance than controls grown from seed pre-treated with water only. Also, seed produced at Bema, Mali generally had greater survival when drought and high temperature stressed than plants grown from seed produced at Cinzana, Mali (INTSORMIL Annual Report, 1988). This suggested to us that perhaps ABA was synthesized and stored in higher quantities in seed produced in the more stressful conditions of Bema. Bema is in a sub-Saharan drought and high temperature prone area of northern Mali and Cinzana is in an east-central region where stress occurs, but not as severe as in the Bema region.

Unexpectedly, when free ABA was determined in seed obtained from the two locations, there were no significant differences between any of the ten genotypes, nor were there any differences between the environments. However, when the conjugated-ABA was determined on four of the genotypes, the seed produced at Bema had on average 2.7 times more conjugated-ABA than those produced at Cinzana, with the exception of Gadiaba, as shown in Table 1. The methodology gave high CV values even among the standards, and because of these high CV's, there were no significant differences between genotypes, although when the means over all genotypes were compared the difference between locations was significant.

Table 1. Conjugated-ABA concentrations in sorghum seeds produced at Bema and Cinzana, Mali.

	Conjugated-ABA (per gdw)	
Genotype	Cinzana	Bema
CSM 219	309	1172
CSM 228	572	3293
Gadiaba	604	171
Malisor-7	847	1673
Means	583 b*	1577 a*
C.V. (%)		
	121.2	

*Means significantly different at $P < 0.05$.

This supports the hypothesis that seed produced in a drought stressed environment accumulates greater quantities of ABA than seed produced in a less stressful environment. While it was not determined in these experiments, it was further hypothesized that the conjugated-ABA is converted to the free form during early germination.

Seedling Stress Resistance

In Mali, stand establishment is an important factor in determining sorghum and millet yields. The stand is very much dependent on seed germination and ability of seedlings to tolerate subsequent high temperatures and drought stress.

Seed from several sorghum genotypes selected from the crossing program at the Samanko Research Station and some introductions were tested for drought and high temperature resistance in the seedling stage when grown at Cinzana. The results of this experiment are shown in Table 2. None of the lines selected from the crosses had superior seedling stress resistance, although, line SK-F4-378-2PL had the highest percent emergence at three days after seeding. The variety CSM 228, which is considered to be stress

Table 2. Emergence and survival of seedlings grown from seed produced at Samanko when drought and high temperature stressed at Cinzana.

Varieties	% Emerged in 3 days	% Emerged in 7 days	% Surviving 15th day
89-SK-F4-53-1PL	45	80	20
89-SK-F4-53-2PL	55	80	25
89-SK-F4-53-3PL	55	70	20
89-SK-F4-184-1PL	35	60	15
89-SK-F4-184-2PL	35	65	20
89-SK-F4-192-1PL	55	65	25
89-SK-F4-192-2PL	50	60	10
89-SK-F4-201-2PL	50	65	15
89-SK-F4-205-1PL	35	55	20
89-SK-F4-349-2PL	55	65	20
89-SK-F4-349-3PL	55	75	30
89-SK-F4-350-2PL	45	65	25
89-SK-F4-352-2PL	50	80	15
89-SK-F4-375-1PL	45	60	15
89-SK-F4-378-2PL	75	90	25
89-SK-F4-397-2PL	55	65	30
89-SK-F4-403-1PL	50	70	05
89-SK-F4-403-2PL	45	60	10
89-SK-F4-37-2PL	45	75	20
89-SK-F4-61-1PL	55	75	35
89-SK-F4-185-3PL	25	55	05
89-CZ-F4-185-4PL	55	75	30
MALISOR 84-1	50	65	25
MALISOR 84-7	65	80	30
CSM 388	65	75	55
CE-90	60	85	40
ICSV 1079	65	85	50
S-34	20	30	10
CSM228	65	85	60
C.V. (%)	29.8	17.1	61.0

resistant, again had the highest survival when stressed, along with CSM 388, CE-90, and ICSV 1079.

Proline Accumulation and Stress Tolerance

We previously reported that proline accumulation differed significantly among genotypes in both field and controlled environment grown plants (INTSORMIL Annual Reports, 1988, 1990, 1991). However, no relationship was shown between proline accumulation and measured stress tolerance. Some researchers have suggested that proline accumulation is the result of plants being stressed, with no beneficial effect.

Our results, shown in Table 3 and obtained under controlled environmental conditions, indicate clearly that there are significant differences between genotypes in quantities of proline accumulating, although the plants were stressed at the same level. The greatest differences occurred in the leaves and stems. There were no significant differences in accumulation among the roots, although there was a marked increase in root proline when plants were stressed.

The Malian locals CSM 228 and CSM 219 accumulated significantly higher quantities of proline in their leaves and stems than did the U.S. genotypes 121-18-2 and Redlan.

When tested for heat and desiccation tolerance (Table 4), it was found that the Malian sorghums had significantly greater stress tolerance (less injury to the imposed stresses) than the U.S. sorghums.

These results indicate that the accumulation of proline is a stress tolerance mechanism that has evolved in the West African sorghums.

Table 4. Levels of heat and desiccation tolerance of U.S. and Malian sorghums.

	Stress	
	Heat	Desiccation
	(% Injury)	
121-18-2	65 b*	85 b*
Redlan	79 b	90 b
CSM 228	22 a	51 a
CSM 219	13 a	56 a

*Values not followed by the same letter in a column are significantly different at P< 0.05.

Networking Activities

Research Investigator Exchanges

The Malian INTSORMIL Coordinator and principal scientist visited collaborating scientists and their facilities in Nebraska.

Table 3. Proline content of leaves, stems and roots of U.S. and Malian sorghums.

	Proline					
	Leaves		Stems		Roots	
Genotype	Cont.	Stress	Cont.	Stress	Cont.	Stress
121-18-2	250 a*	2774 b	349 a	1904 b	419 a	1335 a
Redlan	432 a	2336 b	313 a	2277 b	383 a	1055 a
CSM 228	297 a	6219 a	434 a	3923 a	252 a	1016 a
CSM 219	366 a	4057 a	515 a	3720 a	434 a	1277 a

*Values not followed by the same letter in a column are significantly different at P< 0.05.

Germplasm and Research Information Exchange

Discussions were held with the collaborators on project research, results, and activities, and assistance given in the purchase of research equipment and supplies.

Training Output

The P.I. served as advisor for two M.S. students from Mali, Mr. Bekaye Coulibaly and Mr. Siriba Dione. Both studied in agronomy/crop physiology at the University of Nebraska. Publications and Presentations

Publications

Sullivan, C. Y. 1991. Mechanisms of drought and high temperature resistance in sorghums and pearl millet relative to sustainable production systems. INTSORMIL Annual Report, Lincoln, NE. pp. 81-84.

Coulibaly, Sidi Bekaye. 1991. Physiological characteristics of sorghums [Sorghum bicolor (L.) Moench] related to drought resistance. M.S. Thesis (September), University of Nebraska, Lincoln. 158 pp.

Dione, Siriba. 1991. Influences of abscisic acid on sorghum growth and stress resistance. M.S. Thesis (October), University of Nebraska, Lincoln. 79 pp.

Al-Karaki, G. N., R. B. Clark, and C. Y. Sullivan. 1991. Effects of water stress and phosphorus nutrition on growth, plant water relations, and proline accumulation in beans. p. 122, Agron. Abstracts, Am. Soc. Agron., Madison, WI.

Clark, R. B., G. N. Al-Karaki, and C. Y. Sullivan. 1991. Genotypic responses in sorghum to drought stress and phosphorus nutrition. p. 124, Agron. Abstracts, Am. Soc. Agron., Madison, WI.

Sullivan, C. Y. and A. R. Lansac. 1992. Sorghum pollen germination and viability. p. 42, Abstracts First Int. Crop Sci. Congress, 14-22 July, Ames, Iowa.

Sullivan, C. Y. and A. R. Lansac. 1992. Sorghum pollen germination and viability. Poster. SICNA Summer Sorghum Field Tour, September 10, Lincoln, NE.

Zaifnejad, M., R. B. Clark, and C. Y. Sullivan. 1992. Growth relationships of water deficit and aluminum toxicity in sorghum. p. 134, Agron. Abstracts, Am. Soc. Agron., Minneapolis, MN.

Germplasm Enhancement and Conservation

Pearl Millet Germplasm Enhancement for Semiarid Regions

Project KSU-101

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Drs. W.W. Hanna and G.W. Burton, Pearl Millet Geneticists, USDA/ARS, Coastal Plain Experiment Station, P.O. Box 748, Tifton, GA.

Summary

The primary objective of this project is to develop pearl millet materials possessing agronomic, yield, and quality characteristics that address production constraints common to both LDC's and the U.S. Central Great Plains.

Following drought stress evaluation of S_1 lines of five Malian cultivars in Kansas, remnant seeds of 23 lines with drought tolerance scores ranging from poor to good were returned to Mali for evaluation. Seeds of several hybrids and F_2 progenies from crosses of elite KSU lines and the Malian materials will be sent to Mali for screening in 1993.

Evaluation and advancement of 3500 F_3, S_2, and advanced inbred lines continued with drought stress throughout the growing season providing an opportunity to evaluate all materials for drought tolerance, crown lodging associated with stalk-rot diseases and peduncle lodging. Resistance to peduncle lodging obtained from IP 2789 appears to be inherited as a partial dominant and is being transferred to elite inbred lines. Many of the yellow-seeded segregates from crosses of KSU and 29 ICRISAT/Zimbabwe yellow-seed lines maintained a bright, vitreous appearance under grain weathering conditions.

Male sterilization, by backcrossing into the A_1 and A_4 cytoplasmic-genic systems, was continued with 259 A/B pairs. A group of 140 A-lines were tested in hybrid combinations with two fertility-restorer lines. Population improvement by recurrent selection was continued within eight populations. Glyphosate (Roundup) is being used successfully in the conversion of two normal height populations to dwarf plant heights. Two bristled populations, HMPBR and its dwarf subpopulations, had no seed loss while nonbristled populations were severely damaged by large bird populations. Comparisons of the normal height population and the d_2 dwarf population of 185642 indicate tillering and seed sizes are similar but head lengths of the dwarf population are 13 mm shorter. The dwarf 185642 is receiving further improvement for grain yield potential with the RRPS method in collaboration with Dr. G. Burton. Following three cycles of mass selection for emergence capability, from planting depths of 75 to 85 mm, most of the short mesocotyl and poorly emerging genotypes of population LMSE have been eliminated. Emergence of LMSE from a 50 mm planting depth was two days earlier than the average emergence of unselected long mesocotyl F_3 inbred lines.

Objectives, Production and Utilization Constraints

Objectives

To develop widely adapted, early-maturing pearl millet populations, lines, germplasms, and hybrids with: a) improved drought tolerance, seed size and density, seedling stand establishment characteristics, lodging resistance, and grain yields; b) insect, disease, bird, and striga resistance; and c) acceptable food quality characteristics.

To select and evaluate materials developed in this program under a wide range of environments in developing countries.

Constraints

Numerous constraints to successful pearl millet production exist throughout the dry tropics. Each constraint varies in importance and/or severity in the different ecogeographic zones addressed by INTSORMIL and in the ease and degree of success by which plant breeding efforts influence it. Drought and heat stress are the primary constraints in much of the dry tropics since millet is grown in areas receiving limited amounts and erratic patterns of precipitation. Drought and heat stress are involved with poor seedling establishment when associated with factors such as reduced speed and vigor of germination and seedling elongation, shallow planting depths, elevated soil temperatures, and rapid surface soil drying that interrupts germination. Seed and seedling characteristics are also involved in the capability of a seedling to penetrate and emerge through crusted soils. The need for adequate levels of resistance or tolerance to several insects and diseases such as downy mildew, smut, and rust, and diseases affecting stalk and grain quality is a continuing constraint, as many of these organisms readily mutate to forms that overcome plant resistance. Bird depredation is a common occurrence and the incidence of *Striga* is becoming more severe as fields remain in cultivation for longer periods of time between periods of fallow. Several constraints and problems are associated with the use of the crop, ranging from stalk characteristics needed for construction and forage to the apparent food quality of the grain in regard to nutritional value, ease of processing, and consumer acceptability.

Research Approach and Project Output

Research Methods

Standard breeding procedures for open-pollinated crops are used. The pedigree breeding method is used for early development of nearly all materials entering the program, the advancement of elite lines, and lines extracted from populations undergoing recurrent selection. Mass selection, gridded mass selection, S_1 progeny performance testing, and recurrent restricted phenotypic selection (RRPS) methods are used in population improvement. Screening and evaluation is conducted at several U.S. and LDC locations.

New sources of breeding materials and materials for collaborative work are obtained each year as landraces, improved cultivars, F_1 hybrids, inbred lines, and germplasm sources of desired genetic traits. As these materials pass through the quarantine greenhouse, seed is obtained from random-mated plants (within the line), self-pollinated plants of each line, and from crosses involving elite Kansas materials as seed parents. As part of the collaborative work with Malian millet breeders, a study will determine if it is feasible to select within groups of S_1 lines of Malian introductions for root systems capable of penetrating the B horizon of the silty clay loam soils found in western Kansas. These soils are characterized by a firm, hard, silty clay B horizon that contains an average clay content of 45 to 52% in the B_2t horizon. Many of the accessions entering the program appear to have varying degrees of reduced drought tolerance when planted on these soils, apparently because of difficulty establishing root systems that will penetrate the B horizon, explore the soil profile, and extract stored soil moisture deep in the profile. Selection for improved plant:soil relationships or the ability to penetrate these subsoils is possible within many of the accessions when planted on these soils. This relationship, as a form of drought tolerance, appears to be effective on several other soil types. Differences between lines appear as variations in total biomass production and date of onset of leaf rolling under stress conditions. A primary concern regarding selection for drought tolerance in the absence of downy mildew disease pressure is that reduced levels of resistance to downy mildew occur if selection extends beyond the S_1 or F_2 generations. Selection for this type of drought tolerance will be limited to testing S_1 lines in Kansas and returning remnant seeds of superior S_1's to Mali for evaluation and recombination under Malian growing conditions.

Seed and seedling characteristics affecting stand establishment are studied and evaluated under laboratory, greenhouse, and field conditions. Materials selected for long mesocotyl and seedling lengths are planted 100 mm deep in greenhouse soil beds to obtain initial germination and emergence indices, seedling vigor scores, and plant weights. Field tests are conducted on raised beds to minimize damping-off disease problems associated with water-logged soils and standing rain water. Seeds of materials placed in field screening tests are planted at depths of 75 or 100 mm to identify lines possessing superior emergence characteristics.

Research Results

Emphasis is being placed on developing a population of breeding materials, elite inbred lines, and genetically broad based populations useful to collaborators in LDC's and in U.S. agriculture. This is a continuing activity with imported accessions entering the program each year to increase the genetic diversity within the program. Progress, as measured by increases in yield potential, agronomic fitness, and adaptability to a wider range of environments, is enhanced with new accessions that have received breeding inputs in the cooperating program.

Accessions

Eleven Malian millet cultivars and thirteen synthetic lines were grown in the 1991 and 1992 quarantine greenhouses, respectively. Total numbers of 57 and 112 hybrids were obtained during quarantine from crosses of elite KSU-101 lines used as seed parents and the Mali materials. Several of the improved Malian cultivars, such as Boboni Local, NKK, M2D2, M9D3, and their F_1 hybrids involving KSU lines are photoperiod sensitive and fail to flower at 39° N latitude when grown in the field. Segregation within F_2 families obtained from F_1's grown in the greenhouse has given a low frequency of early-maturing plants, but late-maturing segregates are very vigorous. Malian lines with Souna parentage, such as Souna/Sanio and Souna/Togo, flower in 65 to 75 days under field conditions and their F_2 families have produced several hundred excellent segregates. Grain yield potentials and harvest indices of these hybrids are very good. The Malian lines, GR-P1, PN4, and the variety Magna Nara, failed to flower but in F_1 combinations the early maturity of the KSU seed parents was dominant with anthesis occurring in 60 to 75 days. Several of the best hybrids and their F_2 progenies are being returned to Mali.

Moderate drought stress occurred throughout the 1991 growing season. Only 157 mm of rainfall was received during this period, 52% of normal, forcing the plants to develop root systems capable of extracting stored subsoil moisture which extended to depths of 1.2 m or more in the soil profile. It is estimated that the subsoils contained 180 to 210 mm of stored moisture at the time of planting. S_1 lines of five Malian cultivars showed very pronounced differences in their ability to penetrate the soil profile and extract stored subsoil moisture. Differences in plant height, tiller development and amounts of foliage were apparent throughout the season. During periods of hot weather, differences in time of onset and degree of changes in leaf coloration and leaf rolling were readily observed within and between varietal groups of S_1 lines. Harvesting to determine total biomass production was interrupted by a severe fall snow storm and could not be completed. Remnant seeds of 23 S_1 lines with drought tolerance scores ranging from poor to good were returned to Mali to determine if similar responses occur under Malian growing conditions. It is anticipated that, if the drought tolerance responses obtained in Mali are similar to the Kansas results, this method of selection would not only improve drought tolerance of these materials but it could possibly widen ranges of adaptation as a result of selecting in different environments and latitudes. Limiting selection in Kansas to the S_1 generation, in the absences of downy mildew, should have no effect on levels of resistance in the lines returned to Mali.

Pedigree Breeding

Inbred line development continued with selection within 3500 F_3, S_2, and advanced generation lines derived from both the pedigree breeding and population improvement programs. Drought conditions throughout the growing season provided an opportunity to screen all materials for reduced levels of stalk rot diseases, crown lodging, and lodging caused by breaking of culms in upper internodes and peduncles. Nearly all of the crown lodged plants examined appeared to have stalk rotting organisms associated with the break, above average grain yield potential, and premature loss of green coloration from drought stress. Lodging caused by breaking of the peduncle is also associated with high yield potential and drought stress but occurs at or after physiological maturity. At the time peduncle lodging occurs, the parenchyma tissues of the culm do not appear to be infected with any stalk rot organisms but the tissues are shriveled and detached from the rind of the peduncle.

Lodging was particularly severe in materials being selected for brown mid-rib, a character associated with reduced plant lignin content and increased digestibility. Two sources of brown mid-rib are being used; the Purdue bmr and 90C-77066, a SADCC line received from Dr. A. Kumar. Lodging was characterized as a complete collapse of the plant with culms breaking at both nodal and internodal sites. It was not unusual for a culm to have breakage occurring at two or more places. This type of lodging occurred at an earlier date than either crown or peduncle lodging, often with 100 percent lodging before the plants were physiologically mature. This lodging occurred with equal severity, within materials ranging from F_2 to advanced selections, receiving the third backcross into the A_1 male-sterile cytoplasm.

Several sources of lodging resistance are being used in crosses to improve culm strength of elite materials. Inbred lines with IP2789 parentage have the most effective lodging resistance and are being used extensively in crosses to reduce lodging of elite materials. IP2789 originated in Mauritania and was obtained from the ICRISAT Center germplasm collection. It has a low grain yield potential because of its early maturity and small club-type panicles, i.e., short, large diameter heads. The first sets of lodging resistant progenies selected from crosses involving IP2789 were low yielding and predominantly club-headed. The latest cycle of crosses and backcrosses have produced togo and club-headed types having similar numbers of seeds per head and improved yield potentials.

A severe blizzard in early November deposited 60 to 90 cm of snow in all plot areas and caused lodging of 80 to 100 percent of most materials in the program. Lodging scores recorded in December, approximately 90 days after physiological maturity (DAPM), identified about 80 lines ranging from F_3 to F_8 that had only 2 to 15 percent lodging. Most of these lines eventually lodged during the winter months but line 918264 had 60 percent of its culms standing on April

28, approximately 220 DAPM. Several of these lines had been crossed to lodging-susceptible A-lines. Lodging scores of the hybrids were intermediate to parental readings, ranging from 30 to 60 percent at 90 DAPM, indicating incomplete dominance of this character. Fertility restoration of the A_1 cytoplasm was variable with none of these hybrids showing either complete male-fertility or male-sterility. It is expected that fertility/sterility responses and grain yield potentials will improve as the next group of F_2 to F_4 progenies are advanced. These materials are derived primarily from backcrosses and the third cycle of crosses involving advanced lodging resistant inbred lines and elite B- and R-lines.

In previous years, a low priority had been given to selection and development of materials based only on seed coat color. Partly by chance, but primarily because our best source of maintainer lines had a gene frequency for light yellow to yellow seed color of .2 to .3, the population of cytoplasmic male-sterile and maintainer lines in this program includes a relatively high proportion of yellow-seeded lines. The development of male-fertility restorer lines was based on a wider array of materials with most of these materials having seed coat pigmentation ranging from gray to blue. The flavinoid pigments producing these colors apparently have an influence on the response of the seed coat to weathering. In the course of selecting for agronomic performance, seed quality and seed weathering resistance within possible restorer lines, fewer than 20 white/yellow-seeded advanced inbred lines have survived screening and remain in the program. To date, none of these lines have complete or sufficient male-fertility restoration in hybrid combination with the A_1 cytoplasm to permit isolated field production of white or yellow-colored grain suitable for use in Milri-type food formulation studies by TAM-126 personnel.

Moderate levels of grain weathering were observed throughout the program materials in 1991. At approximately 90 DAPM, observations indicated that a considerable number of yellow-seeded F_2 and F_3 progenies from crosses of elite KSU lines and 29 yellow ICRISAT/Zimbabwe accessions had maintained bright yellow seed coats with vitreous, translucent seed characteristics. More than 20 of these accessions had one to four successful crosses to elite R-lines, so a relatively high probability exists that effective yellow-seeded restorer lines can be developed from these progenies.

Male sterilization by backcrossing in the A_1 and A_4 systems was continued within 259 A/B pairs. Another group of 140 A-lines, including 2 A_4 lines, were tested in hybrid combinations with two tester R-lines. Nearly all of the lines presently in the sterilization program are derived from crosses involving advanced KSU and ICRISAT materials that have received previous breeding attention. Few R-lines selected from initial crosses, involving landrace and village varietal materials, are sufficiently adaptive and productive to survive screening, but their value as sources of diversity increases following additional crossing and backcrossing to elite KSU lines. Seventeen elite A/B pairs derived from KSU/ICRISAT crosses were sent to ICRISAT Center, Hyderabad for another cycle of selection and crossing. Test cross hybrids of these A-lines equaled or exceeded the performance of 79-2068 hybrids in drought tolerance, lodging resistance, and grain yield.

Evaluation of inbred lines for grain yield performance in hybrid combinations could not be completed this year. Only 25 percent of the yield plots were harvested prior to the occurrence of severe storms in late October-early November. Because of several weeks of contact between the lodged heads and snow and wet soil surface, threshing and seed separation was extremely variable resulting in nonsignificant differences in yield. Advancement of early generation parental lines was based primarily on agronomic scores, male-fertility restoration, and drought stress ratings of their F_1 hybrids.

Population Improvement

Population improvement using mass selection and S_1 progeny testing recurrent selection methods was continued within eight populations. Three normal height populations are advanced using mass selection. HMPBR, a bristled population, has a predominately normal height phenotype but also possess d_1 and d_2 dwarfing genes. A dwarf bristled subpopulation is being extracted from the original population using glyphosate (Roundup) to destroy normal height plants prior to anthesis using a wick applicator. At present, the population has an approximate ratio of 25% d_1: 75% d_2 height genes. The dwarf BR population is grown with isolation distances of 0.5 to 0.8 km from several isolated, non-bristled millet plantings and 2 km from the normal height HMPBR. Severe bird depredation by an early migrating flock of blackbirds occurred in all of the non-bristled plantings, but no apparent seed loss was found in the bristled populations.

The normal height population 185642 has been used extensively as a parental germplasm source of large-seeded, early-maturing maintainer lines in the A_1 cytoplasmic male-sterility system. Using glyphosate this population has been converted to a d_2 dwarf height population in three cycles of treatment. Reduction in internode elongation of some of the normal height plants because of drought stress during two cycles permitted the continued presence of normal height plants at low frequencies. Preliminary comparisons indicate the two populations have equal numbers of tillers per plant, similar seed size distributions, and head lengths of the d_2 population are 13 mm shorter than the original population. Plant height ranges are 0.9 to 1.2 m in the d_2 population and 1.9 to 2.4 m in the normal height population.

In collaboration with Dr. Glenn Burton, the dwarf 185642 population has been placed in Dr. Burton's recurrent restrictive phenotypic selection (RRPS) population improvement method to determine if RRPS can, effectively, be used to improve pearl millet grain yield potential. Secondary objectives of this effort are to reduce the incidence of lodging and maintain large seed size in the population. Progenies are generated in the winter greenhouse at Tifton, Georgia, followed by progeny evaluation under field conditions at Fort Hays. Preliminary results indicate plant height must receive consideration and control in the selection process to avoid moving average population heights to the tall end of the d_2 height range in response to selection for increased grain yield. Height modifying genes are present in this population that increase d_2 plant height 20 cm to heights of 100 to 120 cm in dry environments and to heights of 160 or 170 cm with irrigation or above normal rainfall. These modifiers can be desirable in intercropping situations but excessive height limits the taller plants usefulness for mechanized production under good moisture conditions.

The development of population LMSE for improved characteristics affecting stand establishment continues to show promise. Three cycles of selection pressure using uniform planting depths of 75 to 85 mm has eliminated much of the short mesocotyl length portion of the population and long mesocotyl seedlings unable to emerge through the soil overburden. Selective thinning of the stand following emergence has increased the proportion of vigorous seedlings displaying rapid plant development and leaf expansion. When planted as a check in a trial evaluating emergence indices of long mesocotyl F_3 lines from a planting depth of 50 mm, the LMSE had 90 percent emergence at 5.7 days after planting (DAP) compared to the test mean of 7.6 days. Moderate soil crusting resulted from rains received 3 DAP. F_3 lines with rapid mesocotyl elongation and the LMSE check completed emergence before the crust hardened, but late emerging lines had reduced seedling counts. Testing of topcross hybrids involving these populations could not be completed because of severe storm damage.

Present planter configuration and capability gives uniform placement of seed to soil depths of 75-85 mm with normal soil compression by the packer wheels. Planned modifications of the planter are expected to permit planting to uniform depths of 100 or 120 mm to obtain increased selection pressure for improved stand establishment potential.

Networking Activities

Workshops

July 8-12, 1991. Participated in the INTSORMIL CRSP conference at Corpus Christi, Texas. A field planting of KSU-101 pearl millet materials was included in the field tour.

Research Investigator Exchanges

Travel to Mali, September 14-27, 1991 to review collaborative research with IER personnel and plan 1992 research activities.

Dr. J.D. Axtell, Sorghum Geneticist, Department of Agronomy, Purdue University, West Lafayette, IN 47907.

Dr. L.W. Rooney, Cereal Chemist, Department of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843.

Mr. Shankar Podduturi, Pearl Millet Breeder, Pioneer Hi-Bred International, Inc. Box 1506, Plainview, TX.

Dr. J.W. Maranville, Sorghum/Millet Physiologist, Department of Agronomy, University of Nebraska, Lincoln, NE.

Dr. P. Bramel-Cox, Sorghum Breeder, Kansas State University, Manhattan, KS 66506.

Dr. L. Claflin, Plant Pathologist, Department of Plant Pathology, Kansas State University, Manhattan, KS 66506.

Dr. D. Seifers, Plant Pathologist, Fort Hays Experiment Station, Kansas State University, Hays, KS 67601.

Dr. C. Klopfenstein, Cereal Chemist, Department of Grain Science and Industry, Kansas State University, Kansas State University, Manhattan, KS 66506.

Germplasm Conservation and Exchange

Thirteen accessions were received from Mali, and 798 accessions are in storage. Three inbred lines, 24 F_1 hybrids and 12 F_2 families from crosses of KSU-101 and UNL-118 inbred lines were received from UNL-118.

Sixty lines and populations were sent to ICRISAT Center, India, 38 to ICRISAT Sahelian Center, Niger, 23 to IER, Mali, and ten to Belize. Domestically, five items were sent to UNL-118, two to UNL-114, one to PRF-103, one to Tifton, GA, and five to Pioneer Hybrid International, Inc. Approximately 15 seed lots ranging in weight from 0.2 to 5 kg were sent to non-INTSORMIL universities for use in agronomic studies and as instructional materials in crop science classes. About 800 kg of millet grain was given to University of Nebraska personnel for poultry feeding trials.

Seed Production

Variable results in seed production, and particularly seed quality, were obtained because of a September 19 frost that occurred 3-4 weeks earlier than normal. Damage to isolated seed increase blocks planted on low-lying alluvial sites ranged from complete loss to reduction of germination percentages to a range of 10 to 30 percent. As a result, the planned release of two A/B pairs and two R-lines will be delayed until 1993. Small-scale increase of seven A/B pairs being considered for release failed to produce seed with acceptable germination and vigor.

Impact

The cytoplasmic-genic male-sterile line 79-2068A continues to be used extensively as a seed parent of hybrids grown in Northwest India and its maintainer is used by both ICRISAT and Indian national breeding programs as a source of early-maturity, large seed size, and drought and lodging resistance. Hybrid HHB 67 (2068A X H77/833-2) released by the Haryana Agricultural University (HAU) Hisar, Haryana, is typical of hybrids produced with this seed parent. It matures in 60 to 62 days compared to 74 to 80 day maturity requirements of older hybrids HHB 50 and HHB 60. The short growth duration permits a wider range of planting dates giving increased flexibility for use in sequential multiple cropping systems and acts as a drought escape mechanism in years when the monsoon withdraws early. In trials conducted over a five year period, HHB 67 produced 2837 kg ha^{-1} compared to yields of 2944 and 2865 kg ha^{-1} of HHB 50 and HHB 60 indicating HHB 67 has a high per day grain productivity potential. The HAU recently released an improved male-sterile line and its maintainer derived from a cross involving 2068B for hybrid seed production in the State of Haryana.

KSU-101 male sterile line 81-1163A is the seed parent of two hybrids entered in the All India Coordinated Millet Improvement Program trials by ICRISAT Center. This white-seeded line is downy mildew resistant and ICRISAT tests indicate its combining ability for grain yield equals that of 79-2068A.

Publications and Presentations

Publications

Stegmeier, W.D., R.L. Vanderlip, and D.J. Andrews. 1991. The development of pearl millet as a food and feed grain crop for the Central Great Plains. p. 161 IN Agronomy Abstracts. ASA, Madison, WI.

Andrews, D.J., W.D. Stegmeier, and J.F. Rajewski. 1991. Pearl millet development as a feed grain for the Great Plains. IN Proc. of the Third Annual New Crops Symposium, 7-9 October 1991. Indianapolis, IN. In Press.

Presentations

July 11, 1991. KSU-101 pearl millet populations, inbred lines, and elite hybrids were presented at the INTSORMIL CRSP conference, Corpus Christi, Texas.

August 7, 1991. Presented program background information field tour and progress update to aids of the Kansas U.S. Congressional Delegation.

February 25, 1992. Presented an overview of the KSU-101 program and progress to External Review Panel at the University of Nebraska in Lincoln.

Breeding Sorghum for Tolerance to Infertile Acid Soils

Project MSU-104
Lynn M. Gourley
Mississippi State University

Principal Investigators

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Collaborating Scientists

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Dr. Manuel Rosero, Director of Cereal Crops, ICA, Apartado Aereo 6712, Cali, Colombia (Host Country Coordinator)
Mr. Luis de Angulo, Vice President Community Affairs, Arauca Project, Occidental de Colombia, Inc., Apartado Aereo 092171, Bogota, Colombia
Dr. Fabio Polania, Technical Director, FENALCE, Apartado Aereo 8694, Bogota, Colombia
Mr. Alfonso Gonzalez, Sorghum Breeder, ICA, La Libertad, Apartado Aereo 2011, Villavicencio, Colombia
Dr. Tunde Obilana, Sorghum Breeder, SADCC/ICRISAT, Southern Africa Regional Sorghum/Millet Research Program, P.O. Box 776, Bulawayo, Zimbabwe
Mr. J.K. Rutto, Deputy Director, Crops, Soil and Water, KARI; and Dr. A.M. Mailu, Associate Director of Crops, KARI, P.O. Box 57811, Nairobi, Kenya
Mr. B.M. Kanyenji, Sorghum Breeder, Katumani National Dryland Farming Research Center, P.O. Box 340, Machakos, Kenya (National Sorghum and Millet Coordinator)
Mr. C. Mburu, Sorghum Breeder, and Mr. C.O.A. Oduori, Millet Breeder, Kakamega Regional Research Center, P.O. Box 169, Kakamega, Kenya
Dr. Sam Z. Mukuru, Sorghum Breeder, SAFGRAD/ICRISAT, P.O. Box 30786, Nairobi, Kenya
Mr. V.M. Zake, Sorghum Breeder, on study leave at Mississippi State University, Mississippi State, MS
Dr. Guillermo Munoz, Plant Breeder, MSU-111 PI, International Programs and Department of Agronomy, Mississippi State University, CIAT, Apartado Aereo 6713, Cali, Colombia
Dr. Henry Pitre, Entomologist, MSU-105 PI, Department of Entomology, Mississippi State University, Mississippi State, MS
Dr. Jerry Maranville, Plant Nutritionist, UNL-118 PI; and Mr. David Andrews, Sorghum and Pearl Millet Breeder, UNL-118 PI, Department of Agronomy, University of Nebraska, Lincoln, NE
Dr. John Axtell, Sorghum Breeder, PRF-103 PI; and Dr. Gebisa Ejeta, Sorghum Breeder, PRF-107 PI, Department of Agronomy, Purdue University, West Lafayette, IN
Mr. William Stegmeier, Pearl Millet Breeder, KSU-101 PI, Kansas State University, Ft. Hays Experiment Station, Hays, KS
Dr. Darrell Rosenow, Sorghum Breeder, TAM-122 PI; and Gary Peterson, Sorghum Breeder, TAM-123 PI, Texas A & M University Agriculture and Research Center, Route 3, Lubbock, TX
Dr. Fred Miller, Sorghum Breeder, TAM-121 PI, Department of Soil and Crop Sciences, Texas A & M University, College Station, TX

Summary

Acid soil tolerant sorghum varieties and hybrids developed in this project are being evaluated on acid soils or other low input environments in Colombia, other Latin American countries, and in Kenya. The germplasm was developed specifically for the acid soils of Colombia, however, it has been noted that much of this germplasm will also tolerate low fertility levels in nonacid tropical soils. Stress screening for tropical acid soil tolerance appears to impart tolerance to low-input environments.

Just as certain drought tolerant varieties and hybrids will produce higher yields when irrigated, some of the acid soil tolerant varieties and hybrids will also respond to increased fertilizer applications. The reverse does not appear to be true. Germplasm developed under irrigation or high fertility environments does not necessarily maintain its yield advantage under moisture or low fertility stress.

In Kenya and other countries in Africa, sorghum is relegated to marginal production areas while high value cash crops occupy prime land areas. Due to the low prices paid

to farmers for their produce and the high cost of fertilizer, even the high value cash crops are receiving little fertilizer. Sorghum crops receive almost no fertilizer. Farmers use manure, crop rotation, intercropping, relay cropping, fallow, and other management techniques instead of fertilizer. The acid soil stress tolerant lines and hybrids seem to be able to tolerate this treatment better than the highest yielding high-input hybrids. In subsistence agriculture, stable performance under low-input production practices is more important than high yields.

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 very acid, deficient in most macro and micro mineral elements and contain toxic levels of soluble Al and sometimes Mn. Acid soils are found both in humid and arid regions of the tropics.

This project addresses, through breeding, three major production limiting constraints of tropical soils; low-input production on infertile soils, phytotoxic levels of Al and Mn, and low P availability. In addition to yield, every breeding project must strive to maintain disease resistance and grain quality as a goal.

Research Approach and Project Output

Sorghum Research in Colombia

A large number of sorghum lines tolerant to acid soil constraints have been developed in MSU-104 and MSU-111. Some of this germplasm has direct use possibilities as varieties, some B-lines as hybrid seed parents after the development of the male-sterile A-lines, and some R-lines as the pollen parents of hybrids. Field and genetic testing is required to determine the best lines in each category.

Three isolation crossing blocks were established in a MSU-104 winter nursery at CIAT, Cali, Colombia. Two rows each of 86 acid soil tolerant A-lines were planted in each of three crossing blocks. One pollinator was used for each crossing block. The R-lines, each with reasonably good combining ability, were IA 28, Tx430, and ICA Nataima. The males represent three levels of acid soil tolerance with IA 28 being most tolerant, Tx430 very susceptible, and ICA Nataima with an intermediate tolerance level. The two males IA 28 and ICA Nataima produce hybrids with a testa and are used where bird resistance is required. The male Tx430 will produce hybrids which test the genetic tolerance of the corresponding A-line. Hybrids with IA 28 and ICA Nataima as pollinators would be expected to possess the highest degree of acid soil tolerance.

These crossing blocks will also provide information about nick of the female and male and yield of the seed parent. This information is important from a commercial hybrid seed production standpoint.

New acid soil tolerant R-lines are crossed onto tester A-lines using hand pollination. Limited seed quantities of these hybrids are produced until the best combining ability males are determined and a crossing block can be established using the new R-line as the pollinator.

Seed of the hybrids with IA 28 and Tx430 as pollinators and with the new R-line hand pollinated crosses will be sent to Mississippi for evaluation in the U.S. Hybrids using ICA Nataima will be photoperiod sensitive. Seed of all of the hybrids will be evaluated in Colombia and Kenya.

Sorghum and Millet Research in Kenya.

Grain Sorghum Tolerance to Acid Low Fertility Soils in Kenya

Using plants tolerant to soil acidity is an important complementary approach to soil management. In subsistence agriculture, stable performance is more important than high yields in favorable environments.

Thirty-four genotypes consisting of six cytoplasmic genetic male sterile A-lines, represented by their respective maintainer B-lines, as female parents, four restorer R-lines, as male parents, and their twenty-four F_1 hybrids from a North Carolina Mating Design II were utilized in this study. The materials for this study had not been tested in the area before. The genotypes were Tx623, Wheatland, and B-Yel PI acid soil susceptible females; (AT1)-52-2-1-2, (AT 2)-10-6-1-1, and (AT 1)-36-4-2-2 acid soil tolerant females; Tx430 and Tx432 acid soil susceptible males; IS 7254C and IA 28 acid soil tolerant males; and Seredo as local cultivar check.

Four sites were selected in Western Province, Kenya and one additional site at the Plant Science Research Center at Mississippi State University. The sites used in Kenya were of low altitude, low fertile acid soils and were situated in an area where sorghum is an important crop in the subsistence farming system. Three sites, Buburi, Mumias, and Ukwala, were chosen for low soil pH (<5.2) while the Obambo trial site was selected to test performance at low soil pH, but above 5.2. With the exception of Buburi trial site, trials were conducted on sites located on farmer's fields.

Trials were grown in 1990 and 1991 during the long rains season in Kenya and during the summers of 1990 and 1991 in Mississippi. The experimental design for each location was a randomized complete block with four replicates. In Kenya, plots consisted of a single row 5 m in length and 75 cm between rows. Pre-emergence herbicides and fertilizers were not used. This was done to simulate typical sorghum management practices of Western Kenya. All trials were maintained weed free throughout the growing period.

Several characters were investigated, however, only 1991 data for days to flower, plant height (cm), grain yield (kg ha^{-1}) are presented in this report. Mean performance of the crosses and parents at various location sites is shown in Table 1. At Buburi, soil erosion at the early growth stage of the crop and later bird and midge damage had a devastating effect on the performance of the crop. At Mumias, the crop was flooded during the early growing period. Data for these two locations are omitted from this report.

Average location means for days to flower indicated significant delay in flowering as stress due to acidity increased. Highest plant height was obtained at MSU in the temperate zone. In all traits studied, there was expression of heterosis. Not all crosses exhibited heterosis and the magnitude differed from location to location.

At MSU, crosses of Tolerant x Tolerant (TxT) parents flowered earlier than the earliest parent, IS 7254C. At Obambo, TxT hybrids were earlier flowering than female parents. Parent, IS 7254C, had the lowest number of days to flower across sites and was less variable compared to the tolerant female parents. At MSU, Obambo and Ukala, means for days to flower were lower for Tolerant x Susceptible (TxS) hybrids than for their respective earlier parents. Consistently low means for days to flower were obtained for (AT 1)-52-2-1-2 x Tx432 at each location. Means for days to flower in the Susceptible x Tolerant (SxT) group indicated that Tx623 x IS 7254C was comparable to its male parent at all sites. In the Susceptible x Susceptible (SxS) category, Wheatland x Tx432 and B-Yel PI x Tx432 hybrids generally flowered earlier than other susceptible parents.

Male parent, IA 28, generally produced shorter hybrids than male parent, IS 7254C. In the TxT group, all crosses expressed hybrid vigor. Generally, TxS hybrids of male parent, Tx430, were shorter than crosses from male parent, Tx432. In the SxT group, Wheatland had comparable means across locations. Hybrids were taller than their respective parents at all sites. In the SxS group, Wheatland x Tx430 was the shortest across locations.

Hybrid vigor was expressed for grain yield at MSU, Obambo, and Ukala. In the TxT group, it was observed that crosses involving male parent, IA 28, had higher mean yields than crosses involving male parent, IS 7254C. In the SxT group, Wheatland x IA 28 and B-Yel PI x IA 28 hybrids performed better than other crosses across locations. In the SxS group, heterotic response was expressed more at Obambo and Ukwala than at MSU.

Divergent Selection for Drought Tolerant Variables in Two Pearl Millet Populations.

Pearl millet is mainly grown in semiarid areas of Kenya. Once established, millet is very drought tolerant. Therefore, drought escape or avoidance during the seedling stage is one of the mechanisms by which pearl millet establishment and production can be increased in semiarid Kenya. Selection for seedling root length and coleoptile length in pearl millet were two selection indices measured as possible determinants of seedling drought avoidance. Tests to determine the effects of divergent selection for these two characters in pearl millet populations on yield and yield components were done under field conditions in Kenya after one cycle of phenotypic recurrent selection.

The amount of rain received by the crop at Kiboko and Katumani in 1991 during the short rain season was 199.8 mm distributed over 36 days and 294.6 mm distributed over 41 days, respectively. This amount of rain was lower than average, but was well distributed.

Mean performances of the S1 and EDS populations for mature plant characteristics for the tests at Kiboko and Katumani in Kenya during 1991 are presented in Table 2. Analyses of variance (not shown) indicated significant differences (P 0.05) for anthesis dates, plant height, hundred seed weight, and grain weight among S1 populations at Kiboko; and for plant height, and grain weight among S1 populations at Katumani. No significant differences occurred for most traits among EDS populations at both locations. This was expected because laboratory and greenhouse tests to evaluate the direct effect of selection among EDS populations indicated no significant selection responses.

Comparisons between parents and their respective selections, as well as, between the corresponding divergent selections were made using t tests. Significant differences (P 0.05) occurred between S1 parent and S1-LC-TC1, and between S1-LR-TC1 and S1-SR-TC1 for anthesis dates at Kiboko, but no significant differences occurred at Katumani; S1-SR-TC1 for plant height at Kiboko, and S1-SR-TC1 at Katumani; S1-SR-SC1 for grain weight at Kiboko and S1-LR-SC1 at Katumani; and S1-SR-TC1 and S1-LR-TC1, and S1-SR-SC1 for 100 seed weight (grain size) at Kiboko and S1-LR-SC1, S1-LR-TC1, and S1-SR-SC1 at Katumani; and S1-SR-SC1 and S1-LC-TC1 for harvest index at Kiboko. No significant differences occurred between S1 divergent selections at either location, except between S1-LC-TC1 and S1-SC-TC1, for anthesis dates,

Table 1. Means of days to 50% bloom, plant height and grain yield of 35 sorghum genotypes evaluated at Obambo and Ukwala, Kenya and Mississippi State University.

	50% Bloom			Plant height			Grain yield		
Genotype	O	U	MSU	O	U	MSU	O	U	MSU
		----- days -----			----- cm -----			----- kg ha^{-1} -----	
1) IS 7254C	59	70	54	121	120	145	1387	960	853
2) IA 28	60	78	65	80	75	94	2880	160	1707
3) Tx430	75	87	61	82	76	106	53	80	1227
4) Tx432	67	77	59	94	95	110	1067	347	1227
5) Tx623	68	84	57	102	106	142	1040	160	1573
6) Wheatland	57	72	53	88	80	89	1040	347	1440
7) B-Yel PI	70	81	52	87	95	104	640	453	1253
8) (AT1)-52-2	71	81	56	99	99	122	907	453	960
9) (AT2)-10-6	71	77	57	92	98	124	773	453	1333
10) (AT1)-36-4	71	87	56	102	92	122	1120	160	1227
11) 5 x 1	61	73	52	160	155	188	1893	667	1547
12) 6 x 1	58	66	51	130	129	166	800	987	1653
13) 7 x 1	63	74	52	140	140	183	1200	853	1467
14) 8 x 1	62	72	52	143	154	183	880	800	853
15) 9 x 1	64	72	53	127	160	188	507	347	1680
16) 10 x 1	64	73	52	144	157	185	1093	747	1013
17) 5 x 2	60	79	61	126	124	154	2533	373	2453
18) 6 x 2	57	69	53	109	104	123	2320	1120	2107
19) 7 x 2	64	74	55	101	111	136	2373	1227	2267
20) 8 x 2	65	76	57	116	110	140	3627	720	2453
21) 9 x 2	63	74	57	111	112	146	1733	1093	2693
22) 10 x 2	67	77	57	108	126	147	2827	1040	2373
23) 5 x 3	63	78	54	114	106	141	2160	347	1813
24) 6 x 3	59	71	52	100	92	119	2000	747	1413
25) 7 x 3	64	75	51	106	105	128	1600	720	1413
26) 8 x 3	64	75	51	105	109	135	2427	667	1573
27) 9 x 3	67	74	55	107	114	140	2320	960	2000
28) 10 x 3	66	80	52	108	111	138	2240	480	1467
29) 5 x 4	63	82	55	126	115	152	3040	160	1627
30) 6 x 4	58	67	52	101	98	120	1147	613	1467
31) 7 x 4	58	73	50	129	127	145	2507	693	1120
32) 8 x 4	65	71	51	123	132	143	1280	773	1707
33) 9 x 4	62	74	54	122	126	149	1547	640	1947
34) 10 x 4	65	73	50	131	128	162	1760	507	1893
35) Seredo	65	70	—	153	139	—	2667	1147	—
Mean	63.6	74.9	54.2	114.3	115.4	140.1	1733	640	1600
LSD (0.05)	3.9	4.4	1.8	11.9	14.9	10.2	720	293	347
CV %	4.3	4.1	2.4	7.3	9.0	5.2	29.0	30.9	15.8

Adapted from dissertation of Vincent Makumbi Zake, Grain Sorghum Tolerance to Acid Low Fertility Soils in Kenya, Mississippi State University.

and between S1-SR-SC1 and S1-LR-SC1 for 100 seed weight at Kiboko. Few significant differences occurred among EDS populations at either location.

Though differences between divergent selections were not always significant, it was evident that the trend of performance of S1 populations, which were selected towards the long root length and short coleoptile length in both media, was greater than for selections made toward short root length and long coleoptile length. It appears that selecting for seedling root length and coleoptile length in sand culture and germination towels could have some effects on yield and yield components. This seems to occur even after one cycle of selection for this (root length) highly environmentally sensitive trait. The effects may be made more pronounced if the base population has high genetic variability and if more than one selection cycle is practiced on the selections.

Other Sorghum and Millet Research in Kenya

The accomplishments in Kenya during this year were many, however, only a few will be listed. Progress was made in each of the seven Centers in which research for the sorghum/millet (S/M) program was conducted, more in some than in others. The sorghum/millet technical advisor

Table 2. Mean performances of S1 and EDS populations during 1991 at Kiboko and Katumani in Kenya.

Populations	Anthesis date		Plant ht.		100 seed wt.		Dry matter wt.		Grain wt.		Harvest index	
	KIB	KAT	KIB	KAT	KIB	KAT	KIB	KAT	KIB	KAT	KIB	KAT
	(days)		(cm)		(gm)		(gm)		(gm)			
S1 PARENT	60	69	179	98	0.9	0.6	356	326	93	102	0.25	0.28
S1-LR-SC1	59	67	195	101	1.0	0.8	394	432	111	177	0.28	0.37
S1-SR-SC1	54	67	181	106	1.1	0.8	446	407	156	138	0.34	0.32
S1-LR-TC1	55	65	173	97	1.0	0.8	311	412	100	153	0.32	0.37
S1-SR-TC1	57	67	158	79	1.1	0.7	336	264	121	86	0.34	0.31
S1-LC-TC1	54	63	169	89	0.9	0.6	314	284	104	93	0.38	0.32
S1-SC-TC1	58	66	189	109	1.0	0.7	364	339	108	115	0.29	0.29
LSD (0.05)	2.8	7.4	21.0	16.6	0.09	0.13	115.7	127.6	46.5	54.8	0.09	0.93
EDS PARENT	47	57	83	91	1.1	0.7	182	155	73	80	0.40	0.57
EDS-LR-SC1	48	58	86	98	1.0	0.8	160	137	58	68	0.36	0.48
EDS-SR-SC1	49	62	79	82	1.0	0.7	179	135	67	63	0.48	0.45
EDS-LR-TC1	48	63	85	86	1.0	0.7	205	155	73	67	0.36	0.45
EDS-SR-TC1	49	57	85	91	1.0	0.7	180	137	67	66	0.39	0.47
EDS-LC-TC1	48	62	83	86	1.0	0.7	202	139	77	69	0.38	0.50
EDS-SC-TC1	48	61	87	101	1.1	0.7	189	134	71	63	0.39	0.45
LSD (0.05)	1.6	6.0	6.4	20.1	0.11	ns	ns	ns	17.8	ns	0.14	0.10

S1 and EDS = population designations, LR and SR = long root and short root length, LC and SC = long coleoptile and short coleoptile length, SC1 and TC1 = sand culture cycle one and germination towel cycle one, and ns = not significant.

Adapted from dissertation of Lawrence M'Ragwa, Divergent Selection for Drought Tolerant Variable in Two Pearl Millet Populations, Mississippi State University.

feels that more progress will be made in the sorghum/millet research program in the next year or two than was made in all of Phase I. He has therefore agreed to extend his assignment to include the first two years of Phase II.

The most long-lasting accomplishment in the MIAC S/M Project undoubtedly will be in KARI's human resource development. The sorghum/millet research programs do not have any depth in terms of trained personnel. Many of the M.Sc. degree students have returned to Kenya and are developing their research programs. All sorghum/millet programs will be strengthened when the Ph.D. students return with their degrees, provided adequate funding is provided.

Another hopeful sign of sustainable progress was the planting of a total of 39 F_2 sorghum populations at four sites this year. Without development of lines specifically bred for Kenyan conditions, a sustainable sorghum improvement program cannot be achieved. KARI now has complete sorghum/millet breeding programs in which selected parents produce new lines and varieties, instead of just testing and retesting material from farmer's fields or from other breeders.

The first KARI/MIAC Seed Technology Shortcourse was conducted at the Lanet National Seed Quality Laboratory from March 2-20, 1992. It was judged a very successful Shortcourse by students, NSQCS staff and instructors. Thirty-two certificates of completion were given out to commercial and KARI breeders and seed technologists at the conclusion of the shortcourse.

On November 18-19, 1991, the sorghum/millet technical advisor assisted the INTSORMIL Director, Dr. John Yohe, in meetings with KARI Directors to develop a KARI-INTSORMIL Memorandum of Understanding. Discussions were also held with the MIAC Chief-of-Party, Dr. David Daugherty, and the USAID Project Manager, Mr. Jim Dunn.

The sorghum/millet technical advisor works closely with the sorghum/millet breeders and agronomists in the following four regions of Kenya:

Eastern Kenya - The sorghum breeding site at the Katumani sub-Center, Kiboko, is the logical location to spur expansion of the sorghum/millet production area into the semiarid regions of Kenya. Collaboration with ICRISAT and INTSORMIL scientists at this location has assisted the KARI effort. Katumani breeders will prepare the National Performance Trials (NPT's) for their area of responsibility and for Embu, Perkerra and Mtwapa Centers. Entries in these trials will be mainly white or yellow seed colored types with some bird resistant brown seeded check varieties.

Breeding programs in eastern Kenya are well developed and conducted. Breeding and evaluation of germplasm are difficult in this environment because of low and erratic rainfall, distances between test sites and frequent disease and insect outbreaks. The sorghum breeding program has competent leadership since Ben Kanyenji returned to Kenya with his M.Sc. degree. Adequate dryland test sites need to be developed at other Centers to evaluate drought tolerant germplasm. The pearl millet program is mainly in an evaluation mode until Lawrence M'Ragwa returns from the U.S. with his Ph.D. degree.

Western Kenya - Sorghum breeding nurseries at Alupe are backed up with germplasm supplied from Kiboko and INTSORMIL breeding projects because of the difficulty of making hand-pollinations and production of quality seed due to the high rainfall and humid conditions. A large quantity of germplasm from the TA's INTSORMIL project in Colombia was evaluated at Alupe. From these nurseries, over 1000 new lines have been evaluated in variety trials and as hybrid combinations in hybrid trials. Bird and weathering resistant varieties and hybrids are required in the western humid areas.

Mr. Christopher Mburu has returned with his M.Sc. degree and has recently assumed the sorghum breeding activities. The sorghum breeding program at Kakamega/Alupe has lacked trained and experienced leadership since Newton Ochanda left for Ph.D. training. Newton is expected to return to Kenya in February 1993. The finger millet breeding and evaluation program is strong and under the capable leadership of Mr. C. Oduri. This activity is directed from Kakamega and NPT's are prepared and sent out from this location.

Highlands - Breeding activities at Lanet will be limited to selection and evaluation of sorghum and silage varieties. This research is supported by crosses made at Kiboko. The sorghum/millet staff at Lanet are experienced and are conducting quality research.

Cold tolerant sorghum varieties collected by SAFGRAD/ICRISAT were selected at Lanet for future grain and/or silage trials. High quality sorghum silage with low lignin genes will find a market in the Lanet area, provided cold tolerance can be incorporated into these varieties. Crosses to accomplish this breeding goal have been made at Kiboko and are being segregated at Lanet.

Coastal - The sorghum/millet breeding activities for the eastern coast of Kenya are conducted by the breeders in Katumani. This region has received the least of the technical advisor's attention to date. In the future, the different problems caused by the humid lowlands must be addressed.

Networking Activities

Workshops

The MSU-104 PI helped organize and participated in the first KARI/MIAC Seed Technology Shortcourse conducted at the Lanet, Kenya National Seed Quality Laboratory from March 2 - 20, 1992.

Dr. Susana Goggi consulted with the Mid-America Agricultural Consortium and Kenya Agricultural Research Institute by lecturing at the 1st KARI/MIAC Seed Technology Shortcourse at the Lanet National Seed Quality Control Research Center, Nakuru, Kenya. March 2-20, 1992.

Professor David Andrews consulted with the Mid-America Agricultural Consortium and Kenya Agricultural Research Institute by lecturing at the 1st KARI/MIAC Seed Technology Shortcourse at the Lanet National Seed Quality Control Research Center, Nakuru, Kenya. March 7-20, 1992.

Dr. Susana Goggi attended and participated in the 38th Shortcourse for Seedsmen-Vigor Testing Workshop. Seed Technology Laboratory, Mississippi State University, April 13-15, 1992.

Dr. Susana Goggi attended and participated in the 13th Seed Improvement Course. Seed Technology Laboratory, Mississippi State University, June 1-July 11, 1992.

Research Investigator Exchanges

Dr. Charles Campbell, the MIAC Training Coordinator and the sorghum/millet technical advisor had several meetings during his visits to Kenya concerning in-country (Kenya) Ph.D. student research. Most of the sorghum/millet Ph.D. students will conduct all or a portion of their research at Katumani and/or Kiboko.

On August 3 - 17, 1991, Dr. Clarence Watson professor at Mississippi State University and Lawrence M'Ragwa's major professor visited Kenya for the first time. The sorghum/millet technical advisor took them on a tour of KARI Centers in the East and West.

Dr. Susana Goggi consulted with DeKalb Plant Genetics at Dumas, Texas on ways to improve effectiveness when using a gravity table during the seed cleaning process. She visited facilities and familiarized herself with the commercial sorghum breeding program while visiting breeding nurseries and production fields at Lubbock and Dumas, Texas. September 1991.

In September 1991, the sorghum/millet technical advisor traveled to the U.S. where he attended several meetings with Mississippi State University International Programs staff and Department of Agronomy staff. The technical advisor presented a sorghum project report at a Departmental CSRS review and drove to Missouri for consultations with MIAC Kenya Project staff. Some time was also spent visiting with Kenyan graduate students at Mississippi State and, by telephone, with others at other universities.

On November 18-19, 1991, the sorghum/millet technical advisor assisted the INTSORMIL Director, Dr. John Yohe, in meetings with KARI Directors to obtain a KARI-INTSORMIL Memorandum of Understanding.

Dr. Susana Goggi consulted with DeKalb Argentina on the analysis of possible causes for poor seed performance in Sudax sorghum and presented results to the technical and administrative committee. November 1991.

Dr. Susana Goggi visited with Dr. Tony Sotomayor-Rios and Mr. S. Torres-Cardona about the sorghum and maize programs at the USDA/ARS Tropical Agriculture Research Station at Mayaguez, Puerto Rico. She also consulted with Professor Jose A. Quinones, Dean and Director of the College of Agricultural Sciences at the Universidad de Puerto Rico, about sorghum and seed technology programs. January 1992.

Dr. Susana Goggi visited Drs. John Axtell and Gebisa Ejeta's sorghum programs at Purdue University, West Lafayette, Indiana. She attended an intensive personalized course on RFLP's at Dr. Benetzen's Molecular Biology Laboratory. She was instructed on the use of the Gene Gun and the research of Dr. Usha Zeher. Dr. Larry Butler and Mrs. Tishu Cai, Department of Biochemistry, discussed their immature embryo tissue culture protocol and techniques. January 6-17, 1992.

Dr. Susana Goggi consulted with DeKalb Plant Genetics and submitted a written report and recommendations on an analysis of possible causes for poor seed performance in white sorghums under different irrigation systems. February 1992.

February 23 - 25, 1992, the MSU-104 PI and Dr. Susana Goggi traveled to Lincoln, Nebraska and participated in the external evaluation of INTSORMIL Projects.

Professor David Andrews visited several KARI sorghum and millet research Centers, consulted with sorghum and millet breeders and agronomists, and submitted a written report of observations and recommendations. March 1992.

Dr. Susana Goggi visited several KARI sorghum and millet research Centers and consulted with sorghum and millet breeders and agronomists. April 1992.

Dr. Susana Goggi consulted with DeKalb Argentina on the analysis of possible causes for poor seed performance in sunflower seed lots and submitted a written report and recommendations. April 1992.

In June 1992, the technical advisor was in the U.S. for meetings and home leave. He participated in the preliminary examination of his graduate student at Mississippi State University, Mr. Vincent Zake.

Germplasm and Research Information Exchange

Hybrid sorghum seed from crosses made in this project and MSU-111 were imported into Kenya for evaluation at several locations. The hybrid entries were selected to be useful across several Kenyan ecological zones.

Publications and Presentations

Publications

Gourley, L. M., A. S. Goggi, and E. J. Montgomery. 1991. Mississippi Regional Cooperators, 1990 Regional Sorghum Yield Trials. MAFES Bulletin.

Gourley, L. M. and A. S. Goggi. 1991. Breeding sorghum for tolerance to infertile acid soils. pp. 91-99. In J. M. Yohe and T. T. Schilling (Eds.) INTSORMIL Annual Report 1991 - Fighting Hunger with Research . . . A Team Effort. The University of Nebraska, Lincoln, NE.

Gourley, L. M. and G. Munoz. 1991. Sustainable production of sorghum and pearl millet in fragile, tropical acid soils. pp. 51-56. In J. M. Yohe and T. T. Schilling (Eds.) INTSORMIL Annual Report 1991 - Fighting Hunger with Research . . . A Team Effort. The University of Nebraska, Lincoln, NE.

Gourley, L. M. 1991. Breeding sorghum for stress environments of the tropics. pp. 17-22. In F. Gaitan Gaitan (Ed.) Sorgo Para El Futuro. Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia. p.179. (Spanish)

Goggi, A. S., J. C. Delouche, and L. M. Gourley. 1991. Influence of weathering and immaturity on sorghum seed specific gravity and seed morphology. p. 168. In Agron. Abs. October 27-November 1, 1991. Denver, Colorado.

Gourley, L. M., A. S. Goggi, C. Ruiz-Gomez, and R. B. Clark. 1991. Mineral element concentration in 26 acid soil tolerant genotypes. p. 95. In Agron. Abs. October 27-November 1, 1991. Denver, Colorado.

Gourley, L. M. 1992. Sorghum/millet breeding research program. pp. 19-25. In Kenya National Agricultural Research Project Fourth Annual Report of Activities and Progress. MIAC. Nairobi, Kenya.

Vaughan, C. E. and A. S. Goggi. 1992. Report to Mid-America Agricultural Consortium and Kenya Agricultural Research Institute on the Seed Technology Training Course. February 27-March 22, 1992, Lanet Center, Nakuru, Kenya. p. 15.

Presentations

Goggi, A. S., J. C. Delouche, and L. M. Gourley. 1991. Influence of weathering and immaturity on sorghum seed specific gravity and seed morphology. ASA Meetings. October 27-November 1, 1991. Denver, Colorado.

Gourley, L. M., A. S. Goggi, C. Ruiz-Gomez, and R. B. Clark. 1991. Mineral element concentration in 26 acid soil tolerant genotypes. ASA Meetings. October 27-November 1, 1991. Denver, Colorado.

Goggi, A. S. 1992. Seed development and maturation. 1992 Seed Improvement Training Course. USDA/OICD TC-130-3. MSU, June 1992.

Goggi, A. S. 1992. Producing hybrid seed. 1992 Seed Improvement Training Course. USDA/OICD TC-130-3. MSU, June 1992.

Goggi, A. S. 1992. Principles of seed separations. 1992 Seed Improvement Training Course. USDA/OICD TC-130-3. MSU, June 1992.

Goggi, A. S., H. O. Catano, and L. M. Gourley. 1992. Distribution of seeds in sorghum inflorescence according to differences in specific gravity. AOSA/SCST 1992 Meetings. June 11-18, Oklahoma City, Oklahoma.

Breeding Sorghum for Increased Nutritional Value

Project PRF-103
John D. Axtell
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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.

The International Division of the U.S. Census Bureau, in unique agreement with many other agencies, projects that the population of the world will double within the next 40-50 years (Jamison, E. 1989. World Population Profile. Bureau of the Census. Issued September 1989). This means that agricultural scientists will have to learn how to produce as much food, feed and fiber in the next 5 decades as they have learned how to produce during the past 2,000 years. There is virtually no alternative scenario to this view short of a major human calamity. This fact poses an unprecedented challenge to plant and animal scientists around the world. Fortunately, at the same time new and powerful research tools are available from the explosion of knowledge in the biological and agricultural sciences. Crop and livestock yields must increase significantly to avoid a level of human misery in the world which is intolerable to civilized society. Some of this increase will occur on productive land with adequate rainfall, but many of these lands are already stretched to capacity. Much of the increase will have to come from marginal agricultural lands with relatively poor soils and chancy rainfall, which are subject to frequent periods of drought. The goal of the INTSORMIL and McKnight Research Projects is to utilize the best basic information from recent advances in plant biology to understand the mechanisms of drought resistance in crop plants, and to apply this knowledge to the improvement of crop and livestock yields in the U.S. and throughout the world. The model crop used for these studies is sorghum, which has developed mechanisms which have allowed it to evolve in semi-arid regions of the world over the centuries. Sorghum is generally grown in those parts of the world where it is too dry to grow corn or other cereals. Even though the drought resistance of grain sorghum has been known for centuries, relatively little effort has been expended in the study of mechanisms of drought resistance in sorghum at the genetic, physiological and molecular levels. The mission of our interdisciplinary program is to combine the resources of the International Sorghum Improvement Program at Purdue University, with the expertise of scientists in Stress Physiology and Plant Molecular Biology, in a concerted effort toward an under-

standing 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.

Our research accomplishments include the identification of exceptionally drought resistant genotypes of sorghum to use as a model system to study mechanisms of drought resistance. We have developed the first sorghum genetic map (RFLP map) which will now allow us to define the location of the major genes involved in drought resistance in sorghum. We have mutagenized these major genes in order to determine their individual contributions to the drought resistance trait. We are developing a system which will allow us to specifically "tag" and then isolate major drought resistant genes. We are developing a system in which these genes can be reinserted into the sorghum genome (or the genomes of other cereal crops) in order to enhance the drought resistance of high quality sorghum lines, or enhance the drought resistance of other crop species.

We have continued to develop our linkages with the U.S. seed industry and with developing countries. It has been a great pleasure these last eighteen months to have had Dr. Yilma Kebede as a Fullbright Scholar working with the McKnight group at Purdue. Dr. Kebede has primary responsibility for the National Sorghum Improvement Program in Ethiopia, and we look forward to continuing our collaborative research relationships with him as the Pioneer Representative in Africa. The students have especially enjoyed their interaction with Yilma and the view he has presented to them on the problems and prospects for third-world agriculture. He has presented seminars and led student discussion groups where he willingly shared his expertise on sorghum research in the context of a developing country research program. Next year it will be our pleasure to host Dr. Subramanian from ICRISAT Center, who is principal sorghum research scientists for the ICRISAT laboratory programs (pending availability). He will be spending his sabbatical leave with the McKnight group at Purdue and will help consolidate linkages on our drought resistance research with the international sorghum research center program (ICRISAT). Our collaborative research relationships with Dr. Osman Ibrahim, in Sudan, and Mr. Issoufou Kapran and Dr. Mousa Adamou, in Niger, will be continued.

Objectives, Production and Utilization Constraints

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.

Constraints

Nutritional value of sorghum has long been known to be different from other cereals. This includes the tannin problem, the protein quality problem, the protein digestibility problem, and the local processing methods involved in eliminating these problems in the diets of sorghum consuming people. We have made significant progress in cooperation with Dr. Larry Butler on the tannin problem, and Sam Mukuru has now proven, in studies conducted in our laboratory, that high tannin sorghums traditionally grown at high elevations in Eastern Africa are very satisfactory sources of digestible nutrients, if the grain is processed adequately by traditional means. Protein quality improvement will be a major breeding objective during the next five years. We have identified good sources of modified quality protein sorghums which are comparable in yield potential and grain quality to quality protein maize 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 OPM in maize by Brian Larkins and Mauricio Lopez has shown a strong relationship between the gamma-zein fraction and modified vitreous endosperm characteristics. An Elisa technique is being developed which will make selection for vitreous endosperm opaque-2 much more reliable and faster. The same technique will be adapted to sorghum P-721 modified lines in improvement programs. Trials will be conducted at several locations during 1992 to confirm the stability of the vitreous endosperm trait in these QPS lines across temperate and tropical environments. It is interesting to note that the digestibility of P-721 high lysine sorghum is about 10% greater than that of most normal sorghum varieties which should be an additional benefit if it can be confirmed in the QPS lines. The digestibility problem can also be approached at this time by a better understanding of traditional processing technologies. We believe the identification of a low fraction III (cross-linked kafirin fraction) sorghum variety in the World Collection has the potential to provide a genetic and breeding solution to the digestibility problem in sorghum, which would be a significant achievement in utilization of sorghum as a food grain and also as a feed grain.

A major priority will be the development of a vitreous endosperm high lysine sorghum variety using germplasm developed from crosses with P-721 opaque. This will be a combined effort with Bruce Hamaker, Gebisa Ejeta, and Larry Butler. The modified endosperm high lysine sorghum parental materials will be tested in Niger, Sudan, and West Lafayette to verify environmental stability of the vitreous endosperm and the lysine content. An extensive second cycle breeding program will be initiated to further improve the protein quality, vitreous endosperm, and protein digestibility of the new lines.

Another major focus will be to continue to ascertain the nutritional value of thin fermented porridges, as used in eastern and southern Africa, and also to determine what genetic characteristics are necessary in a new variety to successfully prepare these porridges. For example, it is generally known that local varieties have a high diastatic power which is essential for fermentation with either yeast or lactobacillous. Many improved sorghum varieties lack this characteristic and this factor may be responsible for low adoption rate of improved varieties. Joe Mushonga's research on developing rapid assays for diastatic power and studying inheritance of diastatic activity in sorghum cultivars will be continued. Secondly, Dr. Sam Mukuru has completed his study at Purdue on the digestibility of thin fermented sorghum porridges in Uganda and has found that there is no effect of the tannins on digestibility after the traditional wood ash and fermentation treatments. Another focus of activity will be to pursue the development of cold tolerant sorghum lines with markedly improved seedling vigor for higher elevations in eastern Africa and temperate zones. The sources of cold tolerance from northern China continue to be excellent for early spring seedling vigor. Finally, we have identified a sorghum line in the World Collection (IS 2319) which has a significantly reduced cross-linked kafirin fraction and shows very good digestibility results in rat feeding trials, whether cooked or uncooked. Since we believe this cross-linked kafirin is responsible for many of the digestibility problems in sorghum we are giving this activity a very high priority. Studies include inheritance of the low fraction III trait and incorporation with this genetic characteristic into improved broadly adapted sorghum germplasm.

Drought Research

A major drought occurred across a section of the corn belt, including West Lafayette, Indiana, in 1991. While these droughts were not as extensive as in 1988, it was devastating to those corn growers who had the misfortune to farm within the affected regions. The drought in Eastern and Southern Africa in 1992 is reported to be the worst in living memory. Drought continues to be the major source of crop losses 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.

During the past three years we have initiated a unique graduate training and research program which is designed to foster interdisciplinary research in basic plant sciences focused on a problem of extreme importance to both U.S. and third world agriculture; drought resistance. We have recruited 11 outstanding graduate students. These students have already earned a reputation (both on and off the Purdue campus) for their interdisciplinary zeal, their group activities, their high quality research, and exceptional grades in ongoing course work. The philosophy that research can transcend discipline boundaries, and must transcend these boundaries, if we are to solve difficult and complex agricultural problems, has been rapidly grasped and implemented by our student group. The faculty, Department Heads and Deans view this as a major accomplishment of our training program. Internationalization of research through interdisciplinary activities has recently been identified as a priority at Purdue University. The INTSORMIL/McKnight program at Purdue serves as a model of what can be accomplished in this area.

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. Gebisa Ejeta will continue his collaboration with Sudan and Niger on *Striga* tolerance and drought tolerance. John Axtell will focus on cold tolerance screening in Kenya and the Highlands of East Africa. 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 firstly entail constructing hybrids between exceptionally resistant and susceptible (e.g. P721-N) lines and evaluating F2, F3 and subsequent advanced progeny and their backcrosses to the original parents, using traditional plant breeding methods. Secondly, we propose to generate many susceptible revertant lines by mutagenesis of drought resistant P898012 and P954035 sorghum. Seed of these pure line varieties were mutagenized at Purdue in the summer of 1988 and M1 plants were self-pollinated to provide M2 seed to screen for drought sensitive revertants in Mexico under water stress conditions. Stress sensitive revertants will also be obtained by using a controlling element system in sorghum for transposon mutagenesis and tagging. The "candy stripe" sorghum phenotype is analogous to the variegated pericarp controlling element system in maize. Candy stripe sorghum is now being backcrossed to drought resistant sorghum lines to produce a pure line drought resistant sorghum variety which contains the mutable gene system. When this is available, it should be possible to select for genetic events involving transposition of the controlling element away from the pericarp element by selecting seed from fully red sectors on the sorghum panicle. Plants grown from seed having red sectors will then be self crossed and their progeny screened for an alteration in drought resistance. Any drought resistant gene identified can then be cloned using as a probe the candy stripe controlling element we are currently identifying. A genetic map of sorghum is being generated (currently 100 markers) using restriction fragment length polymorphisms, and this will be employed to define specific chromosomal regions containing drought resistance genes and genes determining a range of morphological, physiological and biochemical characteristics of putative adaptive significance in terms of sorghum stress resistance.

Training M.S. and Ph.D. LDC students will continue as in the past.

Research Findings

The principal research accomplishments made during the INTSORMIL/McKnight Foundation funding period for this program are as follows. Our approach to investigating the genetic determinants of the exceptional drought resistance of certain sorghum cultivars has been multidisciplinary, international in scope, and multifaceted. First, we constructed hybrids between exceptionally resistant and susceptible lines and evaluated F_2, F_3 and subsequent advanced progeny and their backcrosses to the original parents, using traditional plant breeding methods. A large number of F_6 recombinant inbred families have been derived from one such cross. These families exhibit an exceptional range of genotypic variation for pre- and post-flowering drought stress resistance, as revealed in recent field evaluations of this germplasm during the drought of 1991 in Indiana.

Second, we developed a sorghum RFLP genetic map and we are now uniquely poised to begin to screen the above recombinant inbred families for RFLPs which are associated with specific drought resistance/susceptibility traits. A major thrust of the proposed research has been to extensively characterize the recombinant inbred families above for morphological, physiological and biochemical traits, and to map the major genes responsible for drought resistance to specific chromosome regions. The concomitant development of sorghum cDNA libraries of constitutive and drought-inducible genes will likely further enhance the sorghum genetic map, and will assist in defining specific genes which are responsive to water deficits.

Third, we generated many susceptible revertant lines by chemical mutagenesis of drought resistant P898012 and P954035 sorghum. Seed of these pure line varieties was mutagenized at Purdue in 1988 and M_1 plants were self-pollinated to provide M_2 seed. These M_2 populations were screened for drought sensitive revertants in Mexico under water stress conditions. In order to provide a focal point for interdisciplinary activities in genetics, physiology and biochemistry, we have identified 38 independently occurring mutants in the epicuticular wax genetic system in sorghum. The latter mutant lines are now providing an exceptional source of genetic material for our multidisciplinary group to investigate the biochemistry and genetics of epicuticular wax synthesis and deposition, and to characterize the contribution of the waxy "bloom" trait not only to drought resistance, but also resistance to fungal pathogens. Biochemical analyses of sorghum sheath waxes indicate that wax loads range from as high as 7.4 mg/dm^2 in wild types to as low as 0.3 mg/dm^2 in certain bloomless mutants. Wild type sheath waxes are predominantly (>90%) comprised of free carboxylic acids of carbon chain length C_{28} and C_{30}. Three bloomless mutants (bm-18, bm-8 and bm-15) resulting from chemical mutagenesis, as well as one bloomless mutant identified in the candystrip population (a putative transposon induced bloomless mutant), exhibit a 60 to 70% reduction in total wax load and accumulate free carboxylic acids of much shorter chain length (predominantly C_{22}, C_{24}, C_{26} and C_{28}). These bloomless mutants appear to prematurely terminate fatty acid chain elongation. In contrast, one sparsebloom mutant (bm-28) accumulates substantially higher amounts of carboxylic acids of chain length C_{32} and C_{34} than the wild type. A tandem mass spectrometry method for determining the composition of epicuticular wax esters has been developed, and has been used to show that wild type wax esters range in total carbon number from C_{28} to C_{48}; these esters are comprised of carboxylic acids of chain length ranging from C_{14} to C_{24}, condensed with alcohols of chain length C_{14} to C_{28}. Future studies will involve continued characterization of the ester, alkane, aldehyde, alcohol and acid fractions of the various bloomless and sparsebloom mutants.

Fourth, we have characterized a controlling element system in sorghum with the view to exploiting this system for transposon mutagenesis and tagging. The "candy stripe" sorghum variety is similar phenotypically to the variegated pericarp controlling element system in maize. The *Y* gene has been identified as the mutable locus in sorghum. The candy stripe sorghum variety has been backcrossed to the drought resistant sorghum lines to produce a pure line drought resistant sorghum variety which contains the mutable gene system. Now that this is available, it is possible to select for genetic events involving transposition of the controlling element away from the pericarp element by selecting seed from fully red sectors on the sorghum panicle. A total of 100,000 independently occurring excision events are being collected. Plants grown from seed having red sectors will then be self crossed and their progeny screened for drought susceptibility. In principle, any drought resistant gene so identified can then be cloned using the candy stripe controlling element probe which we plan to clone from sorghum. A promising lead came recently from our discovery that one of the epicuticular wax genes in sorghum is linked with waxy endosperms, so we may be able to transposon tag the waxy endosperm gene first and then later tag the epicuticular wax gene more readily because of the mechanics of transposition based on observations in other species. Utilizing the genetic map of sorghum generated using RFLPs, it will be possible to define specific chromosomal regions containing drought resistance genes.

Fifth, we have sought genetic variability for a specific biochemical trait which may play an important role in osmoregulation; the accumulation of glycinebetaine. Six glycinebetaine-deficient sorghum genotypes have been identified by screening of the sorghum world germplasm. Genetic analyses of F_2 and backcross progeny from crosses between glycinebetaine-deficient and glycinebetaine-containing sorghum lines have confirmed that glycinebetaine-deficiency is conditioned to be a recessive allele of a single locus. Tracer studies indicate that glycinebetaine-deficient cultivars are capable of oxidizing $^2H_3$-betaine aldehyde to $^2H_3$-glycinebetaine at the same rate as glycinebetaine-containing cultivars, suggesting that the metabolic lesion is at a step proximal to betaine aldehyde dehydrogenase in the glycinebetaine biosynthetic pathway. A sensitive new method for determining choline and glycinebetaine (by stable isotope dilution plasma desorption mass spectrometry) has been developed, and is being applied to these investigations. Future studies will focus on RFLP mapping this locus, testing whether glycinebetaine-deficiency is associated with an impaired capacity to oxidize choline to betaine aldehyde, and developing near isogenic glycinebetaine-containing and -deficient sorghum lines to determine if this trait affects drought resistance.

Sixth, we have developed a sorghum tissue culture, regeneration and transformation system with the view to exploiting many recent advances in the field of plant biotechnology towards sorghum improvement. A number of genes of putative importance in plant tolerance of abiotic and biotic stresses are currently being cloned from other plant sources in anticipation that it may soon be possible to routinely transform sorghum with such genes and their anitsense equivalents. Specific genes of interest include genes encoding enzymes of proline biosynthesis, genes encoding H^+-translocating ATPases, genes encoding proteins involved in cell membrane-cell wall adhesion, and genes encoding pathogenesis related proteins. Currently we are in the process of selecting stable transformants using the herbicide bialaphos. The material will be selected in a step-wise fashion increasing gradually the concentration of the herbicide, starting at the stage of callus formation. As little as 2 mg/L bialalphos is enough to affect the growth of nontransformed callus, and at a concentration of 5 mg/L kills all the tissue whether transformed or not. Bialaphos-resistant calli will be used to regenerate transformed sorghum plants.

Networking Activities

Workshops

Organizer and participant of "The Third Annual Purdue University McKnight Program Retreat." Presentation entitled "The McKnight Foundation Interdisciplinary Research Project on Mechanisms of Drought Resistance." Turkey Run State Park, IN. April 10-11, 1992.

Research Investigator Exchanges

INRAN Staff, ICRISAT Staff and INTSORMIL Staff are regularly involved in exchange visits at Purdue, as well as Pioneer and DeKalb seed company scientists. A partial list follows.

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

Dr. R. Jambunathan, ICRISAT, Patancheru P.O. Andhra Pradesh 502 324, India

Dr. Dallas Oswalt, Training Ofc, ICRISAT, Andhra Pradesh 502 324, India

Dr. D.S. Murty, Plant Breeder, ICRISAT, Andhra Pradesh 502 324, India

Dr. Lee House, SADCC/ICRISAT Sorghum & Millet Prog, Bulawayo, Zimbabwe

Mr. Joe Mushonga, SADCC/ICRISAT Sorghum & Millet Research Progrom, Bulawayo, Zimbabwe

Dr. Vartan Guiragossian, Sorghum Breeder, ICRISAT, Nairobi, Kenya

Dr. John Rogler, Animal Science, Purdue University, W. Lafayette, IN 47907

Dr. Ed Ashworth, Horticulture, Purdue University, W. Lafayette, IN 47907

Dr. Nick Carpita, Botany, Purdue University, W. Lafayette, IN 47907

Dr. Mike Hasegawa, Horticulture, Purdue University, W. Lafayette, IN 47907

Dr. Darrel Rosenow, Texas A&M University Agric. & Res. Ctr, Lubbock, TX 79401

Dr. Lloyd Rooney, Soil & Crop Sci, Texas A&M University, College Station, TX 77843

Dr. Richard Frederiksen, Texas A&M University, College Station, Texas 77843

Dr. George Teetes, Entomology, Texas A&M University, College Station, TX 77843

Dr. William Stegmeier, Ft. Hays Experiment Station, Kansas State University, Hays KS 67601

Dr. Bruce Maunder, DeKalb-Pfizer Genetics, Rt 2, Lubbock, TX 79415

Dr. Kay Porter, Pioneer Seed Co., P.O. Box 1506, Plainview, TX 79072

Dr. Jerry Eastin, Department of Agronomy, University of Nebraska, Lincoln NE 68583

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.

Publications and Presentations

Book Chapters

Chemey, J.H., D.J.R. Chemey, D.E. Akin and J.D. Axtell. 1992. Potential of brown-midrib, low-lignin mutants for improving forage quality. In: Advances in Agronomy. Donald L. Sparks (ed.). Vol. 46. pp. 158-198.

Publications

Chemey, D.J.R., J.H. Chemey, J.A. Patterson, and J.D. Axtell. 1992. In vitro reminal fiber digestion as influenced by phenolic-carbohydrate complexes released from sorghum cell walls. Ani. Feed Sci. & Technology 39:79-93.

Mukuru, S.Z., L.G. Butler, J.C. Rogler, A.W. Kirleis, G. Ejeta, J.D. Axtell, and E.T. Mertz. 1992. Traditional processing of high-tannin sorghum grain in Uganda and its effect on tannin, protein digestibility, and rat growth. J. of Agric. Food Chem. 40(7):1172-1175.

Jenks, M.A., P.J. Rich, P.J. Peters, J.D. Axtell, and E.N. Ashworth. 1992. Epicuticular wax morphology of bloomless (bm) mutants in sorghum bicolor. Int. J. Plant Sci. 153(3):311-319.

Mertz, E.T., J.D. Axtell, G. Ejeta, and B.R. Hamaker. 1993. Development and recent impact of quality protein maize and sorghum. Proc. of the ICC International Symposium on Cereal Science & Technology: Impact on a changing Africa. 10-14 May 1993. Pretoria, South Africa. (In Press)

Premachandra, G.S., D.T. Hahn, J.D. Axtell, and R.J. Joly. 1992. Leaf water relations, gas exchange and water-use efficiency in four bloomless mutants of *Sorghum bicolor*. J. of Experimental Botany (In Press).

Published abstracts

Barwale Zehr, U. and J.D. Axtell. 1992. Use of candy stripe sorghum to tag agronomically important genes. Agronomy Abstr. p. 187. Amer. Soc. of Agron., Minneapolis, MN.

Peters, P.J., J.D. Axtell, and S.E. Wyatt. 1992. Association of epicuticular wax with disease resistance in sorghum bicolor. Agronomy Abstr. p. 110. Amer. Soc. of Agron., Minneapolis, MN.

Jenks, M.A., E.N. Ashworth, P.J. Peters, and J.D. Axtell. 1991. Structure of epicuticular wax in sorghum mutants. HortScience (abstract).

Presentations

Premachandra, G.S., J.D. Axtell, and R.J. Joly. 1991. Leaf water relations, net CO2 assimilation, stomatal conductance, and osmotic concentration as affected by water deficit in sorghum. In: Proceedings International Sorghum/Millet Conference, Corpus Christi, TX. July 8-12, 1991.

First International Crop Science Congress (ICSC). Presiding Chair for Session on "Strategies for Improving Crop Quality: The Next Challenge". July 15, 1992. Iowa State University, Ames, Iowa.

First International Crop Science Congress (ICSC). Paper presented "The INTSORMIL/McKnight Collaborative Research Model for Integrating Biotechnology with Sorghum Improvement" by J.Axtell and U. Barwale Zehr. July 20, 1992. Iowa State University, Ames, Iowa.

Presentation to Dean's Club and Dean's Advisory Council. "McKnight Research Program: Collaborative Research Which Benefits Crop Improvement in Indiana as well as Third World Countries." Nov. 22, 1992.

47th Corn & Sorghum Industry Research Conference. American Seed Trade Meetings. Presentation on "Mechanisms of Drought Resistance in Sorghum." 12/8-11/92.

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

Project PRF-107 and PRF-107A
Gebisa Ejeta
Purdue University

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Collaborating Scientists

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Dr. Abdeljabar T. Babikher, *Striga* Specialist, ARC, Sudan
Dr. Mohamed El Hilu Omer, Sorghum Pathologist, ARC, Sudan
Dr. Ahmad Abu El Gassim, NSA, Sudan
Dr. Omar Fadil, NSA, Sudan
Mr. Shadou Bawa, Director General of INRAN, INRAN, Niger
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Dr. Lee House, Executive Director, SADCC/ICRISAT, Zimbabwe
Dr. John Axtell, Agronomy Department, Purdue University, West Lafayette, IN
Dr. Larry Butler, Biochemistry Department, Purdue University, West Lafayette, IN
Dr. Bruce Hamaker, Food Science Department, Purdue University, West Lafayette, IN
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Dr. Kay Porter, Pioneer Seed Company

Summary

Breeding sorghum varieties and hybrids for use in developing countries requires proper recognition of the major constraints limiting production, knowledge of germplasm and appropriate physical environment for evaluation and testing. Efforts in INTSORMIL Project PRF-107 are attempts to meet these requirements. Through regular dialogue and interaction with colleagues in Niger and Sudan, the sorghum breeding program at Purdue provides the necessary back-up both in terms of germplasm and information.

In Year 13 we report on our latest findings on the role of ethylene in *Striga* germination, genetic control of low production of *Striga* seed germination stimulants, and on genetic and developmental studies on the accumulation of glycinebetaine in sorghum leaves.

In a series of experiments conducted this past year, we demonstrated that the ultimate signal for *Striga* seed germination is ethylene. We also identified key metabolic steps in ethylene biosynthesis possibly vulnerable to attack by manipulation of hormones and herbicides. Based on these observations, we screened an array of chemical compounds for their efficacy on ethylene biosynthesis. Commonly used compounds such as thidiazuron (cotton defoliant) and 2,4-D (herbicide) were found to be most effective in ethylene production and hence in *Striga* seed germination.

In two separate inheritance studies conducted, we established that low production of *Striga* stimulant in selected sorghum cultivars is inherited as a single recessive gene. We also found that deficiency of glycinebetaine, an osmoregulatory compound, is also inherited as a single recessive gene. In both cases, knowledge of their inheritance has been useful in transfer of these traits to breeding stocks of sorghum which are currently under development.

Objectives, Production and Utilization Constraints

Objectives

To strengthen sorghum research capabilities of collaborating scientists in less developed countries, thereby accelerating the rate at which the production and utilization of sorghum in enhanced. To achieve this objective, the technical resources of sorghum research scientists at Purdue University as well as other INTSORMIL institutions will be tapped. Research on specific topics will be undertaken primarily at Purdue University in West Lafayette, Indiana but collaborative applied field experiments will be conducted at the Gezira Research Station in Sudan and at INRAN, Niger.

Research objectives for Year 13 are a continuation of the overall project's research objectives as listed below:

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*, and grain mold infection.

To study inheritance of traits associated with resistance to drought, *Striga*, and grain mold.

To elucidate mechanisms of resistance to drought, *Striga*, and grain mold in sorghum.

Constraints

Moisture stress is perhaps the single most important constraint to sorghum production in both Niger and Sudan. Sorghum germplasm accessions with good levels of drought tolerance, while available in various programs around the world, had not been widely used in research programs in Niger and Sudan. Practical methodologies for screening sorghum germplasm for drought tolerance are also lacking. Breeding efforts to incorporate drought tolerance with higher than average yield potential are limited by lack of a rapid field screening procedure, as well as lack of knowledge of sources of sorghum germplasm processing useful traits.

Striga hermonthica, a parasitic weed, is a major production constraint of sorghum and millets in both Sudan and Niger, as it is in many countries in tropical Africa. Various control measures including the use of resistant varieties, improved cultural practices, and use of high levels of nitrogen fertilization have been suggested. Few resistant sorghum varieties have been identified. However, the inheritance and mechanism of *Striga* resistance in sorghum are not known. The efficacy of integrating various control measures in alleviating *Striga* infestation has also not been investigated.

One of the constraints limiting adoption and use of exotic early maturing, high yielding sorghum varieties in parts of West Africa is the susceptibility of exotic lines to grain mold causing fungi. Tall, late maturing, photoperiod sensitive local varieties completing their grain filling period after cessation of rains tend to escape grain deterioration problems in the field.

Research Approach and Project Output

Sorghum germplasm from various sources is intercrossed in specific combinations and evaluated for higher yield potential under optimum sorghum growing conditions at West Lafayette, Indiana. Advanced breeding lines with improved agronomic characteristics are then sampled to be evaluated for specific adaptation in various locations, primarily in Niger and Sudan, in collaboration with cooperating scientists. Knowledge of specific traits sought in Niger and Sudan is utilized in making elaborate crosses as well as in selection efforts in the breeding program.

Through efforts of graduate students and a cooperative interdisciplinary team at Purdue, we undertake research leading towards better understanding of *Striga*, drought and grain mold resistance. As we gain improved knowledge on these and associated traits, the efficiency of our breeding program should be enhanced.

Research Findings

Striga - Role of Ethylene in Germination (A.G.T. Babiker)

Understanding the physiological and biochemical mechanisms involved in *Striga* germination can lead to development of control strategies as well as better utilization of available control measures. Two of the most promising *Striga* control measures, suicidal germination and resistant varieties, are primarily concerned with manipulating seed germination and seedling establishment. Recent report out of Europe indicated that endogenous ethylene plays a key role in response of *Striga* hermonthica to the strigol analogue GR24 and sorghum root exudates. Since differential response of *Striga* strains to germination stimulants has been known to exist, we were interested in learning about the effect of strigol-induced ethylene in stimulation of *Striga asiatica* germination and the specific role of the ethylene biosynthetic pathway in effecting *Striga* seed germination.

Dr. Abdel Gabar Babiker, Weed Scientist from ARC/Wad Medani and our major Sudanese collaborator, has been on sabbatical leave from ARC and working in our laboratories since January 1992. As part of his collaborative effort, he initiated this study and made several contributions. Using gas chromatography in the laboratory of Dr. Randy Woodson, Horticulture Department, he showed very succinctly that the ultimate signal for *Striga* seed germination is ethylene. Based on his excellent knowledge of chemical herbicides, plant hormones, and growth regulators, he characterized an array of plant hormones and growth regulators, as well as specific herbicides and inhibitors of protein synthesis, with respect to their effect on ethylene formation and *Striga* seed germination. He has not only demonstrated the crucial role of ethylene but also has provided insight into the early stages of the germination process and has illuminated metabolic steps in ethylene biosynthesis possibly vulnerable to attack (for controlling *Striga*) by manipulation of hormones and herbicides in combination. Furthermore, he screened chemical compounds for their effects on ethylene biosynthesis. Rather than synthetic germination stimulants and their analogs, which have proved to be unstable in soil, chemical compounds readily available in agriculture were used. Selection of compounds was based on prior knowledge of their ability to enhance ACC synthesis and/or conversion to ethylene. Dr. Babiker demonstrated that thidiazuron, a substituted urea with cytokinin like activity widely used as a cotton defoliant and auxin-type herbicides such as 2,4-D readily stimulate *Striga* seeds to produce ethylene and to germinate. This combination of chemicals could be used in cleaning up *Striga* infested fields by suicidal germination; they could also be used in the presence of a host crop. Combining this chemical approach with *Striga* resistant crop varieties may delay the emergence of more virulent strains thus prolonging the life of the resistant variety.

Striga - Genetic Control of Low-Stimulant Production in Sorghum (R. Vogler)

Striga seeds have three requirements for germination: 1) after-ripening, 2) conditioning, and 3) stimulation. After-ripening and conditioning allow the seed to mature and to become sensitized to host-exuded compounds that stimulate the *Striga* seeds to germinate. These compounds are produced from the roots of host and non-host plants. Non-hosts, or false hosts, are plants that stimulate *Striga* seeds to germinate, but they are not parasitized by *Striga*. Sorghum cultivars differ in the amounts of stimulant compounds that their roots produce. This variation is responsible in part for the resistance against *Striga* found in some sorghum cultivars. A host plant that produces low amounts of stimulants will cause fewer *Striga* seeds to germinate, and thus will be subject to lower infestation pressure.

Production of germination stimulants is relatively simple to assay, and studies have been conducted with seeds of *S. asiatica* on the genetics of low-stimulant production in sorghum. This study was conducted to elucidate the genetic control and mode of inheritance of low-stimulant production in sorghum. Because of its simplicity and rapidity, the agar gel assay we had recently developed was used instead of the more extensively used double pot technique used by ICRISAT. The agar gel assay is useful in distinguishing sorghum genotypes on the basis of stimulation of *Striga* seed germination, measured as maximum germination distance. We found that germination distance an easier measure than the counting of percentage of germinated *Striga* seeds in the agar medium. Crosses made between our *Striga* resistant variety, SRN-39 (low stimulant producer) and two Chinese varieties, Shanqui Red and IS 4225, both high stimulant producers were evaluated using the agar gel assay.

Our results showed that the means of germination distances observed in the agar gel assay for susceptible and resistant parents were significantly different. Moreover they were found uniquely classed at extreme ends of the range of means observed among all lines. Susceptible parents germinated *Striga* seeds at distances greater than or equal to 1.0 cm from their root, whereas resistant parents germinated *Striga* seeds at distances less than 1.0 cm. The F1 population from low x high crosses had mean germination distances which were not significantly different from the means of their reciprocal F1 population suggesting no maternal effect for stimulant production. The segregation of F2 population and the distribution of the backcross progenies revealed that low production of water soluble stimulant eliciting germination of *Striga* seeds is inherited as a single recessive gene suggesting that progress from selection could be made by screening progenies for *Striga* resistance using the agar gel assay.

Drought - Studies on genetics and developmental processes for glycinebetaine accumulation in sorghum (E. Grote)

Glycinebetaine (N,N,N-trimethylglycine; betaine) is known to accumulate in response to drought in many grass and chenopod species. This accumulation is thought to be a metabolic response to osmotic stress which functions in protection of enzymes during heat and dehydration. This study was undertaken to determine changes in glycinebetaine concentration during plant development, to establish the genetic control of glycinebetaine deficiency and to establish associations between glycinebetaine and major agronomic traits in sorghum [Sorghum bicolor (L.) Moench]. In the first experiment, seven sorghum cultivars were sampled for glycinebetaine levels at 42 days after planting (DAP) and continuing every ten days until 105 (DAP). The second experiment consisted of three crosses between sorghum cultivars deficient (< 1 mol gfw-1) and normal (>20 mol gfw-1) for glycinebetaine concentrations and their subsequent F1, F2, and backcross progenies. The third experiment utilized over 40 F6 recombinant inbred (RI) lines derived from the cross K886 x CS3541. These lines were evaluated at Lafayette, Indiana (no stress) and Lubbock, Texas (moisture stress) and were characterized for glycinebetaine accumulation and agronomic characteristics. In each of these experiments, a colorimetric assay was used to quantify glycinebetaine levels in the leaves. Significant differences for glycinebetaine among sorghum cultivars was seen at all sampling dates. The greatest differences for glycinebetaine levels among sorghum cultivars, however, was at the last sampling date. Segregation ratios were nearly 3:1 as expected for single gene control. Glycinebetaine deficient cultivars had the capacity to synthesize glycinebetaine when supplied with labeled betaine aldehyde. Glycinebetaine did seem to correlate with maturity, especially under stress. These results suggest that sampling for glycinebetaine among sorghum cultivars should be done at the post-flowering stage to detect the greatest differences. The data clearly showed that glycinebetaine deficiency is inherited as a single, recessive, nuclear gene which is largely additive. Biochemical studies indicated that the deficiency is not due to a lesion at betaine aldehyde dehydrogenase.

Grain Mold Resistance

This project has been partially supported by a grant from Pioneer HiBred International. We have sampled our sorghum germplasm collection and characterized 22 genotypes for physical and chemical kernel characteristics. Our preliminary results from this study confirm our earlier finding that both physical and chemical kernel traits confer resistance to grain mold. Among chemical components, we find that high levels of flavan-4-ol correlate strongly with grain mold damage than concentration of 3-deoxyanthocyanidins or the more condensed tannins. Genetic studies show that these components are heritable and that progress from selection can be made. We have also developed a random mating population of sorghum made up of parents with enhanced grain mold resistance. This population could be used both as a source population to initiate selection experiments as well as for basic biochemical studies.

Networking Activities

Workshop and Program Reviews

Participant in the Summer Institute for African Agricultural Research, University of Wisconsin, Madison, July 1991.

Member African Dissertation Internship Award Selection Committee, Rockefeller Foundation, New York, NY, November 1991.

Attended the American Society of Agronomy Meetings at Fort Collins, Colorado, November 1991.

Treveled to Sudan, Agricultural Research Corporation to characterize the Sudan Sorghum Germplasm collection evaluated in cooperation with ARC, INTSORMIL and USDA.

Research Investigator Exchange

Interactions with public, private and international sorghum research scientists continues to be an important function of our program. The following individuals have visited or worked in our laboratories during Year 13.

Dr. Laila Monawar, FRC, Sudan
Dr. Sitt Badi, FRC, Sudan
Dr. Hilu Omer, ARC, Sudan
Dr. Ouendeba Botorou, INRAN, Niger
Dr. Sam Mukuru, SAFGRAD/ICRISAT, Kenya
Dr. Fasil Reda, IAR, Ethiopia
Dr. Paulo Magalhaes, EMBRAPA, Brazil
Dr. A.T. Babiker, ARC, Sudan

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 project is decided upon either by specific request from the collaborators or based on preliminary evaluation of small sets of nurseries introduced the previous season. Such an approach has been found to be satisfactory and workable. A number of early generation as well as advanced breeding sorghum lines were introduced in both Sudan and Niger. Such germplasm constitutes a significant part of the core breeding program in both INRAN and ARC. Likewise, useful local sorghums from Niger and Sudan have also been introduced for initial intercrosses to be made in the winter nursery in Puerto Rico.

A significant networking activity involving information exchange is developing through the efforts of this project and its collaborators. Using information accumulated on germplasm and environmental data from the INTSORMIL collaborative effort in Sudan, varieties and hybrids that showed potential in Sudan are suggested for testing in similar environments in Niger. Research methodologies (on drought tolerance for example), as well as results, therefore, are also shared across countries and zones.

Information and germplasm is routinely contributed to national and international sorghum research programs.

Publications

Hess, D.E. and G. Ejeta. 1992. Inheritance of resistance to *Striga* in sorghum genotype SRN-39. Plant Breeding 109:233-241.

Hess, D.E., G. Ejeta and L. Butler. 1992. Selecting sorghum genotypes expressing a quantitative biosynthetic trait that confers resistance to *Striga*. Phytochemistry 31:493-497.

Monyo, E.S., G. Ejeta and D. Rhodes. 1992. Genotypic variation for glycinebetaine in sorghum and its relationship to agronomic and morphological traits. Maydica 37:283-286.

Mukuru, S.Z., L.G. Butler, J.C. Rogler, A.W. Kirleis, G. Ejeta, J.D. Axtell and E.T. Mertz. 1992. Traditional processing of high tannin sorghum grain in Uganda and its effect on tannin, protein digestibility, and rat growth. J. Agric. Food Chem. 40:1172-1175.

Ouendeba, B., G. Ejeta, W.E. Nyquist, W.W. Hanna and A. Kumar. 1992. Heterosis and combining ability among African pearl millet landraces. Crop Science (In press).

Babiker, A.T., G. Ejeta, L.G. Butler and W.R. Woodson. 1992. Ethylene biosynthesis and strigol-induced germination of *Striga asiatica*. Physiol. Plant. (In press).

Ejeta, G. and D.T. Rosenow. 1992. Registration of P89001 to P89010, 10 fertility-restorer parental lines of sorghum. Crop Science (In press).

Ejeta, G. and L. Butler. 1992. Host plant resistance to *Striga*. In: D.R. Baxton et al. (eds) International Crop Science Congress I. Crop Science Society of America, Madison, WI. (In press).

Monyo, E.S., M. Hassen, J.D. Axtell and G. Ejeta. 1992. Potential methods for improving the nutritive value of high-tannin sorghums in Tanzania. In: Gomez et al. (eds) pp. 61-67. Utilization of Sorghum and Millets. ICRISAT, Hyderabad, India.

Johnson, R.D., B. Siame, G. Ejeta and L.G. Butler. 1992. Phenolic profile and leaf disease reaction of tan and red isogenic sorghum lines. Agron. Abst. p. 101.

Grote, E., G. Ejeta, D.T. Rosenow and W.E. Nyquist. 1992. Genetic variation and yield stability among sorghum inbred lines derived from a single cross. Agron. Abst. p. 98.

Weerasuriya, Y., G. Ejeta and L.G. Butler. 1992. Production of host-derived developmental signals for witchweed. Agron. Abst. p. 118.

Tunistra, M., P. Goldsbrough, E. Grote and G. Ejeta. 1992. Identification and RAPD mapping of quantitative trait loci associated with drought tolerance in sorghum. Plant Genome I.

Invited Research Lectures

Ejeta, G. Potential of commercial sorghum hybrids in Africa. Presented at Pioneer Hi-Bred International Annual Sorghum Research Conference. Plainview, TX 9-10 January 1992.

Ejeta, G. Planning agronomic research in Africa. Presented at the Summer Institute for African Agricultural Research. Madison, Wisconsin, 5-11 July 1992.

Ejeta, G. and L. Butler. Potential breakthrough in *Striga* research. Presented at the U.S. Agency for International Development and at the World Bank, 13 February 1992.

Ejeta, G. and L.G. Butler. Host plant resistance to *Striga*. Presented at the First International Crop Science Congress, Ames, Iowa, 17 July 1992.

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

Project TAM-121

Fred Miller
Texas A&M University

Principal Investigator

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Collaborating Scientists

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Summary

The prime objective of TAM-121 is to reduce the risks of production of sorghum for grain through the enhancement of genetic potentials by creating germplasm pools, lines, and hybrids with good food quality, stable performance, and high potential yields while possessing resistance to significant diseases, pests, and stress factors. Particular emphasis is placed upon development of food quality grain in the sustainable production system.

Nurseries in stress environments were used to identify segregates for drought resistance, downy mildew and headsmut resistance, and food quality grain. Tropical adaptation phenomenon was selected in more southern or tropical environments.

Anthracnose of sorghum is a major disease of concern. SC599-11E, a resistant cultivar, provides control by a single dominant gene. In an attempt to determine if resistance reactions could be enhanced with phytoalexins, the 3-deoxy anthocyanidin phytoalexins luteolinidin, apigeninidin, and caffeic acid ester of arabinosyl 5-0-apigeninidin have been studied. These compounds accumulated to greater concentrations in resistant and resistant x susceptible materials than in susceptible materials.

The two non-senescent cultivars RTx430 and B35 do not produce the nonsenescent response for the same reasons. B35 has either lost the ability to export carbohydrates effectively out of the leaf or never had it. This inability to move assimilate allows build up in the leaf blade and culm, whereas RTx430 effectively exports sucrose to the panicle. This inability to move sucrose in B35 may be the cause of its ability to osmotically adjust in times of water stress. Leaf export, whole plant partitioning and histological data suggest RTx430 and B35 have two distinctly different assimilate movement systems.

West African guinea sorghums have stability of production but at low yields levels. Study showed that yield genes as well as stability factors exist within these sorghums, but successful genetic movement of the traits was not encouraging. Pairwise squared distance measurements of taxonomic groups showed that guinea sorghums were diversely different as a group than zerazera, caudatum, and caffro um (as a second group).

Currently in Paraguay adequate high quality forage and grain (feed and food) sorghum seed is produced to plant 20,000 acres. Because of the success of forage hybrids produced using INTSORMIL materials, it is now estimated that 50% of all dairymen in the Mennonite Colonies use sorghum silage.

INTSORMIL/TAES materials produced yields 2.77 times greater than the Indian hybrids CSH5 and CSH9. ATx635, ATx631, and ATx623 were high performers. A155 proved very productive in Senegal. Best performing males in Senegal were RTx436, R.8504, and R.8509.

Increased usefulness of white or light colored sorghum grain in formulated feeds is being recognized. The market is capitalizing upon cosmetic appeal of the light colored grain for feed and for export. There are currently some yield advantages associated with white grain hybrids. Some of the advantages should persist because of basic biochemical responses. Limitations exist in areas of high humidity due to discoloration of the grain.

The INTSORMIL sorghum research program has and continues to contribute sustainability to the commodity. The blend of practical field evaluations with basic research endeavors, as well as identification and utilization of exotic germplasm with protection traits, create an enhancement of traits to make products more useful and economical for the grower and consumer. The INTSORMIL research efforts in sustainability are focused on increased yield of food energy per unit area, maintenance or increased yield of available protein, and diversification of germplasm to protect and sustain yield.

Objectives, Production and Utilization Constraints

Objectives

Develop, through enhancement procedures, appropriate stable, high yielding, agronomically desirable sorghums with high levels of disease, insect, and agronomic stress resistance, high grain quality with weathering resistance and resistance to environmental stresses.

Determine the heterotic germplasm pools (subspecies) within sorghum and characterize the constraints to yield improvement among West African cultivars (guinese types) and evaluate the germplasm availability suitable for enhancement.

Determine the relationship between yield and photosynthetic capability.

Assessment and utilization of physiological measures of drought resistance to improve sorghum for local and international utilization.

Distribute improved lines, hybrids, and early generation populations possessing superior productivity to collaborating LDCs where sustainable agriculture is critical.

Develop specific germplasm pools and resources for use in impacting productivity in Latin America, South America, and Africa.

Constraints

Sorghum originated in Northeastern Africa and is the primary cereal of choice in several parts of the world because of its resistance to high temperature and water stresses. During the past 35 years, following the introduction of cytoplasmic-genetic male-sterility and the potential of hybrid seed production, yields have steadily increased. This has been accomplished by meeting the needs of producers and remaining ahead of yield limiting constraints (disease, insects, stresses, etc.). Much more progress has been made in some areas of the sorghum world than in others. Those areas where sustainable yield has not changed are these where this project impacts. However, impact in developed sorghum areas has been good.

A sustainable agricultural system is dependent upon an acceptable yield of sorghum in those areas of the world which are constrained by risks, associated with unstable productivity and cultivars, which are incapable of offering solutions to those constraints where sorghum is considered a staple food resource. The overall objective of this project is to reduce the risks through the enhancement of genetic potentials by creating germplasm pools, lines, and hybrids with good food quality, stable performance and potentially high yield, and possessing a high level of resistance to significant diseases, pests, and stress factors while maintaining acceptance and nutritional quality. Sorghum is generally grown under less favorable environmental conditions in areas of the world where human nutritional levels are at marginal levels of acceptability. The constraints to productivity which are addressed through this project are genetic limitations to yield, disease resistance, drought, inadequately developed germplasm resources, unimproved food quality, and inadequate availability of improved seeds.

Because sorghum is a native species to much of Africa where natural resources must be conserved, it is evident that its hardy growth habits will have limited impact upon the environment as we enhance available germplasm. Quality of available food resources and increased economic return to producers should result.

Sorghum production is expanding in Latin America because of the recognition that it is a viable food, feed, and energy resource. Mexico has limited areas of high yield sorghums, but much of the country is marginal for production of current materials where drought, both high and low temperatures and diseases are constraints. Similarly, major food limitations occur with maize production whereas sorghum is a viable supplement to insuring a food supply in Mexico and throughout Latin America. Problems with drought, diseases, adaptation, high and low temperatures and limitations of food quality among existing materials necessitate involvement of INTSORMIL. Perhaps most important to the distribution of a broad base of sorghum technology is the role that Mexico can play as a collaborator. Through Mexico's adoption and assimilation of sorghum technology, such technology is made more easily available and accessible to the rest of Latin America. Therefore, materials utilized in Mexico are evaluated for stepwise enhancement and transfer to Guatemala, El Salvador, etc. and are reinforced in Honduras (prime site) and collaboration in other Latin American countries increases the success of our program of germplasm conservation, improvement, and utilization.

South America offers a new horizon for sorghum production. Brazil, Argentina, and a few others areas have developed production potentials, but with constraints of grain quality, diseases, insects, grain weathering, and yield consistency. Paraguay sorghum production is increasing and has significant potential. Availability of improved seedstocks with adequate disease resistance and acceptable food quality are major limitations to reasonable expansion. Downy mildew, anthracnose, and other diseases limit production throughout South America and through collaboration sources of resistance in higher yielding materials can be introduced. Enhanced germplasm pools which are evaluated cooperatively in this area are moved to other regions and programs. There exist highly virulent strains or biotypes of anthracnose in Brazil which threaten sorghum production in the rest of South America. Control strategies are needed, which include development of improved cultivars with stable sources of resistance.

In Kenya, Sudan, Mali, Tanzania, Zambia, and Cameroon the constraints to production are drought, temperature, diseases, insects, and sensitivity to photoperiod. Photoperiod sensitivity is a preferred trait to allow escape of grain weathering. Food quality is of paramount importance. Materials possessing drought resistance, food quality, and disease resistance from Texas have shown good adaptation in this area. Photoperiod sensitive materials from the Honduran breeding program should be very useful in giving broadened usefulness to elite germplasm already working in these areas. Major constraints in Mali and Niger as well as Burkina Faso are head bugs for which there is limited germplasm possessing resistance. Combining food quality traits with an understanding of head bug resistance should have major impact.

Breeding strategies are utilized by TAES sorghum breeders which are both qualitative and quantitative. Development of RFLP capabilities, tissue culture screening of germplasm, utilization of introduced exotic germplasm in elite line development, as well as characterization of biotic and abiotic stress phenomena, are used to insure the sustainable production of sorghum for grain and forage.

Materials from the Sorghum Conversion Program and breeding materials from other TAES sorghum projects are evaluated for resistance to internationally important diseases in a cooperative program throughout the sorghum growing world. Large nurseries at several locations in Texas using natural conditions are currently utilized, along with artificial inoculations to determine most useful sources of resistance(s) and economical gene deployment. Screening of advanced and selected items are done in Mississippi, Georgia, Arizona, Puerto Rico, Mexico, Honduras, Venezuela, Brazil, Paraguay, Argentina, Mali, Sudan, and other sites in Africa and Asia.

Much of the sustainability of production is dependent on performance in below optimum moisture conditions. Field evaluations and basic physiologic studies are carried out to either identify superior germplasm or mechanisms of resistance to drought. Working with collaborating physiologists, osmoregulation, heat tolerance, leaf wax concentration, and root development patterns are measured and transferred to elite germplasm. The importance of maintaining green leaf area through nonsenescence, high levels of nonstructural carbohydrates in the stem, and the ability to differentiate a large number of seeds per panicle under stress, coupled with the efficient use of water to fill those seeds, give stability to production.

The TAES/INTSORMIL sorghum research program has and continues to contribute sustainability to the commodity worldwide. The blend of practical field evaluations, with basic research endeavors, identification, and utilization of exotic germplasm with protection traits, strengthens enhancement of utilization traits to make products more useful and economical for the gower and consumer. This research effort in sustainability is focused on increased yield of food energy per unit area, maintenance or increased yield of available protein, and diversification of germplasm to protect yield.

Enhancing sorghums for productivity has received considerable attention in the USA, but not until recently has food quality received recognition as a constraint. Stability of yield is important to all major constraints and to all sorghum productions whether in the USA or in LDC's. In order that progress can be made to improve sorghums potential for yield multiple diverse sites must be used in selections and screenings. This project, in cooperation with other INTSORMIL activities, evaluates germplasm for yield, disease resistances and food quality across a wide range of environments. Genotypes must be developed which need further evaluation and selection under sustainable agriculture systems. By augmenting this research with LDC collaboration in Mexico, Honduras, Niger, Mali, Cameroon, Uganda, Kenya, Zambia, Ghana, Paraguay, and other countries, new superior materials can be identified to reduce risk to productivity.

Research Approach and Project Output

Research Methods

Germplasm resources from international breeding programs were collected and evaluated in Texas and Puerto Rico. Those materials which possess merit for utilization in the TAES/INTSORMIL breeding program were routed into either the Sorghum Conversion Program or into the project crossing program. Basic plant breeding strategies were utilized which are both qualitative and quantitative to develop populations of individuals for evaluation and selection. Project involvement in the development of an RFLP map is basic to future use of this technology. Currently there is a program under way to use RAPD's to assist in the identification and utilization of genes associated with height, maturity, grain quality, and basic growth and development. Pedigree breeding with limited backcrossing, after identification of constraints in the elite breeding lines, was used to insure sustainable production of sorghum for grain (feed and food) and forage (silage and pasture).

Materials from the Sorghum Conversion Program and breeding selections from other projects are evaluated annually for resistance to internationally important diseases and insects in a cooperative program throughout the sorghum growing world. An all disease and insect nursery (ADIN) with 70 entries and 2 replications includes critically selected materials from several TAES sorghum projects. Several other similar nurseries are cooperative in nature and these nurseries serve several purposes. Primarily, these germplasm evaluation nurseries are used to collect critical data on genetic/environmental responses which can be used in breeding activities. Secondly, the nurseries provide useful materials for collaborators where ever they are grown.

Large nurseries at several locations in Texas using natural conditions are currently utilized, along with artificial inoculations, to determine the most useful sources of resistance(s) and economical gene deployment. More than 30,000 selections were made in these nurseries during this reporting period. Screenings and critical evaluations of advanced and selected items were made in Georgia, Puerto Rico, Mexico, Honduras, Venezuela, Brazil, Paraguay, Argentina, Mali, Sudan, Kenya, Guatemala, India and China, in addition to Texas based nurseries.

Much of the sustainability of production of sorghum is dependent on performance in below optimum moisture conditions. Field evaluations and basic physiologic studies were carried out to identify superior drought tolerant germplasm and mechanisms associated with resistance to drought. The importance of maintaining green leaf area through nonsenescence, higher levels of nonstructural carbohydrates in the stem, and the ability to differentiate a large number of seeds per panicle under stress with an efficient use of water to fill those seeds, give stability to production. These sorghums with these traits in combination were selected at field locations possessing environmental characteristics to allow expression of superior recombinations.

New breeding populations were generated from specific crosses among elite food quality materials, disease resistance sources, nonsenescence types, lines with greater green leaf retention, and drought resistance. F_2 evaluation and selections were made in 1991 in drought nurseries in South Texas. Field screening of selected populations and advanced lines for disease reaction, utilizing natural infection, supplemented artificial inoculations.

Advanced evaluations of drought responses were completed using field plots at Lubbock. Mechanisms of resistance and interactions with disease reaction were studied in dryland and limited water conditions.

Evaluations of inbred lines and advanced hybrids were made in multi-location trials to characterize yield of parents, F_1, 3-way, and double cross hybrids. Seed stocks were prepared for trials of similar materials in Kenya for use in 1992.

Numerous trials with both broad based and specific objectives were provided to collaborating LDC's for evaluation and use.

Several collections of sorghum germplasm were made and introduced into the U.S. through cooperating plant quarantine agencies. These materials will be evaluated for response to photoperiod and subsequent use the breeding program.

Research Findings

The basic operating activity 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 much interaction and exchange of information and germplasm with TAM-122 and TAM-124. The cooperation and evaluations from TAM-126 insures the inclusion of new sources of food quality and sorghum types for new food uses which are placed into the breeding enhancement program.

In 1991 there was drought and high temperature stress in the large nurseries at Corpus Christi, Robstown, Beeville, and College Station. Disease expression was relatively high in the natural field inoculations. Expression of tropical and temperate adaptation was less than normal because of the drought and temperature extremes experienced in the season. Excellent selection was possible for both biotic and abiotic stresses in the nurseries. More than 7,000 selections from advanced and early generation materials were made at Corpus Christi, Robstown, and Beeville.

At College Station more than 10,000 selections were made from various levels of breeding populations for seed number per panicle, green leaf retention, tropical adaptation, and yield potential. In the female development program there were 1082 sets of A/B lines backcrossed. Selected advanced females were top crossed to elite tester males for evaluation in F_1 hybrid combinations.

Anthracnose *Colletotrichum graminicola* is a major disease of sorghum in much of the higher production areas of the world. Efficient field selection of resistance in sorghum to anthracnose depends on adequate inoculum pressure and a favorable environment during critical stages of the host pathogen interaction for phenotypic discrimination of test cultivars. Since such requirements are not always fulfilled in the field, one method for distinguishing among reaction types is the determination, under controlled conditions, of the biochemical potential for expression of resistance. Experiments were conducted in Indiana and Texas to determine the developmental characteristics of the sorghum anthracnose interaction and their relationships to adult plant resistance. Resistant (R) cultivars SC326-6 and SC599-11E and susceptible (S) cultivars BTx623 and B35-6 and RxS progenies were grown in a growth chamber and in the greenhouse. All were inoculated at 7, 21, 35, 49, and 63 days after emergence. The 3-deoxy anthocyanidin phytoalexins luteolinidin, apigeninidin, and caffeic acid ester of arabinosyl 5-0-apigeninidin were extracted from inoculated tissues and analyzed by HPLC. These compounds accumulated to greater concentrations in R and RxS materials than in S materials. These relationships were unaffected by the developmental stage of the host. Thus, analysis of phytoalexins in juvenile plants appears to be a potential tool for identification and incorporation of host resistance to *C. graminicola* in adult plants.

Field experiments were conducted in the summer of 1991 at College Station to determine adult plant resistance to anthracnose in families derived from crosses between the resistant cultivar SC599-11E and susceptible cultivars B35-6 and BTx623. Parents, F_1, and F_2 derived F_3 progenies were grown in single rows and inoculated eight weeks after emergence. Reaction type and symptom severity were rated at maturity. Data showed that resistance to the isolate tested is controlled by a single dominant gene. Additional experiments will be conducted in 1992 at College Station, in Georgia, and in Puerto Rico to determine if this response pattern holds for races of anthracnose predominate in other locations.

In an effort to use RFLP markers to identify resistance to anthracnose, DNA was extracted from two populations derived from the crosses of SC326-6(R) * BTx623(S) and SC599-11E(R) * BTx623(S). Genomic clones from maize and sorghum are being selected on the basis of their ability to discriminate between resistant and susceptible parents digested with the restriction endonucleases EcoRI, EcoRV, HinIII, BanH, and XbaI. Five clones were shown to reveal polymorphisms among the parents. Refinement of procedures are underway.

Two nonsenescent (RTx430 and B35) and two senescent (BTx378 and RTx7000) sorghums were used to identify variations in ^{14}C assimilate export from leaves, partitioning patterns, nonstructural carbohydrate concentrations, and anatomical differences. Histological results showed that RTx430 had significantly smaller distances between minor vascular bundles and significantly smaller minor bundle phloem areas than the other cultivars studied. Specific radioactivity and concentrations of sucrose within the leaf punches of B35 were greater than RTx430, RTx7000, and BTx378 at all growth stages. Partitioning data supported the conclusion that B35 retained higher levels of ^{14}C assimilate and sugars within leaf punches and the leaf exposed to $^{14}CO_2$. Partitioning data within labeled leaves showed that sucrose concentrations increased gradually within labeled leaves of B35, BTx378, and RTx7000 over growth stages, but were unchanged for RTx430 at the different growth stages. When the whole plant partitioning of ^{14}C assimilate is considered, it appears that B35 has lost, or does not have, the ability to export carbohydrates out of the leaf effectively and allows buildup in both the leaf blade and culm. RTx430 effectively exports sucrose to the panicle out of the leaf and culm. The percentages of ^{14}C-label captured in the grain of RTx430, RTx7000, and BTx378 were significantly greater than that in B35 during grain fill. Conversely, the percentage recovery of ^{14}C assimilate in the labeled leaf of B35 was greater. This may reflect the ability of B35 to osmotically adjust in times of water stress as shown by Khizzah. On the other hand, RTx430 showed consistently higher export rates than either B35, BTx378, or RTx7000. Leaf export, whole plant partitioning, and histological data suggest that RTx430 and B35 have two distinctly different physiological and anatomical characteristics that are involved in photo assimilate export and partitioning and these are related to differences in the stay-green characteristics of B35 and reduced progressive senescence in RTx430. This study suggests the opportunity to genetically manipulate physiological and anatomical differences between B35 and RTx430 to produce a plant with the ability to tolerate drought and charcoal rot and still produce a larger panicle and grain yield.

West Africa guinea sorghums have stability of performance under very adverse production constraints. However, yield level of the guinea type is low on a unit basis. Do these sorghums possess genes for stability or is their low yield performance providing stability? Converted guinea types were used to study performance in contrast to zerazera, caudatum, and caffrorum types. Although the true architecture of the guinea in Mali, etc. was not expressed in U.S. trials, plant type appeared to be important to performance. Extending the data from these shorter converted guinea plants to the tall photoperiod responsive types, guinea sorghums appear to have the ability to mature grain under stress environments by removing higher concentrations of nutrients and water from the culm (base upward removal). This both limits yield because of amount of nutrients and water available and provides stability because some grain is always matured. Although indications were obtained that yield genes and stability traits exist within guinea sorghums, the success of moving these into other sorghum types was not encouraging. However, ATx631 appeared to combine well with guinea sorghums. Pairwise squared distance between taxonomic groups was used to show diversity. This measure suggested more diversity between guinea sorghums and three other groups studied, zerazera, caudatum, and caffrorum, than between any of the latter three when paired. Therefore, these guinea sorghums appear to have evolved in at least restricted isolation.

In Honduras, the hybrid ATx626*R.8503 was entered into PCCMCA multi-site trials by Dr. Francisco Gomez. This hybrid appears to be well adapted to short season sorghum production areas in Honduras, particularly in Olancho. The 1991 ITAT (International Tropical Adaptation Trail) was grown at Comayagua and Zamarano. Best adapted hybrids were ATx626*R.8503, ATx629*R.8503, ATx631*R.8504, ATx631*RTx436, ATx631*R.8510, A8106*RTx434, A8106*R.8504, A8618*RTx430, A8618*RTx436, ATx631*86EON366, A1*RTx430, and A1*R.8503. It appeared that A8618 was providing dominant resistance to SDM at Comayagua. At Olancho, the 1991 IFSAT (International Food Sorghum Adaptation Trial) expressed very high yield. Incidences of rust, zonate leaf spot, leaf blight, and anthracnose were high in the area. There were significant differences among hybrids for disease response. Of 40 hybrids in the trial, 20 had overall desirabilities of 1.6 or better. Those hybrids with the best ratings were ATx635*R.8606, ATx631*R.8510, ATx631*RTx436, ATx631*R.8504, ATx631*(ADN55*B. 8204), and ATxARG-1*R.8510.

INTSORMIL involvement continues to grow in Paraguay thanks to continuing support by Mennonites, Ministry of Agriculture, USAID, and INTSORMIL. Currently the Mennonites produce hybrid sorghum seeds for grain, silage and pasture, as well as an open pollinated variety for human food use. Everything from planting, to rouging, to harvesting seed production fields, to cleaning seeds, drying, treating, and bagging seed for sale is a functioning activity. We began with the production of a hybrid forage for grazing in 1985 and have now progressed to the more difficult production of grain hybrid seeds. Now we are exploring production of female parental basic stockseeds, the most difficult activity.

The trials which are a critical part of keeping current in new parental stocks and monitoring disease, etc. changes are on-going. We have scaled back on some of these and are modifying to look for better adapted females and males for the hybrid seed scheme.

Sorghums used in Human Food

Dorado (food use)	10T
Hegari (food use)	10T
Alex Red (food use)	2T

Seed Sold (approximated)

Alex Red	15T	grain type (ATx378*RTx434)
Chaco-i	60T	silage (ATx623*Hegari)
Fredy	80T	pasture (modified 623*Greenleaf)
1844	22T	duel purpose (1844*TMTx430)
Chaco 101	—	silage & food (Mennonite Hegari)

Because of the success of Fredy and Chaco-i (and Chaco 101), it is now estimated that 50% of all dairymen in the Mennonite Colonies use sorghum silage. Quality of the dairy animal feed is so good now that no longer is feed the limiting constraint to production of milk - but the constraint is the genetics of the milking cow.

Because sorghum pasture types (Fredy) grow so well there are new uses emerging for these sorghums, especially as green manure. Drought tolerance and regrowth make the combination a very useful component in the farmer's systems. We will be looking at some new types of sudan grass derivatives to expand their usefulness in Paraguay.

Both parental A/B and R-lines and several F_1 hybrids were sent to India for evaluation from the project. Results obtained and returned showed that ATx623, ATx629, ATx631, and ATx635 were superior to 261A and 2007A Indian lines for performance in hybrids and overall desirability. ATx631*Dorado and ATx635*Dorado produce more than 275% or 2.77 times the mean yields of CSH5 and CSH9.

Forty food quality hybrid sorghums (including the variety checks of Sureno and Dorado) were evaluated in Bombay and Fanaye, Senegal. Two trials provided the following information. Based upon agronomic data and yield response, eight hybrids appeared to fit the rainfall distribution: A155*RTx2817, A8610*R.8504, ATx635*80C2241, A155*RTx436, A155*R.8504, A1*RTx436, A8606*RTx436, and ATx631*RTx436. Five of the ten best hybrids had A155 as their female while the best males were RTx436, R.8504, and R.8509. In general, these hybrids were 2.3 days later than local types and were tan plant color and good white grain color (planted 8/2, harvested 11/2). In the second seeding the hybrids were again later than local checks and produced at heights of less than 1.5m. The most desirable hybrids in this trial were ATx631*80C2241, A1*RTx436, ATx631*R.8607, A8610*R.8607, ATx630*R.3338wx, A155*RTx436, A155*RTx2817, A155*80C2241, A8610*R.8504, and A155*R.8504.

Significant variety/hybrid improvement of sorghums is underway in the U.S. which has implications worldwide. Improved food quality sorghums are useful as food resources and as improved quality feed stocks. Research continues to define the uses of white color grain produced on tan, red, or purple plants. Eight genes have been identified which affect quality of the grain when destined for food-product usages. The absence of distracting color in the finished product is of utmost importance. Yield of usable grits, flour, or starch particles from harvested grain is also important. Until the present, there has been very limited market development in the U.S. for a quality sorghum. However, because of a favorable price to the manufacturer of food products and the increased availability of improved quality, sorghum is receiving more attention. Foremost at the present time is the increased demand of food quality sorghums for export where previously the U.S. could not meet the quality criteria imposed by some importers.

Increased usefulness of white or light colored sorghum grain in formulated feeds is being recognized. There is research evidence supporting improved poultry and swine economics with white grain when compared to maize. However, there are only scattered results which show pericarp color to be of importance in either efficiency of gain or rate of gain (except where tannins are involved). Basically the market is capitalizing upon cosmetic appeal of the light colored grain in producing a much lighter colored feed formulation.

There are currently some yield advantages associated with white grain hybrids. These may persist because of basic biochemical reactions However, there are limitations to white grain hybrids also, especially those associated with grain weathering and discoloration in higher humidity environments.

Valued added characteristics and traits are just now making their way into new hybrids for producers. Food quality grain, insect resistance, disease resistance, drought tolerance, stubble grazing quality, mineral use efficiency, water use of efficiency, etc. are valued-added traits that go hand in hand with market development. Without a high quality grain none of the other traits really contribute to a more viable product (resource).

With this basic statement of need and importance, Table 1 provides yield performance of the 1991 IFSAT at selected U.S. and international locations. ATx635, ATxARG-1, and ATx631 continue to provide very high yielding hybrids when crossed to a wide array of good R-lines. Stability of performance is evident when looking at the rank of hybrids in the top 10 overall locations.

In 1991-92 more than 24 IFSAT trials were sent to collaborators. This trial contains only materials which have white pericarp color and tan plant color with a few red plant color checks. ATx635 is a jointly developed and released female coming from ICRISAT, ICRISAT (Mexico), El Salvador, and Texas. ATxARG-1 is jointly released by Argentina and Texas. All the males used in these hybrids are from the Texas program except Dorado. Most of these hybrids did not only have excellent yield but also possess extraordinary leaf disease resistance and tropical adaptation.

Sustainability of production is a measure of a crop's success over time and across locations. To monitor germplasm usefulness and select unique combinations for exploitation, this project has established the ITAT (International Tropical Adaptation Trial). In 1991-92 the trial contained 49 entries of which 10 were parental stocks. The goal of this trial is to determine the type of germplasm best adapted to various climatic conditions. The 1991 ITAT was sent to 32 collaborators of which 22 were international. This set of discriminating parents and hybrids contain both feed grain hybrids and hybrids which possess food quality.

Networking Activities

Workshops

To Liaoning Institute of Sorghum Research to train 75 chinese sorghum workers in modern sorghum plant breeding. Sponsored by UNDA. Aug. 26-Sept. 6, 1991.

To Honduras, December 4-9, 1991 to evaluate INTSORMIL/SRN/EAP collaborative research program and plan future research.

To Australia, January 31-February 19, 1992 to participate in 2nd Australian Sorghum conference, Gatton College, Queensland, and to present discussions with farmers and sorghum growers at various field locations throughout Queensland.

To Paraguay, March 9-14, 1992 to evaluate research activities and interact with collaborators on sorghum for human food, animal feed, etc.

To Colon, Argentina, March 14-22, 1992 to collect data on collaborative trials and discuss research needs and long-range objectives.

Worked with Mr. Farno Green (now deceased), Southern Baptist Convention, based in Mississippi, to develop a missionary outreach activity in Zimbabwe. Developed a planting guide and instructions on production. Interaction was

Table 1. **Performance of white grain food quality sorghum hybrids (with two variety checks) at selected U.S. and international locations using the 1991 IFSAT.**

Entry	Pedigree	C	D	E	F	G	H
37	ATX635*86EON361	6421	8347	5709	6888	6841	1
32	ATX635*R8606	6956	7058	3714	9192	6730	2
30	ATX635*DORADO	6567	8082	6204	6048	6725	3
39	ATX635*87EON366	6919	7719	5015	7018	6668	4
22	ATX631*(TX430*TX2816)-1-1-5-3-1-C1-C3K-C	6619	6272	4692	8980	6641	5
9	ATXARG1*R8510	7659	6968	5587	6314	6632	6
21	ATX631*(RTX435*VC 146)-CF2-C1-Ci-C1	7675	7825	3149	7719	6592	7
29	ATX635*84C7730	6645	7238	4974	6965	6449	8
5	ATXARG1*DORADO	7384	7539	3643	6747	6328	9
38	ATX631*87EON366	6489	6916	4553	6674	6158	10
23	ATX631*(TX435*TX430)-14-/2-L5-B1	6700	7096	4220	6466	6121	11
13	ATX630*R3338wx	5880	7226	4935	6384	6106	12
27	ATX631*RTX436	5756	5701	4123	8706	6072	13
19	ATX631*((TX430*TX2816)-1-1-5-3-1*TX435)-	5693	6518	4248	7608	6017	14
14	ATX630*RTX436	5916	6828	4580	6417	5935	15
24	ATX631*DORADO	4823	6554	6053	6222	5913	16
31	ATX635*RTX436	6324	6535	3738	7008	5901	17
16	ATX631*((SC120*TX7000)*TX7000)-10-4-6-2-	6621	6221	3469	7111	5856	18
36	ATX631*86EON361	4205	7066	4803	7260	5834	19
17	ATX631*((SC120*TX7000)*TX7000)-10-4-6-2-	5432	6431	4538	6797	5800	20
40	ATX635*87EON366SIS	6939	5774	3975	6403	5773	21
1	SURENO	5896	5697	4376	7099	5767	22
28	ATX631*R8510	5013	6120	3780	7520	5608	23
33	ATX635*R8608	5456	7041	3593	6219	5577	24
34	ATX635*80C2241	6058	6056	3565	6314	5498	25
20	ATX631*(ADN55*B8204)-F2-B1-B1-B2-B1-T6-C	4694	6623	3138	7173	5407	26
18	ATX631*((SC120*TX7000)*TX7000)-10-4-6-2-	4786	6245	3662	6815	5377	27
4	MALISOR-84-7	5104	5790	3632	6518	5261	28
35	A155*((SC120*TX7000)TX430)-4-1-1-2-OP-2*	4965	6113	3406	6179	5166	29
7	ATXARG1*R8504	5076	6481	2901	6181	5160	30
10	ATXARG1*R8511	4347	6975	2635	6648	5151	31
15	ATX631*((SC120*TX7000)*TX430)-4-1-3-1-3	4959	5500	3311	6584	5089	32
11	ATXARG1*R8605	4509	6174	2166	7451	5075	33
6	ATXARG1*RTX435	4427	6562	2673	6435	5024	34
12	ATXARG1*80C2241	3842	6374	2398	7322	4984	35
2	DORADO	4022	6122	2928	6569	4910	36
8	ATXARG1*RTX436	4153	6343	2392	6697	4896	37
25	ATX631*RTX435	5494	4974	3348	5487	4826	38
26	ATX631*R8504	3684	4334	3075	7776	4717	39
3	VG153	4567	4628	1962	6530	4422	40

C = College Station, TX
D = Lubbock, TX
E = Zamarano, Honduras
F = Guatamala
G = Mean kg/ha
H = Rank of means

established with local villages, ICRISAT, and U.S. based missionary programs.

Research Investigator Exchanges

Mr. Ian Jarvie, Pannar Seed Company, Greytown, South Africa. August 7-8, 1991

Mr. Dries Booyens, Pannar Seed Company, Klerksdorf, South Africa. August 7-11, 1992

Mr. Eliseo Juncos, Colon, Agrentina, August 11-17, 1991

Dr. Vartan Guiragossian, ICRISAT, Nairobi, Kenya, August 18, 1991 (study leave)

Five Mexican Cattlemen - Jalisco Cattleman's Union, November 12, 1991

Mr. Antonio Christian, Guatemala, discussed sorghum inbred lines for hybrids.

Germplasm and Research Information Exchange

In 1991, 27 sorghums were introduced from Kenya which Dr. Vartan Guiragossian had identified with resis-

Table 2. Seed stocks distribution from College Station, TX during 1991-1992.

	International		Domestic	
Materials	No. of accessions	No. of requests	No. of accessions	No. of requests
Varieties	279	28*	627	55
F_2 populations	20	1		
Breeding stocks	1184	17	289	18
Hybrids seeds	68	6	30	9
Trials	48	20	23	10
Σ	1599	72	969	92

*24 different countries

tance to *Striga*, aphid resistance, and drought resistance. Most of these are tan plant color with white translucent seeds. Twenty inbred lines were provided by Queensland Primary Research. These materials were basically drought resistant B35 derivatives and some possess very good levels of midge resistance. One of the excellent examples of germplasm exchanges come from the seed distribution from Liaoning Academy of Agricultural Sciences. Fifteen B-lines were received and all had one parent in their parentage from Texas A&M. In addition, 14 R-lines were received, all had one PRC parent and the other parent was from Texas A&M or ICRISAT. Useful genes for maturity and leafiness were introduced from Honduras, 31 lines. Forty-nine *S. verticilliflorum* collections were introduced from ICRISAT in an effort to broaden the base of germplasm available among pasture type sorghums (sudangrass). Twenty-six elite lowland inbred lines were introduced from Mexico in early 1992. Fifty-nine highland cold tolerant short season sorghum inbred lines and breeding populations were obtained from ICRISAT. These materials will be evaluated for seed set capability, disease response, and earliness before crossing into the TAM-121 breeding stocks. During this reporting period, 241 introductions were obtained for use in the breeding program of TAM-121.

Within the project, basic breeding stocks were increased for distribution. The old line nursery, new germplasm stocks, breeding lines, F_2 populations, converted lines from the Sorghum Conversion Program, several cytoplasm sources, and numerous experimental hybrids were increased for distribution to international and domestic collaborators. More than 2500 different sorghum cultivars were distributed during this reporting period. These materials included both old and new enhanced stocks possessing resistances to various diseases, insects, drought stress, temperature stress, genetic stocks for maturity, height, seed and plant characteristics, tropical adaptation, and other breeding traits. During the winter greenhouse crossing program, 268 different crosses were made and F_1 progenies of 2750 plants were established. Currently 236 F_2 populations were available for distribution to collaborators. In addition, 30 International Tropical Adaptation Trials, 12 International Food Sorghum Adaptation Trials, 3 International Sorghum Virus Nurseries and many sets of other materials were distributed. Table 2 shows the distribution of materials from the program. During the year, 164 separate seed requests were handled.

Sorghum selections were made and entered into cooperative international trials including the ADIN, IDIN, GWT, IDMN, IAVN, UHSN, and several drought screening nurseries.

Provided leadership as major professor to seven graduate students in plant breeding and served on graduate committees for six other graduate students at Texas A&M University.

Developed field lectures for international and domestic exchanges of information in Beeville, Corpus Christi, Robstown, Weslaco, Lubbock/Halfway, and College Station, TX. Presented field tours to delegations from Mexico, Colombia, South Africa, China, Argentina, Mozambique, Kenya, and Uganda.

Publications and Presentations

Publications

Rood, S.B., J.E. Witbeck, D.J. Major, and F.R. Miller. 1992. Gibberellins and heterosis in sorghum. Crop Sci. 32:713-718.

Duncan, R.R., P.J. Bramel-Cox, and F.R. Miller. 1991. Contributions of introduced sorghum germplasm to hybrid development in the USA. In Use of Plant Introductions in Cultivar Development (Part 1) ed Shands, H.L. and L.E. Wiesner. Crop Science Special Publication Number 17; Chapter 5, pp. 69-102.

Beall, F.D., P.W. Morgan, L.N. Mander, F.R. Miller, and K.H. Babb. 1991. Genetic regulation of development in Sorghum bicolor. V. The ma$_3$R allele results in gibberellin enrichment. Plant Physiol. 95:116-125.

Wanous, M.K., F.R. Miller, and D.T. Rosenow. 1991. Evaluation of visual rating scales for green leaf retention in sorghum. Crop Sci. 31:1691-1694

Pietsch, D., R. Gass, D.T. Rosenow, F.R. Miller, and G.C. Peterson. 1991. 1990 Grain sorghum performance tests in Texas. Texas A&M University, Dept. of Soil & Crop Sciences. Technical Report 91-2.

Tenkouano, A., F.R. Miller, and D.T. Rosenow. 1991. Genetic control of nonsenescence, a post-anthesis drought resistance character, in sorghum. Crop Sci. (TA-30027).

Esele, J.P., R.A. Frederiksen, and F.R. Miller. 1991. The association of genes controlling caryopsis traits with grain mold resistance in sorghum. Phytopathology. (accepted)

Tenkouano, A., F.R. Miller, R.A. Frederiksen, and D.T. Rosenow. 1991. Dominant and recessive gene interactions determine resistance to charcoal rot in sorghum. Theo. and Appl. Genetics (in press)

Theu, M.P.K.J., R.W. Toler and F.R. Miller. 1992. Increased host range of sorghum yellow banding virus in sorghum cultivars. Tex. Agri. Exp. Sta. MP-1739.

Miller, F.R., T.F. Dusek, K.L. Prihoda and L.W. Rooney. 1992. Registration of RTx436 sorghum parental line. Crop Sci. (in press)

Miller, F.R., T.F. Dusek, K.L. Prihoda. 1992. Registration of A$_2$/B$_2$Tx636 and A$_2$/B$_2$Tx637 sorghum. Crop Sci. 32:511-512.

Miller, F.R., Christian Domanski and Laura M. Giorda. 1992. Registration of A/BTxARG-1 sorghum. Crop Sci. (in press).

Miller, F.R., R. Clara and V. Guiragossian. 1992. Registration of A/BTx635 sorghum. Crop Sci. (in press).

McBee, G.G. and F.R. Miller. 1992. Stem carbohydrate and lignin concentrations in sorghum hybrids at seven growth stages. Crop Sci. (in press).

Pietsch, D., R. Gass, D.T. Rosenow, F.R. Miller, and G.C. Peterson. 1992. 1991 Grain sorghum performance tests in Texas. Texas A&M University, Department of Soil & Crop Sciences Technical Report. 92-2.

Miller, F.R. 1992. Sorghum Improvement - An INTSORMIL Involvement. Star Vol. ___. U.S. Agency for International Development, Washington, D.C.

Khizzah, William. 1991. Genetic control of post-flowering osmotic adjustment and dehydration tolerance components in sorghum [Sorghum bicolor (L.) Moench] under induced drought stress. Ph.D. dissertation, Texas A&M University, College Station, TX.

Dahlberg, Jeffery. 1992. Variation of ^{14}C assimilate export and partitioning in reduced progressive senescent and senescent sorghums [Sorghum bicolor (L.) Moench] and the potential use of anatomical features as a genetic marker for variation in sorghum. 1992. Ph.D. dissertation, Texas A&M Univ., College Station, TX.

Toure, Aboubacar. 1992. Heterosis, combining ability, and breeding potential studies for grain and yield components in guinea and guinea derivative sorghums Sorghum bicolor (L.) Moench. Ph.D. dissertation, Texas A&M University, College Station, TX.

Presentations

Miller, F.R. 1991. Sorghum Improvement - Past and Present. Liaoning Commission of Science and Technology. Shenyang, Peoples Republic of China. September 2.

Miller, F.R. 1991. Germplasm collection, preservative, and utilization in sorghum. Liaoning Commission of Science and Technology. Shenyang, Peoples Republic of China.

Miller, F.R. 1991. Genetics of important characteristics in sorghum breeding. Liaoning Commission of Science and Technology. Shenyang, Peoples Republic of China.

Miller, F.R. 1991. Breeding and physiologic relationships in the improvement of sorghum. Liaoning Commission of Science and Technology. Shenyang, Peoples Republic of China.

Miller, F.R. 1991. Texas A&M sorghum research activities. INTSORMIL Review. Corpus Christi, TX. July 8-11

Miller, F.R. 1992. Food quality sorghums. Dalby Sorghum Growers Seminar. Dalby Agricultural College. Dalby, Queensland, Australia.

Miller, F.R. 1992. Protein in sorghum. Central Highlands Sorghum Growers Seminar. Emerald, Queensland, Australia.

Miller, F.R. 1992. Human consumption of sorghum. Biloela Sorghum Growers Seminar. Biloela, Queensland, Australia.

Miller, F.R. 1992. Improvements in sorghum during the last 25 years. Proc. 2nd Australian Sorghum Conference. Gatton, Queensland, Australia.

Germplasm Enhancement for Resistance to Pathogens and Drought and Increased Genetic Diversity

Project TAM-122
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Dr. Dan Meckenstock, Sorghum Breeder, INTSORMIL/SRN/EAP, Apto Postal 93, Tegucigalpa, Honduras
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Dr. El Hilu Omer, Pathologist, ARC, Wad Medani, Sudan
Dr. Moussa Traore, Physiologist, DAR/IER, Bamako, Mali
Dr. Aboubacar Toure, Sorghum Breeder, SRCVO/DAR/IER, Bamako, Mali
Mr. Karim Traore, SRCVO/DAR/IER, Bamako, Mali
Mr. Mamourou Diourte, Pathologist, SRCVO/DAR/IER, Bamako, Mali
Dr. L.E. Clark, Sorghum Breeder, TAM-122 (Cooperating Investigator), Texas A&M Univ., Vernon, TX
Dr. R.A. Frederiksen, Pathologist, TAM-124, Texas A&M University, College Station, TX
Dr. F.R. Miller, Sorghum Breeder, TAM-121, Texas A&M University, College Station, TX
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Dr. R.D. Waniska, Cereal Chemist, TAM-126, Texas A&M University, College Station, TX
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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 country 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.

Ten white seeded or yellow endosperm male parental lines were jointly released by Purdue and Texas A&M, and were developed partially in cooperation with the Sudan sorghum program.

From the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program, 110 new fully converted lines were released, providing new diverse germplasm for use in sorghum improvement programs worldwide.

Over 3,100 sorghum cultivars of known Sudan origin were planted in Sudan in 1991 for seed increase, classification, description, evaluation, and correcting. Seed and descriptive traits will be made available to all sorghum researchers.

Resistance to the head bug in Mali is inherited as a recessive trait and appears to be multigenic in nature. Corneous endosperm alone does not appear to give resistance to head bug.

Two new sources of good resistance to the head bug were identified in Mali, R6078 and BTx635(BVar).

F_2's involving Maicillos Criollos from Honduras segregated well for a broad range of maturity in southern Mali, providing a useful source of late maturity for long rainy season regions.

The resistance to *Striga* in SRN-39 appears to be expressed under natural field *Striga* infestations in Mali.

Objectives, Production and Utilization Constraints

Objectives

Enhance the germplasm of LDC's by developing and distributing early generation breeding germplasm involving genetically improved disease and drought resistance and other desirable traits for use and selection in host countries with emphasis on Honduras, Sudan, Mali, and Niger.

Develop high yielding cultivars for LDC's and the U.S. with genetically enhanced resistance to internationally important diseases with emphasis on downy mildew, charcoal rot, grain mold/weathering, anthracnose, head smut, head blight, viruses, and acremonium wilt.

Develop through breeding and selection, high yielding, agronomically desirable types with superior combination of pre- and post-flowering drought tolerance for use in the U.S. and host countries.

Identify, in basic sorghum germplasm lines, new sources of drought tolerance and resistance to diseases of importance in the U.S. and LDC's.

Collect new sorghum germplasm and evaluate for traits needed in the U.S. and developing countries, and introgress these traits into improved lines.

Constraints

Drought is the major constraint to sorghum and millet production around the world. Large differences have been demonstrated among sorghum cultivars in their reaction to drought and performance under drought stress. Texas has a semiarid environment and high temperatures and is ideal for large scale field screening and breeding for improved drought tolerance. Sorghums with identified high levels of specific types of drought tolerance in Texas, such as pre-or post-flowering drought tolerance, perform as expected regarding drought response in other countries of the world, including Sudan, Mali, and Niger. However, other adaptation traits such as grain quality and disease resistance must be combined with drought resistance to make a new cultivar useful.

Diseases are important worldwide but specific diseases are often region or site specific, and on-site evaluation is necessary to determine severity and possible race differences. Most of the internationally important diseases are present and are serious constraints in Texas, especially downy mildew, charcoal rot, grain mold/weathering, head smut, head blight, and MDMV. Many other diseases such as anthracnose, leaf blight, rust, zonate, and gray leaf spot are also present in Texas. The Texas environment, particularly South Texas, is ideal for screening and breeding sorghums with high levels of resistance to most internationally important diseases.

In Sudan, the major constraint is drought, and drought related production problems. Moisture-stress related charcoal rot and subsequent lodging is a serious disease problem. Many U.S. sorghums perform quite well in Sudan, but improved drought resistance, local adaptation, and kisra food quality are needed.

Mali and Niger are both drought prone areas. Thus, drought tolerance, including both the pre- and post response, is extremely important to both countries. Foliage diseases such as anthracnose and sooty stripe are important in the central and southern parts of Mali. Long smut is very important in Niger and in the drier northern portion of Mali. High yielding improved introductions often fail in West Africa due to the head bug - grain mold - grain quality complex, stand establishment problems, improper maturity, or lodging, whereas the local sorghums appear well adapted. Head bugs appear to be the major constraint for the use of nonguineense type sorghums in much of West Africa. Head bug damage is often compounded by grain mold resulting in a soft and discolored endosperm, rendering it unfit for traditional food products. The early maturity of introduced types also compounds the grain deterioration problem. Therefore, head bug resistance, grain mold/weathering resistance, and proper maturity are essential. In southern Mali, later maturing, photoperiod sensitive sorghums are needed to assure grain maturity after the rainy season. In the drier northern areas of Mali and in Niger where drought stress is severe, earlier, less photosensitive material can be used, and drought tolerant Durra and Feterita sorghums generally perform well.

Striga is a major constraint in Mali, Niger, and Sudan, and soil toxicity problems are important in Mali and Niger. Genetic sources of resistance to *Striga* and soil toxicity problems are used whenever possible in crosses involving disease, drought, and head bug resistance to develop breeding progeny for selection in host countries.

In Honduras, diseases are a major constraint, including downy mildew, foliar diseases, acremonium wilt, and the grain mold/weathering, food quality complex. Drought is also important in Honduras and the Central American Region. Improvement in the photoperiod sensitive, food-type maicillos criollos grown in association with maize on small, hillside farms in southern Honduras (as well as in southeast Guatemala, El Salvador, and northwest Nicaragua) is a unique challenge, and the breeding and selection must be done under the specific daylengths and environment in the host region. Improvement in the nonphotoperiod sensitive combine-type sorghums used over much of Central America can result directly from introduction of Texas adapted cultivars or hybrids.

There is a constant need for new diverse germplasm sources of resistance to pests, diseases, and environmental stress. New collections can provide new sources of desirable traits.

Research Approach and Project Output

Research Methods

Introductions from Mali, Sudan, Niger, Honduras, Zimbabwe, Zambia, Botswana, Somalia, Senegal, and ICRISAT with desirable drought or disease resistance, or specific desirable grain or plant traits, were crossed in Texas to appropriate elite U.S. lines and elite breeding materials. Seed of the early generations was sent to LDCs, particularly Sudan, Mali, Niger, and Kenya, for selection of appropriate traits and adaptation. Technical assistance is provided, as time and travel permitted, in the selection and evaluation and use of such breeding material in the host country.

New breeding material was generated from crosses among various disease resistant sources, agronomically elite lines, and new sources of resistance. Advance generations of breeding lines also were selected in 1991. Initial screening was done in large disease screening nurseries utilizing natural infection in South Texas, supplemented by artificial inoculation in the field and laboratory screening. Selected advanced materials were sent to LDC's for evaluation and incorporated into various standard replicated trials for extensive evaluation at several locations in Texas and host countries.

New breeding crosses among various sources of drought tolerance (i.e., pre- and post-flowering drought tolerance) and elite, high yielding lines were made. Progeny were selected under field conditions for pre- and post-flowering drought tolerance, yield, and adaptation at several locations in West Texas in the Lubbock area and at Chillicothe. The locations vary in their degree and time of moisture and heat stress. Selected advanced materials were sent to LDC's for evaluation and use, as well as incorporated into standard replicated trials for extensive evaluation at several locations in Texas and host countries.

Converted and partially converted lines from the Sorghum Conversion Program, exotic lines, new introductions, and breeding materials were screened and evaluated in Texas for new sources of resistance to internationally important diseases and resistance to drought.

New sorghum germplasm was 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 were designated for entry into the cooperative TAES-USDASorghum Conversion Program. Cultivars that were not photoperiod sensitive and with known merit were incorporated directly into the regular breeding program.

Research Findings

A large number of new crosses and new sorghum breeding material was generated for use both in the U.S. and Host Countries. The crosses involve lines with sources of drought and disease resistance as well as other desirable traits including head bug resistance, *Striga* resistance, lodging resistance, improved grain quality, sugarcane aphid resistance, and resistance to the acid soil/toxicity problem of West Africa. Much of the resulting F_2 and early generation germplasm was planted and selected in Texas as well as sent to various host countries for selection and use. Some of the breeding progeny involving Malisor 84-7 and such lines as Sureño, Dorado, M90318, 86EON361, and 87EON366 show outstanding potential in Texas for use in the U.S. and Latin America as improved food type sorghums.

In Texas, the disease resistance and drought resistance breeding programs continued in 1991 with large field screening nurseries for disease and adaptation in South Texas, and large field screening drought nurseries in West Texas. The disease nurseries were excellent while the drought nurseries had moderate stress. Major diseases evaluated were downy mildew, head smut, grain mold/weathering, charcoal rot, and anthracnose.

Recombinant F_6 inbred lines involving the "stay green" (post-flowering drought resistant) line, B35, were developed for use in RFLP and RAPD genome analysis of the "stay green" and other drought tolerant traits.

Ten white-seeded, tan-plant or yellow endosperm male parental/breeding sorghum lines developed cooperatively with Dr. Gebisa Ejeta, Purdue University were jointly released by Purdue and Texas A&M in late 1991. These lines are designated 89001 through 89010. These lines resulted from crosses of elite U.S. parental lines with sorghum lines identified by Dr. Ejeta as drought resistant in Sudan. The released lines were selected on the basis of evaluation of lines and in hybrid combinations in Texas, Indiana, and Sudan, and should be useful as pollinator parents of hybrids in the U.S. and in Sudan.

One hundred and ten new fully converted lines from the cooperative TAMU-TAES/U.S.DA-ARS Sorghum Conversion Program were released. One set of 60 was released in January, 1992 and a set of 50 was officially released in mid-summer, 1992. A listing of the released lines is shown in Table 1. They should be useful sources of diverse photoperiod insensitive germplasm for both public and private sorghum improvement programs throughout the world.

In Honduras, rust was severe at Zamorano, but several entries in the TAES All Disease and Insect Nursery (ADIN) and Grain Weathering Test (GWT) showed excellent resistance. Data on selected lines from those tests with good rust resistance or excellent agronomic desirability are presented in Table 2, along with the number of downy mildew infected plants in the Pathotype 5 Downy Mildew Nursery at Comayagua. Some of these lines appear to possess resistance to P5 downy mildew.

Table 1. **Converted sorghum releases from the Sorghum Conversion Program and information on the original exotic cultivars.**

Designation[1]	SC No.[2]	Group[3]	Fertility[4] reaction	Origin[5]	Designation[1]	SC No.[2]	Group[3]	Fertility[4] reaction	Origin[5]
Group A (Set of 60)					IS11443C	1014	DurDoc	R	Ethiopia
IS121C	770	CauKaf	R	Swaziland	IS11549C	1017	SubDurDoc	R	Ethiopia
IS219C	635	Caffr	B	U.S.A	IS11624C	1022	Sub	R	Ethiopia
IS1044C	817	Durra	R	India					
IS1186C	435	Rox	R	India	IS11637C	1025	Sub	P	Ethiopia
IS1213C	609	NervKaol	B	China	IS11792C	975	Sub	R	Ethiopia
					IS12156C	982	Zera	R	Ethiopia
IS2225C	659	CaffRox	B	U.S.A	IS12170C	1038	DurDoc	R	Ethiopia
IS2510C	259	Consp	R	Sudan	IS12171C	1039	SubDurDoc	R	Ethiopia
IS2615C	951	Rox	P	Sudan					
IS2618C	600	Rox	R	Sudan	IS12604C	99	Consp	R	Nigeria
IS2748C	598	S.virg	B	Uganda	IS17208C	1069	CauKaf	R	Nigeria
					IS17209C	1070	CauKaf	R	Nigeria
IS2821C	649	CaffBprf	B	Rhodesia	SC970C	970	CauNig	R	Uganda
IS2840C	673	CaffFet	B	Rhodesia	SC1056C	1056	Caud	R	Sudan
IS2856C	650	Caffr	B	So. Africa					
IS2868C	620	Doch	B	So. Africa	Group B (Set of 50)				
IS2872C	851	Durra	B	Egypt	IS399C	935	SubMilo	-	U.S.A?
					IS648C	950	CauBic	B	U.S.A
IS2904C	568	Caud	B	Nigeria	IS1105C	192	Cem	R	India
IS2990C	593	Sub	P	Ethiopia	IS1596C	213	DocLeoti	P	India
IS3138C	627	Caffr	B	So. Africa	IS2454C	682	NigFet	R	So. Africa
IS3155C	700	Caud	R	So. Africa					
IS3196C	941	Sudan	Seg	U.S.A	IS2463C	42	NigGuin	P	Ethiopia
					IS2562C	734	CauKaf	B	Sudan
IS3201C	937	Sudan	P	U.S.A	IS2655C	113	CauNig	R	Uganda
IS3212C	942	Sudan	R	U.S.A	IS2681C	324	Nigr	R	Uganda
IS3340C	755	Sudan	R	U.S.A	IS2820C	797	Zera	-	Zimbabwe
IS3389C	773	CauKaf	R	China					
IS3402C	757	CauKaf	B	Botswana	IS3056C	430	Durra	B	Ethiopia
					IS3515C	323	Nigr	R	Sudan
IS3511C	774	CauKaf	R	Sudan	IS3693C	632	Caffr	B	U.S.A
IS3546C	751	CauKaf	R	Sudan	IS4307C	1085	Cem	B	India
IS3568C	716	Caud	R	Sudan	IS4370C	826	Durra	B	India
IS3587C	731	Caud	R	Sudan					
IS3623C	350	Caud	R	Nigeria	IS4382C	827	Durra	P	India
					IS4572C	831	Durra	P	India
IS4430C	863	Durra	B	India	IS5457C	1109	DocRox	R	India
IS4822C	875	Durra	P	India	IS5651C	839	Durra	R	India
IS5037C	910	DurMemb	B	India	IS5839C	919	Nand	P	India
IS5066C	958	Durra	R	India					
IS5146C	454	Durra	R	India	IS6213C	516	Rox	R	India
					IS6893C	1111	Nigr	R	Sudan
IS5437C	762	CauKaf	R	India	IS6899C	913	DurBic	R	Sudan
IS6057C	782	CauNig	B	India	IS6948C	730	Caud	R	Sudan
IS6153C	902	Durra	R	India	IS7017C	339	Caud	R	Sudan
IS6164C	624	DocDur	B	India					
IS6330C	842	CauNig	B	India	IS7072C	779	CauKaf	P	Sudan
					IS7302C	1116	Caud	R	Nigeria
IS6920C	756	CauKaf	R	Sudan	IS7590C	1229	Consp	-	Nigeria
IS7098C	784	CauNig	R	Burkina Faso	IS7649C	956	Consp	B	Nigeria
IS7156C	807	CauDur	R	Rhodesia	IS7797C	1123	Consp	R?	Nigeria
IS7243C	781	CauKaf	R	Nigeria					
IS8088C	712	Caud	B	Japan	IS7801C	1124	Consp	P	Nigeria
					IS7808C	1125	Consp	R	Nigeria
IS8120C	749	CauBic	B	Japan	IS8093C	705	Caud	R	Japan
IS8264C	680	Dobbs	R	India	IS8136C	422	Zera	R	India

Designation[1]	SC No.[2]	Group[3]	Fertility[4] reaction	Origin[5]
IS9370C	1080	Caffr	B	So. Africa
IS11065C	1046	Durra	R	Ethiopia
IS11343C	1049	Durra	R	Ethiopia
IS11815C	1155	SubDur	P	Ethiopia
IS11894C	1033	SubDurDoc	R	Ethiopia
IS12018C	1160	Sub	Seg	Ethiopia
IS12153C	979	Zera	R	Ethiopia
IS12571C	61	Consp	R	Sudan
IS12582C	73	Sumac	R	Kenya
IS12631C	140	DurDoc	B	Ethiopia
IS17206C	1067	CauKaf	R	Senegal
IS17211C	1072	Caffr	Seg	Nigeria
SC1103C	1103	Zera	R	Nigeria
SC1104C	1104	CauKaf	R	Uganda
SC1172C	1172	CauBic	B	U.S.A
SC1203C	1203	NigGuin	R	Brazil

[1] Designation of converted lines was obtained by addiing C to the IS number used in the World Sorghum Collection. Those without an IS number were given a C following the SC number

[2] The SC number is the serial number designation given to the exotic variety used in the Sorghum Conversion Program during conversion.

[3] The group number and name of the exotic variety is based on a Modified Snowden's Classification used to classify the World Sorghum Collection. See B.R. Murty, et al., 1967. Classification and catalogue of a world collection of sorghum Indian J. Gen & Pl. Breeding 27:1-312.

[4] The fertility reaction as determined from crosses between a milo-kafir genetic-cytoplasmic, male sterile (A_1) plant and the exotic line: R=Restorer (progeny all male fertile); B=maintainer (progeny all male sterile); P=partial restorer (progeny) from 5-80% seed set; Seg=progeny segregate male sterile and male fertile.

[5] "Origin" indicates the indigenous country of origin of each exotic line insofar as records indicate.

Mali

Head bug resistance appears to be inherited as a recessive trait and to be quantitative in nature. Several Malisor 84-7 derivative breeding lines selected in Texas for grain hardness and grain mold/weathering resistance were evaluated in Mali under severe head bug pressure. Only a few showed acceptable levels of head bug resistance, indicating that endosperm hardness alone does not result in head bug resistance. It also indicates that the trait tends to be recessive and multi-genic, and that the most efficient method of selection for resistance is under head bug infestations. Experimental hybrids planted at Sotuba and Cinzana with Malisor 84-7 and the Malisor 84-7 derivatives mentioned above indicated the recessive nature of head bug resistance. However, many hybrids showed excellent expression of yield, indicating a good potential for increasing yield through the use of adapted hybrids.

Results from two years of intensive screening of a broad range of sorghum germplasm for head bug resistance by Dr. Y. Doumbia in Mali indicate that the most resistant genotypes include Malisor 84-7, as well as R6078 (SC170-6-17*MR4-4671), a red seeded, weathering/grain mold resistant line developed in Texas, and BTx635 (BVar), a white-seeded, tan-plant parental line cooperatively released by Texas and ICRISAT/LASIP. This line also has excellent head smut resistance in Texas, a moderate level of stay green (post-flowering drought tolerance), and produces high yielding, agronomically desirable hybrids in Central America and Mali.

Table 2. Data on selected entries from the ADIN and GWT, Zamarano and Comayagua, Honduras, 1991.

Designation	Desirability[1] rating (ZAM)	Rust[2] rating (ZAM)	Downy mildew (No. pl) (COMAY)
87BH8606-6/((Tx433*(SC748*SC630))	1.8	2.8	0
88B1016/(Tx430*R10)-15	1.6	4.0	17
MB108B	1.5	3.5	46
86EON361	1.7	3.0	2
Sureno	1.8	3.0	0
R6078	1.9	3.0	0
87EON366sis	2.0	2.0	3
B1	1.9	3.0	0
Tx2883	2.0	2.3	2
SC326-6	2.5	2.4	4
90EON328/(Sureno*BDM499)	1.9	3.5	0
86EON362	2.0	2.8	0
87EON366	1.6	1.9	0
82BDM499	1.9	4.5	0
B8618	2.0	3.2	0
90CW8147/(BDM499*87EON366)	2.0	2.1	0
88BD1749/(R4317*SC425)	2.3	2.4	0
Tx7078(Check)	2.5	4.5	8
TAM428(Check)	1.7	3.0	1
SC414-12E(Check)	2.0	3.5	7
TP21R02-106-3	1.8	2.2	-
SC1123-11E	3.8	2.1	-
85C13082/(CS3541*TAM428)	1.8	1.9	-
90BE3533/(R6078der.)	1.8	2.2	-

[1] Desirability rating 1=very good, 5=very poor

Table 3. Performance of selected entries from the International Food Sorghum Adaptation Trial (IFSAT) at Cinzana, Mali, 1991.

Hybrid/Cultivar	Days to 50% flower	Plant Height (In)	Desirability[1] rating	Sooty stripe3 rating	Grain quality[2] rating	Dehull yield[4] (%)	Grain yield[5] (t/ha)
ATx631Dorado	62	2.2	1.9	3.0	3.2	49	5.02(1)
AArg34*Dorado	60	1.9	1.8	2.8	3.5	52	4.84(2)
ATx635(A Var)*Dorado	61	1.9	1.8	3.0	3.0	67	4.11(3)
ATx630*R8505	58	1.6	2.6	4.0	3.2	68	3.84(4)
ATx635(A Var)*87EON366	59	1.7	2.0	3.5	3.0	74	3.36(5)
AVar*R8608	60	1.7	2.0	3.5	3.0	51	3.15(6)
ATx630*R3338wx	60	1.5	2.5	2.0	3.0	64	3.09(7)
ATx631*87EON366	60	1.5	2.0	3.5	3.2	51	2.98(11)
AVar*86EON361	62	1.7	1.7	2.5	3.0	56	2.97(12)
ATx631*86EON361	64	1.5	1.7	2.5	3.0	48	2.89(13)
AVar*80C2241	56	1.7	2.9	4.5	4.3	59	2.77(15)
VG153	66	2.4	2.6	3.0	2.5	64	2.73(16)
AVar*R8505	57	1.8	3.0	4.2	4.0	68	2.73(16)
ATx631*R8505	55	1.5	3.2	4.5	4.2	49	2.31(26)
Dorado	65	1.5	2.5	3.5	2.5	76	2.31(26)
Sureno	66	2.1	2.3	3.0	2.3	63	2.27(29)
Malisor 84-7	66	1.3	2.6	2.5	2.0	70	2.04(34)
AArg34*R8505	56	1.4	3.2	4.8	4.8	-	1.51(39)
AArg34*80C2241	56	1.3	3.4	4.5	4.8	52	1.38(41)

Mean yield=2.59 t/ha; CV=23%

[1] Planted July 16, 1991. Cooperative IER/INTSORMIL trial. Ratings by D.T. Rosenow on one replication only. Other data taken on three replications.

[2] Rating: 1=very good, 5=very poor. Grain quality rating is on combined head bug and grain mold, but primarily head bug.

[3] Rating: 1=very resistant, 5=very susceptible.

[4] Dehulling (decortication) yield in percent (higher=better) by IER Cereal Technology Laboratory.

[5] Number in parenthesis is rank in yield of 42 entries.

Malisor 84-7 continues to show excellent potential as a source of head bug resistance in Mali, with several progeny of direct crosses with Malisor 84-7 looking very good. They combine head bug resistance with other desirable traits such as tan plant and appropriate height, maturity, and head type. Several will be extensively tested in national yield trials over Mali in 1992.

Grain yield from the International Food Sorghum Adaptation Trial (IFSAT) at Cinzana, Mali was excellent in 1991, with the top three yielding entries being hybrids with Dorado (Table 3). However, head bug/grain mold damage was severe, along with sooty stripe. The overall field grain quality ratings generally correlate well with the dehulling yield, with poor quality (high rating) giving low dehulling yield. The head bug resistance of BVar (BTx635) consistently expressed itself in the grain from its hybrids, as compared to grain from comparable ATx631 or AArg34 hybrids. This line may be very useful a source of head bug resistance in B-line breeding programs in West Africa. The lines Sureño, Dorado, and VG153 show some resistance to head bugs, along with Malisor 84-7, based on grain quality ratings and decortication yields. Sooty stripe probably reduced yield in the highly susceptible entries.

Several F_2 populations involving the late-maturing, photoperiod sensitive Maicillo Criollo or Improved Maicillo Criollos developed by Dan Meckenstock, INTSORMIL breeder in Honduras, were planted in southern Mali near Sikasso. Segregation for maturity was excellent with a wide range of maturities present among individual plants. The Maicillo derivatives should be a useful source of late maturity for southern Mali. It appeared, however, that the grain of the progeny were very susceptible to the head bug/grain mold complex. F_3 progenies were planted in southern Mali in 1992.

Forty F_3 selections from the cross (SRN-39*Malisor 84-7) were sent from Texas and evaluated under natural *Striga* infestation at Katibougou in Mali in 1991. Ten F_3's were selected for further use based on *Striga* infestation and grain yield. It appears that the resistance of SRN-39 is expressed under natural *Striga* infestations in Mali.

Sudan

The Sudan Sorghum Collection of over 3100 items was grown at Wad Medani, Sudan in 1991, as a collaborative effort among the ARC, INTSORMIL, ICRISAT, and U.S.DA/ARS. This included all sorghum cultivars of known Sudan origin, including those in the World Sorghum Collection at ICRISAT, from various sorghum researchers in the U.S., as well as those held in various collections in Sudan. The items were described, classified, and evaluated for possible inclusion in a Working Collection. Seed was increased, with a set of the seed and the data and notes are to be made available to the USDAand the GRIN system in the United States. Professor Mahmood, retired Sudanese breeder, and K.E. Prasada Rao, ICRISAT Genetic Resources, assisted in the classification, description, and checking of correctness of entries.

The drought screening nursery at Wad Medani was excellent in 1991 with strong pre- flowering drought stress along with moderate post-flowering stress in the same nursery. The most drought resistant lines were: Tx7078, Koro Kollo, Ajabsido, P954035, P898012, 82BDM499, SC414-12E, CE151-262-A1, SC701-14E, SC56-14E, SC23-14E, TP4-5, (Tx430*Rio)-15, P37-3, P40-1, and El Mota. The best F1 hybrids were A1*P37-3, A35*P37-3, A1*P46-1, A1*P33-1, A35*P33-1, A35*P69-2, A1*Karper1597, and A1*82BDM499. Also, several A.BON23 and A.BON34 hybrids performed well, and particularly in the irrigated trials. Both BON34 and BON23 have a waxy endosperm, and its effect on common Sudanese food products is being evaluated.

Networking Activities

Workshops

Led field tours of research plots at the International Sorghum and Millet CRSP Conference, July 8-12, 1991, Corpus Christi, TX.

Presented talks on drought resistance in sorghum at growers seminars for sorghum producers in sorghum production area in Queensland, as part of the Second Australian Sorghum Conference, Gatton, QLD, Feb. 7,8,9, 1992.

Research Investigator Exchanges

Participated in the International Sorghum and Millet CRSP Conference, July 8-12, 1991, where presented paper on sustainability, led field tours and interacted with U.S. and host country PI's regarding research findings and future plans.

Traveled to Mali, Oct. 6-19 1991, to evaluate the INTSORMIL/IER collaborative research program, plan future collaborative research, and coordinate research with the ICRISAT/Mali Program and the ICRISAT West African Regional Sorghum Program.

Traveled to Sudan Nov. 6-16, 1991 to evaluate the INTSORMIL/ARC collaborative research program, plan future research, and evaluated and classified the Sudan Sorghum Collection growout of over 3,000 cultivars.

Traveled to Honduras Dec. 4-10, 1991 to evaluate the INTSORMIL/SRN/EAP collaborative sorghum research program, plan future collaborative research activities, and coordinated INTSORMIL research in the area.

Traveled to Australia Jan. 29-Feb. 17, 1992 to participate in the Second Australian Sorghum Conference at Gatton, QLD, present poster paper, and present talks on drought resistance of sorghum at three producer meetings in sorghum production areas of Queensland.

Coordinated six week sorghum breeding training session for Aboubacar Toure, Malian sorghum breeder, Aug. 28-Oct. 6, 1991, at Lubbock (included travel to Nebraska and Purdue), and paid for his travel to Lubbock, Oct. 21-25, 1991 for breeding selection and training.

To College Station, TX, Feb. 19-21, 1992 to participate and make presentations at the INTSORMIL External Evaluation Panel (EEP) Review.

To Puerto Rico, March 19-27, 1992 to harvest winter nursery, and evaluate new introductions with Dr. Jeff Dahlberg, new USDASorghum Collection Curator.

To College Station, TX May 11-13, 1992 to discuss Latin America collaborative program with ICRISAT, Drs. Lewis Mughogho, Dan Meckenstock, Francisco Gomez, Guillermo Munoz, John Yohe, and other INTSORMIL PI's.

To INTSORMIL joint EZC/TC meeting July 29-30, 1991, at Kansas City, MO., and EZC meeting April 16-17, 1992 at Lincoln, NE.

To Purdue University, October 26-28, 1991, to review collaborative research and plan future breeding research with Dr. Gebisa Ejeta.

Investigator visits to Lubbock

Dr. Paula Bramel-Cox and graduate students, Sept. 13-14, 1991.

Mr. G. Trouche, Senegalese sorghum breeder, Sept. 22-25, 1991.

Drs. Fred Miller and Vartan Guiragossian, Sept. 30-Oct. 2, 1991.

Dr. Gebisa Ejeta, Oct. 3-4, 1991.

Dr. Fred Miller, Mr. George Ombakho (Kenya M.S. student), and Mr. Aboubacar Toure (Mali Ph.D. student), Oct. 20-25, 1991.

Dr. Yilma Kebede (Ethiopia sorghum breeder), Oct. 30-Nov. 2, 1991.

Mr. Jack Eberspacher, Nat. Grain Sorghum Producers, Reed Richardson, Rod Preston, and L.W. Rooney, March 16, 1992.

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.

Dr. Oumar Niangado, Millet Breeder and Head, Plant Breeding Section, SRCVO/DAR/IER, Cinzana, Mali.

Mr. Issoufou Kapran, Sorghum Breeder, INRAN, Maradi, Niger

Mr. G. Trouche, Sorghum Breeder, CNRA, ISRA, Bambey, Senegal

Dr. A. Tunde Obilana, Sorghum Breeder, SADCC/ICRISAT, Bulawayo, Zimbabwe

Dr. Vartan Guiragossian, Sorghum Breeder, ICRISAT/SAFGRAD/OAU, Nairobi, Kenya

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

Mr. Ben Kanyenji, Sorghum Breeder, Katumani Station, Machakos, Kenya

Mr. Alejandro Palma, Sorghum Breeder, EAP, Zamorano, Honduras (M.S. student, TAMU)

Dr. Compton Paul, Agronomist, ICRISAT/CIMMYT, El Batan, Mexico

Ing. Rene Clara, Sorghum Breeder, ICRISAT/CIMMYT, El Batan, Mexico

Dr. Guillermo Munoz, INTSORMIL/CIAT, Cali, Colombia

Dr. Manuel Terregroza, Director of Annual Crops, ICA, Bogota, Colombia

Dr. A. Sotomayor - Rios, Geneticist, 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 (Currently Sorghum Breeder, MIAC/KARI Project, Nairobi, Kenya)

Prof. D.J. Andrews, Sorghum/Millet Breeder, UNL-115, University of Nebraska, Lincoln, NE

Dr. J.D. Eastin, Physiologist, UNL-116, University of Nebraska, Lincoln, NE

Dr. R.R. Duncan, Sorghum Breeder, University of Georgia, Experiment, GA

Dr. K.F. Schertz, Geneticist, Texas A&M University, College Station, TX

Dr. John H. Mullet, Biochemist, Texas A&M University, College Station, TX

Dr. A.B. Onken, Soil Scientist, Texas A&M University, Lubbock, TX

Dr. Henry Nguyen, Geneticist, Texas Tech University, Lubbock, TX

Germplasm and Research Information Exchange

Germplasm Conservation and Use

Seventy-six new exotic sorghum cultivars from Western Kordofan in Sudan, Somalia, the dry northern region of Nigeria, Zambia, Malawi, Ethiopia, Gambia, Niger, Mauritania, Ghana, Mali, Benin, and ICRISAT were entered into the cooperative TAMU/U.S.DA-ARS Sorghum Conversion Program. Nineteen of these lines were aluminum tolerant exotics identified in Georgia. Twenty-six elite breeding lines from the Mali program and from the ICRISAT West African Program were also introduced into the U.S.

Seed Production and Distribution

A large number of sorghum breeding and germplasm lines, including F_2 to advanced generation breeding progeny, A, B, and R lines, converted lines, and experimental hybrids were increased and distributed to numerous international and domestic collaborators. These contained sources of desirable traits such as disease resistance, pre- and post-flowering drought resistance, grain mold and weathering resistance, and lodging resistance. Also, seed was increased and many sets of standard replicated trials containing elite germplasm and source lines were packaged and distributed in the U.S. and internationally. These include the ADIN (All Disease and Insect Nursery), IDIN (International Disease and Insect Nursery), GWT (Grain Weathering Test), DLT (Drought Line Test), DHT (Drought Hybrid Test), CLAT (Converted Line Anthracnose Test), and the UHSN (Uniform Head Smut Nursery). Countries to which large numbers of germplasm items were distributed include Mali, Sudan, Niger, Kenya, Honduras, Zimbabwe, ICRISAT/LASIP, Colombia, and Botswana.

Impact

Sureño, the white seeded, tan plant sorghum cultivar released in Honduras is now being grown by a large number of small farmers in southern Honduras. It is estimated that perhaps 15% of the crop area of the small farmers of southern Honduras is now planted to Sureño. It is grown because its grain makes excellent tortillas, and its stover makes good livestock feed.

Assistance Given

Joint evaluation of germplasm was done collaboratively with national scientists in Mali, Honduras, and Sudan. 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 breeding and disease nurseries in Texas.

Publications and Presentations

Publications

Rosenow, D.T. 1992. Using germplasm from the world collection in breeding for disease resistance. p.319-324. In: Sorghum and Millet Diseases: A Second World Review. (de Milliano, W.A.J., Frederiksen, R.A., and Bengston, G.D., eds). Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics. 378p.

M.K. Wanous, F.R. Miller, and D.T. Rosenow. 1991. Evaluation of visual rating scales for green leaf retention in sorghum. Crop Sci. 31:1691-1694.

Clark, L.E. and D.T. Rosenow. 1992. Off-type sorghum plants. Texas Agric. Exp. Stn. MP-885 (Revised). 7p.

Pietsch, D.R., R. Gass, D.T. Rosenow, F.R. Miller, and G.C. Peterson. 1992. 1991 Grain sorghum performance tests in Texas. Dept. of Soil and Crop Sciences Departmental Technical Report No. 92-2. 111p.

Meckenstock, D.H., F. Gomez, D.T. Rosenow, and V. Guiragossian. 1992. Registration of 'Sureño' sorghum. Crop Science (accepted).

Ejeta, Gebisa, and D.T. Rosenow. 1992. Registration of 10 fertility restorer parental lines of sorghum. Crop Science (accepted).

Collins, D., R.A. Frederiksen, and D.T. Rosenow. 1992. Registration of Tx2891 sorghum. Crop Science (accepted).

Jorgensen, J.A., D.T. Rosenow, and H.T. Nguyen. 1992. Genotypic comparison of heat-shock protein synthesis in sorghum. Crop Science (accepted).

Gilbert, M.L., N.W. Kramer, D.T. Rosenow and H.T. Nguyen. 1991. Strategies for sorghum inbred development in the 90's. p.11-14. In: Proc. 17th Biennial Grain Sorghum Research and Utilization Conference, Feb. 17-20, 1991. Lubbock, TX.

Collins, S.D., D.T. Rosenow, and R.A. Frederiksen. 1991. Progress of head smut resistant sorghum populations. p.94. In: Proc. 17th Biennial Grain Sorghum Research and Utilization Conference, Feb. 17-20, 1991. Lubbock, TX. (Abs).

Isbell, V.R., D.T. Rosenow, and G.G. McBee. 1991. Stem anatomical features related to lodging in sorghum. p.58. In: Proc. 17th Biennial Grain Sorghum Research and Utilization Conference, Feb. 17-20, 1991. Lubbock, TX. (Abs).

Khizzah, B.W., R.J. Newton, F.R. Miller, and D.T. Rosenow. 1991. Post-flowering osmotic adjustment and dehydration tolerance response of four sorghum [*Sorghum bicolor* (L.) Moench] cultivars to induced water stress. p.27. In: Proc. 17th Biennial Grain Sorghum Research and Utilization Conference, Feb. 17-20, 1991. Lubbock, TX. (Abs).

Tenkouano, A., F.R. Miller, R.A. Frederiksen, D.T. Rosenow, and J.T. Cothren. 1991. Nonsenescence and resistance to charcoal rot in sorghum: Genetics and relationships to nonstructural carbohydrates. p. 28. In: Proc. 17th Biennial Grain Sorghum Research and Utilization Conference, Feb. 17-20, 1991. Lubbock, Tx. (Abs).

Xiang, Z., H.T. Nguyen, and D.T. Rosenow. 1991. Tagging drought tolerant genes in sorghum using molecular markers. p.27. In: Proc. 17th Biennial Grain Sorghum Research and Utilization Conference, Feb. 17-20, 1991. Lubbock, TX. (Abs).

Khizzah, B.W., R.J. Newton, F.R. Miller, and D.T. Rosenow. 1991. A study of physiological components of drought resistance in some inbred sorghum [*Sorghum bicolor* (L.) Moench] lines and progenies subjected to prolonged water stress. p.261-262. In: Proc. International Sorghum and Millet CRSP Conference, July 8-12, 1991. Corpus Christi, TX. INTSORMIL Publication No. 92-1.

Mansuetus, S.B.A., G.N. Odvody, R.A. Frederiksen, J.F. Leslie, and D.T. Rosenow. 1991. Investigation of the mating groups of *Fusarium* section *Liseola* on Sorghum in Texas. p.275. In: Proc. International Sorghum and Millet CRSP Conference, July 8-12, 1991. Corpus Christi, TX. INTSORMIL Publication No. 92-1.

Onken, A.B., G.C. Peterson, M.D. Doumbia, A.A. Sow, and D.T. Rosenow. 1991. Interaction effects of sorghum genotypes, water level, and nutrient level. p.263. In: Proc. International Sorghum and Millet CRSP Conference, July 8-12, 1991. Corpus Christi, TX. INTSORMIL Publication No. 92-1.

Tenkouano, A., F.R. Miller, R.A. Frederiksen, D.T. Rosenow and J.T. Cothren. 1991. Sugar partitioning and resistance to charcoal rot in sorghum. p.265. In: Proc. International Sorghum and Millet CRSP Conference, July 8-12, 1991. Corpus Christi, TX. INTSORMIL Publication No. 92-1.

Rosenow, D.T. 1992. Drought resistance in sorghum-Concepts and breeding procedures. In: Proc. Second Australian Sorghum Conference, Feb. 4-6, 1992, The University of Queensland Gatton College, Gatton, QLD. (Abs). (In Press).

Matches, A.G., J.W. Keeling, and D.T. Rosenow. 1992. Yield and quality of grain sorghum stover. p.21-24. In: Proc. Total Forage Management Symposium, Feb. 18, 1992, Texas A&M Research and Extension Center, Amarillo, TX, AREC-SP-92-1.

Frederiksen, R.A., and D.T. Rosenow, F.R. Miller, and G.N. Odvody. 1992. Disease resistance in sorghum. Abstr. D-9. In: Proc. of Durable Resistance, a Symposium on Durability or Disease Resistance, Feb. 24-28, 1992. ICA Wageningen, Netherlands.

Gorman, C.Tennant. 1992. Characterization of drought resistance of exotic sorghums. M.S. Thesis, Texas Tech University, Lubbock, TX 144p.

Isbell, Verne. R. 1992. The lodging complex in sorghum [*Sorghum bicolor* (L.) Moench]: Morphological, chemical, and anatomical stem features associated with lodging in sorghum. Ph.D. Dissertation, Texas A&M University, College Station, TX. 182p.

Toure, Aboubacar. 1992. Hetrosis, combining ability, and breeding potential studies for grain yield and yield components in Guinea sorghums [*Sorghum bicolor* (L.) Moench]. Ph.D. Dissertation, Texas A&M University, College Station, TX. 224p.

Presentations

Rosenow, D.T. 1991. Breeding sorghum and millet for sustainable production systems. International Sorghum and Millet CRSP Conference, July 8-12, 1991. Corpus Christi, TX.

Rosenow, D.T. 1992. Drought resistance in sorghum. Presented to three Sorghum Growers Seminars at Dalby, Emerald, and Biloela, Queensland, Australia, Feb. 7, 8, & 9, 1992, respectively.

Rosenow, D.T. 1991. Use of exotic sorghums and breeding for drought resistance in sorghum. At Chillicothe/Vernon TAES Field Day, Sept. 26, 1991.

Germplasm Enhancement through Genetic Manipulation for Increasing Resistance to Insects and Improving Efficient Nutrient Use in Genotypes Adapted to Sustainable Production Systems (Joint with TropSoils)

Project TAM-123

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Summary

Additional sources of resistance to sorghum midge, *Contarinia sorghicola*, have been identified. The new resistance sources offer the potential to broaden the genetic diversity of improved sorghum for this trait and to develop parental lines with uniquely different sources of resistance. Sources of resistance to biotype I greenbug have been identified and are being used to develop new breeding populations. Genes for resistance to sugarcane aphid have been recovered in temperate photoperiod insensitive germplasm.

Data presented clearly shows the potential synergistic effects of interactions between soil fertility, available water and sorghum genotypes. It also shows a number of important responses of sorghum to moisture stress, soil fertility and applied inputs to be under separate genetic control. Consequently, there is great potential for exploitation of available germplasm resources for development of multiple stress tolerant sorghums to take advantage of synergistic interactions for a wide range of climatic and input conditions.

Objectives, Production and Utilization Constraints

Objectives

Obtain and evaluate germplasm for resistance to arthropod pests. Determine the resistance source or mechanisms most useful to sorghum improvement.

Determine the inheritance of insect resistance.

Develop and release high yielding, agronomically improved sorghum resistant to selected insects including the sorghum midge.

Identify and define potential sources of more efficient plant nutrient extraction and/or utilization in sorghum.

Develop agronomically elite sorghum with improved nutrient use efficiencies.

Develop new methods for determining nutrient use efficiencies and study responsible mechanisms when appropriate.

Determine the effects of nutrient use efficiency on water use efficiency in sorghum.

Develop analytical procedures for determining chemical and physical properties of Sahelian soils and diagnostic techniques to use in predicting crop response and need for fertilizers or corrective amendments.

Identify and define sorghum genotypes with varying levels or tolerance to drought and chemical stress of Sahelian soils and determine how each trait is inherited.

Constraints

Sorghum production and yield stability is constrained by numerous biotic and abiotic stresses. Insects pose a production risk in all areas of sorghum production, the severity of damage depending on the insect and local environment. To reduce the impact of stress, research is needed to develop crop genotypes with enhanced environmental fitness suitable for use in more sustainable production systems. Genetic resistance to multiple stresses in a single genotype will further reduce environmental risk and contribute to improved productivity in LDC and DC production systems. This is particularly important as local production ecosystems (relative to cultivars and technology) experience induced change with natural balance between cultivars and biotic stresses also being changed and insect damage becoming increasingly severe.

Sorghum midge, *Contarinia sorghicola*, is the only cosmopolitan sorghum insect pest and is among the sorghum species destructive insect pests. As LDC programs cross exotic germplasm with improved agronomic traits to indigenous genotypes, progeny and eventually cultivars will be developed which are more photoperiod insensitive and midge damage will become increasingly severe. Cultivars resistant to insects will readily integrate with other required inputs as part of an integrated, ecologically sound production and stress control strategy with large potential benefits in subsistence and mechanized agriculture. Host plant resistance to insects is a continual effort in response to a dynamic evolving production agroecosystem.

It has long been assumed that water was the first limiting factor to plant growth in much of the semiarid tropics. However, Stroosnijder and his associates from the University of Wageningen have shown, conclusively, that due to a lack of nutrients, principally N and P, usable water is left on the soil profile even by native range plants. We have determined that on Aflisols in Texas (same soil family as many in SAT areas of Africa) usable water is left in soil zones of low nutrient supply. Consequently, increasing grain production under simultaneous low soil water supply and low soil fertility is important as well as conditions of low soil fertility with adequate water.

Research Approach and Project Output

Research Methods

Germplasm is evaluated for resistance to insects of economic importance in the collaborative breeding/entomology program in field nurseries or greenhouse facilities, depending on the insect mode on infestation. Sources of germplasm for evaluation are elite accessions from other programs (including ICRISAT), introductions, and partially or fully converted exotic genotypes from the sorghum conversion program.

New sources of resistance are crossed to elite material in the breeding program and to other germplasm lines with superior trait(s). Studies to determine the genetics of resistance and the resistance mechanism are conducted when possible. Advanced elite materials are evaluated at diverse locations for stability of resistance, adaptation, and reaction to additional stress factors. Based upon data collected, crosses are made among elite lines to produce additional germplasm for subsequent evaluation. Improved adaptation, other stress resistance (disease resistance and/or drought tolerance), and additional favorable traits are incorporated into insect resistant germplasm whenever possible.

Elite lines and hybrids are provided to LDC cooperators for evaluation in indigenous environments. The germplasm is evaluated under the local production system (fertilizer, tillage, plant population, etc.) and agronomic and yield data collected. TAM-123 will assist in evaluation at maturity. Larger quantities of germplasm are provided to cooperators based upon initial observation.

For insects important in LDC's but not in the U.S., an array of germplasm is provided to the LDC cooperator. The germplasm will be evaluated for resistance to the specific insect by the cooperator. Based upon experimental results crosses are made to produce relevant populations for inheritance and entomological studies. These populations are provided to the cooperator for further evaluation.

Diverse cultivars of grain sorghum from the breeding programs at Lubbock, and introductions from LDC's are screened for N, P, and Fe use efficiencies in nutrient culture in greenhouse studies at Lubbock and field nurseries in Mali, West Africa and at Beeville and Lubbock, Texas. Priority is given to lines that have shown promise in previous tests including nurseries in LDC's. Lines from the sorghum conversion program are also evaluated. Genotypes relatively different in N and/or P nutrient use efficiency will be grown in a greenhouse in soil deficient in the respective nutrient. Water use will be determined and water use efficiency defined as dry weight production per unit of available water. Water use efficiency for selected genotypes differing in N use efficiency will be determined in an N deficient soil under field conditions based on grain and forage yields, available water, and water used. Water use will be determined by neutron probe. Particular attention will be given to determination of soil chemical and physical characteristics for nurseries in Mali.

Crosses will be made among lines for preliminary assessment of heritability. Based on heritability studies, crosses will be made among cultivars with high nutrient use efficiency and elite lines to produce breeding lines with high nutrient use efficiency and favorable adaptation and agronomic characteristics. Verification of selection will be made in the progeny of improved lines under field and solution culture screening.

Research Findings

Evaluation of germplasm developed in TAM-123 continued at domestic and international locations. In addition to developing and distributing tests for resistance to sorghum midge and biotype E greenbug, TAM-123 contributed entries and germplasm to the ADIN (All Disease and Insect Nursery), ITVAN (International Tall Variety Adaptation Nursery), TAT (Tropical Adaptation Test), IFSAT (International Food Sorghum Adaptation Test), EON (Elite Observation Nursery), and BON (B-line observation nursery). The ADIN, ITVAN, TAT, and IFSAT are evaluated at many locations, domestically and internationally.

Selections for resistance to sorghum midge were made in populations from the F2 through advanced generations. Progress was again hindered by harsh environmental conditions in the Texas Coastal Bend (too wet early in the season which delayed planting and then post-flowering drought stress late in the season). Based upon replicated trials at three locations (Corpus Christi, TX, College Station, TX and Experiment, GA) three pollinators (R-lines in A1 cytoplasm) were selected for advanced yield testing in 1993. The midge resistance of each line is at least as good as Tx2767 (resistant check) and each line exhibits good yield potential.

Twenty female (B-lines in A1 cytoplasm) lines were selected for further evaluation and yield testing. Hybrid seed was produced during 1992 on nine of the lines for yield testing in 1993. The remaining lines are being sterilized as rapidly as possible, and hybrid seed will be produced in 1993 for subsequent yield testing. The lines possess midge resistance equal to Tx2755 and better agronomic characteristics. Seed set in hybrid seed production appears to better than that of Tx2755.

The second year of testing fifty-two new converted exotic sorghum lines for resistance to midge was completed in 1992. Mean of selected lines over two years (at two locations per year) is given in Table 1. Based upon the data additional potentially useful sources of resistance to midge are present in the world collection. Lines with potentially useful resistance include IS8179C (SC752-14), IS6919C (SC846-14), IS2655C (SC113-14), IS3693C (SC632-14), and IS17211C (SC1072-14). Two lines, IS6919C and IS3693C, are B-lines in A1 cytoplasm and offer the potential of using different genes in female parents of resistant hybrids. Additionally,

Table 1. Mean midge damage rating of selected converted exotic sorghum lines, 1991-92.

IS Number	SC Number	Group	1991 MDR	1992 MDR	Mean 1991-92 midge damage rating
TAM2566			7.00	3.50	5.25
5803C	892	Dur	6.75	3.75	5.25
9370	1080	Caf	8.25	5.00	5.00
8120C	749	CauBic	6.25	3.25	4.75
OC	1103	ZZ	4.75	-	4.75
7156C	807	CauDur	5.25	4.00	4.63
12153C	979	ZZ	6.25	3.00	4.63
Tx2767			5.00	3.00	4.60
Tx2755			5.00	3.00	4.00
17211C	1072	Caf	4.75	3.25	4.00
3693C	632	Caf	4.25	3.75	4.00
2655C	113	CauNig	4.75	3.25	4.00
Tx378			3.25	-	3.25
Tx2782			3.00	2.50	2.75
Tx2872			3.00	2.25	2.63
6919C	846	Dur(aZZ)	2.50	2.00	2.33
Tx2878			2.25	2.00	2.13
8179C	752	CauKaf	2.25	2.00	2.13
$\bar{x}$			7.15	5.90	6.55
$LSD_{.05}$			1.64	1.68	1.34
CV			16.49	19.27	20.07

IS6919C is a tan plant line and offers that potentially useful trait in B-line germplasm.

Partial results from the initial evaluation of seventy-five additional converted exotic sorghum lines and four introductions from ICRISAT are given in Table 2. Based upon initial evaluation at one location, additional potentially useful sources exist. Lines that could possess useful resistance include; IS3568C (SC716-14), IS8179C (SC752-14), SC970-14, IS8264C (SC680-14), IS6893C (SC1111-14), IS12156C (SC982-14), IS5437C (SC762-14), and IS3546C (SC751-14). The experiment will be repeated in 1993 at two locations to confirm the existence of additional resistance sources.

Table 2. **Mean damage rating of selected converted exotic sorghum genotypes of 1992 converted line midge test #2.**

IS Number	SC Number	Group	Midge damage rating
TAM2566	-	-	4.5
3693C	632	Caf	4.5
2856C	650	Caf	4.5
2820C	797	ZZ	4.5
7017C	339	Cau	4.5
1104C	1104	CauKaf	4.5
PM13613	-	-	4.5
3511C	774	CauKaf	4.0
8088C	712	Cau	4.0
11549C	1017	SuDuDo	4.0
11065C	1046	Dur	4.0
2681C	324	Nig	3.5
Tx2755	-	-	3.0
Tx2767	-	-	3.0
3546C	751	CauKaf	3.0
5437C	762	CauKaf	3.0
12156C	982	ZZ	3.0
6893C	1111	Nig	3.0
PM13668	-	-	3.0
PM15929	-	-	3.0
PM15936	-	-	3.0
Tx2872	-	-	2.5
Tx2878	-	-	2.5
8264C	680	Dob	2.5
970C	970	CauNig	2.5
8179C	752	CauKaf	2.0
3568C	716	Cau	2.0
Tx2782	-	-	-
$\bar{x}$			6.02
$LSD_{.05}$			1.49
CV			12.30

Germplasm resistant to sorghum midge was provided to Honduras and to Dr. Guillermo Munoz, the INTSORMIL P.I. in Colombia. Data had not been received when this report was prepared.

Diverse germplasm resistant to biotype E greenbug was evaluated in segregating generations and selected at several locations. Superior resistance to biotype E greenbug is being combined with wide adaptation and other useful traits (resistance to head smut, pathotype three downy mildew, anthracnose, rust, and other leaf diseases; resistance to insecticide phytotoxicity; and phenotypic traits such as tan plant and white pericarp). Advanced germplasm, R-lines in A1 cytoplasm, is being presently selected for final testing based upon adaptation and combining ability in hybrid combination. The lines will be released following final testing.

The presence of a new greenbug biotype, designated as biotype I, was confirmed in Texas during 1991-92. Two sources of resistance, PI550607 and PI550610, have been confirmed in the cooperative breeding/entomology project. Crosses to introduce this gene into adapted germplasm were made during the summer of 1992. Seed will be sent to a winter nursery in Puerto Rico for generation advance and backcrossing to adapted germplasm to develop resistant germplasm as quickly as possible.

During the summer of 1991 flowering was induced at Lubbock by controlling day-length in two photoperiod sensitive lines, PI457709 and PI453951. Both lines are resistant to yellow sugarcane aphid, *Sipha flava*. Seed resulting from crosses was grown in Puerto Rico during 1991-92 and F2 progenies were grown at College Station in 1992. From the F2 populations short, early plants were selected for evaluation for resistance. Preliminary evaluation indicated that the resistant gene(s) were recovered in short insensitive genotypes. Six resistant selections were selected for inclusion in the 1992-93 winter nursery for generation increase and additional crossing.

Flowering was induced in several photoperiod sensitive introductions from West Africa, principally Mali. The germplasm was crossed with MB9-41, a line used in nutrient/water use efficiency studies, and with selected lines resistant to sorghum midge. F2 seed from the populations was sent to Dr. A. Toure, sorghum breeder with IER in Mali, for use in his program. Germplasm from additional crosses (made during the 1992 growing season) will be sent to Dr. Toure in June 1993.

Data in Table 3 are results of a study conducted in cooperation with TropSoils in which the objective was to determine the effects of soil fertility on transpirational water use efficiency (WUE_T). Previously we have reported increases in WUE_T in grain sorghum due to increases in soil fertility from lysimeter studies. The most popular current theory for soil fertility increasing evapotranspirational water use efficiency (WUE_{ET}) is that improved nutrient status results in increased leaf area and soil shading, thus, reducing evaporation (E) and leaving more water for transpiration (T). Recently, a model has been developed that allows separation of E and T under field conditions. We obtained the necessary data under field conditions for the breeding line MB9 and working with TropSoils scientists utilized the model to calculate T and E in Table 3.

Table 3. Water and nitrogen level effects on evapotranspirational and transpirational water use efficiencies of field grown grain sorghum.

Water level[1] (% ET)	N rate (lbs/a)	Grain yield (lbs/a)	ET (inches)	T (inches)	E (inches)	WUE_{ET}[2] lbs/in	WUE_T lbs/in
				1988			
50	0	3300	13.9	7.8	6.1	237	423
50	80	5900	14.2	8.9	5.3	415	663
100	0	3190	20.6	11.4	9.2	155	280
100	80	6410	21.4	15.0	6.4	300	427
				1989			
50	0	2970	16.3	9.8	6.5	182	303
50	80	5040	17.7	11.8	5.9	285	427
100	0	3460	19.7	12.8	6.9	176	270
100	80	5660	20.9	14.7	6.2	270	385

[1] Applied weekly.
[2] Calculated on grain weight.

Water level had large effects on ET and lesser effects on grain yield while fertilizer level had only small effects on ET and large effects on grain yield. As a result, increasing water level reduced WUE_{ET} while fertilizer N increased WUE_{ET}. Increased water level increased both E and T and with one exception increased yield. However, the increased T was proportionally greater than the increase in yield and WUE_T decreased with increased water level. On the other hand, E decreased with N application and grain yield increases were proportionally greater than increases in T which resulted in increased WUE_T. Therefore, while fertilizer N did decrease E and increase T, it also resulted in grain sorghum metabolically utilizing water more efficiently.

After a number of studies we have hypothesized that nitrogen use efficiency for sorghum is, at a minimum, a three component system from an agronomic perspective. We have defined nitrogen use efficiency as follows:

Gw/Ns = (Gw/Nt)(Nt/Np)(Np/Ns)

where:Gw/Ns =nitrogen use efficiency - grain weight (Gw) per unit of available soil N (Ns).

Gw/Nt =metabolic N use efficiency - grain weight per unit of N in above ground tissue (Nt).

Nt/Np =translocation efficiency - proportion of total plant N (Np) in the above ground tissue.

Np/Ns =uptake efficiency - proportion of available soil N taken up by the plant.

In a lysimeter study with two diverse sorghum genotypes of similar maturity (MB9 and B35), we determined that at low to moderate soil N levels, significant differences existed between genotypes for each of these components. Differences tended to disappear at very high N levels.

A new project to be conducted cooperatively between INTSORMIL and TropSoils, in collaboration with the IER in Mali, has been approved by all entities and has been initiated. This project is entitled "Screening Sorghum Genotypes for Nutrient or Water Stressed Soils in Mali." As the title implies, this project will be conducted in its entirety in Mali. Test locations have been selected at Cinzana and Samanko. As resources permit, a third location will be selected at Bema.

Networking

Research Investigator Exchanges

G.C. Peterson - Sudan, Nov. 4-16, 1991. Evaluated and worked on classification of the Sudan sorghum collection at Wad Medani. Evaluated cooperative ARC/INTSORMIL research activities at the Gezira Research Station. Evaluated hybrid seed production conducted by the Gezira Board.

G.C. Peterson - Honduras, Dec. 4-9, 1991. Evaluated cooperative SRN/EAP/INTSORMIL research at Zamarano, Danli, Olancho, Choluteca, and Comayagua. Evaluated on-farm research in Choluteca region conducted by LUPE program. Discussed collaborative research program activities with representatives of the Ministry of Natural Resources (SRN), USAID/Honduras, and the Pan American School (EAP).

Germplasm and Research Information Exchange

Participated in classification and description of the Sudan sorghum collection at Wad Medani. Germplasm was distributed to the following countries: Honduras, Colombia, Mali, Niger, Uruguay, India, Senegal, South Africa, Botswana, Peoples Republic of China, and Japan. Germplasm was sent to several individuals or companies domestically. Germplasm distributed was released lines and/or hybrids developed in TAM-123.

Cooperator in release of 110 converted exotic genotypes from the sorghum conversion program.

Publications and Presentations

Publications

Manthe, C.S., G.L. Teetes, G.C. Peterson, and K. Leuschner. 1991. Sorghum resistance to the sugarcane aphid in Southern Africa. In Proc. of the International Sorghum Millet CRSP Conference. July 8-12, 1991. Corpus Christi, TX. p. 268.

Onken, A.B, R.J. Lascano, J.L. Mabry and C.W. Wendt. 1991. Interaction Effect of Nitrogen and Water Levels on Transpirational Water Use Efficiency Under Field Conditions. Agronomy Abstracts. p. 296.

Onken, A.B., G.C. Peterson, M.D. Doumbia, A.A. Sow, and D.T. Rosenow. 1991. Interaction effects of sorghum genotype, water level, and nutrient level. In Proc. of the International Sorghum Millet CRSP Conference. July 8-12, 1991. Corpus Christi, TX. p. 263.

Peterson, G.C., G.L. Teetes, J.W. Jones, and R.M. Anderson. 1992. Yield and selected traits of sorghum midge resistant hybrids in the presence and absence of the pest insect. Texas Agric. Exp. Stn. Progress Report 4922. 4p.

Presentations

Onken, A.B., R.J. Lascano, J.L. Mabry and C.W. Wendt. 1991. Interaction Effect of Nitrogen and Water Levels on Transpirational Water Use Efficiency Under Field Conditions. Annual Meetings American Society of Agronomy Denver, CO. October 27- November 1, 1991.

Tropical Sorghum Conservation and Enhancement in Honduras and Central America

Project TAM-131

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Mr. Manuel Granados, 4th year student, EAP, Department of Agronomy, P.O.B. 93, Tegucigalpa, Honduras
Mr. Leonel Molina, 4th year student, EAP, Department of Agronomy, P.O.B. 93, Tegucigalpa, Honduras
Ing. Patricio Gutierrez, M.S. degree candidate, University of Nebraska, Agronomy Department, Lincoln, NE
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Summary

Sorghum breeding project TAM-131, "Tropical Sorghum Conservation and Enhancement in Honduras and Central America," has operated in Honduras since October 1981. Its overall objective is to improve the quality of life of farm families in Honduras that produce sorghum. This is accomplished through *in situ* conservation and enhancement of local landrace sorghum populations and the development and promotion of advanced technology intended to shift sorghum production from a tradition led enterprise to a science based industry. The transfer of new sorghum technology is accomplished primarily through on-farm demonstrations and publications of research results and educational materials.

Screening of 54 broomcorn varieties for resistance to pathotype 5 of *Peronosclerospora sorghi* at the International Sorghum Downy Mildew Nursery in Comayagua indicates that five varieties (Acme, IS11, IS13, IS24, and IS18132) have good resistance to this pathotype, the most virulent reported in the Americas.

The average crop growth rate (CGR) and net assimilation rate (NAR) of an enhanced maicillo hybrid (H1105) to a popular commercial hybrid (DK64) was compared. Although both hybrids had similar maturity, the enhanced maicillo hybrid, which has pedigree ATx631 x [(SC326*SC103)SB III]-12-1-2-2-8 or 25% maicillo genome, was associated with greater productivity. The CGR of H1105 was 44.8 g m^{-2} d^{-1} compared to 36.1 g m^{-2} d^{-1} of DK64. Average net assimilation rate of the H1105 was 9.3 g m^{-2} d^{-1} whereas DK64 was 8.1 g m^{-2} d^{-1}. As a result, total dry matter accumulation was greater in the enhanced maicillo hybrid (21.0 vs. 17.1 t/ha) compared to the commercial hybrid. The greater NAR in H1105 suggests a more efficient assimilation system is at work in the enhanced maicillo hybrid and that maicillo germplasm has the potential to make a significant contribution to the hybrid sorghum industry.

The TropSoils CRSP has signed a Memorandum of Agreement with the MNR and will begin working in the Choluteca area with LUPE and INTSORMIL. Enhanced maicillo cultivars will be used to help measure the benefits derived from stone wall barriers with leguminous trees and grass strips at LUPE work site.

Objectives, Production and Utilization Constraints

Objectives

Determine the resistance of 54 introduced broomcorn varieties to pathotypes 1 and 5 of *Peronosclerospora sorghi* (Weston & Uppal) C.G. Shaw.

Determine the difference in dry matter accumulation, crop growth rate, and net assimilation rate between an enhanced maicillo hybrid (H1105) and a commercial hybrid (DK 64).

Coordinate Inter-CRSP activities in Honduras.

Constraints

According to the 1989 FAO agricultural production yearbook, sorghum is grown on about 350,000 ha in Central America. This region has undergone a net increase of some 50,000 ha since 1981, with Guatemala and Honduras adding about 35,000 ha each and Costa Rica reducing production to practically nothing. The two largest producers of sorghum are El Salvador (123,000 ha) and Honduras (90,000 ha).

Conservation and Evaluation of Maicillo Diversity. 'Maicillo Criollo' is the local name for tropical landrace sorghum populations found in semiarid 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 an epidemic occurring.

Low Yield Potential. National sorghum yield in Honduras is less than one metric ton per hectare. Not only is this a reflection of the adverse environment in which sorghum is grown, but it is also a result of the preponderant use of landrace sorghum populations which have low but stable 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.

Traditional Farming Systems. Maicillo is an old world crop that has adapted to neotropical slash and burn agroecosystems. More than 90 percent of the sorghum planted in Honduras and El Salvador is late maturing landrace populations which are intercropped with early maturing maize. Although maize is the preferred staple, it is often intercropped with sorghum by subsistence farmers in hot, erratic rainfall areas as a hedge against drought. Maicillo's sensitivity to photoperiod and its ability to withstand shading are essential for its adaptation to traditional maize intercropping systems. In contrast, introduced cultivars require genetic modification before they can be used in these systems. Study of sorghum/maize intercropping systems is necessary to develop an understanding of how they work and what agronomic and genetic changes will increase their productivity.

Photoperiod Sensitivity. Maicillo Criollo has an acute sensitivity to photoperiod and day lengths of 12 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.).

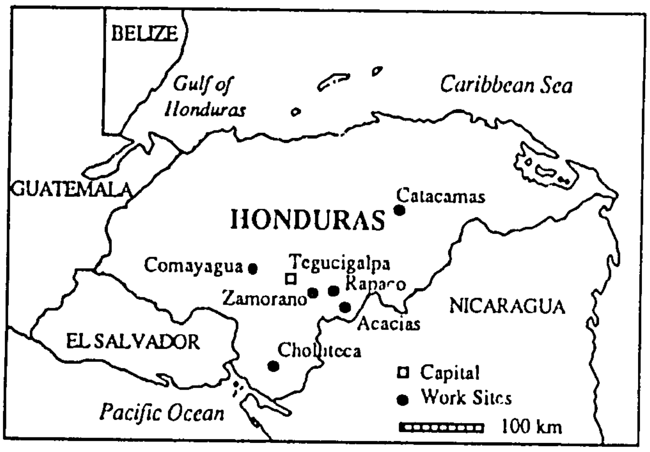
Insect Pests. An early season lepidopterous pest complex, called the langosta by Honduran farmers, is an important constraint to sorghum and maize production in the region. The fall armyworm, along with other lepidopterous larvae—*S. eridania, Metaponpneumata rogenhoferi, and Mocis latipes*—wreck havoc 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.

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 which 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. The introduction and deployment of resistant genes offers the best alternative for control.

Research Approach and Project Output

The Honduran sorghum program is a small program consisting of a national coordinator, an INTSORMIL counterpart, three Ingeniero Agronomos, and a secretary. In spite of its size, the program has been very productive. Much of its success stems from the continuity and stability provided by the union of its three composite institutions—INTSORMIL, MNR, and EAP—and extensive collaboration with other sorghum researchers. Dr. Gómez shares an office with Dr. Meckenstock at the EAP and this daily collaboration has been instrumental in the success of the program. The program has established an elaborate network of collaborators in Honduras that includes both GOH and PVOs. At present, six sites are used to evaluate commercial hybrid performance. Four of these sites—Choluteca, Comayagua, Rapaco, and Zamorano—are also utilized to screen maicillo breeding materials for an array of biotic and abiotic stress factors (Figure 1). Numerous other collaborators and sites are used to validate new sorghum cultivars and other technologies

Figure 1. Sorghum work sites in Honduras, 1991.



on-farm. Multilocation testing is essential for developing cultivars with broad adaptation and resistance to multiple diseases.

Two technical thrusts which TAM-131 has initiated are conservation of local landrace sorghum populations and their enhancement. Both thrusts deal with maicillo or photoperiod sensitive sorghum and the success of one depends upon the other. Our approach to conservation is a passive, *in-situ* approach, whereas enhancement is an active, more aggressive approach.

Conservation

The success of all breeding programs depend 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 which 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.

The greatest perceived threat to maicillo diversity is loss by replacement. Consequently, our approach to sorghum enhancement breaks with traditional development strategies which have stressed creating widely adapted cultivars that can be disseminated around the world. Although the introduction and release of elite germplasm impacts yield almost immediately, we believe this process causes irreversible damage to our genetic resources in regions where primitive cultivars predominate by narrowing the germplasm base, which, in turn, increases the potential to destabilize crop production over time. Our approach strives to conserve maicillo *in situ* and is relevant to areas of crop origin or where landrace populations dominate traditional farming systems. Its success hinges on our ability to upgrade local landrace populations which are then returned to farmers fields.

It is difficult to place a value on maicillo genes lost by replacement, since these genes disappear before they are discovered. However, since we began working with maicillo, useful traits that contribute to acid soil tolerance, drought tolerance, antibiosis to fall armyworm, resistance to multiple diseases (anthracnose, ladder spot, and rust), and shade tolerance have been found. Although the value of these genes are 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.

Of course, the argument can be made that maicillo came from Africa, and that these same genes can be found there as well. However, we believe that some traits, such as fall armyworm antibiosis and shade tolerance, evolved as a direct result of intercropping with maize over the years (Note: Other researchers have reported antibiosis to fall armyworm in sorghum, but evidence suggests antibiosis is manifested differently in maicillo, Environ. Entomolo. 20:1259-1266). Therefore, the only place these traits can be found is in Central America. Similar events of rapid evolution have been reported elsewhere. For instance, an aquatic relative to the earthworm developed resistance to toxic nickel-cadmium pollutants in Foundry Cove on the Hudson River in less than 30 years (Scientific American 267:84-91).

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.

To date, enhanced maicillo varieties with exotic germplasm from GPR148, TAM428, SC414, and SPV346 inbred lines have made their way on-farm (Table 1). All of these enhanced maicillos carry elite genes for yield and/or insect and disease resistance. Two of the non-recurrent exotic parents, TAM428 and SC414, came from the sor-

Table 1. Enhanced maicillo cultivars deployed on-farm.

Years	DMV	Pedigree
1989	150	(81LL691*Porvenir)-16 tan
1989-1990	134	(TAM428*Porvenir)-20-2-6
1989	143	(TAM428*San Bernardo III)-23
1990-1992	179	(SPV346*Gigante)-1-1-2 tan
1990	180	[(TAM428*GPR1482)Billy]-24-1 tan
1990-1992	198	TAM428*Porvenir)-29-1
1991	194	(SC414-12*Plano de Namasigüe)-53
1990	106	(81LL691*Porvenir)-16 tan

ghum conversion program. Ironically, our means of conservation has taken the sorghum conversion program full circle, by introgressing elite genes back into primitive cultivars.

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, and Sureño. Our present short-term goals are to round out our sorghum portfolio with the release of a sorghum-sudangrass forage hybrid 'Ganadero' (ATx623*Tx2784), a red seeded grain sorghum hybrid (ATx626*R8503), and a broomcorn variety. Both hybrids are ready for release, but work on the broomcorn variety is just beginning. This next generation of releases reflects a change in our attitude towards development which is shifting from self-sufficiency to self-reliance.

Ganadero. This forage hybrid has been tested extensively in production fields at the EAP. Fresh weight silage yields have ranged from 28 to 40 t/ha. Since the EAP began to use Ganadero to meet its annual production goal of 2,000 tons of silage, it has significantly reduced the amount of land it normally reserves to meet this need, from 91 to 64 ha. Much of the land that Ganadero has freed up at the EAP has been put into seed production. It is this kind of intensification of land use that Ganadero is intended to assist throughout Honduras.

Broomcorn. At the request of the MNR, the national sorghum program introduced 54 broomcorn varieties from the World Collection via ICRISAT/Mexico. Our goal is to release 1 or 2 broomcorn varieties with resistance to sorghum downy mildew. Preliminary tests conducted by Leonel Molina in his Ingeniero Agronomo thesis in 1991 indicates that five varieties (Acme, IS11, IS13, IS24, and IS18132) have good resistance to P5 of *P. sorghi*. A complete listing of P1 and P5 infestations are published in Sorghum Newsletter 33:38-39. Data on resistance to P1 was collected at Zamorano whereas resistance to P5 was obtained at CEDA, Comayagua. As expected, P5 devastated most of the broomcorn varieties.

The A.I.D mission in Honduras estimates that broomcorn has a potential 800,000 dollar annual market in Honduras. Although the ministry's interest is in developing that market, it is now evident that broomcorn can also play an important role in the integrated pest management of melons—cantaloupe and watermelon—in southern Honduras. Because broomcorn is harvested immature (= 80 d) it can be planted in the spring (May-June)—the melon off-season—and harvested in time to plant melons in August-September. Once sufficient seed of an acceptable broomcorn variety is available, the rotation of broomcorn with melons is an IPM strategy we plan to test in Choluteca. We hypothesis that such a rotation would help break aphid and white-fly insect life cycles which threatens the lucrative melon export industry. Presently, the IPM work with melons is conducted by the Honduran Integrated Pest Management Project (MIPH) at the EAP. Ms. Lorena Lastres, who received her M.S. degree at TAMU with Frank Gilstrap, is the IPM specialist who leads this work. Already, sorghum is recommended for live barriers with melons, as a means to reduce the spread of viral diseases carried by aphids. Broomcorn can be readily substituted into this system. Another positive aspect of farming broomcorn is that its harvest is labor intensive and this will create more jobs.

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 plant color which reduces the amount of polyphenols in the pericarp and thereby improves grain quality for making tortillas; 3) increase resistance to foliar diseases like rust and Cercospora which enhances forage quality, as well as, grain yield; 4) incorporate resistance to sorghum downy mildew which is endemic in the region and threatens stable maicillo production; 5) select for longer panicles and better head exertion which augments yield through increased seed number; and 6) maintain several important maicillo characteristics such as maturity, white seed color (w/o testa), and shade tolerance. Other characteristics which have carried over from maicillo, but that we have not directly selected for are resistance to anthracnose and an increased level of soluble carbohydrates (brix) in the stem. Because photoperiod sensitivity is maintained in enhanced maicillo cultivars, this work can only be done in the region.

We use the pedigree breeding method to develop our materials because it allows us to concentrate on specific traits and because maicillo generally has good combining ability. As the enhanced maicillo lines progress through the system, F_2 and F_3 selections are made to stabilize desirable height, maturity, pericarp color, and plant color traits. Because we use three locations to screen this material, we also select for drought stress and shade tolerance at Rapaco, resistance to sorghum downy mildew at Comayagua, and resistance to foliar diseases at Choluteca. As superior lines are identified in more advanced generations, F_5-F_7, they are placed in our International Improved Maicillo Yield Trial (IIMYT). This multilocation yield test, referred to as EIME

Table 2. Performance of 37 enhanced maicillo cultivars in the 1991 IIMYT at five locations

Pedigree	DMV no.	Sd/Plt[1] color	Yield[2] t/ha	Yield[3] t/ha	Flower[4] date	Ht[5] m	Lodge[6] %	P1[7] %	P5[7] %	Rust[8] 1-5	GLS[9] 1-5	Gleo[10] 1-5	Anth[11] 1-5
ATx631*(D71020*Billy)-48	P1	wh/T	4.7	2.6	30 Oct	1.7	43	0	1	1.9	1.5	2.3	2.0
ATx631*[(TAM428*SBIII)Billy]-7	P1	wh/R	4.6	2.5	27 Oct	1.9	23	0	5	2.1	2.0	2.0	2.3
A(Tx623*Pespire)-1*DMV193	P1	wh/R	4.5	2.2	8 Nov	1.9	18	0	0	2.3	1.8	2.7	2.5
A(Tx623*Pes)*(SPV346(691*Billy)]-36	P1	wh/R	4.4	2.3	6 Nov	1.8	21	0	0	1.9	1.8	2.1	2.7
A(Redian*Coludo)-3*DMV193	P1	whT/P s	4.3	2.1	4 Nov	1.9	32	0	3	2.8	2.6	2.9	2.5
A155*DMV206	P1	wh/T	4.3	1.7	30 Oct	1.6	16	0	1	1.9	1.6	2.3	3.0
A(Tx631(691*Por)]-17*DMV203	P1	wh/sgT	4.2	3.1	7 Nov	1.7	12	0	0	1.6	1.7	2.0	2.0
ATx631*DMV180	P1	whT/T	4.2	3.0	27 Oct	1.8	35	0	2	1.7	1.5	2.2	2.0
ATx631*[(TAM428*77CS3)P.N.]-52	P1	wh/T	4.2	2.8	30 Oct	1.7	33	0	1	2.0	1.6	2.1	1.9
A(BTx631(691*Por.)]-17*DMV206	P1	whT/T s	4.2	2.1	11 Nov	1.7	9	0	1	1.6	1.5	2.3	1.9
ATx631*(CS3541*Liberal)-6	P1	wh/T	4.1	2.9	26 Oct	1.8	33	0	2	1.6	1.7	1.9	2.3
A(SEPON77*Sta Isabel)-6*DMV203	P1	wh/T	4.1	2.6	6 Nov	1.6	10	0	1	1.4	1.5	2.5	2.4
A(BTx623*Pes.)-1*(Billy*CS3541)-1	P1	wh/R	4.0	2.7	3 Nov	1.7	13	0	1	2.0	1.8	2.3	2.7
A(SEPON77*Sta Isabel)-6*DMV180	P1	whT/T s	4.0	2.2	9 Nov	1.7	29	0	1	1.7	1.6	2.3	2.2
A(BTx623*Pespire)-1*DMV211	P1	wh/R	4.0	2.0	12 Nov	2.2	18	0	1	1.7	1.7	2.1	2.2
A(BTx623*Pespire)-1*DMV180	P1	wh/R	4.0	1.7	9 Nov	1.7	6	0	0	2.0	1.7	2.7	2.0
ATx631*DMV206	P1	wh/T	3.9	2.0	30 Oct	1.6	25	0	0	1.8	1.5	2.5	2.3
(TAM428*Porvenir)-29-2-3	137	wh/R	3.9	2.0	9 Nov	1.5	1	0	1	2.0	2.1	2.3	2.0
A(BTx2801(691*Por.)]-10*DMV193	P1	whT/P s	3.8	2.7	6 Nov	1.8	28	0	1	2.6	2.2	2.7	2.6
(81LL691*Porvenir)-16-1	107	wh/T	3.5	2.5	15 Nov	1.4	4	0	1	1.4	1.4	2.0	1.2
(TAM428*Porvenir)-29-1-1	198	wh/R	3.5	2.1	15 Nov	1.5	8	5	1	1.7	2.1	1.7	1.6
A(Redlan*Coludo)-3 BC4*DMV 180	P1	whT/P s	3.5	1.8	4 Nov	1.7	35	0	1	2.7	2.0	2.9	2.6
San Bemardo III	MC	whT/P	3.4	2.6	14 Nov	1.8	7	8	39	2.7	2.6	2.2	2.0
(TAM428*MC100)-2-2	210	whT/P	3.4	2.2	13 Nov	1.6	5	3	0	2.2	2.2	2.5	2.0
(TAM428*SBIII)-23	143	wh/R	3.3	2.6	14 Nov	1.6	0	0	0	1.6	2.4	2.2	1.9
A(BTx2801(691*Por.)]-10*DMV203	P1	wh/T	3.2	2.6	6 Nov	1.5	5	0	1	1.6	1.5	2.4	1.4
Peloton	MC	wh/P	3.1	1.4	21 Nov	1.7	3	0	6	2.5	2.5	2.4	2.5
Porvenir	MC	wh/P	3.1	1.0	22 Nov	1.9	5	2	30	2.7	2.4	2.7	2.1
(SPV346*Gigante Pavana)-1-1-2	179	wh/T	2.8	2.1	12 Nov	1.6	15	0	0	1.5	1.5	2.0	1.9
Lerdo Ligero	002	whT/P s	2.7	2.0	28 Oct	1.4	9	0	1	3.0	3.0	2.7	3.1
(SC414-12*Plano Namasigüe)-53	193	wh/R	2.7	2.0	14 Nov	1.6	16	0	0	1.8	1.7	2.5	2.8
(ICSV151*Cola de Perico 168)-25	212	whT/T	2.6	2.2	10 Nov	1.7	6	2	31	1.4	1.3	1.8	1.2
(TAM428*Pes.)(SPV346[(691*Billy)]-1	214	wh/T	2.4	2.1	14 Nov	1.5	4	0	0	1.6	1.7	2.1	1.5
Variedad Blanca	003	whT/P s	2.3	3.1	31 Oct	2.1	14	0	0	2.7	2.6	2.4	3.1
ES 727	MM	wh/P	2.1	1.8	14 Nov	1.2	13	0	0	1.7	1.8	2.7	2.1
(SPV346(691*Billy)][(SC414*P.N.)]-7	213	wh/T	1.9	2.3	17 Nov	1.6	4	0	0	1.5	1.3	2.0	1.5
(San Bemardo III*TAM428)-6-1-1	177	whT/R	1.9	1.2	17 Nov	1.7	3	0	2	1.4	1.4	1.6	1.6
A(SEPON77*Sta Isabel)-6*84ES134	P1	wh/P	1.6	2.0	5 Nov	1.6	35	0	0	2.6	2.4	2.5	2.9
(TAM428*SBIII)Billy]-7	215	whT/R	1.6	1.6	4 Nov	1.2	7	0	0	2.0	2.4	2.0	1.9
{82EON112[(SC326*SC103)SBIII]}-43	211	wh/T	1.6	1.0	29 Nov	1.5	1	0	1	1.5	1.5	1.9	1.1

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[1] Seed/Plant color: wh=wh pericarp, whT=white translucent pericarp, Br=testa present, S=dominant spreader gene, s=recessive spreader gene, P=purple plant color, R=red plant color and T=Tan plant color.

[2] Yield in pure stand, mean of four locations: LaLujosa, Choluteca; CEDA, Comayagua; ENA, Olancho; El Zamorano, Francisco Morazán.

[3] Yield Intercropped with maize in aporque system, Rapaco, El Paraíso. Maize 'Maicito', planted 19 Jul., sorghum planted 5 Jul.

[4] Date of flower, mean of two locations: Rapaco and Zamorano (planted = 23 Aug.).

[5] Plant height in pure stand, mean of two locations: La Lujosa (planted 20 Sep.) and Zamorano.

[6] Mean of five locations.

[7] Percent systemic infection of sorghum downy mildew caused by pathotype 1 (P1) of *P. sorghi* at El Zamorano, Terrace #9 and the more virulent pathotype 5 (P5) at the International SDM Nursery, CEDA, Camayagua.

[8] Scale of 5, where resistant=1 and susceptible = 5. Rust caused by *Puccinia purpurea*. Mean of two locations: CEDA and ENA.

[9] Scale of 5, where resistant=1 and susceptible = 5. GLS=Gray Leaf Spot caused by *Cercospora sorghi*. Mean of two locations: CEDA and ENA.

[10] Scale of 5, where resistant = 1 and susceptible =5. Gleo = Zonate leaf spot caused by *Gloeocercospora sorghi* at Olancho.

[11] Scale of 5, where resistant = 1 and susceptible = 5. Anth = Anthracnose cause by *Colletotrichum graminiccla* in Olancho.

[12] Taken at La Lujosa.

in Spanish, is used to select materials for on-farm demonstration plots. The 1990 IIMYT consisted of 40 entries and was planted at five locations in Honduras: Catacamas, Choluteca, Comayagua, Rapaco, and Zamorano (Table 2). In the past, this test has been distributed to collaborators in El Salvador and Guatemala.

Since 1990, enhanced maicillo hybrids have represented about half of the entries in the IIMYT. Two general conclusions can be made about the performance of this test: 1) maicillo hybrids have consistently out yielded varieties, and 2) little progress has been made in pushing varietal yield beyond (TAM428*Porvenir)-29-2. Of course, one of the reasons for this varietal yield plateau is that we are dedicating most of our energy to developing hybrids and shade tolerant cultivars. Shade tolerance, we believe, adds a new dimension to the role of sorghum in sustainable agricultural systems—particularly alley cropping systems designed to check deforestation and desertification.

Hybrid Maicillo. Heterosis is the best tool sorghum breeders have at their disposal for increasing yield. Our long-term goal is to develop photoperiod sensitive food type hybrids for hillside farmers. We believe that hybrids not only will maximize forage and grain yield, but will enhance shade tolerance and help farmers defend against drought. Although there is skepticism whether small farmers will purchase hybrid seed, it is our position that the sorghum project should not be the limiting factor to this end, and, therefore, it is our responsibility to make this technology available for farmers to choose. Contrary to popular belief, many small farmers procure seed each season, mostly from neighbors, and these seed buyers are a target group for maicillo hybrids. Also, those farmers who have adopted other technologies, such as soil and water conservation practices, are seeing their incomes rise as a result and they are also a target group.

Although sorghum hybrids have been with us since the mid-fifties, developing photoperiod sensitive 2-dwarf hybrids breaks new ground. There is a whole new set of options that must be considered. Some of these options obviously deal with setting the industry standard for height and maturity genotypes, just as the Dw_2 and ma_1 genes set the standard for conventional hybrids.

In order to make 2-dwarf hybrid maicillo seed production economical, one breeding objective is to develop combine-height (3-dwarf) parental lines that make use of complementary genes to restore height in their hybrids. This way, seed producers can mechanize seed production and small farmers can reap the yield advantage of 2-dwarf sorghum. To assist the development of parental lines with complementary height genes, we have begun to develop a set of 3-dwarf isolines in the Tx631 background. In 1991, we completed the first backcross in this process which is on schedule.

Because preliminary tests indicate that heterozygous photoperiod sensitive hybrids—e.g., Texas A-lines x maicillo—are too early to be used in the spring planting season (primera), we have begun to develop photoperiod sensitive female lines which will produce later maturing hybrids. This backcross work is conducted at the EAP where daily attention can be given to nurseries.

Interestingly, an experimental hybrid, (AVar1 x SC1207-2-1-1), composed from two photoperiod insensitive lines and planted June 15, did not flower until October 6 or 112 d later in our hybrid observation nursery. This hybrid was significantly later than either parental line, which is some what unique, and had a maturity comparable to many heterozygous photoperiod sensitive hybrids. This suggests a unique combination of maturity genes may be at play in this particular hybrid and introduces the prospect that photoperiod sensitive hybrids can be derived from insensitive parental lines that share certain complementary maturity genes. Conceivably, if this is true, maicillo hybrids could be developed in the United States and sent to Central America or any place else in the tropics where photoperiod sensitivity is a critical factor in adaptation. Also, International seed companies could further assist developing countries, by employing their resources in the temperate zone to produce photoperiod sensitive hybrid seed for the tropics. This would be particularly advantages for those countries, where the local seed industry has not yet geared up to hybrids.

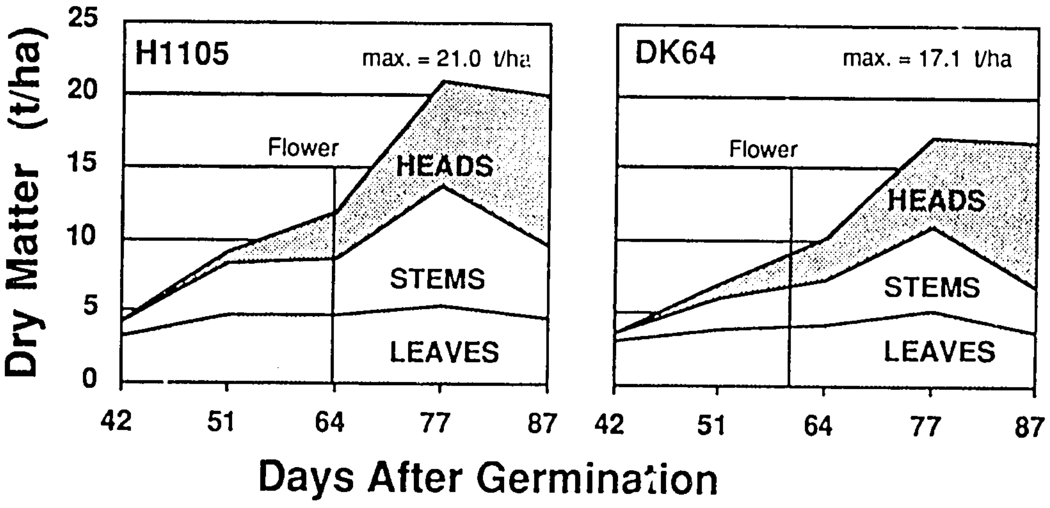
In an effort to learn more about hybrid maicillo, Antonio Granados used his Ingeniero Agronomo thesis to compare the average crop growth rate (CGR) and net assimilation rate (NAR) of an enhanced maicillo hybrid (H1105) to a popular commercial hybrid (DK64). This was a single location replicated study conducted at the EAP under irrigation in 1991. Both hybrids had similar maturity. The enhanced maicillo hybrid, which has pedigree ATx631 x [(SC326*SC103)SB III]-12-1-2-2-8 or 25% maicillo genome, was associated with greater productivity. The CGR of H1105 was 44.8 g m^{-2} d^{-1} compared to 36.1 g m^{-2} d^{-1} of DK64. Average net assimilation rate of the H1105 was 9.3 g m^{-2} d^{-1} whereas DK64 was 8.1 g m^{-2} d^{-1}. As a result, total dry matter accumulation was greater in the enhanced maicillo hybrid (21.0 vs. 17.1 t/ha) compared to the commercial hybrid (Figure.2). The greater NAR in H1105 suggests a more efficient assimilation system is at work in the enhanced maicillo hybrid and that maicillo germplasm has the potential to make a significant contribution to the hybrid sorghum industry.

On-Farm Research

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.

Of the eight enhanced maicillo cultivars that have been deployed on-farm since 1989 (Table1), half have tan plant

Figure 2 Maicillo hybrids like H1105 optimize dry matter production



color (*pp qq*). Since all maicillo landraces collected to date have purple plant color (*PP QQ*), tan plant color in the enhanced cultivars serve as marker genes. This will facilitate followup studies on the introgression of exotic genes into the maicillo population.

Forty-five on-farm demonstration plots were sent out in 1991 with yield data returned from just one. Because crop performance information is important feedback for directing our breeding program, we have hired Hector Sierra to coordinate our on-farm demonstration plots in 1992. Performance data will also be used to determine potential impact and effectiveness of different soil and water interventions.

Special Projects

Dr. Gómez has been successful in establishing two special projects which augment the effectiveness and stability of the program. These are the commercial hybrid performance test, which is sponsored by private seed companies, and the control of sorghum downy mildew, which is sponsored by the EEC. Both projects are administered by the EAP and managed by Dr. Gómez and are exemplary of the kinds of sustainability we are trying to build into the program.

Commercial Hybrid Testing. One A.I.D mission objective is to privatize the national 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. Testing presently takes place in seven States: Choluteca, Colón, Comayagua, El Paraíso, Francisco Morazán, Olancho and Yoro, with Colón and Yoro entering the program in 1992. Since initiating the performance test, we estimate from seed import records that hybrid sorghum acreage has increased by 20 percent or 10,000 hectares. Some dealers are so pleased with the results of this service that a similar test for forage hybrids is being considered for 1993. Of course, we do not take all the credit for increasing production area since changes in government price policy have played an important role. However, favorable prices coupled with performance information, obviously, has led farmers to choose sorghum over other crops.

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, Northrup King has reduced the number of hybrids it now markets in Honduras from 3 to 1 after some of their hybrids gave a poor showing in 1990. Cristiani Burkard hybrids, which did well in Danlí in 1990, are now the preferred hybrids in that area. As a direct result of the performance test, Cristiani Burkard's sales have grown from zero to 4,456 bags in just two years (1990-1992). 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. Forth, farmers often adopt some of the management practices we use to achieve higher yields; e.g., treating seed with insecticide, adjusting plant densities, and using higher fertilizer rates. Fifth, the MNR uses the results to grant seed import permits. And sixth, credit institutions are beginning to look at our reports and consider the possibility of making loans to sorghum producers. Presently, the three largest sorghum seed companies in Honduras, Cristiani Burkard, DeKalb, and Pioneer subscribe to our service.

Control of Sorghum Downy Mildew. After losing our collaborator in the International Sorghum Downy Mildew Nursery last year, Dr. Gomez won a mini-grant from the EEC to continue this work in 1992. 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 is now managed by Dr. Napoleon Reyes-Discua, Director of CEDA. The advantage of screening for downy mildew in Comayagua is that lines resistant to P5 hold resistance elsewhere in the Americas. Some commercial companies that must meet downy mildew resistance requirements in other countries in Latin America are now opting to screen their materials in Comayagua.

Sureño Update

Sureño (PI 561472 and NSSL 259979.51) has found widespread acceptance throughout the sorghum growing regions in Honduras. It is the first sorghum cultivar released by the MNR that has found its way into informal seed markets. Consequently, it not only has sustained its survival, but continues to increase its acreage share with nominal institutional help. Much of its success is due to its cereal quality, yield potential, and dual purpose or use for forage and grain. Previous studies found that pure stand Sureño increases grain yield over maicillo by 63%. This translates into an increase in farm family income from \$1.60 to \$2.70 per day ha^{-1} (Miguel López 1988). Also, those farmers who tried Sureño in 1988 continue to use Sureño three years later on an average of 28% of their maicillo acreage (David Erazo 1991). It is because of this success that we have begun the process of registering Sureño in Crop Science. Sureño is a joint registration of the MNR, INTSORMIL, and ICRISAT.

Pearl Millet Update

Several years ago (1986), TAM-131 mediated the introduction of several pearl millet *Pennisetum glaucum* lines from KSU-101 and UNL-118. This seed was given to Dr. Raul Santillán in the Animal Science Department at the EAP who works in tropical pasture and forage research. His interest with pearl millet was making interspecific forage hybrids with elephant grass, *P. purpureum*. Recently, Dr. Santillán announced plans to release a pearl millet x elephant grass hybrids.

Although elephant grass produces about 40 t/ha of dry matter per year, its wide spread adoption as pasture has been constrained by vegetative propagation. The traditional practice of establishing elephant grass pasture requires about 2 tons of fresh cut stems per hectare, which are not always available when needed.

The innovative aspects of this research, is that the pearl millet-elephant grass hybrid allows pastures to be established by seed. The advantages of using the interspecific hybrid is that seed is combine harvested from the pearl millet female parent, it can be stored until needed, it is easier to transport, it can be planted with conventional grain drills, and about 10 pounds of seed is sufficient to plant a hectare. Although the interspecific hybrid produces about 30 t/ha of dry matter per year, its digestibility (= 66%) is better than that of elephant grass (=60%). Because the hybrid is sterile (its triploid like seedless watermelon and bananas) and has no rhizomes, it does not become a noxious weed when it comes time to convert the pasture back into crop land.

Networking Activities

Institutional Arrangements

MNR-EAP MOA. In 1991, the MNR signed an MOA with the EAP which places the responsibility of sorghum research with the school. This MOA was elevated to the status of Acuerdo (no. 3524-91) when it was approved by the Honduran President December 9, 1991. This restructuring of the NAR sorghum component is consistent with AID/H and GOH objectives on privatization and serves as a model for privatizing other agricultural services in the ministry. INTSORMIL's long-term relationship with the MNR has enabled Honduras to develop a long-term comprehensive sorghum research program that is beginning to gain support from the sorghum industry in Honduras and other international donors.

PL480 support. The GOH and AID/H provide local currency support for the sorghum project through the Title I PL480 program. The present PL480 funding level is 479,000 lempiras which is equivalent to 88,700 dollars. Local currency covers the lion's share of in-country costs, including counterpart and support staff salaries. An AID mission initiative is underway to have the GOH match PL480 funds programmed for all CRSPs with national funds by 1994. This is in lieu of the fact that U.S. assistance to Honduras will be cut back drastically in the next five years until, finally, all aid is stopped in 2000.

Additional funding. Special projects are being developed to create new funding sources. To date, these projects have focused on commercial hybrid testing and the international sorghum downy mildew nursery in Comayagua. Projected earnings from testing commercial hybrids in 1992 are 6,700 dollars from private seed companies and 1,000 dollars from the PCCMCA. Also, the national sorghum program won its first strengthening grant (9,260 dollars) from the EEC this year for the control of sorghum downy mildew in Honduras. Both DeKalb (100 lines) and Cargill (130 lines) seed companies have contracted the national sorghum program to screen some of their materials for resistance to pathotype 5 of downy mildew in Comayagua and this accounts for another 1,150 dollars in earnings.

Inter-CRSP

Our concept paper for mounting an Inter-CRSP activity in southern Honduras was published in the 1991 INTSORMIL Conference Proceedings. It focuses on three agroecosystems in southern Honduras: 1) low input hillside subsistence farming in dry tropical forest, 2) high input cash crops (primarily cantaloupe) on the coastal plain (tropical savanna), and 3) shrimp production in the Gulf of Fonseca and estuaries. This Inter-CRSP initiative proposes collaborative research with MNR, EAP, LUPE and FPX and links the CRSPs to the agricultural sector strategy programs of the A.I.D mission by addressing agricultural production constraints that mission projects like LUPE and FPX face. Because of our commitment to Inter-CRSPing, we have shifted most of our time and resources previously committed to sorghum networking in Central America to developing an Inter-CRSP program in Honduras.

Four CRSPs have signed MOAs to work in Honduras (i.e., INTSORMIL, Bean/Cowpea, Pond Dynamics/Aquaculture and TropSoils) and two others (i.e., Peanut and SANREM) are taking steps to join in. We are basically building the Inter-CRSP initiative from the ground up by redirecting resources. Because of our commitment to Inter-CRSPing, we have shifted most of our time and resources previously committed to sorghum networking in Central America to developing an Inter-CRSP program in Honduras. Important events this past year follow.

TropSoils. This soil management CRSP negotiated and signed an MOA with the MNR January 10, 1992. The status of this agreement was elevated to Acuerdo 1646-92 when it was approved and signed by the president of Honduras 3-Ago. 1992. PL480 local currency support for activities in 1992 and 1993 has been requested by the GOH. These funds are to support: 1) activities related to completing the soils map, 2) soil and water conservation research with LUPE, and 3) graduate student research in Honduras.

Marc Thompson, a TropSoils graduate student from TAMU who worked with LUPE in 1992, completed his thesis and filed a report on his research with AID/H. Some interesting findings are: 1) many hillside soils derived from basaltic parent material in southern Honduras are just as fertile as those in the U.S. corn belt, but are shallower, 2) soil loss is as high as 114 t ha^{-1} in some areas, 3) stoner wall terracing can make a significant long-term contribution to productivity, and 4) there is a great need to increase farmer and community awareness to the long-term benefits of soil conservation.

Peanut CRSP. Because Honduras has tremendous peanut production and consumption potential an MOA between the Peanut CRSP and MNR has been developed and submitted to the mission for approval. Ostensibly, funding constraints has placed signing of this MOA on hold. Although the Peanut CRSP is not directly involved in Honduras, the EAP continues to evaluate 14 peanut varieties provided by the CRSP for the purpose of releasing a variety for its seed production unit. Also, the EAP has provided these varieties to FHIA who has obtained a small grant from a large grocer in San Pedro Sula to develop a technological package suitable for peanut production in Honduras. The long-term objective of FHIA is to develop peanut for export production.

SANREM. This new CRSP will receive its grant in July 1992. A global workplan has been developed that includes Honduras as a prime site.

Other Cooperating Scientists

TAM-131 collaborates with ten INTSORMIL projects representing five land-grant universities. Much of this collaboration centers on supervision of graduate student research in Honduras and germplasm exchange.

Dr. Max Clegg, Agronomy, UNL-113.
Dr. Richard Frederiksen, Sorghum Pathologist, TAM-124.
Dr. Frank Gilstrap, Entomologist, TAM-125.
Dr. Fred Miller, Sorghum Breeder, TAM-121.
Dr. Gary Peterson, Sorghum Breeder, TAM-123.
Dr. Henry Pitre, Entomologist, MSU-105.
Dr. Lloyd Rooney, Cereal Chemist, TAM-126.
Dr. Darrell Rosenow, Sorghum Breeder, TAM-122.
Dr. John Sanders, Economist, PRF-105.
Mr. Bill Stegmeier, Millet Breeder, KSU-101.

Other Collaborators in Honduras

Ing. David Laínez, ENA, Catacamas, anthracnose nursery.
Mr. David Leonard, Associates in Rural Development, LUPE, Tegucigalpa, Honduras.
Dr. Napoleon Reyes Discua, Director, Center for Agricultural Development (CEDA), Comayagua, Honduras.
Ing. Ricardo Rivera, Friederich Ebert Fundation, Colón, hybrid performance test collaborator.
Ing. Miguel Sosa, DRI-Yoro, hybrid performance test collaborator.
Ing. José Torres, MNR, Las Acacias, hybrid performance test collaborator.
Ing. Luis Welchez, MNR-FAO, Lempira, low-input hillside on-farm demonstration plots

Other Collaborating Institutions in Honduras

COHASA, Choluteca, low-input hillside on-farm demonstration plots
CORASUR, Choluteca, on-farm demonstration plots
L.L. Ag. School, Nacaome, on-farm demonstration plots
LUPE-MNR, Choluteca, low-input hillside on-farm demonstration plots
San José Obrero, Choluteca, low-input hillside on-farm demonstration plots

World Neighbors, Choluteca, low-input hillside on-farm demonstration plots

CLAIS, Dr. Gomez just completed a two year term (1990-1991) as the elected president of the Council of Latin American Sorghum Researcher (CLAIS).

EEC/PRIAG, In 1990, Dr. Gómez was appointed the EAP's representative to the National Council of PRIAG (i e., the Regional Program to Strengthen Agronomical Research on Basic Grains in Central America) which is sponsored by the European Economic Community and administered by IICA. As a senior scientist, he has provided valuable council to PRIAG in establishing their research grants program. A portion of his responsibilities include evaluation of research proposals submitted by eligible sorghum workers in the region. This position adds an important new facet in networking. Dr. Gómez attended regional PRIAG meetings 23-24 Jul. 1991 in San José, Costa Rica and 16-20 Mar. 1992 in Managua, Nicaragua. He also attended a national meeting 28-31 Jan. 1992 in Valle de Angeles, Honduras.

PCCMCA, Dr. Gomez and Guillermo Cerritos attend the 38th annual meeting of the PCCMCA. 23-27 Mar. 1992. Managua, Nicaragua.

Scientist Exchange

Dr. Meckenstock and Dr. Gomez attended a LUPE planning session in Choluteca 7 April, 1992 to introduce Ing. Hector Sierra, our on-farm coordinator, to the group and to encourage LUPE participation in on-farm trials in 1992. Dr. Gomez gave a presentation on advances in enhanced maicillo development and planned activities.

Dr. Meckenstock and Dr. Gomez traveled to College Station, TX May 11-13, 1992 to attend a planning session with ICRISAT. Dr. Lewis Mughogho was the ICRISAT representative. Future networking activities in Central and South America were discussed. It was agreed that INTSORMIL and ICRISAT would submit a joint proposal to the Inter American Development Bank to support regional activities in the Americas.

Hector Portillo, MSU graduate student, visited the EAP May 7 through August 25, 1992. He collected ovipositional preference data for his dissertation and worked on several manuscripts for publication. The sorghum project shared its office with Hector and the Plant Protection Department loaned the use of its laboratories.

Germplasm Exchange

Dr. Fred Miller, on behalf of the sorghum project, sent 5000 seed of Sureño (PI 561472 & NSSL 259979.51) to the National Seed Storage Laboratory in Fort Collins, Colorado. 23 April 1992.

Ten cultivars (100 g ea.), including Sureño, Ganadero and its parental lines, were sent to Ing. Claudio Prates, Sementes Agroceres in Brazil for observation. 19 September. 1991.

Four forage sorghum varieties: Brandes (50 g), Ganadero (440 g), Tx2784 (360 g), and Sureño (330 g), were sent to Dr. Raul Santillán at the Animal Science Department in the EAP for observation. 10 October 1991.

SC40-9 (50 g), which has height genotype $dw_1\ dw_2\ dw_3\ Dw_4$, was sent to Dr. Fred Miller for studies in height genetics. 29 October. 1991.

Twenty drought tolerant F_2 lines were increased at Rapaco and returned to Dr. Darrell Rosenow. 9 Dec. 1991.

Basic seed of ATx623 (18 lbs.) and BTx623 (5 lbs.) were donated to the seed production unit at the EAP. 13 Feb. 1992.

Six enhanced maicillo varieties (5 g ea.), with the highest brix (18.5-21) levels in the 1990 IIMYT. were sent to Dr. Tony Sotomayor, USDA/TARS, Mayaguez, Puerto Rico for evaluation. One line was the A & B pair of DMV179 which would be useful in making photoperiod sensitive forage hybrids. 19 March. 1992.

Ten pounds each of Ganadero, Sureño, and Tx2784 was sent to Ing. Doroteo Osorto, Head of the INFOP training center in Danlí, for use in instruction of cattle producers. 27 March. 1992.

Three broomcorn (Acme, IS 13, and IS 24) varieties (400 g ea.) were sent to Hernando Domínguez, Department of Plant Protection, EAP for evaluation in live barriers to whitefly on melons in Choluteca. 27 April. 1992.

Twelve broomcorn varieties (450 g ea.) was sent to Guillermo Alvarado for adaptation studies in Comayagua. All were resistant to pathotype 1 of *P. sorghi*. 27 April 1992.

Basic seed of Tx2784 (5.5 lbs.) was donated to the seed production unit at the EAP. 6 May 1992. This is the sudangrass male parent of Ganadero.

Three maicillo varieties (100 g) and six enhanced maicillo varieties (50 g) were sent to Patricio Gutierrez, University of Nebraska, for use in his M.S. research on shade tolerance. 18 May 1992.

The following enhanced maicillo cultivars were sent to Hector Sierra for use in on farm demonstration plots:

Designation	Pedigree	Generation	kg
DMV 179	(SPV345*Gigante)-1-1-2		3.1
DMV 198	(TAM428*Porvenir)-29-1	10	1.3
H 1202	A(Tx623*Pespire)*(SC414*P.N.)-53	1	1.8
H 1204	A1(SEPON77*Sta. Isabel)*DMV 203	1	1.8
H 1205	A(Tx623*Pespire)*[SPV346(81LL691*Billy)]-36	1	1.2
Sureño			6.8

Publications and Presentations

Publications

Cerritos, G., D. H. Meckenstock, F. Gomez, and T.C. Hash. 1992. Introduction of 54 broomcorn varieties in Honduras (In Spanish). p. 121-128. Agronomy Department Annual Report, vol. 4, Escuela Agrícola Panamericana, El Zamorano, Honduras.

Gómez, F. and D.H. Meckenstock. 1992. 1990 Grain sorghum performance tests (In Spanish). Tech. Rep. EAP/SRN/INTSORMIL-3. Escuela Agrícola Panamericana. El Zamorano, Honduras.

Granados, M.A. 1992. Growth and absorption of NPK in two grain sorghum hybrids in three densities (In Spanish). Ing. Agro. Thesis. Panamerican Agricultural School. El Zamorano, Honduras.

Gutierrez, P.F., D.H. Meckenstock, and M.D. Clegg. 1991. Growth and yield of honduran sorghum in pure stand and intercropping. p. 61. In Agronomy abstracts. ASA, Madison, WI.

Meckenstock. D. H. 1991. The power of the CRSPs. pp. 104-106. In T. Schilling and D. Stoner (ed.) International Sorghum and Millet CRSP Conference. Proc. INTSORMIL, Corpus Christi, TX. 8-12 July 1991. University of Nebraska, Lincoln, NE.

Meckenstock, D.H. 1992. Tropical sorghum conservation and enhancement in Honduras and Central America. p. 140-152. INTSORMIL Annual Report 1991. Sorghum/Millet Collaborative Research Support Program, Univ. of Nebraska, Lincoln, NE.

Meckenstock, D.H., M.C. Castro, H.N. Pitre and F. Gomez. 1991 Antibiosis to fall armyworm in Honduras landrace sorghum. Environ. Entomolo. 20:1259-1266.

Meckenstock, D.H., D.R. Coddington, J.C. Rosas, H. van Es, M.S. Chinnan and M.M. Murillo. 1991. Honduras concept paper: Towards a sustainable agriculture in southern Honduras. pp. 107-119. In T. Schilling and D. Stoner (ed.) International Sorghum and Millet CRSP Conference. Proc. INTSORMIL, Corpus Christi, TX. 8-12 July 1991. University of Nebraska, Lincoln, NE.

Meckenstock, D.H., F. Gomez, N. Reyes-Discua and C.T. Hash. 1992. Broomcorn resistance to sorghum downy mildew. Sorghum Newsletter 33:38-39.

Meckenstock, D.H., E. Moncada and F. Gomez. 1992. Shade tolerant sorghum. Sorghum Newsletter 33:52-53.

Molina-Juarez, L. 1992. Preliminary evaluation of 54 broomcorn varieties (In Spanish). Ing. Agro. Thesis. Panamerican Agricultural School. El Zamorano, Honduras.

Thompson, M., A.S.R. Juo and D.H. Meckenstock. 1992. The effect of stone retention walls on soil productivity and crop performance on selected hillside farms in Southern Honduras. p. 72. In Agronomy abstracts. ASA, Madison, WI.

Wall, G.C. and D.H. Meckenstock. 1992. Sorghum diseases in Central America and the Caribbean Basin. pp. 67-73. In Sorghum and millets diseases: a second world review. eds. W.A.J. de Milliano, R.A. Frederiksen and G.D. Bengston. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Presentations

Meckenstock, Dan. Honduras Update: Inter-CRSPing in Latin America. TAMU Staff Conference. 6 Jan. 1992. College Station, TX.

Meckenstock, Dan. The collaborative research support program. Short course on research methodology. Kellogg Training Center, EAP. 31 Jan. 1992. El Zamorano, Honduras.

Meckenstock, Dan and Francisco Gomez. Advances in sorghum research in Honduras. External Evaluation Panel Review at TAMU. 19 February 1992. College Station, TX.

Cerritos, Guillermo. Introduction and adaptation of 54 broomcorn varieties in Honduras. PCCMCA, 23-27 March 1992. Managua, Nicaragua.

Breeding Sorghum for Stability of Performance Using Tropical Germplasm

Project UNL-115
D. J. Andrews
University of Nebraska

Principal Investigator

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Mr. Peter Setimela, Sorghum Breeder, Department of Agricultural Research, P.O. Box 0033, Sebele, Botswana
Dr. Tunde Obilana, Sorghum Breeder, SADCC/ICRISAT, Southern Africa Regional Sorghum and Millet Research Program, P. O. Box 776, Bulawayo, Zimbabwe
Mr. Gilles Trouche, Sorghum Breeder, CNRA, Bambey, Senegal
Dr. J. W. Stenhouse, Sorghum Breeder, ICRISAT/India
Dr. Fred W. Miller, Sorghum Breeder, TAM-121, Texas A&M University, College Station, TX
Dr. D. W. Rosenow, Sorghum Breeder, TAM-122, Texas A&M University, Lubbock, TX
Dr. Paula Bramel-Cox, Sorghum Breeder, Kansas State University, Manhattan, KS
Dr. J.D. Eastin, Physiologist, UNL-116, University of Nebraska, Lincoln, NE
Dr. J. W. Maranville, Physiologist, UNL-114, University of Nebraska, Lincoln, NE

Summary

Most sorghum is grown for food in low resource semi-arid conditions in Africa and Asia where there are many environmental constraints to production, the principal of which are low nutrient levels, a variable and uncertain moisture supply and many severe pests and diseases. Actual production is the interaction of these constraints on the genetic yield potential (the comparative yielding ability) of the cultivar. The tolerance of the genotype to the sum of these constraints constitutes adaptation. Good adaptation alone, however, is not enough, since yield potential has to be raised to increase production. Though some constraints are more common than others, there are different combinations of constraints in different regions, and hence there are different areas of adaptation which need to be bred for separately. Many cultivars from ICRISAT's breeding programs, while they have raised yield potentials in many LIDA regions, have not, in general, involved much of the high yield potential available in U.S. combine sorghum parents. In turn the genetic base of hybrid parents in the U.S. is very narrow in terms of the total range of genetic diversity available. There is a fertile breeding area, therefore, that this project seeks to exploit, of crossing higher yielding adapted food quality tropical sorghums and U.S. parents.

On the one hand, the resulting segregating populations are selected *in situ* in collaborative LIDA breeding programs to the benefit of developing countries, and on the other, selections are made from the same crosses for adaptation and combining ability to broaden the genetic diversity in parental lines in the U.S.

This project works principally with the breeding programs in Senegal and Botswana (but has also provided material in 1991 to India, Mexico, South Africa, and Zimbabwe), as well as in the Midwest of the U.S.

In Senegal, lines from segregating materials supplied earlier have been selected for initial yield tests. One hundred and thirty-five new F_1 and F_2's from custom made crosses with Senegalese parents were supplied. INTSORMIL seed parents (from projects UNL-115, UNL-116, TAM-121, and TAM-122) have variously given superior hybrids both in dryland tests and under irrigation in the Senegal River Valley, where the government is exploring possibilities of diversifying rice monoculture.

In Botswana, seed parents are being developed from lines which were selected *in situ* through several drought years. SADCC/ICRISAT, Bulawayo, has assisted in providing winter nursery space and making designated backcrosses.

In the U.S., through collaboration with KSU, new seed parents and their hybrids were screened in dryland tests. Hybrids with N122A, a seed parent released earlier from the project, continued to perform well in Nebraska state tests. New material from Russia was introduced and evaluated for resistance to the new biotype, I, of greenbug. Ten sources of resistance were identified.

Ms. Chibwe Chungu, of Zambia, obtained her M.S. with a thesis on tester choice in evaluating new parent lines in sorghum.

Objectives, Production and Utilization Constraints

Objectives

Objectives have changed little from the previous year as this is a long-term breeding project. A principal aim of this project is to introduce and utilize newly bred high yielding tropical food quality sorghums which have so far not been widely used in U.S. breeding programs. Utilization will be mainly through selection of progeny from crosses with superior U.S. lines. Conversely, through the same crosses, high yield traits from U.S. sorghums are made available for selection in developing countries. Appropriate parts of this variability in early generations will be used to support breeding projects in developing countries, and in the U.S. to develop new varieties and parental lines.

Constraints

Constraints to sorghum production are both genetic and physical factors in the growing environment and the effects of fragile markets. Many existing landrace varieties, though they are well adapted to low moisture and fertility situations and to numerous pests and diseases, are not efficient in converting dry matter they produce into grain. Their harvest index (HI) efficiency is poor. There are breeding stocks such as U.S. hybrid parent lines, which are twice as efficient in this process but they generally perform poorly in African conditions because they have little adaptation or pest/disease resistance. A combination of traits conferring adaptation and grain production efficiency is required through breeding, as well as further improvement in the basic breeding stocks (particularly seed parents) for grain yield potential per se. Combinations (lines/plants) with good adaptation and seed qualities can only be identified *in situ* in developing countries. Thus, segregating material generated from crosses with stocks known to perform well in the region concerned, in crosses with selected high HI lines, are supplied for selection in collaborative projects.

Research Approach and Project Output

Research Methods

The most widely adapted high yielding lines and seed parents from the ICRISAT sorghum food quality breeding program in India and Mexico, and the Botswana and 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_2's of crosses between appropriately adapted exotic lines are provided to LDC breeders to initiate collaborative selection programs. At F4/F5, selections with per se worth are tested for drought/heat stress resistance, in conjunction with UNL-116, and for combining ability. Those which act as nonrestorers will be considered for producing new seed parents. Well adapted partial inbreds/lines are released as germplasm stocks/parental lines for use in the U.S.

The introductions are also tested for per se performance and in hybrid combinations for possible dissemination in international nurseries. However, these nurseries will eventually contain 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. Both selection and testing in the UNL-115 project is conducted without added fertilizer (about 50 kg N/ha is available from the proceeding soyabean crop), since most LDC's use little chemical fertilizer on dryland cereals but can use rotations with legumes.

Research Findings

One hundred and one new F_1's were grown, with emphasis on utilizing tropical, large seeded germplasm with good evident food grain quality. Two thousand and four hundred F_2 to F_6 lines were evaluated for potential use in host country programs and the U.S. Seed parent development was continued on 208 lines and 58 were increased.

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. At Garden City, KS, normally a location of season long drought stress, excessive early rains allowed only the expression of post-flowering stress. At Heston, KS, stress was extreme. Results of 6 of 18 UNL-115 entries and two checks are shown in Table 1. At each location one or more hybrids with new seed parents exceeded the yield of the commercial check, however, no hybrid was consistently superior over all locations.

A second test was also grown at Mead and Garden City, which compared seed parent performance per se, and their general combining ability, as determined by crosses with three testers. In this test, 6 out of 10 UNL-115 seed parents showed higher than average combining abilities (Table 2). The correlations between line per se and hybrid performance were low ($r = 0.12$ and 0.07 at Garden City and Mead, respectively).

Two hybrids with N122A, an earlier release from this project, were entered into Nebraska State tests. N122A x Tx430 again averaged 5-8% more than the mean of all commercial hybrids in tests in Zones A (South East and South Central), B (South West), and C (West Central) zones. Additionally, N122A x RTx2737 recorded 18% more than the commercial average in Zones B and C.

Table 1. Grain yields (kg/ha) of 6 of 58 entries and two checks at four locations in the 1991 joint KSU/UNL Sorghum Hybrid Test.

	Garden City				
Hybrid	Dryland	Irrigated	Hesston	Mead	Mean STD[1]
90M362 x RTX2721	5720	7820	1570	5840	0.371
90M523 x RTX2721	4820	7690	2070	4960	0.600
90M676 x RTX433	8920	9100	1730	1510	0.735
90M676 x RTX2721	6350	7370	1750	6930	0.677
90M709 x RTX8505	7720	7920	1800	2980	0.643
90M593 x RTX8505	5620	6320	2300	6580	0.248
N122A x RTX430[2]	6500	6450	1320	7830	0.609
P. 8379[2]	6120	8900	1620	4940	0.515
Mean (58 entries)	5190	6580	1770	4430	0.000
LSD 0.05	2493	2052	1402	2153	--

[1] Expressed as mean of yields in standardized deviation units at each location.
[2] Check hybrids.

Table 2. Standardized yields[1] of 10 of 50 seed parents and their hybrids with three testers over two locations in 1991.

	Parent		Hybrid		GCA	
Seed parent	GC[2]	M[2]	GC	M	GC	M
1072	-1.133	-0.739	0.744	0.165	0.495	0.021
1086	-1.201	-1.218	0.361	0.770	0.112	0.625
1104	-0.688	0.347	0.474	0.278	0.225	0.133
1133	-0.680	-0.317	0.397	0.753	0.148	0.608
1143	0.140	-0.888	-0.160	0.327	-0.409	0.182
1176	-0.874	-0.055	0.540	0.499	0.291	0.355
1184	-0.341	-0.828	0.679	-0.289	0.430	-0.434
1432	-0.009	-1.358	0.584	0.356	0.335	0.211
1437	-0.292	-0.779	0.445	0.087	0.196	-0.057
1444	-0.079	-0.523	0.309	0.090	0.060	-0.054
Mean[3]	-0.707	-0.613	0.248	0.144	SE ±0.283	0.259

[1] In standardized deviation units from site mean yield of all entries.
[2] GC = Garden City, KS; M = Mead, NE
[3] Mean of 50 seed parents, or 150 hybrids relative to site mean of all entries.

Chibwe Chungu, from Zambia, in her M.S. thesis study, compared three different testers—an inbred, an F_1 and a population, for their relative utility in determining the combining abilities of 18 potential seed parents. The identification of a good general tester would reduce the number of lines needing to be sterilized, and increase the potential of a breeding program to identify and develop good seed parents. The experiment was conducted at three locations. The range in yield of test crosses as percent of mean was, as expected, greatest with the population tester (-30 to + 22%) and least (-9 to + 11%) for the inbred tester which, although it made high yielding hybrids, appeared too dominant. There was, however, no correlation between testers over or within locations in how they ranked the lines being tested, providing no resolution to the problem and indicating the need for further research. However, with no evidence to the contrary, one or several F_1 testers would be easiest to use operationally.

Introductions

One hundred and ten introductions were made from Russia, 159 from South Africa, and 8 from India. All were made to increase the diversity available to the project, but the Russian material, from Krasnodar, was made for the specific purpose of searching for sources of resistance to the new race of greenbug, biotype I. In a collaborative project between KSU (Drs. Paula Bramel-Cox and Jerry Wilde) and UNL-115, and partially funded by NPGS through the Sorghum Crop Advisory Committee, screening was conducted in two replicated tests in quarantine in growth chambers. Ten sources of resistance were identified (Table 3), the best of which, PI550610, equalled that of the only known hybrid carrying resistance. Seed of the resistant sources was generally available in time for 1992 planting.

Table 3. Mean average damage scores in Test 1 and Test 2 of the best 10 sorghum plant introductions from Russia and the checks to greenbug biotype I infestation.

		Score†					
		Test 1			Test 2		
PI No.	Cultivar	1	2	3	1	2	3
550610	Dirra Belaya	1.4	4.2	5.8	2.3	3.2	5.5
550607	Dzhugara Belaya	1.6‡	5.0	6.6	2.3	3.3	6.8
550614	Kashtanovaya	1.4	3.2	6.4	1.8	3.0	7.0
550631	Kashtanovaya 2	1.2	3.6	6.8	1.7	2.7	7.0
550629	Amurskaya I	1.6‡	5.2	8.0	1.7	2.8	7.0
550630	Krasnaplenchataya 16	1.4	4.4	7.4	2.0	3.2	7.5
550635	Kazanskaya	1.6‡	5.8	7.6	2.3	3.5	7.7
550627	Stanichnaya 7	1.6‡	6.8‡	8.2	3.2	4.0	7.8
550615	Kashtanovaya Sochnostebelnaya 30	1.8‡	5.2	8.4	2.3	3.3	7.8
550640	Khegari Buroe L-107	1.6‡	5.8	8.4	3.3‡	4.3	8.0
	Test 1						
	Mean 111 entries	1.9	6.5	9.2			
	Susc. check N122	2.0	7.9	9.5			
	LSD ($P \leq 0.05$)	0.6	1.8	1.1			
	Test 2						
	Mean 18 entries				2.7	3.8	7.8
	Susc. check N122				3.8	5.7	9.3
	Resist. check (Cargill 607E)				3.2	4.0	5.5
	LSD ($P \leq 0.05$)				0.6	0.6	1.0

† 1 = average damage score at 7 d after infestation (8 d in Test 2).
2 = average damage score at 10 d after infestation (11 d in Test 2.)
3 = average final damage score at 13 d after infestation (14 d in Test 2).
Damage scale: 0 = 0, 1 = 1 to 10, 2 = 11 to 20, 3 = 21 to 30, 4 = 31 to 40, 5 = 41 to 50, 6 = 51 to 60, 7 = 61 to 70, 8 = 71 to 80, 9 = 81 to 90 and 10 = 91 to 100% (death of the plant).
‡ Not different from susceptible check.

Networking Activities

Botswana

Involvement continued with a collaborative selection program *in situ* at Sebele with scientists of the Department of Agricultural Research. The 1991/92 season was again one of severe drought with only a total of 250 mm between September and February. Selection and backcrossing continued in 1991 to develop drought resistance adapted seed parents; and procedures developed to more quickly evaluate emerging lines. This has involved the use of off-season nurseries provided by the SADCC/ICRISAT sorghum breeder, Dr. Tunde Obilana, at Aiselby and Mzerabani to accelerate backcrossing and produce testcrosses. A 150 entry Botswana backcross nursery was evaluated with Dr. Obilana at Aiselby and selections identified to produce testcrosses for evaluation in Botswana in 1992/93. Backcrossing was also continued on 12 new seed parents at Sebele, where good sterility was expressed.

Senegal (see also Senegal Country Report)

INTSORMIL collaborated with the ISRA/CIRAD sorghum breeder at Bambey, Mr. Gilles Trouche on the supply and evaluation of segregating material and parental lines from several INTSORMIL projects (UNL-115, UNL-116, TAM-121 and TAM-122). One hundred and twenty-five F_1's and progenies from crosses with Senegalese introductions were provided from UNL-115 in 1991. Selections in the dryland program at Bambey have been advanced to F_4 and F_5 and will enter yield tests next year. Hybrid parental lines have been identified which variously give higher yielding hybrids in all three production conditions (dryland, summer and winter irrigated) including UNL-115 seed parents, 336A and 737A. Visits were arranged for three scientists from Senegal to workshops or to see research in INTSORMIL projects in Nebraska, Kansas, and Texas.

Germplasm Exchange

Ten lines and 9 seed parents sent to Botswana, 135 populations, lines, and seed parents sent to Senegal, 18 to Mexico, 5 to SADCC/ICRISAT-Zimbabwe, 45 to South Africa, 2 each to France and Yugoslavia, 110 sorghums were received from Russia, 159 from South Africa, and 8 from ICRISAT-India.

Publications

Assibi, A. M. D. J. Andrews, and J. H. Harris. 1991. Relation of seedling vigor in sorghum [Sorghum bicolor (L.) Moench] inbreds to seed size and mobilization of seed reserves. Agron. Abstr. p. 85.

Chungu, Chibwe. 1992. Tester choice in evaluating new parental lines in grain sorghum. M. S. Thesis, Univ. of Nebraska-Lincoln. pp. 128.

Chungu, Chibwe, A. M. Abdullai, J. H. Harris, and D. J. Andrews. 1991. Tester choice in evaluating new parental lines in grain sorghum (Sorghum bicolor). Agron. Abstr. p. 90.

Zavala-Garcia, F., P. J. Bramel-Cox, J. D. Eastin, M. D. Witt, and D. J. Andrews. 1992. Increasing the efficiency of crop selection for unpredictable environments. Crop Sci. 32:51-57.

Breeding Pearl Millet for Stability Performance Using Tropical Germplasm

Project UNL-118

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Summary

Pearl millet is the only cereal adapted to the driest and hottest of the lowland crop cultivation zones in Africa and Asia, principally in the sandy regions of West Africa and northwest India. Though pearl millet will grow well in more humid areas with better soils, it is in these harsh climates, where it is the major food cereal, where improvements to production are primarily needed. Physical constraints to production are low and erratic rainfall with frequent drought periods, and low soil nutrient status. Principal among many biotic constraints are downy mildew and ergot diseases. Actual production is a result of the interaction of these production constraints on the yielding ability of the cultivar. Where the physical constraints (drought, low soil nutrients) are strong, agronomic interventions will have large effects on production, however, these are often too expensive, or otherwise unacceptable, to low resource farmers. Seed of new cultivars of higher yielding ability is more cost effective, even without agronomic support, but more effective with and encourages the use of better agronomic practices. However, seed of new pearl millet cultivars, both varieties and hybrids, have been widely accepted, even without changes of agronomic practice by low resource farmers in India.

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 USA. To research ways of improving breeding populations and the best ways of making varieties and hybrids for developing country breeding programs, and in the USA, to research various constraints to growing pearl millet as a combine feed crop. And, finally, to provide students from the on-going research, thesis topics which are relevant to the problems they will face in their research programs at home.

Pearl millet research continued both in collaboration with ISRA in Senegal, and DAR in Botswana. In Botswana, a new variety made with assistance from SADCC/ICRISAT from the most widely used cultivar, Botswana Serere 6A,

which was highly variable, was not significantly better in two out of the five tests which produced results, however, several introduced varieties were higher yielding. Following research on topcross hybrids in this project and elsewhere, these will be tried using the best cultivars in Botswana. In Senegal, project material was utilized in both the dryland breeding program, to produce adapted lines for synthetic variety production, and in irrigated conditions in the Senegal River Valley. Here, in disease free environments, dwarf varieties and hybrids from UNL 115 and KSU 101 yielded up to 30% more, and were earlier maturing, than locally produced cultivars. Grain yields exceeded 4000 kg/ha in 75-85 days.

In the U.S. joint research with Glenn Burton, USDA/ARS, Tifton, GA, on population improvement continued and good evidence of potential gain was shown. Barnabas Kiula, Tanzania, continued research on producing topcross hybrids, showing that this is normally possible without the use of cytoplasmic male sterility. Two germplasms were released, the first to be made in U.S. specifically for grain production. Research on the use of a new male sterile cytoplasm greatly increased the possibility of its early utilization, through the discovery of several restorers in agronomically useful backgrounds.

Lisa Boggs, Nebraska, in her M.A. thesis on pearl millet cultivation, showed that atrazine herbicide was more effective in weed control than mechanical cultivation in early plantings on a dwarf grain hybrid in medium or narrow row spacings which are needed for highest yields. Dr. Anand Kumar, visiting from the ICRISAT, Sahelien Center, Niger, showed that short photoperiods, as in the Niger growing season, still had an effect on cultivars bred in Nebraska, by reducing their time to maturity, with a consequent effect on yield, however, the number of tillers surviving to produce grain surprisingly increased 45%. Chinch bugs are a potential threat in some areas of possible pearl millet production in the U.S. Three seasons of selection have shown there is tolerance present in adapted germplasm. Using grain from the regional pearl millet tests grown in Indiana and Nebraska, the level and variability of grain nitrogen content was compared between parents, hybrids, varieties, and sorghum checks. Total grain nitrogen averages varied significantly across locations from 1.6% to 2.0% for pearl millet and 1.2% to 1.8% for sorghum. Levels were highest in inbreds, but varieties, hybrids, and topcross hybrids as groups, were not different. Pearl millet always had higher grain N contents than sorghum.

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 LDC's 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 is being tested on the Nebraska dwarf millet population (NBDMP) generated from introductions from Senegal, India, Hays, KS, and Tifton, GA, prior to 1984. Recurrent restricted phenotypic selection has commenced 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 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 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 will be important in generating collaborative material for selection.

Research Approach and Project Output

Research Methods

Inbreds and partial inbreds are being produced from crosses with existing and new introductions (since 1984). These are selected for suitability as parental material for varieties, parent lines (particularly seed parents) for hybrids and as parents to cross with LDC material—to supply both hybrids and segregating populations for selection in collaborative LDC 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 cytoplasmic male sterility in CMS A-lines are being explored. This is because the development of A-lines both delays and restricts the development of hybrids to a small percentage of the total useful hybrid combinations possible among the inbreds and varieties being produced in a breeding program. When pearl millet flowers, the period of protogyny, when the head is only female fertile, prior to anther dehiscence, provides a natural opportunity to make hybrid seed with any line or variety shedding pollen at that time. Since some self-pollination in the female "seed" parent lines is possible with this method of making hybrid seed, the effect of controlled amounts of this on hybrid performance is being measured. In developing countries, where such protogyny hybrids (pro-hybrids, as they are termed) may be most useful, the use of tall pollinators on dwarf or semidwarf female lines will minimize the effects of any self pollination in the female parent through the unequal competition between hybrid and inbred plants. Pro-hybrids will also avoid the additional sensitivity to ergot commonly associated with hybrids made with any cytoplasmic male sterility (cms) seed parent.

Since pearl millet is a cross-pollinating crop, population improvement is a relevant breeding approach, particularly for LDC conditions where selection is needed simultaneously for many adaptive traits and heterozygosity must be maintained. Research into the utilization of recurrent selection is being conducted (using the NBDMP and the NTPC populations) and ways of using products of recurrent selection relevant to LDC conditions are being 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 fourth year of the regional grain yield test coordinated.

Pedigree Breeding

Fifty-four new exotic x adapted and adapted x adapted F_1's were grown and 600 F_2 to F_6 lines evaluated. New introductions were made from ICRISAT breeding programs in Niger and India. Selection emphasis continued on per se performance and lodging resistance for material intended for the USA. The continued presence of chinch bugs enabled further selection to be made for resistance to this pest. Screening was continued for propachlor and atrazine herbicide tolerance in a separate inbred nursery and in three isolations composed of random-mating progeny derived from F_1 crosses of herbicide tolerant lines.

The development of good combining seed parents based on the A_1 cms system continued and yield testing confirmed the usefulness of seed parents 293A, 378A, and 413A. Several new restorers were also identified. Significant advances were made in utilizing the A_4 (monodii) cms system which acts independently of the A_1 system. Unlike the A_1 system, almost all lines are maintainers (which means most good lines can be converted to seed parents) so the utility of the system depends on finding good restorers. Ten different elite A_4 restorer lines, each in different backgrounds but derived in total from three sources of restoration, were discovered and a random-mating restorer population was initiated. Additional testcrosses to an A_4 seed parent line were made with all lines in the program which contained any of the known A_4 restoration sources in their parentage.

Observations in the winter nursery, where strong stress exists on fertility restoration in testcrosses, indicate that restoration in the A_4 system is either under simpler genetic control than the A_1 system and/or is less environmentally sensitive.

Recurrent Selection

Two dwarf grain germplasms were released, NPM-1 and NPM-2, generated from the Nebraska Dwarf Pearl Millet Population (NBDMP). Both germplasms and their topcrosses had been multi-locationally tested in the Regional Pearl Millet Grain Test for three years and had shown good combining ability (22 and 23%, respectively) (Table 1). The principal aim of these releases is to provide breeders with germplasm from which A_1 restorers can be selected.

In collaboration with Dr. Glenn Burton, Tifton, GA, recurrent selection was commenced on a narrow based

Table 1. **Mean grain yield of two pearl millet germplasm populations, NPM1 (MLS) and NPM2 (EDS), and their respective topcrosses to a male sterile A_1 inbred (68A) at seven locations in the U.S. (data taken from 1988, 1989 and 1990 Pearl Millet Regional Tests)**

	Cultivar				Regional test	LSD§
Location†	NPM1	NPM2	68A x NPM1	68A x NPM2	average‡	(0.05)
	kg ha^{-1}					
Tifton, GA	2050	2030	2640	2540	2870	1990
West Lafayette, IN	3110	2840	3740	3670	3030	470
Hays, KS	2390	1870	3160	2820	2480	490
Mead, NE	3100	2620	3990	3680	3390	460
Sidney, NE	2910	3050	3480	3550	2870	1350
Starkville, MS	1850	2190	3020	2900	2790	1780
Carrington, ND	3090	2580	3670	3670	2370	840
Mean (16 tests)	2660	2440	3410	3260	2880	240

† Mean yields are calculated using a three year average at West Lafayette, Hays and Mead, a two year average at Tifton, Sidney and Starkville, and a single year test at Carrington.

‡ Mean yield of all pearl millet varieties, topcross hybrids and single-cross hybrids entered in regional tests (13 entries in 1988, 8 entries in 1989 and 12 entries in 1990).

§ LSD calculated using genotype x environment interaction mean squares as error term.

Table 2. **Selection differentials for grain yield, head number, height and days to bloom on progeny retained for random-mating from the first cycle of selection in the Nebraska Tifton Polycross Composite (NTPC) grown in a 9 x 9 lattice square at Mead, 1991.**

	Plot yield		Head/plot		Height		Bloom	
	(g)	SD%[1]	no.	SD%	(cm)	SD%	days	SD%
16 selected entries	1056.5	30.0	64.3	18.6	104.1	8.1	63.7	2.3
Mead exp. var. (entries 38, 55, 56 & 76)	1083.3*	33.3	61.8	14.0	94.1	-1.7	64.9	-0.5
Mean of all 80 progenies	812.7	—	54.2	—	96.3	—	65.2	—

[1] Selection differential = mean of selected progenies/mean of all progenies.

population (NTPC) based on four genetically different parents of known high combining ability, as evidenced by their single-cross hybrid performance at several locations including Sidney, NE. This parallels work Dr. Burton has done with Pensacola bahia grass, where equally good progress has been made with narrow based as compared to broad based populations. The advantage of narrow based populations is the relatively high yield level of the base population. In the first NTPC progeny test, a 9 x 9 lattice of 80 restricted half-sib progenies (each derived from a single superior plant from a random-mated population pollinated with bulk pollen from all 80 superior plants), a good range of phenotypic variability for grain yield (50-150% of mean) was shown. As expected, however, correlations of grain yield with increased plant height (r = 0.65) and higher head number (r = 0.89) were relatively strong but weak with maturity (days to bloom, r = 0.26). A 30% selection differential was possible with a 20% selection pressure (Table 2) with little adverse affect on height.

Parents for an experimental variety (a subpopulation made from four of the highest yielding most agronomically elite progenies) were identified for random-mating separately. A slightly higher selection differential was possible with a reduction in the adverse correlation of yield with height and maturity (Table 2).

Hybrids

Tests of mixtures with various percentages of selfed female parent seed in four pro-hybrids (hybrids made using the natural protogyny period which occurs in the flowering process of pearl millet, instead of cytoplasmic male sterility, see 1990 AR) were conducted by Barnabus Kiula, Tanzania, as part of his M.S. thesis. These confirmed that in three out of the four pro-hybrids tested (one topcross and three single-crosses), the presence of up to 20% selfed seed of the female parent, has a less effect on performance of the hybrid than expected. In the topcross hybrid 68A x MLS the mean reduction in three years' tests from adding 20% of selfed seed to the hybrid was 6.5%, indicating that the inbred seedlings competed weakly with the hybrid seedlings, and that the hybrid largely compensated for the decrease in its plant population. Similarly, in two of the single-crosses the mean yield reduction for adding 20% of selfed parental seed to the hybrid seed was 2 and 7%, respectively.

In the third single-cross hybrid, 205 x 319, there was again a significant reduction (21%) in yield when 20% parental seed was added to the hybrid. The explanation may be that the inbred plants, though they were lower yielding, were vigorous and the hybrid, in this case, was not much taller than the parents.

Table 3. **Effect of planting date, weed control and row spacing on grain yield (kg ha^{-1}) on a dwarf pearl millet hybrid (2068Ax57028R) at Mead, NE in 1991.**

		Row spacing		
Planting date	Weed control	30.5 cm	61.0 cm	91.5 cm
Early	Cultivation	4000	4040	3430
	No cultivation	2980	3150	2560
	Atrazine	4310	4380	3880
Medium	Cultivation	4150	3820	3930
	No cultivation	3500	3560	2300
	Atrazine	3530	3430	3040
Late	Cultivation	2330	2140	2440
	No cultivation	2470	2600	1770
	Atrazine	2140	2510	2480

Planting date LSD (0.05)=891
Weed control LSD (0.05)=232
Row spacing LSD (0.05)=217

The inferences so far are that where the hybrid will be taller than the inbred/population used as the female (as in a cross between a tall African cultivar and a short adapted cultivar) this method of producing hybrids even with 20% female selfing (5% has previously been measured in West Africa) with its many advantages to low input agriculture, is feasible. Hybrids between two dwarf parents may also work, but the affect of the presence of selfed female parent seed will need to be quantified.

Photoperiod Effects

Dr. Anand Kumar, a visiting scientist at UNL from the ICRISAT Sahelien Center, Niger, using growth chambers investigated the effects of a short day photoperiod of 13 hrs. (as typical of Niger) on pearl millet genotypes bred in Nebraska where day length reaches 15 hrs. The main effect of short days was to reduce time to bloom and total dry matter accumulation. Average relative growth rates were reduced from 0.94 to 0.74 g/plant/day. Seed number and size were also reduced resulting in a 26% reduction in grain yield/plant. A major difference was that 45% more tillers survived under short days to produce yield.

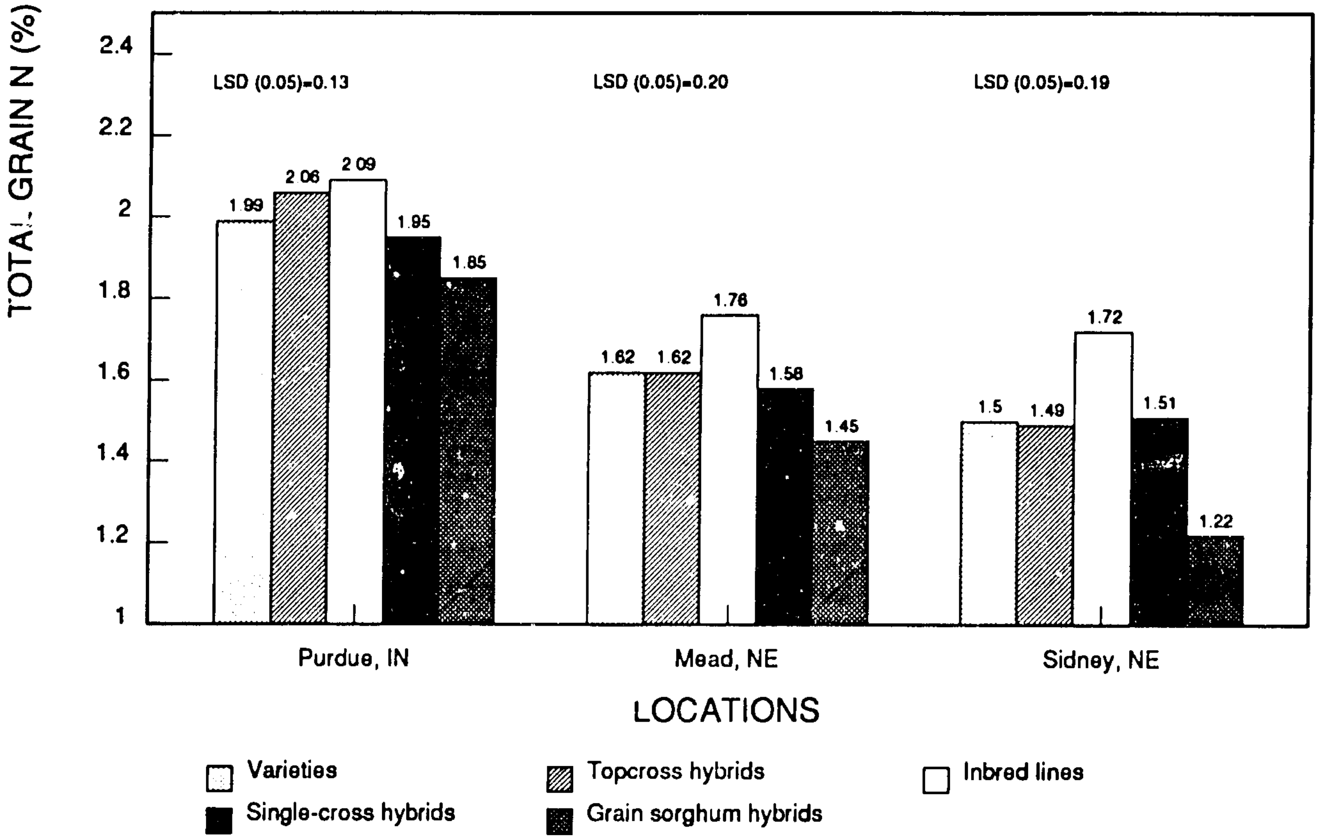
Agronomy

The introduction of pearl millet into U.S. farming systems requires the investigation of several factors that affect overall yield. Lisa Boggs of Nebraska in her M.S. thesis investigated effects and interactions of planting date, row spacing, and weed control. Pearl millet in narrow row spacings may utilize its tillering capacity to increase yield in some farming systems. Although pearl millet lacks tolerance to most grass herbicides (though progress has been made in selecting for propachlor resistance), low rates of atrazine on silty clay loam soils will not normally reduce emergence or hybrid growth. Experimental treatments were 3 planting dates (May 20, June 7 and 24), three weed control treatments (no cultivation, hand cultivation, and use of pre-emergence atrazine at 1.12 kg/ha), and three row spacings (30.5, 61.0, and 91.5 cm apart) where an equal number of hybrid seeds/m^2 were planted. Late planting significantly reduced grain yields compared to yields from early and medium planting dates, which were not greatly different (Table 3). There was no difference in the yields from 30.5 or 60 cm rows in cultivated and noncultivated treatments but both were significantly better than 91.5 cm rows except in the latest planting where grain development was arrested by an early killing freeze. The use of atrazine was effective in reducing weed competition and produced grain yields which were better than cultivation alone or no cultivation in the earliest planting. Yields in the later plantings with atrazine were significantly better than no cultivation in only the widest row spacing.

Chinch Bugs

Chinch bugs (*Blissus leucopterus leucopterus*) occur in some areas of the U.S. where pearl millet could potentially be grown as a grain crop. In these situations, pearl millet would be another alternative host along with barley, wheat, corn, grain sorghum, and many wild grasses. The effects of the natural incidence of chinch bugs on grain yield, time to senescence and other traits were investigated by John Rajewski on three hybrid trials grown at Mead, NE, in 1990 and 1991. Since genotypic differences in the duration of plant development periods particularly after anthesis, can change in different environments, growing degree unit (GDU) accumulation was used to help standardize effects. Post-anthesis chinch bug tolerance was measured as both the date of plant senescence (when 50% of the plants had died due to chinch bug attack) and by the duration of the post-anthesis nonsenescence interval (PANSI). Results showed that pearl millet hybrids differed significantly for chinch bug tolerance measured either as days or GDU's to senescence or for PANSI, however, the use of GDU's was more effective in detecting differences in tolerance. Grain yield, seed weight and seed number/m^2 were higher and lodging decreased with the delay in senescence. Earlier anthesis was associated with a larger PANSI suggesting that

Figure 1. Total Grain N (%) means of pearl millet cultivar types and grain sorghum hybrids at three locations in 1988.



several earlier hybrids had good post-anthesis tolerance. Breeding programs should be able to develop genotypes of various maturities with chinch bug tolerance.

Grain Nitrogen

Previous work has shown that selection for protein has been effective in increasing the level of grain protein of pearl millet inbred lines. Since topcross and single-cross hybrids have the potential to out yield varieties in many environments, a preliminary study was conducted to determine the effect of cultivar types and environment on the nitrogen content of the grain. Total grain N was analyzed from four pearl millet cultivar types (3 varieties, 3 topcross hybrids, 7 inbred lines, and 7 single-cross hybrids) and two sorghum hybrids grown in 1988 at three environmentally diverse locations in Indiana (Purdue) and Nebraska (Mead and Sidney). Total grain nitrogen location averages ranged from 1.6 to 2.0% for pearl millet and 1 2 to 1.8% for the sorghum checks. Pearl millet varieties did not differ significantly from their respective topcrosses in total grain N (Figure 1), but total grain N of the inbreds was significantly greater than their single-cross hybrids. A genotype x environment interaction for total grain N was observed only within the group of inbred lines. Correlation analysis indicated that grain yield, seed number, and seed weight did not influence total grain N of the varieties, topcross hybrids, and single-cross hybrids.

Regional Test

The fourth pearl millet regional grain yield test containing 18 pearl millet entries (from ARS, Tifton, GA; Kansas State University, Hays, KS; and University of Nebraska, Lincoln, NE) and two medium-early sorghum checks were planted in 1991 at 7 locations in Georgia (Tifton), Indiana (Purdue), Kansas (Hays), Nebraska (Lincoln and Sidney), North Dakota (Carrington), and Oregon (Hermiston). Poor establishment or early frosts damaged the tests in Purdue and Sidney.

Mean pearl millet yields varied at different locations from 1470 to 3170 kg/ha. One or more pearl millet hybrids exceeded both sorghum checks at Tifton, Carrington, and Hermiston but no entry was consistently top yielding. Combined results to date suggest that at least two adaptation zones exist. A southern zone, as represented by Georgia where slightly later and certainly rust resistant cultivars are needed, and the Midwest/Great Plains zone where earlier (particularly in western Nebraska and further north) lodging resistant cultivars are required.

Networking Activities

Botswana

An experimental variety 92 BS 6-1 developed in collaboration with the Department of Agricultural Research, Botswana, and the SADCC/ICRISAT millet program at Bulawayo was tested in 5 multilocation tests in Botswana. Due to continued severe drought conditions, results were only obtained from two locations, Sebele and Matsaudi, where experimental mean yields were 670 and 1390 kg/ha. The yields of 92 BS 6-1 were not significantly different than its parent population, Botswana Serere 6A. However, yields of a number of new varieties from the SADCC/ICRISAT program at Bulawayo were significantly higher than 91 BS 6-1, including SDMV89004, which was recently released in neighboring areas of Zimbabwe as PMV-2. Work will be suspended on Serere 6A but studies will continue on the utilization of topcross hybrids in stress production conditions. This follows findings from sorghum research conducted in Botswana, showing that hybrids or mixtures of hybrids (analogous to topcross hybrids in pearl millet) give better and more stable yields than varieties in low production environments.

Senegal (See also Senegal Country Report)

Work continued in the third year of participating in the SAR II project funded by USAID/Dakar in supporting pearl millet research and pathology at CNRA Bambey, and, at the request of the Government of Senegal, evaluating pearl millet for potential under irrigation in the Senegal River Valley, with the objective of providing alternatives to rice monoculture.

At Bambey selection for yield and downy mildew resistance continued in the F_4/F_5 inbreds derived from F_2's provided by INTSORMIL, and synthetic varieties will now be produced. Further crosses were made, and F_2's grown. Pathology work continued on the identification of stable sources of downy mildew resistance, and screening for ergot resistance.

Variety tests on tall varieties and earlier maturing (75-85 days to maturity) dwarf varieties and hybrids were conducted under irrigation in both the rainy season and the hot, dry season (planting February) in the Senegal River Valley. General conclusions to date are that dwarf cultivars give higher yields than tall cultivars and that the hot dry season is the best opportunity for pearl millet to fit into the cropping pattern because yields are highest then (4000 kg/ha from varieties, 20% more from hybrids). Experience from conducting experiments in the Senegal River Valley indicate the necessity of using soils with some drainage (which would be less suitable for rice) for successful pearl millet production. The factors of irrigation frequency and amount, and fertilizer response which were investigated in two tests in the hot, dry season to provide some data for the construction of partial production budgets. No difference was observed between irrigation treatments but less frequent (once a week) irrigations which meet 75% of the crops potential evapotranspiration needs were the most economical. Average yield levels in the irrigation test were 4000 kg/ha. In the fertilizer test the nil treatment gave 3300 kg/ha while the response from a split dose totalling 66 kg/N and 21 kg each of P and K was an additional 1570 kg/ha.

The data gathered in this phase of the Senegal support project has identified the best cultivars and will enable the feasibility of growing pearl millet in the Senegal River Valley to be calculated.

Germplasm Exchange

Thirteen hybrids and varieties were supplied to Senegal
One variety and five hybrids to Colombia
Five lines and hybrids to TAMU
Twenty-one lines to ICRISAT-India
Twenty-five lines to ICRISAT-Niger
Twenty-four lines and populations were received from ICRISAT-Hyderabad.

Publications

Publications

Anand Kumar, K., and D. J. Andrews. 1991. Effect of photoperiod treatments on morphological traits and yield components in pearl millet. Agron. Abstr. p. 85.

Andrews, D. J., Bamabas Kiula, and J. F. Rajewski. 1991. The use of protogyny to make grain hybrids in pearl millet. Agron. Abstr. p. 85.

Andrews, D. J., and J. F. Rajewski. 1992. 1991 Pearl Millet Regional Grain Yield Test. Dept. of Agronomy, UN-L. pp. 5

Boggs, L. L. 1992. Planting date, row spacing, and weed control effects on dwarf grain pearl millet production. M.A. thesis, Chadron State College, Nebraska. pp. 33.

Chirwa, R. M., D. J. Andrews, and J. F. Rajewski. 1991. Estimation of synthetic variety yields in grain pearl millet through parental line evaluation, per se and in tester combinations. Agron. Abstr. p. 90.

Jain, R. P., S. B. Chavan, B. S. Talukdar, and D. J. Andrews. 1991. Registration of ICMS 7703 pearl millet. Crop Sci. 31:1381-1382.

Rajewski, J. F., D. J. Andrews, and F. R. Muza. 1991. Grain yield and total grain nitrogen of pearl millet single-cross and topcross hybrids. Agron. Abstr. p. 112.

Stegmeier, W. D., R. L. Vanderlip, and D. J. Andrews. 1991. The development of pearl millet as a food and feed grain crop for the Central Great Plains. Agron. Abstr. p. 161.

Presentations

Andrews, D. J., J. F. Rajewski, and Anand Kumar. 1991. Pearl millet, a new grain crop. Second New Crops Symposium, Indianapolis, Purdue University, October 5-9, 1992.

Crop Utilization and Marketing

Chemical and Physical Aspects of Food and Nutritional Quality of Sorghum

Project PRF-103B
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Summary

Sadly, 1992 was a year of transition for the food quality project at Purdue with the death of Dr. Allen Kirleis in March after a long struggle with cancer. Dr. Hamaker arrived in February 1992 and directed the Year 13 PRF-103B project until June. In July, following a national competition, a new food quality project (PRF-112) was awarded to Purdue. The work reported here is, in part, a report of a continuation of Allen's studies, though it also contains findings from projects recently developed in the area of sorghum utilization. Future plans include an additional emphasis on projects related to sorghum and millet processing, as well as fundamental studies to improve grain quality.

We are coming closer to understanding the biochemical basis of the poor protein digestibility problem in sorghum. Such knowledge would permit breeding studies to develop sorghum with digestibility comparable to maize and would increase our ability to process sorghum to a highly digestible product. Immunolocation studies by transmission electron microscopy of the sorghum endosperm, using antibodies developed against α-, ß-, and γ-kafirins in the rabbit, showed digestion of the protein bodies to be different in uncooked and cooked flour. Pitting of protein bodies occurred during uncooked digestion, was not observed after cooking, though was present if flour was cooked with a reducing agent. Indigestible remnants of protein bodies appeared to contain more ß- and γ-kafirin. These proteins may form relatively indigestible complexes possibly with other proteins that would decrease the rate of digestion of the protein bodies. A high molecular weight nonkafirin protein, in the 100 kDa range, was identified that may be associated with the γ-kafirin. This protein was the last nonkafirin protein to be digested prior to kafirin digestion in cooked sorghum and was only extractable under the same conditions necessary to extract γ-kafirin. We are conducting further studies on this protein. A study on grain development showed protein digestibility to be high at early stages and decrease at later stages of development, and markedly after kafirin synthesis was complete. This was shown to be related to grain drying and disulfide bond formation.

Sorghum tuwo, the Nigerien porridge, was evaluated in Niger by sensory panels and texture attributes were compared with objective laboratory methods to measure texture. The Precision Penetrometer and Instron UTM both correlated significantly with consumer ratings, although the slope of the compression curve of the Instron test was the best predictor of consumer acceptance. Engineering units were also used to describe firmness and were applied to differentiate porridges made from cultivars differing in endosperm hardness. A cultivar/flour-water ratio interaction for porridge firmness was found to be significant indicating that increasing flour concentration does not always lead to increases in porridge firmness. Percent endosperm vitreousness and amylose content significantly correlated with Instron firmness.

Objectives, Production and Utilization Constraints

Objectives

Develop an understanding of traditional village sorghum food processing and preparation procedures and determine the grain characteristics that influence the functional and organoleptic properties of traditional food products.

Develop laboratory screening methods for use in LDC breeding programs to evaluate the food quality characteristics of sorghum grain.

Determine relationships among the physical, structural, and chemical components of grain that affect the food and nutritional quality of sorghum.

Determine the biochemical basis for the poor protein digestibility of cooked sorghum preparations.

Constraints

Research on the food and nutritional quality of sorghum grain is of major importance in developing countries. Factors affecting milling properties, food quality, and nutritional value of sorghum critically affects other efforts to improve the crop. If the grain is not acceptable to consumers, then grain yield and other agronomic improvements to the crop are lost. In addition, the breeding grains that have superior quality traits will more likely give rise to processed food products that can be successfully and competitively marketed. This is especially true for sorghum which is perceived in some areas to have poor quality characteristics. 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 sorghum germplasm for end-use quality, develop processing techniques to make the grain more nutritious, and improve grain utilization through processing.

Research Approach and Project Output

Digestibility of Sorghum Proteins

Digestion of α-, ß-, and γ-Kafirin Proteins

In vivo and *in vitro* digestibility studies on sorghum have shown that the prolamin storage protein fraction, kafirin, is the least digestible protein in the grain. This resistance to digestion increases when sorghum is cooked, a characteristic unique to sorghum and rice, though more pronounced in sorghum. Digestibility of cooked sorghum was previously shown to increase to the level in the uncooked grain when a reducing agent, which cleaves disulfide bonds, was added to the cooking mixture. Thus, it is proposed that cooking promotes the formation of relatively indigestible disulfide-linked protein polymers. The prolamins are classified as α, ß, and γ-kafirins based on differences in molecular weight, solubility, and structure. These proteins are found in protein bodies in the sorghum endosperm and were previously shown in this laboratory to be oriented in different locations with in the bodies. The majority of the kafirins are found in the central part of the protein body and are of the α type; ß- and γ-kafirins are located in the periphery and dark-staining inclusion bodies of the protein bodies. The latter two classes contain relatively high amounts of cysteine residues which can form intra- and intermolecular disulfide bonds. The relative digestibility of each kafirin class was the subject of the following study.

Immunocytochemical methods, using rabbit antibodies against the three kafirin classes, were employed to examine the relative digestion of the kafirin proteins in uncooked and cooked sorghum flour with and without a reducing agent. Following digestion with pepsin, samples were immunolabeled with gold-conjugated antibodies against each kafirin and were observed by transmission electron microscopy (TEM). Uncooked partially digested sorghum flour protein bodies showed surface pitting under TEM. As in the native protein bodies, α-kafirins were immunolocated in the central light-staining regions and ß- and γ-kafirins were in the periphery and dark-staining regions. After further digestion a darkly stained remnant appeared to be left, possibly representing the inclusion bodies. Treatment with the reducing agent sodium bisulfite increased the number of protein bodies that were digested. Following cooking, protein bodies changed in shape becoming oblong; no pitting was observed after partial digestion. When cooked with a reducing agent, surface pitting was observed as was more rapid digestion of the protein bodies.

In order to quantitate the disappearance of the three kafirins, enzyme-linked immunosorbent assay (ELISA) was developed using the rabbit antibodies. Uncooked sorghum samples, treated with or without a reducing agent, were digested with pepsin and the undigested protein residue was extracted and immunoassayed for the different kafirins. Unexpectedly, it was found that in uncooked flour ß- and γ-kafirins were digested more completely than the α-kafirins. However, this may simply be due to the fact that the α-kafirin lies inside the protein body while the other kafirins encase it. Slow digestion of the peripheral proteins may limit the rate of total kafirin digestion. When the flour was treated with a reducing agent, the indigestible residue contained insignificant amounts of kafirins following 120 min digestion.

Cooked sorghum flour is now being studied in the same manner. Because gelatinized, retrograded starch inhibits protein extraction, we have used a heat-stable α-amylase to liquify the starch component which has thereby increased protein extractability. It was noted that even in the absence of starch, sorghum protein digestibility decreased on cooking to the same degree as with gelatinized starch present.

Changes in Digestibility During Grain Development

In this study we investigated the relationship between the synthesis of the α-, ß-, and γ-kafirins at different developmental stages and changes in *in vitro* protein digestibility in uncooked and cooked sorghum flour. At each stage, moisture and protein content, and the amount of cross-linked kafirin was also determined. Two crop years (1987 and 1992) of sorghum grain (P721N) were used. Harvested at

10, 20, 25, 30, 35 (1992 only), and 40 days after half-bloom (DAHB), and at maturity. The rabbit-based ELISA developed above was used to estimate amounts of the three kafirins and digestibility was determined by the pepsin method.

Protein digestibility in early developmental stages (10 to 20 DAHB) in both years was high for uncooked (90- 95%) and cooked (about 80%) grain. At 25 DAHB cooked flour digestibility decreased and continued to do so in subsequent developmental stages. This coincided with the highest rate of kafirin synthesis, though it was not clear that ß- and γ-kafirin were preferentially synthesized at this time. All kafirins were synthesized by 35 DAHB. The dry-down process itself appears to be an important factor affecting protein digestibility. Grain with high moisture content (above 35%) gave uncooked digestibilities between 90 and 95%. Digestibility of the 1987 material (22% moisture) at 40 DAHB was reduced approximately 20%, however, did not decrease in the 1992 material (37% moisture). After the 1992 grain was field-dried, it also decreased in digestibility. Protein digestibility of the cooked grain in the later developmental stages decreased substantially in grain from both years. The percentage of crosslinked ß- and γ-kafirin was lower at earlier stages, compared to later stages, and increased in the mature, dry grain (approximately 14% moisture). We suggest the decrease in digestibility in maturing grain is due to a drying effect and concomitant protein interactions, including disulfide bonding, that occur at late stages of development after kafirin synthesis has been completed. Cooking the flour would further promote these interactions among the proteins.

Potential Non-kafirin Influences on Digestibility

Although it is known that the kafirin proteins are the least digestible of the sorghum proteins, and become even less digestible after cooking, it is still somewhat unclear whether these proteins are themselves responsible for the low digestibility of sorghum. While the high-cystine γ-kafirin is a plausible candidate, maize contains a similar amount of the nearly homologous γ-zein, yet is well digested both in the uncooked and cooked form. There must still be an aspect unique to this protein or a nonkafirin constituent of the grain to explain the difference in digestibility of sorghum and maize. We are investigating various possibilities.

Oxidized phenolic compounds, or quinones, conceivably could promote the oxidation of free sulfhydryls to disulfide bonds. Sorghum (P721N) flour and whole grain were extracted with methanol, methanol + 1% HCl, water, or water + HCl and dried, and the whole grains were reduced to flour. Extracts were added to maize flour and dried. *In vitro* protein digestibility of the treated sorghum samples showed no difference compared to untreated sorghum. Digestibility decreased approximately 20% after cooking in all treatments, with the exception that acid alone decreased the digestibility of uncooked flour the same degree as cooking. Extracts added to maize flour did not change its digestibility and no decrease was seen on cooking. It does not appear that phenolic compounds in essentially tannin-free sorghum play a role in digestibility. The poor protein digestibility of sorghum appears to be a property specific to the proteins themselves.

A high molecular weight (HMW) nonkafirin protein, in the range of 100 kDa, was identified which appears by sodium dodecyl sulfate-polyacrylamide gel electrophoresis to be present in sorghum but not maize, and may be located close to the protein bodies. In a time course digestion of cooked sorghum flour this protein was the last nonkafirin protein to be digested prior to kafirin digestion. A solubility study showed it to be only extractable when a reducing agent was present. Flour exhaustively extracted with a nonreducing SDS/urea buffer, followed by the same with 2-mercaptoethanol, showed this protein and γ-kafirin to be the principal proteins extracted in the second solvent. Amino acid analysis of the HMW protein showed only about 1.5 mole% cysteine compared to about 7% in the γ-kafirin, however, both proteins must be disulfide bound in fairly large polymers to avoid extraction in the nonreducing solvent. This data suggests that the HMW protein and γ-kafirin may be disulfide bound together. Such a conformation might also explain the high amount of "cross-linked" prolamins in sorghum compared to maize, which has been proposed as a reason sorghum is poorly digested, relative to other cereals. We are conducting further studies on this protein, as well as others, in the attempt to identify a component that could be reduced through breeding or altered through processing to produce a highly digestible sorghum grain.

Tuwo Quality

Consumer test panels carried out at two villages in Niger, using several local and improved sorghum cultivars, showed that texture was the most important attribute affecting the acceptability of tuwo (1991 INTSORMIL Annual Report, p. 167). In this report, laboratory methods for measuring the textural attribute of firmness have been evaluated and their results compared to consumer evaluation of tuwo texture. The methods were: alkali gel consistency test, Precision penetrometer, and a compression test on an Instron Universal Testing Machine. From the latter, two parameters were observed, the slope and maximum force of the load-deformation curve.

With the exception of the gel consistency test, instrumental measurements correlated significantly with consumer ratings for both locations (Table 1). However, the slope of the compression curve of the Instron test seemed to be the best predictor of consumer acceptance. It is likely that the slope, measured at small deformations, is more comparable with consumer's evaluation since most panelists judged firmness by simply pressing the tuwo sample with the fingers.

Table 1. Correlations between objective measurements of tuwo firmness and sensory ratings of texture by consumers at two locations in Niger.

Test	Adraoua	Bengou
Gel consistency	0.42	0.37
Penetrometer reading	-0.65**	-0.56*
Instron slope	-0.79**	-0.67**
Instron force	0.66**	0.64**

*, ** Significant at $P<0.05$ and $P<0.01$, respectively

Sorghum Porridge Texture

In most African countries sorghum is consumed as a thick porridge by simply mixing decorticated flour in boiling water until gelatinization. Consumer acceptability of the porridge depends not only on color and taste but also on texture. A number of instrumental techniques have been developed for measuring thick porridge firmness and were mostly aimed at providing breeders with an estimate of the food quality of early generation material. However, all of these procedures were empirical in nature with the results dependent on sample size and shape and on the type and operating conditions of instrument used. Simple compression tests are commonly applied to evaluate the mechanical characteristics of food materials and constitute the basis of many empirical tests used to predict textural properties. However, well-defined, basic units of engineering can be obtained from such tests. The advantage of using basic, fundamental units is that the results are independent of test geometry, thus allowing comparison of data obtained using different machines and different shapes and/or sizes. Reporting sorghum porridge texture in universal units can enhance collaboration between the different breeding programs. The objective of this study was to investigate the possibility of obtaining some fundamental information on porridge texture from a compression test on an Instron machine.

A uniaxial compression test was applied to cylindrical samples of porridge made from several sorghum cultivars differing in endosperm texture. Effects of flour/water ratio and time after cooking on the firmness of porridge were also investigated. Apparent deformability modulus (E_{app}), defined as the engineering stress, divided by engineering strain at 20% deformation, and yield stress (S_y), defined as maximum force, divided by the area of unstrained sample were determined. E_{app} was found to be more reproducible than S_y. Yield stress (or force to breakdown) seemed to be affected by sample stickiness (friction effects) and shape changes during the test and tended, therefore, to give higher-than-usual values for firmness.

Three flour-water ratios were tested and porridge samples from seven sorghum genotypes differing in hardness were compressed on the Instron at 15, 30, and 60 min. after end of cooking. Instron firmness (E_{app}) was different for the seven cultivars and was very sensitive to changes in flour-water ratio. A cultivar/flour-water ratio interaction for porridge firmness was found to be significant indicating that the effect of flour concentration was not consistent across genotypes (Figure 1). Although most cultivars exhibited improved firmness with increase in flour ratio, the ranking of cultivars was different at the ratios investigated. Between 15 and 60 min. all cultivars showed increases in firmness (Figure 2). Regression analysis indicated this change with time could be represented by a logarithmic model ($Y=a+\log X$). However, the rate of firmness development was different for different cultivars; hard endosperm cultivars exhibited a high rate compared to the soft cultivars.

It is concluded that the apparent deformability modulus could reliably be used as a measure of comparing porridge firmness, provided that factors such as flour concentration and time of testing are carefully controlled. At a medium flour-water ratio, percent vitreousness and apparent amylose content showed correlation coefficients with E_{app} of $r=0.771$ and $r=0.801$, respectively (significant at the 0.05 probability level). We are currently investigating the rate of cooling of porridge cylindrical samples between 0-60 min. in an attempt to relate it to the differences found in the retrogradation rate.

Networking Activities

Research Investigator Exchange

Dr. Abdel-Mageed Abass Mohamed from the Department of Food Science and Technology, University of Gezira, Wad Medani, Sudan

B. R. Hamaker traveled to Niger March 31 - April 8 to become acquainted with collaborating scientists, evaluate program, and coordinate research on sorghum and millet utilization.

Dr. Sitt Badi, Cereal Chemist from the Food Research Centre, Khartoum, Sudan visiting Purdue and the laboratory in August to attend a meeting of Sudan collaborating scientists and discuss plans for future research.

Publications and Presentations

Journal Papers

Shull, J.M., Watterson, J.J., and Kirleis, A.W. 1992. Purification and immunocytochemical localization of kafirins in Sorghum bicolor (L. Moench) endosperm. Protoplasma (in press). B.M.S. Thesis

Aboubacar, A.I. 1992. Relationships between consumer ratings and laboratory measurements of grain sorghum tuwo quality parameters. M.S. Thesis, Purdue University, West Lafayette, IN.

Figure 1. Firmness (apparent deformability modulus) of sorghum porridge cylinders at three flour-water ratios, measured one hour after cooking.

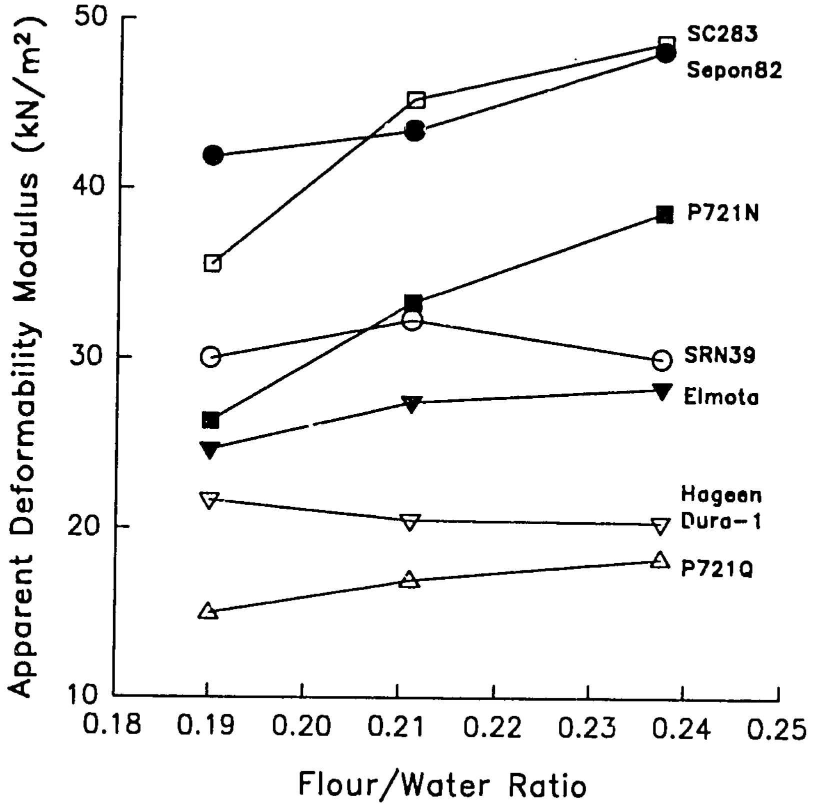
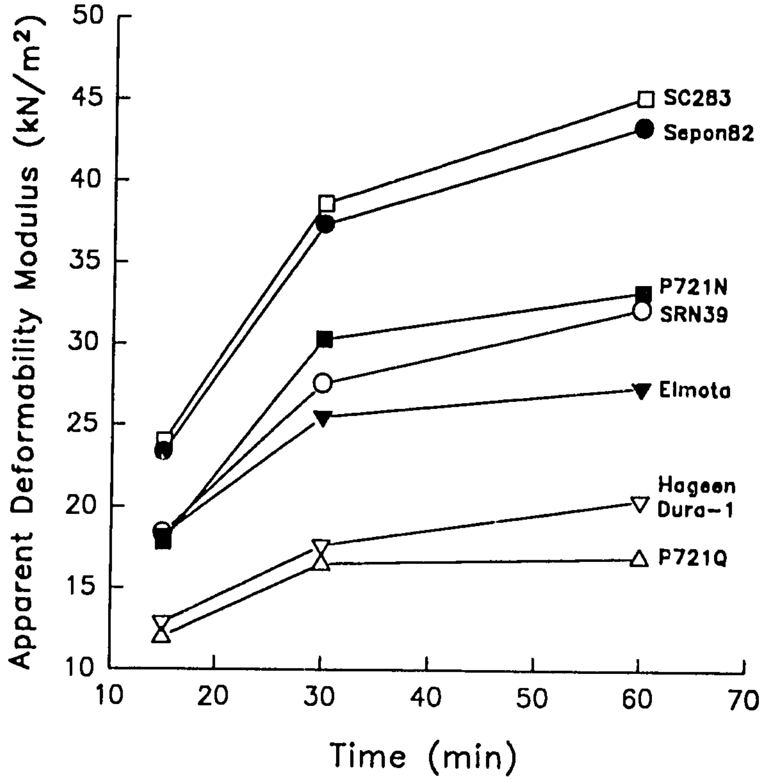


Figure 2. Changes in porridge firmness with time after cooking for seven sorghum genotypes at a medium flour-water ratio.



Utilization and Quality of Sorghum and Millet

Project TAM-126

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Summary

Methods to evaluate the malting properties of sorghum cultivars including alpha and beta amylase activities, extract, density, soluble nitrogen and free amino nitrogen were standardized. Sorghum amylase activities were affected by germination and steep times. Each cultivar had an optimum time requirement. Dorado, a white, tan plant food sorghum from El Salvador, had the best overall malt properties with high amylase activities, low dry matter losses during malting and the best extract levels. For the five cultivars evaluated none of the raw grain tests were very good predictors of malt quality assuming germination was high. The rapid viscosimetric analyzer provides a simple quick measure of alpha-amylase activity while a colorimetric method works well for beta-amylase. Sorghum malt was relatively low in beta-amylase compared to barley malt. Our results show that significant variation in beta-amylase exists.

Sorghums with food characteristics were steam flaked into attractive flakes that had excellent properties for feeding because of flake properties and color. The light color is attractive and desirable in feedlots where subjective evaluations can be significant. The same food sorghums were processed into acceptable micronized flakes for granola and other products. Moreover the waxy sorghums processed more thoroughly than the nonwaxy counterparts. JOWAR crunch is a low fat (10%) snack produced from food sorghums which demonstrates the usefulness of the new improved sorghum hybrids. Noodles, bread from sorghum-cassava blends and other products have been tested. All benefit from the new types of sorghum.

Tortilla quality of improved maicillo criollo sorghum cultivars developed in the INTSORMIL program in Honduras and grown in farmers fields was improved over that of the native maicillo criollo grown in the same fields. Color was the major improvement especially for the cultivar with tan plant color. The harder grain of the improved types requires longer cooking time but it resists insect attack during storage. The variety Sureño is now grown by many farmers mainly because it produces tortillas with light color and improved acceptability. Sorghums in Mali with white grain and purple plant color damaged by molds and head bugs produce poor quality food products. It is imperative that new cultivars have tan plant color for improved processing quality.

Objectives, Production, and Utilization Constraints

Objectives

Develop new food products from sorghum and millet using appropriate technology for use in less developed areas.

Develop simple, practical laboratory methods for use in breeding programs to assess important grain quality characteristics.

Determine physical, chemical and structural factors that affect the food and nutritional quality of sorghum; seek ways of modifying the properties or improving methods of processing.

Determine the factors that affect resistance to grain molds and field deterioration in sorghum and devise laboratory procedures to detect genotypes with resistance.

Constraints

Factors affecting food quality, processing properties and nutritional value of sorghum/millet critically affect the significance of other attempts to improve the crops. If the grain cannot be processed and consumed for food, then the agronomic and breeding research has been wasted. This project relates quality to measurable characteristics that can be used to select for sorghum and millet with acceptable traditional and industrial utilization attributes. It has defined quality attributes and incorporates those desirable properties into new cultivars at early stages in the breeding and improvement programs. The project also seeks to find more efficient ways of processing sorghums and millets into new foods with better acceptabilities that can generate income for village entrepreneurs.

Research Approach and Project Output

Sorghum and millet grains grown locally and from various areas of the world were analyzed for physical, chemical, structural, processing and food products. Some of these findings are summarized.

Parboiling and Aroma of Millet

The best parboiling process is a soak-boil process with three main steps. The pearl millet is cleaned and allowed to soak overnight (14-16 hrs) in excess water. The grain is brought to a boil and held there for five minutes with constant stirring. After boiling, the millet is drained and spread on screens in thin (1cm) layers to air dry. The result is a product with a higher decortication yield and no off-aroma production during milling.

A combination of gas chromatographic and mass spectroscopy analysis indicates that 2-acetyl-1-pyrroline is responsible for the off-aroma that develops in pearl millet during milling and storage of flour.

Dr. Larry Seitz, U.S. Grain Marketing Research Lab, Manhattan, KS worked with Mr. L. Wright, our graduate student, to determine that 2AP is associated with the aroma. Using a sniff port in the gas chromatograph, the mousey aroma was detected and coincided with the 2AP fraction identified with mass spectroscopy and other data. 2AP is responsible for the beneficial aroma of the aromatic rices during cooking. We do not know if the undesirable odor is due to the concentration of 2AP or modified by some other compound that is very similar. Sometimes, aromatic rices produce faint aromas that are described as the typical smell of a room infested by mice. Thus, the concentration of 2AP may affect the aroma perceived in pearl millet or there are modifying compounds that affect the aroma. Parboiled pearl millet samples have very small quantities of 2AP with little, if any, noticeable aroma at the sniff port of the gas chromatograph. Thus the off aroma of pearl millet appears to be caused by some reaction that produces 2AP shortly after milling and wetting of the grain. Then, later oxidative rancidity of the lipids can occur. Of the two, the production of the mousey aroma is most deleterious to product quality.

Sorghum Malting Quality

Sorghum malt is used extensively for the production of baby food, and traditional nonalcoholic and alcoholic beverages in Africa. The ban on the importation of barley and barley malt into Nigeria has stimulated the use of sorghum for malt to use in production of malt extracts, baby foods and clear beer. The greatest use of industrial malt in Nigeria is for nonalcoholic beverages which are very popular soft drinks. Several multinational companies including Nestles, Cadbury, Guiness Brewing and Heineken Brewing have switched to sorghum and sorghum malt-based products.

The Nigerian decision to ban barley and malt has made the large companies invest in significant R&D on sorghum/malt and processing. Progress to utilize sorghum has been excellent. Currently, the companies have found a way to use sorghum for food and alcoholic beverages. Their investment in research has enhanced great progress in understanding of sorghum quality.

Recently, 65 brewers and industrial processors participated in a conference on sorghum utilization for food and brewing organized by the Institute of Brewing, S. African section, held in Harare, Zimbabwe. This most significant meeting attracted outstanding participation because African industry now recognizes the need for sorghum of industrial quality. Though mainly related to brewing, the conference participants were keenly aware of the need for sorghum with improved food quality. Thus, the Nigerian decision and the drought in S. Africa has increased the awareness of sorghum quality for industrial use. The concerted interest and support for improved sorghum quality by industry can make sorghum quality improvement happen relatively quick. The

Nigerian experience has shown that producers will respond by producing improved quality grain for higher market prices and more profits.

Malting Evaluation of Sorghum Cultivars

Five cultivars grown in Halfway, Texas were used to determine the factors affecting malting quality of sorghum. The grains were subjected to varying steep and germination times. The malt characteristics were evaluated by a number of techniques that had been devised for sorghum malt and included physical, chemical properties of the grain and malt. Effects of steeping 6, 12, 18 and 24 hrs and germinating from one to six days on dry matter losses, enzyme activities, extract levels, density changes and composition were determined.

In general, 18 hours of steeping and five days germination gave optimum levels of enzymes, extracts and dry matter losses. However, each variety varied significantly in the rate of enzyme proliferation and dry matter losses. Some varieties had more vigorous root and shoot growth but lower enzyme levels. In these studies, the roots and shoots were removed which probably reduced the ß-amylase by 50%. According to Professor Dufour (Belgium) who found that the acrospire of the root contains up to 50% of the ß-amylase. Sound, whole-grain sorghum contained small amounts of both α and ß amylases. Some cultivars like Dorado have significant amylase activities after two days germination. Thus, it appears likely that certain varieties can be found that have great advantages for use in production of malt extracts for nonalcoholic beverages and weaning foods.

Five-day malts of the five cultivars were subjected to extensive analysis to compare the malt quality produced from the grains (Table 1). The varieties included a soft floury brown, a waxy endosperm type, a very hard, corneous and an intermediate type. The density decreased steadily over germination time and was related to the extent of modification of the kernel. The change in density was related to enzymatic activities and extract yields up to a point. Malisor 84-7 grew vigorously, but had very poor enzyme activities and low extract levels. The waxy sorghum had very poor enzyme activity and extracts were low. The waxy variety had very poor overall malting quality. The sorghum malts had lower levels of enzymatic activity and less soluble solids after mashing than barley malt. The protein solubility and free amino nitrogen of sorghum malts were very similar among cultivars and compared favorably with barley malt. Since the malts had roots and shoots removed prior to analysis, our ß-amylase values are too low, possibly by 50%.

Sorghum malt is quite different from barley malt in structure, as well as composition and enzymatic activities. The structure of the sorghum kernels were modified during malting, but cell walls were not destroyed. SEM revealed that small holes were present in malt which confirms the results of scientists in S. Africa and Scotland. We observed that the corneous endosperm of sorghum is attacked during malting and some of the starch granules are partially degraded. This is especially true for hard texture varieties. The extract of hard sorghum was reduced compared to soft, floury sorghums. The friability of sorghum malt is quite different from that of barley. Thus, the milling techniques used for measurement of barley malt modification do not apply to sorghum malt.

Additional experiments are being conducted to determine the malting properties of 18 sorghum cultivars produced in three locations in Texas in 1992. The cultivars grown were selected on the basis of high amylase activity reported by various investigators around the world. The samples of grain will be malted and essential malt parameters will be measured using the assays developed in our previous research. The goal of this work is to understand some of the grain characteristics that affect malt quality for use in non-alcoholic beverages and extracts. We are not as concerned about

Table 1. Characteristics of five day germinated malts.

Parameter	Dorado	Malisor 84-7	Tortillero	ATx623 *Sc103	ATx630 *R3338
Density (g/cc)	1.31^{a}	1.23^{b}	1.24^{b}	1.17^{c}	1.24^{b}
Dry matter loss (%)	20.17^{ab}	29.63^{a}	14.86^{b}	23.01^{ab}	26.74^{a}
α-amylase (U/g)*	107.50^{a}	33.74^{d}	71.28^{b}	83.30^{b}	51.45^{c}
β-amylase (U/g)**	43.16^{a}	40.48^{ab}	36.45^{ab}	41.75^{ab}	33.51^{b}
Diastatic power (SDU/g)***	15.38^{a}	4.28^{c}	7.86^{b}	7.90^{b}	5.25^{c}
Total nitrogen (% dry)	1.69^{bc}	1.59^{b}	1.92^{a}	1.80^{ab}	1.68^{bc}
Soluble nitrogen (% dry)	0.52^{a}	0.46^{b}	0.39^{c}	0.47^{b}	0.44^{b}
Kolbach index (%)	30.90^{a}	29.30^{ab}	20.40^{c}	26.10^{b}	26.20^{b}
Extract (%`	70.10^{a}	44.30^{d}	68.10^{a}	54.90^{c}	63.10^{b}
Free α-amino nitrogen (mg/L)	188.80^{a}	179.30^{a}	137.50^{b}	187.70^{a}	167.50^{a}

*Malt flour (control) = 156.2±9.5 U/g, Barley malt = 178±1.8 U/g.

**Barley malt was used as a reference; b-amylase activity = 74.2 U/g.

***Sorghum diastatic units/g; one SDU is defined as the amount of enzyme, when acting under the conditions of the method, gives a thiosulfate titre of 0.5 mL of 0.05 N solution.

All values in this table are the average of two experiments with either duplicate or triplicate measurements per sample.

ß-amylase as those who produce lager or clear beer, but we want to maximize it where possible.

Changes in Composition During Malting: Sorghum loses 20 to 30% of its dry matter during malting. Major losses are starch, protein and some fat when the roots and shoots are removed. For opaque beer and extracts, the roots and shoots are not removed, so losses are less. The respiration losses increase with germination time, so varieties that modify and develop enzymes quickly are desirable. That is why soft, floury sorghums have an advantage for malting, and hard endosperm types are not so desirable. There will be a tradeoff for malt quality. The malting process tends to eliminate the adverse properties of the condensed tannins, so that is why red (brown) sorghum is used preferentially for traditional village malting. There is a controversy concerning the role of tannins. Some say that tannins give a necessary bitterness to the beer, but most dispute that idea.

In industrial malting and brewing, tannins are not desirable. Formaldehyde and other treatments are used to inactivate the tannins to reduce their anti-souring activity. The current situation in Southern Africa has resulted in use of imported Argentine sorghum that is brown and of poor germination. It produces terrible malt. Intermediate to soft red sorghums are preferred for industrial malt. A major challenge is to actually document the kind of sorghums actually required for malt for extracts and opaque beer and for lager beer. The two major processes will likely require sorghum with different characteristics to enable malt production with optimum properties for these two major uses.

Methods of Malt Evaluation

The colorimetric methods to measure specifically α- and ß-amylases proved to be very accurate, precise, quick and cost-effective under our situation. The cost of reagents was $0.50 per assay which is prohibitive under certain circumstances. We found that the rapid viscosity analyzer (RVA) could be used to measure the decrease in viscosity of a standard corn starch slurry treated with malt extract in about 10 min. The decrease in viscosity was highly correlated to α-amylase activity measured with the specific colorimetric procedure. The RVA has great potential for those labs that have the equipment. It is especially useful in breeding programs for α-amylase determination. Additional information is required to determine the validity of this relationship over a range of sorghum malts.

Determination of malt extract with the RVA has been evaluated with modest success. The procedure will work, but the variation is presently too great because of system cooling problems between extraction runs. More work is being done to standardize the method.

Prediction of Malt Quality: The use of simple techniques to predict malt quality from the measurements on the grain or the malts has been only partially successful. None on the analytical and physical measurements of viable raw grain were good predictors of malt quality. There is an association of soft, floury texture with improved malting properties but within soft, floury types there is no indication that certain types are better. Considerable more research to define quality attributes of sorghums with improved malt properties is necessary. Progress is possible, but it will require the coordination of worldwide efforts to succeed.

The use of sorghum for malt/beer by large industrial companies is the single most important development in sorghum quality improvement in the last 25 years or more that I have worked with sorghum. These developments help all segments of sorghum including small producers and subsistence farmers. If rich people consume sorghum in beer and nonalcoholic drinks, I believe the social stigma of sorghum as a poor man's food may be decreased. Moreover, the resources put into sorghum cultivar development and acquisition of a consistent supply of good quality grain will open the way for other uses of the grain. Payment of premiums to farmers for producing the right kind of sorghum will help all farmers eventually. It is certainly true that larger farmers will benefit from the technology first but small farmers will benefit eventually by the improved cultivars, the enhanced status of sorghum and the potential of converting some excess grain into value added products for sale in urban markets.

The single most difficult aspect of working with sorghum has been to define quality. In other commodities, the large industries have defined quality and promoted its improvement. For sorghum and millet, no industry has existed to promote and lead efforts to improve quality. So no quality standards have been developed. Now if the larger companies are to be successful more rigid definition of quality attributes of the grain is necessary to develop useful products with consistent quality. More has been learned about sorghum quality for malting in the past few years than ever before because of the interest of the larger companies and their financial commitments. The spin-off from these activities will lead to improved sorghums for food types of all kinds.

Sorghum Processing Quality for Food and Feed

Micronizing

Several experiments were conducted with a laboratory micronizer to compare the processing properties of grains from new improved food type sorghums. Significant differences in response to micronizing were obtained with waxy sorghums (Table 2) which were more thoroughly processed than the nonwaxy and heterowaxy grains. In addition, the same information was obtained when waxy and nonwaxy sorghums grown in 1991 were compared. The waxy sorghum flakes were excellent for production of ready-to-eat breakfast foods and granola bars. The information obtained shows that the sorghums have a great variation in response to processing which could be used to produce food and feeds more efficiently. The greater expansion rate of waxy sorghums has also been shown in extrusion experiments. These

Table 2. Enzyme susceptible starch of micronized sorghum flakes (Exp 1).

Sample	Endosperm type	Test wt. (lb/bu)	Density (g/cc)	Total Starch %	ESS/Tot. St. %
ATx631 x Tx436	nonwaxy	23.2	1.257	70.30	80.74
AISC34 x Tx436	heterowaxy	15.9	.830	69.88	87.95
B. BON 34	homowaxy	11.8	.643	63.41	89.45
BTx631	nonwaxy	23.5	1.336	69.42	83.84
ATx399 x RTx430	nonwaxy	19.7	1.046	69.42	84.70

types could be grown in sorghum consuming areas to enable diversification of products from sorghum.

Steam Flaking

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. Experienced steam flaker operators have observed significant differences in the response of sorghum hybrids to processing. Some feedlots pay a small premium for white or yellow sorghums because they flake more efficiently. The goal of the research conducted jointly by Texas Tech University and the Cereal Quality Lab is to document differences in the performance of sorghum in steam flaking. Several experiments were conducted at the Feedlot Research Center near Lubbock, Texas to evaluate the performance of new food type and waxy sorghums.

Results comparing hybrids to date have shown that sorghum varieties respond differently to steam flaking. White food-type sorghums produce flakes that are subjectively very attractive because of their white color. That alone could help improve the image of steam flaked sorghums because cosmetic aspects of quality are critically important. The appropriate sorghums were planted to increase grain for additional experiments in 1993.

Factors Affecting Flake Quality

The structure of good and poor quality sorghum flakes was determined with light and scanning microscopy and other measurements such as starch gelatinization. The steam flaking process consists of conditioning the grain to 16 to 18% moisture followed by steaming the grain for 20 to 30 minutes (final moisture = 20 to 22%) and immediately passing the hot grain through corrugated rollers operated under high pressure with a narrow gap between them. If water, contents, steam and cook time are optimum, the kernels are transformed into an individual, thin, translucent flake that retains its form during subsequent blending into rations and feeding operations. Flakes that break into fines during handling are unacceptable.

An optimum level of starch swelling and gelatinization is required to obtain sufficient starch "glue" to hold together the other constituents during flaking and thereafter. The tempering moisture level, conditioner, steaming time, roller pressures and gaps and the variety of grain affect steam flake quality. Our studies showed that significant initial gelatinization of starch granules occurred during steam cooking, but major changes occurred during the actual flaking in the rolls where the partially gelatinized granules are converted to a glue that surrounds the endosperm pieces during crushing of the kernel. Upon cooling, the glue solidifies and holds the particles together. Thus, it is necessary to precondition the grains prior to flaking to insure sufficient water is distributed throughout the endosperm to cause swelling and partial gelatinization of starch granules prior to actual flaking.

Defective flakes did not have a thin continuous phase of gelatinized starch glue distributed throughout the kernel particles. Thus, they were opaque to light, easily broken during handling and were generally unacceptable.

We believe that understanding the factors affecting sorghum quality in steam flaking provides fundamental information that relates to the use of sorghum for many processed food products that are used around the world. The demonstration that certain sorghum hybrids process better than others in large industrial complexes (modern feedlots) can provide significant economic interest to force development of improved sorghums for both food and feeds.

Laboratory Steam Flaking Method

We have been developing a simulated steam flaking procedure that would require only a few pounds of grain for processing. Even the small steam flaker at Texas Tech requires 75 pounds of grain. A lab method that produces steam flakes resembling commercial flakes has been developed. However, the results must still be compared to those of the commercial flaker at Texas Tech. The Texas Sorghum Producers Board will continue to partially support this program through a grant to fund a graduate student.

The Tortilla Making Properties of Two Improved Maicillo Cultivars from Honduras

Recently, the INTSORMIL Honduran Breeding Program has focused on the improvement of photosensitive Maicillo Criollos which are traditionally cultivated for both forage and grain on hillsides throughout Central America where maize and sorghum are interplanted. These sorghums are often used for tortillas. Two improved food-grade Maicillos (DMV 197 and DMV 179) were grown in trials in farmer's fields during 1990 crop year. Grain from these trials was

Table 3. Pedigree and physical properties of sorghum grains grown in Honduras[a].

Property	DMV-197	DMV-179	Criollo	Sureño
Pedigree	TAM 428* Porvenir 29	SPV436* Gigante	Unknown	...
Pericarp color	White	White	White	White
Plant color	Red	Tan	Purple	Tan
Pericarp thickness	Thin	Thin	Thick	Thin
1,000 kernel Weight (g)	22.2±0.4	25.8±0.4	25.1±0.6	31.3±0.4
Test weight (lb/bu)	61.1±0.1	60.2±0.1	58.3±0.1	61.7±0.1
Density (g/cc)	1.370±0.005	1.380±0.005	1.350±0.005	1.37±0.005
Hardness or % removal(b)	15.4±0.7	17.2±0.1	26.0±0.6	12.7±0.4
Endosperm texture(c)	1.5	1.5	3.0	2.0

[a] Values are means ± standard deviations (three replications).
[b] Estimated as amount of material abraded in a TADD mill.
The higher the value the softer the grain.
[c] Subjectively rated on the scale of 1 to 5. 1 = hard endosperm; 5 = soft endosperm.

Table 4. The nixtamal properties at optimum cooking time and temperature for the four sorghum cultivars grown in Honduras.

Property	DMV-197	DMV-179	Criollo	Sureño
Optimum cooking time (min)(a)	20	10	6	20
Steeping time (hr)(b)	8-12	8-12	8-12	8-12
Nixtamal color(c)	2.5	2.0	2.5	2.0
Pericarp removal(d)	3.0±0.0	2.5±0.5	3.0±0.3	1.7±0.2
Nixtamal moisture (%)	50.8±1.3	52.8±1.5	50.5±1.6	55.5±1.2
Dry matter losses (%)	5.0±0.5	5.4±1.0	3.0±0.3	4.6±0.4

[a] The cooking temperature was 90°C.
[b] The temperature of the lime solution decreased at 0.15°C/min. until equilibrated to room temperature during the steeping.
[c] Subjectively evaluated on the scale of 1 to 5, where 1 = good (light-clean yellow) and 5 = poor (dark stained).
[d] Subjectively evaluated on the scale of 1 to 5, where 1 = pericarp removed and 5 = all pericarp attached to the grain.

used to compare, under pilot plant conditions, the tortilla making properties of these two improved Maicillos, one native Maicillo (Landrace) and an improved white sorghum variety (Sureño).

All cultivars had white pericarps. Improved Maicillo DMV-179 and Sureño had tan plant color and straw glumes (Table 3). The other improved Maicillos, DMV 197, had red plant and glume colors. The Maicillo Criollo had purple plant and glume colors. The improved Maicillo cultivars produced kernels with harder endosperm and thinner pericarps than the native Criollo population. The thick pericarp in criollo kernels gave chalky appearing grain.

DMV 197 had the smallest kernels whereas the criollo and DMV 179 had similar 1,000 kernel weight (Table 3). Kernels from Sureño were heavier than the other kernels. Both improved Maicillos had higher test weights, densities and hardness values than the Criollo indicating that the breeding process has successfully produced grains with harder endosperms that are more suitable for storage. With the exception of 1,000 kernel weight, the improved Maicillo cultivars had physical grain properties similar to Sureño. Almeida-Dominguez (1991) also found that a composite Maicillo Criollo sample contained smaller, softer kernels than Sureño and other improved Central American food sorghum types.

Nixtamal moisture content and dry matter losses increased with longer lime-cooking times. Sorghum nixtamal with 51-52% moisture produced the best masa and tortillas. Nixtamal with <50 and >55% moisture produced crumbly (non cohesive), and sticky masa after stone grinding, respectively. Preliminary trials indicated that cooking at 90° was the optimum cooking temperature. Improved Maicillos and Sureño required longer cooking times than the criollo (Table 4). The lower cooking requirement of the criollo was related to its softer endosperm texture and lower hardness value (Table 3). Similar trends were observed by Almeida-Dominguez et al. (1991) who tested and compared 13 different sorghum types.

Results of the pilot plant cooking trials are summarized in Table 4. DMV 197 and Sureño had comparable cooking requirements. The soft Maicillo Criollo required a lower cooking temperature and cooking time. The dry matter losses of sorghum cooked at 90°C ranged from 3.0-5.4% which are significantly lower than losses observed when cooking maize. Dry matter losses were mainly related to the amount of pericarp removed during cooking. The three

Table 5. Properties of tortillas from four sorghums grown in Honduras.

Property	DMV-197	DMV-179	Criollo	Sureño
Color(a)	3.0±0.3	2.0±0.5	4.0±0.6	2.0±0.3
Texture(b)	1.2±0.3	2.9±0.6	2.5±0.2	1.0±0.0
Moisture content (%)	41.7±0.8	41.8±0.5	42.0±0.4	42.5±0.5
pH	8.2±0.1	8.0±0.1	7.8±0.2	8.2±0.0
ESS(c)(g gluc./g dry tort.)	766±20	759±18	759±15	738±19
Tortilla yield (Kg tort./ Kg grain)	1.47±0.05	1.48±0.08	1.52±0.09	1.41±0.02

[a] Subjectively evaluated on the scale of 1 to 5, where 1 = good (light-clean yellow) and 5 = poor (dark-stained).
[b] Tortilla rollability subjectively evaluated on the scale of 1 to 5, where 1 = breakage and 5 = no breakage.
[c] Enzyme susceptible starch ratio. Values provide an indication of starch gelatinization. The raw grains had values of less than 280 mg glucose/g dry sample.

Table 6. Chemical composition of sorghum grains and tortillas from four sorghums grown in Honduras(a).

Cultivar	Protein (Nx 6.25)	Ash (%)	Fat (%)	Carbohydrate (%)
DMV-197				
Grain	10.6±0.0	1.8±0.1	2.4±0.2	81.1±2.8
Tortilla	11.9±0.2	1.7±0.1	2.1±0.1	79.7±0.7
DMV-179				
Grain	9.8±0.1	2.0±0.1	2.2±0.3	82.2±1.2
Tortilla	10.8±0.3	1.8±0.1	1.9±0.2	79.4±1.1
Criollo				
Grain	9.6±0.1	1.8±0.1	2.4±0.3	79.8±0.3
Tortilla	10.8±0.3	1.7±0.1	2.1±0.2	79.2±0.4
Sureño				
Grain	10.4±0.2	1.8±0.1	2.2±0.2	78.5±0.8
Tortilla	11.0±0.1	1.7±0.1	2.3±0.1	79.2±0.5

(a)Values are expressed on dry basis.

Maicillos had comparable pericarp removal values which were better than that of Sureño.

Nixtamals were ground into fine masa suitable for table tortillas. All sorghums had similar yields of different masa fractions and excellent masa machinability.

Tortilla color, visually determined, showed that the tortilla made from the criollo sorghum had the worst appearance due to its gray, dirty like color (Table 5). All sorghum tortillas had acceptable rollability immediately after baking. One day storage at room temperature caused significant firmness in tortillas, being DMV-197 and Sureño tortillas were most flexible. The others were too stale to roll without breaking. Tortilla moisture contents and pH were similar. The degree of starch gelatinization in tortillas, measured as enzyme susceptible starch, and tortilla moisture content were similar among the sorghums. The Criollo produced slightly more tortillas per kilogram of raw grain likely due to its lower dry matter loss. Tortilla yields are very comparable to yields obtained from maize and sorghum (Almeida-Dominguez et al., 1991).

Color of nixtamal, masa and tortillas was the factor that varied the most. DMV-179 and Sureño produced the best colored nixtamal, masa and tortillas. These sorghums had white pericarp and tan plant and glume color. DMV-179 and Sureño produced the whitest (high L value) and yellowest (high b value) tortillas. The other improved Maicillo Criollos with red plant color and glumes produced better looking tortillas than the criollo (purple glume color) confirming that glume or plant color plays a critical role in tortilla acceptability. Phenolic compounds present in the pericarp, glumes and damaged areas of weathered kernels darken during lime-cooking. Glumes still attached to the pericarp leach their pigments into the kernel producing a dirty colored masa which darkened even more during baking.

The chemical composition of the improved Maicillos was comparable to that of criollo and Sureño grains (Table 6). Therefore, the genetic improvement did not have any major effect on the overall chemical composition.

Additional tortilla trials of grain from these cultivars grown in 1991 has confirmed the results we obtained on 1990 grain samples. Farmers in southern Honduras are planting Sureño because of its improved tortilla quality, better storage properties and improved forage quality.

Other Food Products

Graduate students are working on factors that affect quality of noodles, breads and snacks made from 100% sorghum products or in some cases composite flours. Noodles from 100% sorghum flour have been developed using a procedure that partially gelatinizes part of the sorghum flour which forms a paste to hold the dough together. The noodles have desirable organoleptic properties. The best sorghum flour is from a white tan plant sorghum. However, the dry milling procedure must be modified to eliminate the black specs from the hilum layer to produce the best product. It is possible to produce acceptable 100% sorghum noodles.

Jowar crunch, a snack containing 10 to 15% oil was produced from special sorghum grains by alkali cooking drying, and frying in oil. The dried alkali cooked kernels can be stored for six months or longer and then fried to produce a very acceptable snack. This product has unique texture and oil properties.

Composite breads using 70% sorghum flour and 30% cassava flour and starch produce bread with reasonably acceptable taste when consumed fresh. However, the storage properties are terrible; the bread stales rapidly and has a very poor texture and taste. Various additives and techniques are being investigated in these studies.

Collaborative Sorghum Improvement Research

This project cooperates closely with other members of the sorghum program to incorporate the best quality characteristics into sorghum. Samples from the breeding nurseries and from the food quality tests grown at different locations are tested for kernel characteristics and for processing properties such as decortication and tortilla processing. The alkaline cooking tests are especially sensitive and pick up off colors and aromas.

From this research, Texas A&M has released several inbreds that produce white, tan-plant sorghum hybrids which have excellent food and feed processing quality. These sorghums produce excellent quality grain when grown under dry conditions. Because of reduced anthocyanin pigments, the grain can withstand some humidity during and past maturation. However, these sorghums need more resistance to molds and weathering to be grown in the hot humid areas of the world.

Grain Molding

Twelve sorghums with different levels of grain molding resistance (susceptible, moderately resistant), pericarp color (red, white) and presence of a pigmented testa (Type I, II, III) were sampled during kernel development. An *in vitro*, *Fusarium* fungal-growth assay is being developed to determine bioactivity of extracted compounds. Bioactivity of extracts from spikelet, glume and caryopsis tissues will be tested in the bioassay. A natural products chemistry approach is being taken to determine which compounds are involved in the resistance mechanisms of sorghum. Bioactive compounds (of whatever chemical nature) will be quantified in collected sorghum tissues and correlated to grain mold resistance. Grain molds remain the number one problem limiting the quality of sorghum worldwide.

Networking

Travel

L.W. Rooney traveled to Mali to develop work plans, Amendment #9, to the Memorandum of Understanding and to collaborate with personnel in the Food Technology Laboratory (IER) to further the activities on parboiling, weaning foods from cowpeas and millet, instant masa flours and quality evaluation of breeders samples.

L.W. Rooney traveled to ICRISAT, Hyderabad, India to participate in a consultative group meeting on sorghum malting and brewing research. The discussions led to a set of proposed standard procedures for evaluating sorghum cultivars for malt quality. Drs. Murty of ICRISAT-Kano and Rooney conferred with personnel at Heineken Brewing R&D facilities near Amsterdam, Holland. The group discussions permitted more efficient research activities in malting quality of sorghum.

L.W. Rooney participated in the 9th International Cereal and Bread Congress held in Paris, France where he became the new Chairman of the Sorghum and Millet Working group of the International Cereal Chemistry Association. He presented a summary of INTSORMIL sorghum quality research in the Sorghum and Millet Special Symposium. In addition, L.W. Rooney (along with Prof. John Taylor of Pretoria, S. Africa) is organizing a sorghum millet symposium in S. Africa in May 1993.

L.W. Rooney presented information on sorghum and maize quality/ technology to participants at the Monterrey Institute of Technology Symposium on Food Science and Technology in Monterrey, Mexico. Two-hundred plus food technology graduate students from Mexico participated in the conference.

L.W. Rooney participated (no expense to INTSORMIL) in an International Cereal Chemistry Congress in Brisbane, Australia with a presentation on sorghum food quality. Then, he presented a special seminars/discussions at Gatton College to Australian sorghum breeders, food technologists, nutritionists and industrial processors. A feedlot and other sorghum processors were reviewed.

Juan Corujo completed his MS and accepted a teaching position at LaSalle University in Mexico City. Dr. H. Almeida Dominguez, Institute of Technology of Merida, received European Economic Community funding for teaching and initiating research activities on food processing, including a project on sorghum quality for food in which the Texas A&M Cereal Quality Lab is a collaborator. Cooperation with the University of Sonora continues, informally.

North America

Several papers were presented at the annual American Association of Cereal Chemists conference in Seattle, Washington and the Institute of Food Technologists Food Exposition in New Orleans, Louisiana. L.W. Rooney presented sorghum quality/utilization discussions to Texas Sorghum Producers Board Members and other farm groups.

L.W. Rooney resigned from the Ecogeographic Zone Council for INTSORMIL and as Country Coordinator for Mali, effective June 30, 1992,

Acknowledgment: The assistance of Dr. M. Gomez, Research Scientist, and Ms. C. McDonough, Research Associate, has been very helpful. Several graduate and undergraduate students have worked long hours on this research.

Publications

Dissertations and Theses

Clegg, Chally. August 1991. Pearl Millet: Parboiling Methods and Factors Affecting the Process and Cooked Product. M.S. Thesis. Texas A&M University, College Station, Texas. 90 pp.

Refereed Journal Articles

Almeida, H.D., M.H. Gomez, S. Sema-Saldivar, R. Waniska, L.W. Rooney, and E. Lusas. 1992. Extrusion cooking of pearl millet for weaning food production. Cereal Chemistry (in press)

Almeida-Dominguez, H.D., S.O. Sema-Saldivar, M.H. Gomez, and L.W. Rooney. 1992. Production and nutritional value of weaning foods from mixtures of pearl millet, cowpeas and sorghum malt. Cereal Chemistry (in press)

Almeida-Dominguez, H.D., S.O. Sema-Saldivar, L.W. Rooney. 1992. Properties of new and commercial sorghum hybrids for utilization in alkaline cooked foods. Cereal Chemistry 68(1):25-30.

Boren, Bruce and Ralph D. Waniska. 1992. Sorghum seed color as an indicator of tannin content. Journal of Applied Poultry Research 1:117-121.

Kotarski, S.F., R.D. Waniska and K.K. Thum. 1992. Starch hydrolysis in the ruminal microflora. Journal of Nutrition, p. 178-190.

Sema-Saldivar, S.O. 1992. Nutritional Value of Cereals. Encyclopedia of Food Science, Food Technology & Nutrition (in press).

Waniska, R.D. and M.H. Gomez. 1992. Dispersion Behavior of Starch. Food Technology 46(6):110-123.

Waniska, R.D., L.F. Hugo and L.W. Rooney. 1992. Practical methods to determine the presence of tannins in sorghum. Journal Applied Poultry Research 1:122-128.

Proceedings/Presentations

Almeida-Dominguez, H.D., M.H. Gomez, S.O. Sema-Saldivar and L.W. Rooney. 1992. Proceedings of International Sorghum and Millet CRSP Conference: Weaning Food from Composite of Extruded or Press Dried Pearl Millet and Cowpea. pp 268-269.

Clegg, C.J., L.W. Rooney and R.D. Waniska. 1992. Proceedings of International Sorghum and Millet CRSP Conference: Parboiling Technologies Applied to Pearl Millet (Pennisetum americanum), p 269

deFranca, J.G.E., L.W. Rooney, R.D. Waniska and F.R. Miller. 1992. Proceedings of International Sorghum and Millet CRSP Conference: Evaluation of Malting Characteristics in Sorghum Genotypes. p 269.

Gomez, M.H., R. Young, R.D. Waniska and L.W. Rooney. 1992. Proceedings of International Sorghum and Millet CRSP Conference: Changes of sorghum starch during parboiling, p 270.

Gous, F., R.D. Waniska, L.W. Rooney and F.R. Miller. 1992. Proceedings of International Sorghum and Millet CRSP Conference: Tannins and Phenols in Black Sorghum, p. 270.

McDonough, C.M., R. Young and L.W. Rooney. 1992. Proceedings of International Sorghum and Millet CRSP Conference: Microstructure of Parboiled Sorghum Using Scanning Electron Microscopy, p. 271.

McDonough, C.M., C.J. Clegg and L.W. Rooney. 1992. Proceedings of International Sorghum and Millet CRSP Conference: Microstructure of Parboiled Pearl Millet, p. 271-2.

Rooney, L.W. 1992. Proceedings of Cereals International, Brisbane, Australia: Factors affecting the food, feed and industrial utilization of sorghum, p 127-130.

Rooney, L.W. 1992. Methods of Processing Sorghum for Livestock Feeds. Proceedings of Utilization of Sorghum and Millets, ICRISAT 167-171.

Rooney, L.W. 1992. Wet Milling Nixtamalization and Micronization of Sorghum. Proceedings of Utilization of Sorghum and Millets, ICRISAT 19-21.

Rooney, T.K., L.W. Rooney and J.R. Lupton 1992. Proceedings of International Sorghum and Millet CRSP Conference: Possible health benefits of sorghum and millet bran. p. 272.

Sema-Saldivar, S.O., C.J. Clegg and L.W. Rooney. 1992. Proceedings of International Sorghum and Millet CRSP Conference: Effects of Parboiling and Decortication on the Nutritional Value of Pearl Millet and Sorghum. P. 272.

Sema-Saldivar, S.O., M.H. Gomez, F.A. Gomez, D.H. Meckenstock and L.W. Rooney. 1992. Proceedings of International Sorghum and Millet CRSP Conference: The Tortilla-making Characteristics of Three Improved Sorghum Cultivars Compared to Maicillo Criollos in Honduras. p. 272.

Waniska, R.D., G.A. Forbes, R. Bandyopadhyay, R.A. Frederiksen and L.W. Rooney. 1992. Sorghum and millets diseases: a second world review: Cereal chemistry and grain mold resistance. International Crops Research Institute of the Semi-Arid Tropics, Patancheru, A.P. 502 324, India, pp. 265-272.

Rooney, L.W. 1991. Sorghum Nutritional Quality: The Sorghum Producers Views on Sorghum Quality Improvement. Proceedings of International Conference on Nutritional Improvement of Sorghum, West Lafayette, IN, Feb. 26 - March 1, 1990. p 6-7.

Rooney, L.W. 1991. Sorghum Nutritional Quality: Processing Methods to Improve Nutritional Value of Sorghum for Livestock. Proceedings of International Conference on Nutritional Improvement of Sorghum, West Lafayette, IN, Feb. 26 - March 1, 1990. p 206-210.

Waniska, R.D., S.F. Kotarski and K.K. Thum. 1991. Sorghum nutritional quality: starch digestibility in sorghum. Proceedings of International Conference on Nutritional Improvement of Sorghum, West Lafayette, IN, Feb. 26 - March 1, 1990, pp 177-190.

Reports

Rooney, L.W. 1991. Utilization and quality of sorghum and millet. INTSORMIL TAM-126 Annual Report, University of Nebraska, 54 Nebraska Center, Lincoln, NE 68583, pp 171-182.

Rooney, L.W. 1991. Sustainable Systems for Production, Utilization and Marketing of Sorghum and Millet. INTSORMIL Annual Country Report - Mali, University of Nebraska, 54 Nebraska Center, Lincoln, NE 68583, pp 195-204.

Abstracts

Beta, T., C. McDonough, L.W. Rooney and R. Richardson. 1992. The physical and structural characteristics of steam-flaked sorghum. Program and Abstracts, 1992 IFT Annual Meeting, June 20-24, New Orleans, Louisiana.

Islas-Rubio, A.R. and L.W. Rooney. 1992. Amylase activity in sorghum malts. Program and Abstracts, 1992 IFT Annual Meeting, June 20-24, New Orleans, Louisiana.

Wright, R.L., L.M. Seitz, R.D. Waniska and L.W. Rooney. 1992. Effects of parboiling on off-aroma development in pearl millet flour. Program and Abstracts, 1992 IFT Annual Meeting, June 20-24, New Orleans, Louisiana.

Almeida-Dominguez, H.D., M.H. Gomez, R.D. Waniska and L.W. Rooney. 1991. Malting of Sorghum. Cereal Foods World 36(8):706.

Host Country Program Enhancement

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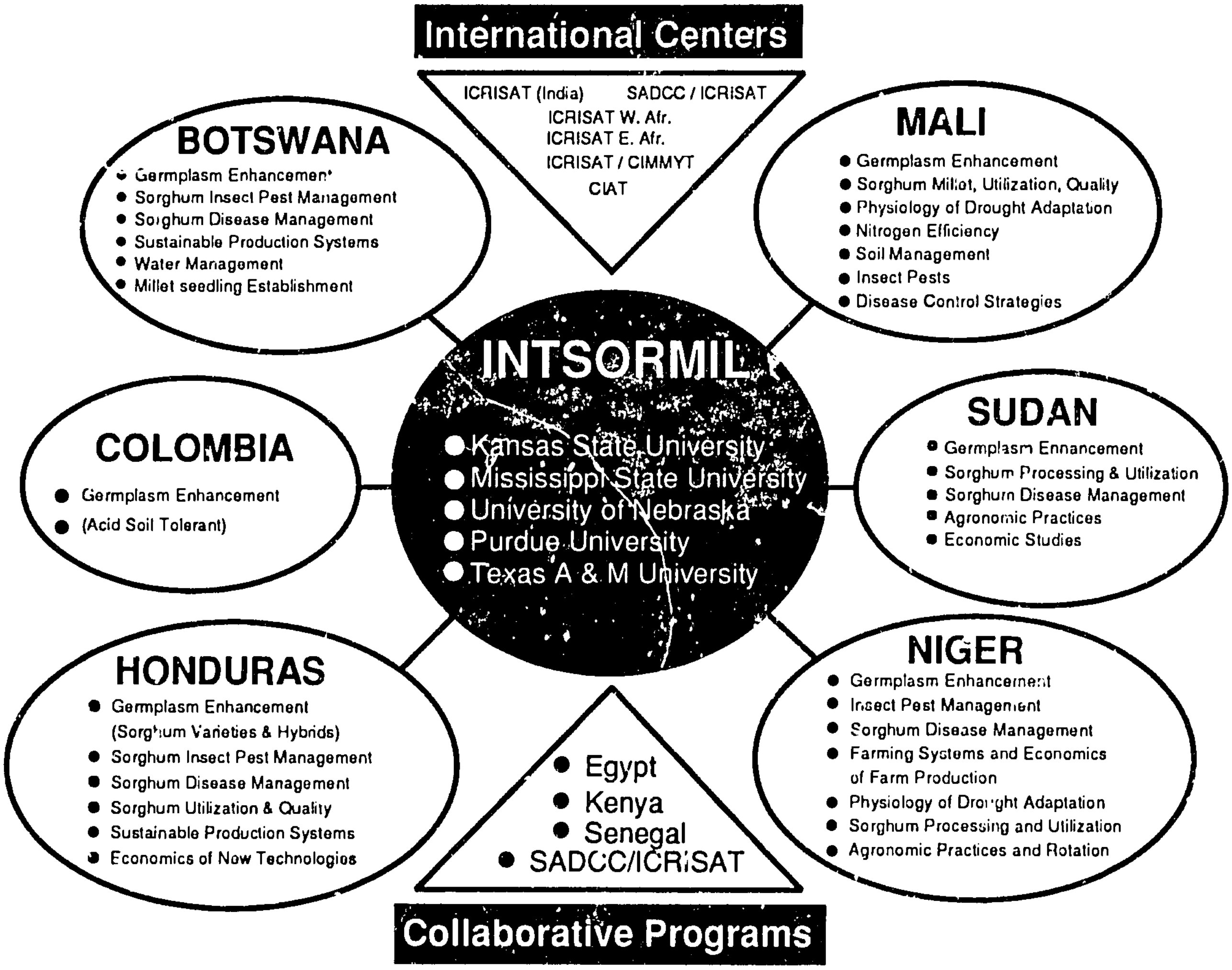
INTSORMIL Collaborative Sites



International Centers

- ICRISAT (India)
- SADCC / ICRISAT
- ICRISAT W. Afr.
- ICRISAT E. Afr.
- ICRISAT / CIMMYT
- CIAT

BOTSWANA

- Germplasm Enhancement
- Sorghum Insect Pest Management
- Sorghum Disease Management
- Sustainable Production Systems
- Water Management
- Millet seedling Establishment

MALI

- Germplasm Enhancement
- Sorghum Millet, Utilization, Quality
- Physiology of Drought Adaptation
- Nitrogen Efficiency
- Soil Management
- Insect Pests
- Disease Control Strategies

INTSORMIL

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

COLOMBIA

- Germplasm Enhancement
- (Acid Soil Tolerant)

SUDAN

- Germplasm Enhancement
- Sorghum Processing & Utilization
- Sorghum Disease Management
- Agronomic Practices
- Economic Studies

HONDURAS

- Germplasm Enhancement (Sorghum Varieties & Hybrids)
- Sorghum Insect Pest Management
- Sorghum Disease Management
- Sorghum Utilization & Quality
- Sustainable Production Systems
- Economics of New Technologies

NIGER

- 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
- Kenya
- Senegal
- SADCC/ICRISAT

Collaborative Programs

Botswana

M.D. Clegg
University of Nebraska

Coordinators

Dr. Lucas Gakale, Director of Agricultural Research, Botswana (Host Country Coordinator), Gaborone, Botswana

Dr. Max D. Clegg, Department of Agronomy, University of Nebraska, Lincoln, NE 68583 (U.S.A., Coordinator)

Collaborative Program

INTSORMIL's involvement in Botswana was initiated July 1983 and staffed in April 1984 under the INTSORMIL/Kansas State University KSU-107 project. Dr. D.C. Carter held the position of Agronomist with KSU-107 from its inception until September 1990. In December 1987, Dr. N. Persaud was appointed the soil management specialist to support the activities of the USAID-funded bilateral Agricultural Technology Improvement Project (ATIP). When ATIP ended in September 1990, INTSORMIL amended its Memorandum of Understanding with the Government of Botswana and USAID to continue the services of the soil management specialist until September 1992. Funding for the KSU-107 project is jointly shared by INTSORMIL, USAID/Botswana, and the Government of Botswana. The INTSORMIL contribution for KSU-107 is provided by the U.S. Government under the provisions in Grant DAN-1254-G-00-0021-00 to the University of Nebraska, the Management Entity for INTSORMIL and by subgrant to Kansas State University. The plan of work attached to the Memorandum of Understanding between the Government of Botswana, USAID/Botswana, and the INTSORMIL ME describes the current scope of work and operational procedures for the KSU-107 project. The Department of Agricultural Research (DAR), provides all operational facilities for KSU-107. The technical objective was to continue and expand the on-farm and on-station research on tillage and fertilizer practices across the various rainfall and soil conditions in Botswana.

The Botswana program has two related components; an INTSORMIL researcher stationed in the country and scientist to scientist collaboration in the areas of agronomy, plant pathology, plant breeding, entomology, food science and technology and soil science. Various aspects of collaboration can be seen in other projects. Collaboration and/or contact with various scientists are detailed in individual projects. In the agronomic area, Dr. Max Clegg (UNL-113), with Drs. Lucas Gakale, Louis Mazhani and Joyce Macola; and Dr. Richard Vanderlip (KSU-107) with Nieso Mokote and Etani Lele; plant pathology area is Dr. Gary Odvody (TAM-128) with Baikabile Motalaote; the area of plant breeding is Professor David Andrews with Dr. Louis Mazhani; in entomology are Drs. George Teetes (TAM-125) and Gary Peterson (TAM-123), with Dr. Chris Manthe; and in the area of food science and technology is Dr. Lloyd Rooney (TAM-126) with Rosemary Lekalake.

Financial Inputs

USAID/Botswana and GOB ($100,000) and INTSORMIL ($103,000) provide funds for operating, equipment, facilities, technical assistants and an in-country scientist. These resources allowed the Botswana program to undertake comprehensive and collaborative research on dryland sorghum/millet production.

Collaboration with Other Organizations

Collaboration is occurring with the DAR, Palapye Development Trust, Arable Lands Development Program, Meteorology Services, and FAO sponsored Soil Survey and Mapping Services. Dr. Naraine Persaud has been interacting with these various organizations. Entomology, pathology, and plant breeding are also coordinated with the ICRISAT SMIP Program in Bulawayo, Zimbabwe.

The Planning Process

Several multidisciplinary working groups have been established. These are; 1) cereals, 2) grain legumes, 3) oil seed, 4) horticulture, 5) soil and water management and 6) production system programs. The planning of research by the in-country scientist is reviewed at the annual DAR planning meeting in September or October. The work plans are circulated with the national scientists plans for review and then presented at the meeting. Other collaborative research, scientists and/or administrators of DAR are involved in the planning process.

Sorghum/Millet Constraints Researched

Production Constraints

Sorghum is an important crop in Botswana. The grain is a food source for the general population and the stalks are used as feed for livestock. Even in dry years, 70% of the land planted is harvested. However, over the last 10 years (80's) farmers' yields have averaged 161 kg ha^{-1}. These low yields somewhat reflect hectares that are planted but are not harvested. Farming essentially is subsidized by other enterprises, especially by cattle.

The low, irregular, and low-efficient rainfall pattern, sandveld and hardveld soils with low moisture retention, low N and P content, broadly graded sand fractions, and unstable surface contribute to the low yield of sorghum and millet. Broadly graded sand fractions and unstable surface are properties which result in a high bulk density and a massive hard structure when dry, and surface sealing and crust formation. This tends to impede rain infiltration and root penetration. Moisture conservation and redistribution technologies, fertility improvement, residue incorporation, and weed control are urgently needed to improve soil structure and rainfall infiltration and availability for promoting crop establishment and improved grain and stover yields.

The 1991-1992 season was probably one of the driest years ever. This emphasizes the importance of water and management needed to help stabilize crop yields.

Research Methodology

Because of the diverse nature of research being conducted it is not possible to outline specific research procedures. These will be included in the various individual reports.

Research Progress

Agronomy

Dr. Naraine Persaud, INTSORMIL/Botswana, Gabarone. The objectives for this period were to evaluate several tillage practices with and without fertilizer; evaluate animal versus tractor draught for tillage operations and make fertilizer recommendations from developed response curves for dryland conditions.

Results from this project have been fully documented, presented and disseminated locally in Botswana. All the data has been computerized and archived in an easily accessible database. The data has already been used for model validation and Botswana College of Agriculture (BCA) students have requested the data for use in term papers.

Etani Lele is working with Dr. R. Vanderlip on the effects of weed competition on sorghum yield and yield compensation. He should complete his M.S. program in the spring of 1993

Entomology

Chris Manthe, Entomologist, DAR, has completed his Ph.D. at TAMU (advisors, Drs. George Teetes and Gary Peterson) and has returned to Botswana. His research was conducted on sorghum resistance to sugarcane aphid. He is now Coordinator of the Cereals Working Group.

Sorghum/Pearl Millet Breeding

Professor David Andrews continued collaboration between his projects, UNL-115 and UNL-118, and the sorghum and pearl millet breeding program being conducted by the Department of Agricultural Research at Sebele. The SADCC/ICRISAT regional program is also involved as the sorghum and pearl millet breeders there have provided off-season generation advance and seed increase for the Botswana/INTSORMIL selections.

INTSORMIL's involvement in the Botswana sorghum and pearl millet breeding programs has been in supplying both segregating populations and advanced sorghum lines and information on, and participation in the Botswana recurrent selection program in pearl millet. PI visits have been timed so material can be jointly evaluated and selected in the field.

Food Science and Technology

Ms. Rosemary Lekalake, working with Dr. Lloyd Rooney, initiated studies in food science and technology in January, 1991. She is conducting research on methods of converting sorghum into various food products, including noodles made from white, tan plant, straw glume hybrids. The sorghum flour was produced by dehulling with an abrasive mill followed by milling into flour with a wheat flour roller mill. The flour had light acceptable color free of black specs from the hilum. Sorghum with a white pericarp and purple plant and glume color had off white flour and unacceptable noodle color. The noodles produced had acceptable texture compared to 100% wheat noodles but the dry matter losses during cooking of the noodles were too high. The next phase of the project will be to use rice noodle technology to reduce the dry matter losses. It is possible to produce noodles from only sorghum flour using small, low technology equipment. Thus, the use of sorghum can be diversified.

Mutual Research Benefits

Information exchange and other interactions between African and U.S scientists result in many mutual benefits. Presently, food types of sorghum and millet are being utilized more in the U.S. These types offer better grain quality. Techniques in breeding and soil fertility developed in the U.S. are being utilized for improving agricultural production in Botswana. Emphasis on sustainable agriculture will lead to improvements in crop production management for the mutual benefit of the U.S., Botswana and southern Africa.

Value added technologies for sorghum can be obtained with studies of sorghum flour use in products such as noodles and improved malting characteristics of the grain. Progress has been made in adapting technologies for measuring alpha and beta-amylases, malting losses and degree of modification of sorghum malts that can be applied in breeding and selection programs.

Institution Building

Since 1980, many of the major agricultural research administrative positions have been staffed with Botswanians. SADCC/ICRISAT/INTSORMIL, and USAID/Botswana have contributed to educating many of them. There needs to be continual training of research personal for identified areas as earlier trained scientists continue to move into administrative and teaching positions in the Botswana College of Agriculture. The greatest benefit of the Agricultural College is that there now are agricultural graduates from Botswana which can help fill the void of needed researchers for various agricultural research positions. Eventually some will be identified for more advance training.

Within the DAR, various staffed regional research stations are being implemented. Botswana funding is available to establish stations at Kgalagadi and Francistown regions and to improve existing research facilities at Maun, Pandamatenga and Sebele.

Some of the students that have or are obtaining advanced training are, Mr. Willie Emmanuel, seed technology, Mississippi State University (B.Sc.), Dr. Chris Manthe, entomology, Texas A&M (Ph.D), Dollina Malepa, soil fertility, University of Nebraska (Ph.D), Ms. Rosemary Lekalake, food science, Texas A&M (M.Sc.), Mr.Etani Lele, agronomy, Kansas State University, (M.Sc) and Mr. Emest Makhwaji, FSR\economics, Kansas State University, (M.Sc).

Networking

A multidisciplinary working group of DAR researchers, ALDEP, field managers the SADCC/ODA Land and Water Management Project, and the FAO/UNDP supported Soil Mapping and Advisory Services jointly planned and implemented the field research. Dr. Naraine Persaud initially chaired this group.

The INTSORMIL researchers are working directly with the DAR, so there is direct communications of research results. Research reports are shared with DAR. Information is also distributed in other southern African areas through SACCAR and ICRISAT. Collaborative research continues to be published as reports, bulletins and journal articles. These include: The Bulletin of Agricultural Research, Botswana; Agrinews, Ministry of Agriculture, Botswana; Experimental Agriculture, printed in Great Britain.

Some more recent publications are:

Carter, Douglas, and Naraine Persaud. 1990. Manure and stover management for sorghum and millet production in eastern Botswana. Part II. The effect of manure, mulch and soil incorporated stover on the physical and chemical properties of two soil types. 8:10-14.

Persaud, N. 1990. National Tillage Research Programme Report on 1988/ 1989 National Tillage Trials. Part One, Main Report. Compiled for the Working Group on Tillage Research. Department of Agricultural Research, Gaborone, Botswana, 12 February 1990.

Persaud, N. 1990. National Tillage Research Programme Report on 1988/ 1989 National Tillage Trials. Part Two, Detailed Site Reports. Compiled for the Working Group on Tillage Research. Department of Agricultural Research, Gaborone, Botswana, 12 February 1990.

Persaud, N., C.M. Sakamoto, W.D. Joshua, D.L. Lesolle, D.Dambe, and R. Vanderlip. 1990. Coefficients of Penman's Formula for Calculating Evaporation and Potential Evapotranspiration in Botswana. Department of Agricultural Research, Gaborone, Botswana, 25 February 1990.

Persaud, N., and N. Mokete. 1992. Progress Report on Soil Moisture and Soil Resistance Measurements in the 91-92 tillage trials. Department of Agricultural Research, Gaborone, Botswana, 22 January 1992.

Persaud, N., W.D. Joshua, N. Mokete, F. Pule, and T.S. Moroke. 1992. Tillage and Fertilizer Research Programme. Report on the Soils of the Tillage and Fertilizer Trial Sites. Compiled for the Working Group on Tillage and fertilizer Research. Department of Agricultural Research, Gaborone, Botswana, 29 March 1992.

General Comments

The greatest impact that can be derived from INTSORMIL is the training of students. In Botswana there is a small number of trained personnel. Many of the students that have been trained to do research have been assigned administrative roles, taken positions in the Botswana College of Agriculture and some have moved into the private sector. A positive development is that students with a B.Sc. in Agriculture are being trained and hired into the available research positions from the BAC.

What is needed? As students with a B.Sc. and M.Sc. in Agriculture come into the research system, they have little experience in designing and implementing a research project. Projects are generally developed for a five year period. A provision of technical advisors to aid in developing and implementing programs could be supported by INTSORMIL, DAR, and other donor agencies. The advisors would spend a year with the scientist in design, day to day operations and final analysis, interpretation and reporting of the results. The technical advisors would continue on a collaborative basis to support the scientists. Selected scientists would continue for further graduate studies which will address the more technical aspects of their projects.

The recent growing season drought was severe across Botswana with much failed sorghum. The harvest forecast was less than 20,000 tons which is less than 10% of the national grain need of approximately 250,000 tons. Management for improved water use and water harvesting needs to be continued. This is very important because improved cultivars yield better under more favorable growing conditions.

Other Southern African Students

Research by other students in southern Africa has relevance to utilization by the entire region.

Mr. Lawrence Hugo, SADCC/ICRISAT/INTSORMIL sponsored student from Zimbabwe, spent January through July, 1992 at the SADCC/ICRISAT Center at Motopos, Zimbabwe working with Dr. Mahmood Osmanzai on the field portion of his Ph.D. program. He screened 30 sorghum genotypes which Dr. Osmanzai is looking at for stand establishment under a range of soil moisture and temperature conditions. Results were used to select the two best and two poorest genotypes for controlled growth chamber studies on his return to Kansas State University (details in Project KSU-106).

Ms. Ruth Mandulu, M.S., from Tanzania is working on yield compensation of sorghum hybrids and varieties as affected by crop management (KSU-106).

Ms. Leda Hugo, M.S., Food Science and Technology from Mozambique has initiated research designed to evaluate the use of sorghum and cassava starch in production of a leavened bread using a modified baking technique reported by scientists from Nigeria. The procedure is to completely gelatinize part of the cassava starch (66%) in water and mix the sorghum flour, other ingredients, and ungelatinized cassava starch into the paste to form a dough which is proofed and baked. The bread has a very short shelf life but it does mimic bread. Initial results look promising (TAM-126).

Ms. Trust Beta, M.S., Food Science and Technology from Zimbabwe, is conducting research on steam flaking and micronizing white sorghum for use in ready to eat breakfast cereals. However, her major effort is to evaluate the malting quality of sorghum cultivars using a micro malting procedure followed by analysis of alpha and beta-amylases and the SDU method from Southern Africa. Procedures have been established and 25 cultivars are under analysis (TAM-126).

Mr. Greyson Mrema, M.S., Food Science and Technology from Tanzania, has been determining the effect of steeping and germination times on the dry matter losses and enzyme activities. The alpha and beta amylases, SDU and malt density was affected by variety as well as germination time. Steeping time variation did not influence the malt quality as much as germination time variation. Sorghum varieties differed in the time required to obtained optimum enzyme levels. A food type of sorghum with a hard endosperm had the poorest malting characteristics (TAM-126).

Ms. Sitsembile Kunene, from Swaziland, completed her Ph.D. (1991) with her dissertation being "Gaertneriomyces Species as a Potential Biological Control Agent of Sorghum Downy Mildew". She has since returned to her home country. (TAM-124 and TAM-128)

Mr. Anaclet Mansuetus, from Tanzania, is continuing his doctoral research on characterization of the *Fusarium* species that occur on grain in Tanzania. (TAM-124 and TAM-128)

Mr. Charles Maliro, Ph.D. candidate in agronomy from Malawi, is determining the influence of nitrogen and distribution of water stress on sorghum yield. Another study is determining the effects of different levels of weeds and nitrogen fertility on total biomass and resource partitioning into weeds and sorghum grain and stover.

Summary

Since the establishment of the project, drought has been the norm. Thus, the necessity for emphasis has been on crop production management. This has included studies of different cultural and physical practices that improve water use and availability.

Application of manure and crop residue (stover) which increases the intake of rainfall and availability of soil water results in increased yields. Manure is effective, but in combination with stover was more effective. With deficient soil moisture, response to nitrogen fertilizer and rotation with legumes are ineffective.

Segaolane, a popular variety, yields better than other locals and demonstrated drought tolerance.

Results indicate any method that increases water availability will increase yield. This is through double plowing, residues, and collecting through various water harvesting mechanisms, i.e. diversion of runoff to portions of fields, reduction of runoff with row orientation, and land shaping.

Classification of 22 soils has been completed. The report includes pedon descriptions and other analytical data providing a valuable data base.

Studies of seed quality on sorghum and millet stand establishment indicate seed quality results in little improvement of stands. This probably relates to water availability. Also, studies of previous data on planting date, indicate there is really no optimum planting date. Planting date is probably dependent on the time the first rains occur and their continuation.

Research on tillage and fertilizer practices and evaluation of animal and tractor draught tillage operations was emphasized the last few years. Results have shown that tillage performed as early as possible at the inception of rains can conserve sufficient moisture and give better use of that rain. It was better to apply fertilizer broadcast before planting than banding next to the seed. Financial benefits of tractor and animal draught systems were comparable. However, grain yields were higher with the use of the tractor system. Addition of P gave a yield increase. Mean over all tillage treatments showed yield of 661 kg ha^{-1} with no P and 2095 kg ha^{-1} with P (15 kg ha^{-1}). But, the response was not economical where soil P tested greater than 5 mg kg^{-1}.

Sorghum crosses made at the University of Nebraska between U.S. B-lines and Segaolane, a widely popular Botswana food quality variety which itself is a B-line, are being used. After four years of selection at Sebele, characterized by severe drought stress, 24 lines have been retained from which seed parents can be produced. Backcrossing has commenced. More advanced lines from Nebraska have been evaluated during the 1990-91 season and 50 of these were retained. These also, after being tested for combining ability, have potential to be converted into seed parents. Six seed parents and one restorer were chosen from parental lines developed in UNL-115. This research is being continued.

In the pearl millet program at Matopos, Zimbabwe, with the assistance of Dr. Emmanuel Monyo (SADCC/ICRISAT program), 46 superior progenies were identified for recombination and production of progenies for the third cycle of selection, and 6 elite progenies for the production of an experimental variety.

Resistance to the sugarcane aphid in sorghum lines has been identified. Resistant x susceptible crosses indicated that sorghum resistance is simply inherited and controlled by a single completely dominant gene. Different virulence within the Botswana, and between the Botswana and Zimbabwe aphids suggest different biotypes exist among the populations.

To complement the data on 22 soils collected by the Soil Conservation Service, USDA/SMSS, research relating to the soil fertility of 14 of these soils from the major grain producing regions of Botswana (Gaborone to Maun) are being conducted. Soils have been subjected to adsorption isotherms and soil analysis using a variety of soil extractants for N, Ca, Mg, K, S, P, Mn, Cu, Fe, and Zn. Baseline critical levels for this family of soils for the elements listed are being established in greenhouse studies. Using sorghum, this data will allow us to more precisely interpret soil test data, to make decisions as to the best extractant to use to assess availability, and to guide field fertility trials by concentrating field experiments on the most limiting nutrients to sorghum nutrition. Included in the greenhouse trials were treatments designed to assess the effect of lime on nutrient availability and relative contribution of subsoil nutrients to sorghum nutrition.

Many students have been trained through SADCC/ICRISAT/INTSORMIL, INTSORMIL, USAID/BOTSWANA, and USAID/ATIP educational/research programs. These scientists are providing a good core but individuals moving to administration and private industry tend to reduce actual research scientists. Additional training programs need to continue as qualified people become available.

A summary of the soils of the tillage and fertilizer trial sites was compiled. This included soil profile morphology, pH in $CaCl_2$, % organic carbon, CEC, P and bases Ca, Mg, K and Na, particle size distribution and infiltration data. Productivity is related to the soil texture. The light texture soils require more fertilizer. Early plowing before planting results in some benefit especially on the medium texture soils.

The research of Dr. Douglas Carter (INTSORMIL agronomist in collaboration with ATIP), Dr. Wayne Youngquist (agronomist who continued the sorghum-legume rotation research of Dr. Lucas Gakale, when he was on leave in the U.S. obtaining a Ph.D. degree) and Naraine Persaud (INTSORMIL/AID Botswana scientist) has added to the knowledge base for crop production in Botswana. Much of the research has been summarized, utilized in workshops, seminars and published.

Egypt

J.D. Eastin
University of Nebraska

Country Coordinators

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Principal Investigators

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Collaborating Scientists and Institutions

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Dr. Ibrahim El-Fangary, Principal Investigator, ARC, Giza, Egypt
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Dr. Anis El-Sharkway, Plant Pathologist, ARC, Alexandria, Egypt
Dr. Osman El-Nagouly and Colleagues, ARC, Giza, Egypt
Staff at Fayoum on Water and Nutrient Use Efficiencies
Staff at Shandoweel on Water Use Efficiency and Stress Screening
Mr. Mohamed R. Hovny, Shandweel Scientist at Nebraska

Plant Pathology

Objectives

1. Determine whether aerial infestation with a spore/hyphal fragment suspension, toothpick infestation, or soil infestation is the most effective method for assaying sorghum resistance to *Acremonium strictum.*

2. To identify sorghum germplasm with tolerance to Pokkah Boeng and Fusarium stalk rot.

3. To characterize genetic diversity within the pathogen population and to identify pathogenic strains to be used in breeding challenges and nonpathogenic strains to be used in a biological control program.

Methods and Materials

Toothpick inoculation: Wooden toothpicks were boiled in water to leach out fungal growth inhibitors in several changes of water. Toothpicks are placed in a test tube containing media and then inoculated with an agar disc from the fungal culture. The tubes are incubated at room temperature for fungal growth. Sorghum plants (55-60 days) are inoculated by puncturing the stalk with a sharp metal nail and then inserting the infested toothpick.

Soil infestation: Fungal inoculum will be produced on sterilized grain sorghum kernels in 500 ml milk bottles. *A. strictum* will be added to the bottles and then incubated at 30 C for 3-4 weeks. The inoculum is added to Nile silt at the rate of 5-7 g/kg soil and then placed into 25 cm diameter clay pots. Disease ratings are made 90 days after sowing.

Aerial inoculation: An aqueous conidial suspension is made with 10-day-old *A. strictum* cultures. Leaves of one-month-old plants will be clipped with scissors, sprayed with inoculum, and then covered with a plastic bag for 24 hours.

Eighty-six accessions from the Sorghum Section, Field Crops Research Institute were examined for stalk rot due to natural infestation at two locations (Shandaweel and Gemmeiza). A limited (7) number of lines were evaluated for resistance to *Acremonium strictum* using the toothpick infestation method.

Results

An extensive survey throughout all sorghum production regions in Egypt was conducted in September, 1991. The major diseases of sorghum identified during this survey included: sorghum downy mildew, *Acremonium* wilt, pokkah boeng, maize dwarf mosiac virus, long smut, and covered kernel smut.

The following table reports on results from an experiment that was conducted during 1992 with only infested soil containing *A. strictum*. In 1993, all treatments will be evaluated with 3-5 cultivars.

Cultivar	% Plants Infected
Giza 3	60
Giza 15	40
Giza 114	50
Giza 123	30
Local 169	80
CS 3541	25

Vegetative Compatibility Groups (VCG) are very useful techniques for detecting different strains within the same genus and species of fungi. Nearly 120 Egyptian isolates (59 from maize and 60 from sorghum) have been analyzed and 58 different VCG's have been identified. Twenty-one of these groups have more than one strain; 13 can be found at more than one location, and 7 of these 13 were found on both maize and sorghum. This pattern is very different than observed on maize and grain sorghum in the United States. This will likely be a very important parameter for breeding for resistance to fusarium stalk and root rot in maize and sorghum. Contamination of seed and feed grains with fumonisin mycotoxins is also an important aspect of the VCG strain variability within *Fusarium moniliforme*. Some VCG's have negligible amounts and other strains produce fumonisin at unacceptable levels for food products.

Physiology/Production

Objectives

1. Develop water control irrigation systems which permit control and measurement of water applied to research plots for water and nutrient use efficiency investigations.

2. Determine the influence of water level and nutrient level on water use efficiency (WUE) and nutrient use efficiency (NUE).

3. Evaluate short, white seeded, tan plant selections at Shandoweel for general adaptability in preparation for later stress screening tests when sprinkler systems become available.

Research Methods and Approach by Objectives

1. Little is known about WUE in sorghum and other crops in sorghum based cropping systems because of inadequate water application control and measurement. Therefore, considerable time has been spent in designing a flexible recycling irrigation system suitable for small plot work. The system will be field tested in April, 1993.

2. Objective 2 will be addressed in 1993.

3. Six hundred plus lines from a stress resistant population were grown out to assess their general adaptability.

Research Results

Research results in general are meager due to delays in receiving equipment funding but should progress satisfactorily from this point on. Irrigation equipment for cultural NUE and WUE experiments is available and should be used effectively in the summer of 1993. A LICOR 6200 is in place and training on it will commence in early 1993. Proper water stress screening systems are not yet readily available. 1993 should be a productive year.

Honduras

Darrell T. Rosenow
Texas A&M University

Coordinators

Dr. Darrell T. Rosenow, Texas A&M University, Lubbock, Texas
Dr. Francisco Gomez, Sorghum Breeder, EAP/SRN, Zamorano, Honduras
Dr. Dan H. Meckenstock, Sorghum Breeder, INTSORMIL (Texas A&M) EAP/SRN, Zamorano, Honduras

Institutions Involved

Secretaria de Recursos Naturales (SRN), Honduras
Escuela Agricola Panamericana (EAP), Honduras
Texas A&M University
Mississippi State University
Purdue University
University of Nebraska

Collaborative Program

Memorandum of Understanding

The MOU between INTSORMIL and SRN (Secretary of Natural Resources) was signed in February 1983. In October, 1988, a MOU between INTSORMIL and the Panamerican Agricultural School (EAP) was signed, covering the officing of INTSORMIL at Zamarano at the school, collaborative activities with INTSORMIL graduate students, and EAP/USAID collaboration with INTSORMIL/EAP/SRN/USAID sorghum research activities. In December 1991, an MOU was signed between SRN and EAP, which officially placed the responsibility for sorghum research with the EAP and established a collaborative relationship between SRN and EAP in the conduct of sorghum research throughout Honduras.

Program Structure

The INTSORMIL collaborative program in Honduras is multidisciplinary and multiinstitutional in scope. The program includes all aspects of sorghum improvement with major emphasis on the tall, photoperiod sensitive local landrace varieties called maicillo criollos, which are grown in association with maize by subsistence farmers on small hillside farms. The program has centered around Dr. Dan Meckenstock, INTSORMIL sorghum breeder hired through Texas A&M University stationed in Honduras and his project, TAM-131, Tropical Sorghum Conservation and Enhancement in Honduras and Central America. Dr. Franciso Gomez, PhD-Texas A&M, is a full time sorghum breeder and Head of the National Sorghum Program. He offices at the EAP along with Meckenstock, at Zamorano, 30km southeast of Tegucigalpa. Meckenstock's responsibilities include support and coordination of INTSORMIL graduate students doing research in Honduras, training local scientists, making breeding crosses, increasing seed, packaging and distributing regional uniform trials. He heads the breeding effort on hybrid maicillos. Dr. Gomez works with Meckenstock in all phases of the breeding and is responsible for all research plots at Choluteca, Comayagua, La Lujosa, Catacamas, and Danli. He is responsible for all on-farm trials throughout the entire country, but with emphasis on the Choluteca area, the center of sorghum production in southern Honduras. He also is responsible for the SRN/EAP/USAID collaborative financial and administrative support of the National Sorghum Program and serves as CLAIS Steering Committee Chairman, coordinating networking activities in the entire Central American Region.

In addition to sorghum breeding, the Honduras program involves collaborative activities in entomology, pathology, cereal quality, agricultural economics, and agronomy. Major collaborative programs in place in Honduras are as follows: Breeding - D.T. Rosenow (TAM-122), F.R. Miller (TAM-121), and G.C. Peterson (TAM-123) of Texas A&M; Entomology - H.N. Pitre (MSU-105) Mississippi State, and F.E. Gilstrap (TAM-125) Texas A&M; Pathology - R.A. Frederiksen (TAM-124) Texas A&M; Cereal Quality - L.W. Rooney (TAM-126) Texas A&M; Agricultural Economics - J.H. Sanders (PRF-105) Purdue; and Agronomy - Max Clegg and Steve Mason (UNL-113) University of Nebraska.

Financial Inputs and Management

In addition to the TAM-131 budget, the USAID/H Mission provides major financial support through PL 480 local currency funds to the National Sorghum Program and to the INTSORMIL collaborative program. In 1991, they contributed 479,000 lempires for use in the collaborative INTSORMIL/SRN/EAP sorghum research throughout the country. These funds pay Gomez's salary and support research at

Zamorano, Rapaco, Choluteca, Comayagua, Catacamas, and Danli, as well as the cooperative on-farm trials with LUPE. Additionally, collaborating U.S. projects contribute substantial amounts of funds "in", "for", or" on behalf of" the Honduras program and the entire Central America, Mexico, Caribbean region.

Collaboration with Other Organizations

The program in Honduras has extensive collaboration and networking activities with researchers and organizations in other countries of the region. Extensive collaboration exists with the ICRISAT/LASIP program at CIMMYT, and countries of the region through annual CLAIS meetings, regional CLAIS trials, seed and germplasm exchange, co-sponsoring regional workshops, and through the annual PCCMCA meetings. Networking exists with Mexico (sorghum tortilla quality), Guatemala (breeding - ICTA and quality - INCAP), El Salvador (CENTA - breeding, entomology, and pathology), and CATIE. Recent proposed changes in the ICRISAT/LASIP program to move from CIMMYT possibly to CIAT will likely affect the collaborative activities in the region and networking needs. A new initiative on InterCRSP activities in Honduras is underway, involving INTSORMIL, Bean/Cowpea, Tropsoils, SANRAM, and Pond Dynamics. Dr. Meckenstock has served as the focal point and informal coordinator of the activities.

Collaborative Work Plans

Annual research plans and work plans are developed jointly by Meckenstock and Gomez in consultation with SRN, EAP, INTSORMIL, and USAID. Graduate student research plans are developed annually and submitted to SRN for approval. Budgets for AID/H support are jointly developed each year by Gomez and Meckenstock, and submitted by SRN through the Ministry of Finance to AID/H.

Constraints Researched

Major emphasis is on improving sorghum production and the economic well-being of the small subsistence farmers of the steep hillside agricultural areas of Honduras and Central America where tall, photoperiod sensitive sorghums, called maicillos criollos, are intercropped with maize. Major constraints to production and utilization are low yield potential of the MC's, drought, insects (fall armyworms, seed and seedling pests, stem borers, and midge), diseases (downy mildew, grain mold, acremonium wilt, foliar diseases), food grain quality, as well as soil, low fertility, topography, and related agronomic problems. Of less importance, but also a priority, are the larger commercial farms and lowland valleys where shorter, photoperiod insensitive sorghums, including commercial hybrids, are adapted. Similar constraints exist in these areas. Availability of seed of improved cultivars is also constraint.

Research Methods

Standard research methods are used for all of the Honduras related research. Research is concentrated at Choluteca, Comayagua, and Zamorano, with another site, Rapaco, used to grow early generation breeding material and screen for adaptation and drought resistance. Entomological field work, on-farm trials, and agricultural economics research is largely done in farmers fields in Southern Honduras, the major sorghum area. The maicillo criollo breeding is all done on site in Honduras. Some of the breeding and selection for nonphotoperiod sensitive varieties and hybrids is done in the U.S., with advanced material then sent to Honduras for evaluation and use. Elite U.S. breeding lines serve as the major source of desirable traits in the maicillo enhancement breeding program.

Research Results

Detailed results covering much of the research in Honduras can be found in the TAM-131 Project Report within this 1992 INTSORMIL Annual Report.

Maicillo Enhancement and Hybrid Maicillo

The major breeding effort in Honduras is two-pronged: one is to develop improved maicillo varieties and the other is to develop female and male maicillo derivative parental lines to be used in the production of photoperiod sensitive hybrids. Selected enhanced maicillo varieties have been extensively tested in research station plots and in on-farm trials, with promising results. The enhanced maicillos show an advantage in yield, especially when combined with improved agronomic practices, as well as in traits such as grain quality and disease resistance. Some of the improved maicillos have been saved and are being maintained and used by farmers.

The experimental hybrid maicillos, containing varying proportions of maicillo criollo germplasm, show outstanding yield potential, demonstrating the advantage of hybrids over pure line varieties. The photoperiod sensitive improved maicillos and the maicillo derivative parental lines should be very useful to sorghum breeding programs in Africa and around the world where photoperiod sensitivity is needed. F2's involving improved maicillos were planted in southern Mali in 1991, and they segregated for a wide range of maturity from early to very late. They appear to be an excellent source of lateness for the areas of Mali with a long rainy season.

Nonphotoperiod Sensitive Hybrids and Breeding

Several excellent hybrids parental lines and breeding germplasm source lines were identified in the Texas A&M developed ISTAT (International Sorghum Tropical Adaptation Trial), IFSAT (International Food Sorghum Adaptation Trial), ITVAN (International Tall Variety Adaptation Nursery), ADIN (All Disease and Insect Nursery), and GWT

(Grain Weathering Test). These trials contain a wide array of elite Texas A&M developed parental lines and hybrids, elite germplasm sources, and elite new breeding lines from the various Texas A&M sorghum improvement programs. They were grown at various locations in Honduras in 1991 including Zamorano, Choluteca, Comayagua, and Olancho. The best male parents were 86EON361, 87EON366, R8510, R8503, Dorado, 84C7730, Tx434, R8606, SC1207-2, and some new lines (R8505*Tx2817) der., (Tx430*Tx2816) der., and (Tx435*Tx430) der. The best females were ATx631, ATx626, ATx635 (A Var), ATxArg1(AArg34), A1, A8106, and A4R.

Outstanding breeding lines identified from the ADIN, GWT and ITVAN include: (Tx430*Rio)-15, 87BH8606-[illegible], 90CCEON362, 87EON366sis, B1, 86FON362, 82BDM499, TAM428, B8618, 90CW8147, MB108B, 88B1214, 90EON328, 88C4910, 88B943, (Malisor 84-7*VG153) sel90L19178, and (Malisor 84-7*VG153)sel19037, TP21RB02-130, (RTAM428*SC414-12)-CSPBKF2-12 and-CSPBKF5, and (Malisor 84-7*87EON366)sel19254, and (Sureño*VG153)sel90CC549.

Research on head smut resistant sources and breeding was conducted by Alejandro Palma (Honduran, M.S., TAMU, Miller) in Texas.

Germplasm Conservation

The maicillos criollos of Central America are a unique group of sorghums regarding their adaptation, use, photoperiod sensitivity, and type. Their exact origin is unknown and no similar types are known to be present in the current World Sorghum Collection. Maintaining this valuable source of genetic diversity, while at the same time enhancing the germplasm is a major objective of the INTSORMIL/Honduras sorghum improvement program. Conservation of genetic diversity *in-situ* is a major thrust and is being accomplished by the extensive use of a large number of maicillo cultivars in all breeding efforts. Also important in this effort is the extensive use of on-farm trials as a method to get enhanced maicillos in use by farmers, where additional selection and evolution can occur.

Forage Hybrid

A sorghum-sudan hybrid, ATx623*Tx2784, was in pilot production by EAP, and performed well in feeding trials. It as planned for release in early 1993. It is resistant to pathotype 1 of downy mildew.

Cereal Quality and Utilization

Forty sorghum grain samples, grown in 1991 at Choluteca and at Comayagua in the EIME Advanced Improved Maicillo Crillo Trial, were evaluated for alkaline cooking and tortilla production in the cereal quality laboratory at Texas A&M using standard methods developed over the past few years. They also were evaluated for physical and chemical characteristics. The grain was generally clean and bright at both locations with significant variation in pericarp removal, color of the alkaline cooked grain, hardness and other properties. Some of the lines had good potential for use in tortillas, however, they are more dense with a harder endosperm requiring more cooking than the maicillos currently used. The soft maicillo grain cooks more quickly than the new lines but the color of the tan plant, straw glume sorghums is far superior. Some new lines have thick pericarp which is removed readily during lime cooking and is a definite advantage. Additional trials of the promising samples are underway.

In addition, seven entries from the PCCMCA sorghum trials are being analyzed for tortilla making potential and kernel characteristics. Grain from farmers fields of two experimental improved maicillos will be evaluated for tortilla making properties using the pilot scale equipment at Texas A&M to confirm tortilla quality.

Evaluation of the grain of the improved maicillos DMV-179, DMV-197, local criollo, from on-farm trials, compared to Sureño indicated the improved maicillos to be equal to, or superior to the local maicillo criollo in most traits. The IM's require a greater cooking time than the criollo, but the vastly improved color of tortillas and keeping quality of the harder grain of the IM's are excellent advantages. There are instances where farmers are planting Sureño because of its enhanced tortilla quality.

Entomology

Noncrop host plants in and around intercropped sorghum and corn fields were identified. A grass weed *Ixophorus unisetus* was observed to be a good ovipositional host plant. This information will be useful in developing sampling procedures for fall armyworm eggs and/or young larvae in early season.

Two of the armyworms, *Spodoptera frugiperda* and *S. latifascia*, in the "langosta" complex were observed in larval host preference and host feeding performance studies. Results have elucidated the importance of noncrop vegetation around the crops as preferred or not preferred by young larvae. Larval and adult developmental studies with *S. latifascia* included observations on mortality, weight gain, developmental time, sex ratio, fecundity and adult morality. The influence on fitness of the insect pest fed certain host plants explains, in part, the decline in numbers of this pest as the season progresses. Those insects feeding on corn or sorghum do not have a high survival rate.

Larval feeding induction studies were conducted to determine if larvae that initiate feeding on a weed plant get induced to it and are thus less likely to move in search of another host than those that do not get induced. Information obtained included sequence of hosts visited, time spent on host, weight of food consumed, and weights of the insects. This information will assist in determining the extent of weed management necessary for specific production areas having different plant communities. Several Honduran landrace sorghums were identified with antibiosis resistance to fall armyworm, *S. frugiperda.* (Table 1.) Insects responded to feeding on resistant plants by having low net reproductive rate and/or low intrinsic rate of natural increase of the population. Antixenosis (non-preference) and/or antibiosis resistance mechanisms were identified. Levels of resistance in some lines were maintained over five generations.

Table 1. Useful traits found in local maicillo criollios

Trait	Landrace/Cultivar	Other designation
Anthracnose, Ladder Spot and Rust resistance	Billy -203	SC1370
	Porvenir	SC1371
	Nance Dulce	SC1375
Fall Armyworm resistance	San Bamardo III	SC1207
	Lerdo -104	SC1384
	Pina -61	SC1385
Drought tolerance	Cacho de Chivo	SC1211
Shade tolerance	Cacho de Chivo	SC1211
	Billy -203	SC1370
	Coludo -110	SC1377
	Lerdo -104	SC1384

Pathology

The new pathotype 5 downy mildew nursery site near Comayagua at CEDA (former Japanese Irrigation Training Center) is developing well with good distribution of P5. A screening program has been established by Francisco Gomez using the CEDA site to screen, for a modest fee, private seed company lines and hybrids they desire tested. This is a valuable service to seed companies selling seed in Latin America, where many countries demand downy mildew resistance on imported hybrid seed, or hybrid grown in the country. Several breeding lines in the ADIN were resistant to P5 downy mildew at Comayagua, including: 87BH8606-6, QL3, Sureño, 90CCEON362, R6078, B1, 90EON328, 86EON362, B8710, 82BDM499, B8618, 90CW8147, and 88BD1749. In hybrid trials, it appears that A8618 is providing a dominant form of resistance to P5.

The ISDMN (International Sorghum Downy Mildew Nursery) and ISAVN (International Sorghum Anthracnose Virulence Nursery) were grown at several locations in Honduras in 1991. Although downy mildew is now found in most sorghum producing regions, the ISDMN indicates that pathotype 1 only is present, except for the P5 found in the Comayagua Valley. Anthracnose is a problem, primarily, in the areas of commercial hybrid production such as Olancho and Danli regions. Rust is a severe foliar disease. Several good sources of rust resistance were identified in the TAMU trials: TAM428, SC326-6, 87EON366, 88S61, 90CW8147, 87EON109, 88BD1749, 87H8606-6, 87EON366sis, TP21RB02-106, SC1123-11E, 85C13082, 90BE3533, BTx631, and Tx2883. It is noteworthy that many TAM428 derivatives show good resistance.

Economics

The economics program continued to publish the results from the earlier fieldwork on the introduction of new cultivars and associated technologies in southern Honduras. These results demonstrated the high returns to research and the need for complementary agricultural policy to avoid the price collapses resulting in good rainfall years (Lopez-Pereira et al., 1992).

The importance of first introducing conservation measures in hillside units to prevent farms washing down into the valleys was also stressed in a paper to the annual meeting of the Soil and Water Conservation Society (Lopez-Pereira and Sanders, 1992).

Sureño has found widespread acceptance throughout the sorghum growing regions. In 1991, Ing. David Erazo conducted a follow up study of those farmers who tried Sureño in 1988 and found that Sureño had substituted for 28% of the maicillo area. Much of its success is due to its improved cereal quality (due to tan plant color and grain traits), yield potential, and dual purposes for use as a forage and grain.

Agronomy

The physiologic and agronomic response of 'maicillos criollos' landrace sorghum to light intensity and intercropping was studied. Traditionally, maicillos are planted intercropped with maize to hedge against drought spells that severely reduce the grain yield of maize. To evaluate the effect of intercropping and the tolerance to shade of maicillo, 12 sorghum cultivars (3 maicillo landrace cultivars, 3 temperate varieties and 6 enhanced maicillo cultivars) were evaluated using three cropping systems, pure stand, casado and aporque.

An experiment was planted at Mead, NE (see project UNL-113) using these genotypes and cropping systems. Since maicillo won't flower in Nebraska, due to its sensitivity to photoperiod and seasonal requirements, a similar experiment was planted in Honduras with the aid of Dr. Dan Meckenstock (TAM-131), therefore starting a collaborative effort to improve sustainable production systems in Honduras. Details of the results can be obtained from project UNL-113.

Mutual Research Benefits

The landrace food type sorghums (maicillos criollos) from Central America are providing a new source of several useful traits for use by U.S. public and private breeders. Useful traits identified in the maicillos include fall armyworm resistance, anthracnose, ladder spot, and rust resistance, shade tolerance, drought resistance, and arid soil tolerance (Table 1). Honduran researchers have access to elite U.S. photoperiod insensitive food type sorghums, and parental lines, and elite sources of resistance to all major disease and insect pests, drought, and lodging, as well as, diversity from the converted sorghum lines which are from sorghum growing areas throughout the world. The entomology and pathology research in Honduras is identifying sources of resistance and developing germplasm useful in the U.S. The food quality research in Honduras can enhance the utilization of sorghum in the Central America region as well as contribute to alternate uses of sorghum in U.S. and throughout the world. The improved maicillos being developed in Honduras are an important source of late maturing germplasm for use in sorghum improvement programs in Africa where highly photoperiod sensitive types are needed. The hybrid breeding program of photoperiod sensitive sorghums in Honduras is the only one in the world, and should have worldwide implications.

Institution Building

Research Supplies and Support

The USAID/H Mission contributed 479,000 lempires of PL480 funding (equal to $88,700) in 1991 to the EAP for sorghum research.

Training of Host Country Researchers

Dr. Francisco Gomez (Ph.D., TAMU) is currently a sorghum breeder and Head of the National Sorghum Program.

Carlos Trabanino (M.S., MSU) and Lorena Lastres (M.S., TAMU) are entomologists with the MIPH (integrated pest management) project at EAP.

Marco Castro (M.S. and Ph.D., MSU) is an entomologist with Standard Fruit Company in Honduras.

Host and U.S. Scientists Visits

To Honduras

Darrell Rosenow, Fred Miller, Gary Peterson (breeding), Bobby Eddleman (INTSORMIL Board of Directors), and Aboubacar Toure (Ph.D. - Texas A&M, currently plant breeder and INTSORMIL Host Country Coordinator in Mali), Dec. 4-10, 1991.

Frank Gilstrap (entomology), Fall, 1991 to recruit student.

Henry Pitre and Hector Portillo (entomology), June 16-22, 1992.

Hector Portillo (entomology), summer, 1992.

To United States

Ing. Robert Villeda Toledo, MNR (Advisor to the Minister), Francisco Gomez, and Dan Meckenstock to the International Sorghum and Millet CRSP Conference, July 8-12, 1991, Corpus Christi, TX.

Francisco Gomez and Dan Meckenstock to Kansas City for INTSORMIL EZC meeting, July 29-30, 1991.

Francisco Gomez and Dan Meckenstock to College Station, TX, May 11-13, 1992 to discuss INTSORMIL/ICRISAT collaboration in Central and South America.

Mr. Jose Monroy (entomology), to Texas A&M Feb. - June, 1992, short term training with F.Gilstrap.

Networking

In-Country

Frequent meetings of INTSORMIL, SRN, EAP, and USAID researchers and administrators are used to plan research and share research results. Extension personnel identify problems and research needs and assist in on-farm research and distribute seed of new cultivars. Most on-farm trials with improved sorghum cultivars are in cooperation with LUPE, a USAID sponsored soil and water conservation project in Southern Honduras. Technical assistance is provided on seed increase of newly released cultivars. Graduate student research conducted in Honduras is planned through visits of the U.S. PI with appropriate collaborators and institutions in Honduras. A new USAID supported InterCRSPing program is being developed for Southern Honduras involving INTSORMIL, TropSoils, Bean/Cowpea, Pond Dynamics, and SANRAM. Meckenstock is serving as the key coordinator among these CRSP's, USAID, and SRN.

Regional

Regional networking consists of direct contacts at the annual regional meetings of CLAIS, PCCMCA, and the Latin American Workshops (cosponsored by INTSORMIL and ICRISAT). Francisco Gomez currently serves as chairman of the CLAIS Steering Committee. Research results, through improved breeding lines and materials, are disseminated through regional nurseries and tests developed by ICRISAT/LASIP/CLAIS. PI's from the U.S. attend and participate in these meetings and workshops, and make direct contacts and present research results. Another networking activity is direct visits to countries such as El Salvador and Guatemala (as security permits), with exchange of sorghum breeding germplasm and collaborative research activities developed through such visits.

Research Accomplishments

INTSORMIL activities in Honduras began in October, 1981 with the placement of Dr. Dan Meckenstock, INTSORMIL/TAMU sorghum breeder, at Choluteca in southern Honduras. He was instrumental in renovating the La Lujosa Experiment Station near Choluteca, rejuvenating the Honduran National Sorghum Program, and establishing an active sorghum improvement program in Honduras.

A landmark study of the sorghum-maize intercropping farming systems, as well as nutritional studies, was done by Billie and Kathleen DeWalt and graduate students (UK) in the subsistence farm, hillside agricultural area of southern Honduras. They found sorghum to be an important risk aversion crop in the area because of its drought tolerance. Sorghum serves as a multipurpose crop with the grain used to make tortillas for human consumption, especially when the corn crop is poor, and grain and stover being fed to livestock. The major constraints to production and utilization were identified and are the basis for the direction of the INTSORMIL/SRN collaborative program.

Extensive sociological and nutritional field research studies were done by Mary Futrell (MSU) and students in three localities in southern Honduras where sorghum is a staple food. Although a substantial amount of malnutrition exists, it was determined that with the use of sorghum in the diet, it is possible to grow enough maize, sorghum, and beans to meet energy and protein requirements.

Three releases of photoperiod insensitive improved sorghums have resulted from the SRN/INTSORMIL collaborative program. The variety Tortillero was released in 1982, the hybrid Catracho was released in 1984, and the variety Sureño was released in 1985. All are white seeded, food type sorghums that produce good quality tortillas. Sureño is a dual purpose variety with good disease resistance, tan plant and grain with resistance to the maize weevil, grain mold, and weathering. Extensive seed increases have been made of all three, especially of Sureño, in cooperation with the Honduran Department of Seed Production, and distributed to farmers through Recursos Naturales and Extension personnel. Sureño has been accepted quite well in southern Honduras, with one survey indicating 28% of the farmers had tried it, and 48% of those have adopted it.

Extensive on-farm testing indicates that Sureño and Catracho produce higher grain yields than traditional maicillo criollo varieties. Data from 47 sites showed an increase over local cultivars with traditional practices of 23% and 38% respectively. The magnitude of their yield advantage increased considerably when seed was treated with a systemic insecticide (37% and 63% respectively) and when seed treatment was combined with 60 kg/ha nitrogen (68% and 113% respectively).

The improved maicillo advanced breeding lines performed very well in yield trials, including the EIME Advanced Improved Maicillo Yield Trial, and the most promising have been used in extensive on-farm trials. On-farm trials in 1989 indicated that the improved maicillo lines yielded slightly better than the traditional maicillo with traditional cultural practices, but had 30 to 50% higher yield when using an insecticide, seed treatment, and fertilizer. Grain of the IM's is supplied to the Cereal Quality Laboratory at Texas A&M University, where extensive grain quality evaluation is performed. A few of the improved maicillos had grain and tortilla quality equal or superior to the local cultivars. The tan plant, straw glume lines were particularly good for tortilla quality.

Hybrid maicillos have shown a large yield advantage over local maicillo varieties. Breeding for hybrid maicillos has become a priority breeding objective. Some B-line improved maicillos have been identified and are being sterilized and new restorer lines have been developed.

A sorghum-sudan-grass F1 hybrid (ATx623xTx2784) to be called Ganadero, for use as a forage for livestock is planned for release in early 1993.

Research on grain quality indicates that sorghum grain with certain traits can produce tortillas of comparable quality to those of maize. Important traits were found to be white grain with an absence of pigment or staining, grain with little or no grain mold or weathering, grain with a thick pericarp to facilitate pericarp removal, and grain which retains a light color in the presence of alkali. Tan plant color and tan or straw colored glumes are also desirable. Quick quality tests and cooking trials have been developed to screen breeding material for these traits. Development of high yielding, food type sorghums with these grain quality traits should have direct and significant application not only to Honduras, but to surrounding countries such as El Salvador and Guatemala where sorghum is a traditional food, as well as to Mexico and other countries of Central and South America where sorghum can be used as a replacement or substitute for maize.

The released variety, Sureño, and some of the improved maicillo lines produce tortillas superior in quality to the local landrace maicillo criollo cultivars, especially those with tan plant and glume color, and enhanced grain mold/weathering resistance.

Diseases of sorghum in Honduras have been identified, and their importance determined through incidence, severity, and loss assessment studies. Diseases of major importance are downy mildew, MDM, grain mold, acremonium wilt, and foliar diseases such as gray leaf spot, rust, zonate, ladder spot, gray leaf spot, and oval leaf spot. Local and introduced germplasm has been screened for resistance, and resistance sources have been incorporated into the breeding program. Acremonium wilt, a new disease of sorghum, has been identified as a potentially serious disease in Honduras.

Downy mildew was identified as a serious disease in several areas in Honduras. A new, virulent pathotype (P5) was identified in 1986 at Comayagua which attacks most of the commonly used sources of resistance in the U.S. New sources of resistance have been identified. A downy mildew screening nursery has been established at Comayagua.

Studies on biological control of the fall armyworm and stem borers have been completed, and an exotic parasite effective in controlling stem borers was mass reared and released in Honduras and El Salvador and apparently has become established, at low numbers, in both countries.

The complex of insect pests, especially seed and seedling pests, on intercropped sorghum and corn in southern Honduras has been identified, studied, and control strategies developed. Important seed and seedling pests include several soil inhabiting arthropods: white grubs, wireworms, rootworms, ants, and millipedes. The Langosta, a lepidopterous larval pest complex which ravages young sorghum and maize plants in southern Honduras in May and June, was identified to include southern armyworm, fall armyworm, and two grass loopers. A study of the ecology and population dynamics of these pests indicated that the presence of noncrop vegetation is important in the buildup of insect infestations prior to feeding on the crops. A grass weed was observed to be a good ovipositional host plant. Several native maicillos criollos, AF28, and TAM428 were identified as possessing a good level of resistance (antibiosis) to the fall armyworm. Midge resistant sorghums from the U.S. also show good resistance in Honduras.

Conservation of genetic diversity *in-situ* is a major thrust, and is being accomplished by the extensive use of maicillos in breeding lines, and through the extensive use of on-farm trials where improved maicillo are evaluated and then saved and used by farmers along with the landrace cultivars.

Over 200 native maicillos criollos (local sorghums) have been collected from Honduras and neighboring countries. Over 75 have been introduced into the U.S. and 44 have been entered into the cooperative TAES/USDA-ARS Sorghum Conversion Program. They should be very useful in broadening the sorghum germplasm base available in the U.S. and as sources of desirable grain quality and disease and insect resistance.

Numerous U.S. derived sorghum germplasm lines have been evaluated in Honduras and provide the primary sources of disease resistance, high yield potential, insect resistance, and weathering resistance used in the Honduran sorghum improvement program.

A close networking of sorghum researchers has developed in the Central America, Mexico, and Caribbean area as a result of the INTSORMIL activities. This is accomplished through cosponsoring five Latin American workshops with ICRISAT/LASIP at CIMMYT since 1981 (one each on pathology, quality, breeding, farming systems, and seed production), participating in and presenting research results at the annual CLAIS and PCCMA meetings, participating in regional CLAIS sorghum trials and nurseries, through germplasm exchange such as breeding lines, breeding nurseries, and collection exchange of local landrace varieties, and through direct visits to neighboring countries by INTSORMIL and Honduran scientists.

In late 1987, a major regional workshop emphasizing research on the maicillos criollos was held in Honduras, cosponsored by INTSORMIL, SRN, and ICRISAT/CLAIS.

A growth analysis study of a native maicillo and improved maicillo in pure stand and in association with maize indicated that the late maturing native maicillo has tremendous potential to produce biomass in the tropics.

Shade tolerance has been identified in several maicillos and improved maicillos. This trait could be very useful, not only in Honduras, but in other countries.

Seven Hondurans, plus two other Central American students, have been trained with most conducting their research in Honduras. Several Central American researchers have been involved in short term training missions to the U.S.

An extensive farm-level analysis conducted in southern Honduras was used to estimate the effects of adoption, income impact, and constraints to new technology introduction. On the hillsides, once soil conservation practices (rock terraces) were in place, farmers were interested in other new technologies. The combined use of terraces and new cultivars (Sureño and Catracho) increased expected income by 15%. If price collapse in good rainfall years is avoided, the income increase would be 58%. Estimates of the adoption of the new cultivars (primarily Sureño) by hillside farmers of southern Honduras range from 5% to 13% of the sorghum area.

Sureño has found widespread acceptance throughout the sorghum growing regions in Honduras. A study was conducted of farmers who tried Sureño in 1988, and results showed that Sureño had substituted for 28% of the maicillo area. Much of its success is due to its improved grain and cereal quality (tan plant and glume color and grain traits), yield potential, and dual purpose for use as both a forage and grain.

Mali

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Collaborative Program

The program in Mali is a coordinated effort among INTSORMIL and the IER. The vital collaboration continues to provide efficient use of resources. In Mali, each Malian scientist develops research plans cooperatively with an INTSORMIL counterpart which provides for effective research planning, communication and coordination. Major INTSORMIL collaborators travel to Mali annually during the critical period of the crop year to consult, review progress and plan future activities with their Malian counterparts. Individual INTSORMIL investigators transfer funds to Malian counterparts to provide additional support to accomplish the research.

Memorandum of Agreement

A Memorandum of Agreement to allow transfer of funds was signed in Mali on October 10, 1984. The 1991-92 work plan and budget were developed and approved by IER in July of 1991.

Production and Utilization Constraints

Yield stability in sorghum/millet production is of major importance where food production is marginal relative to population. Low soil fertility, drought, diseases, and insects are major factors affecting yield instability.Milling properties of the grain are critically important. Head bugs and molds adversely affect grain quality, especially of the high yielding introduced sorghum lines, sometimes rendering the grain unfit for human food. Surplus production of grains in good years causes reduced prices. Transformation of sorghum and millet into new shelf stable foods and industrial products is required to encourage local production of grains and to enhance agribusiness activities, i.e., food processing and poultry feeding.

Efforts are concentrated to strengthen research on breeding, crop physiology, soil and water relationships, entomology, pathology, and food processing and technology. An effort to develop new food products from cereals and legumes is emphasized. Selection for enhanced drought resistance is a major concern. Major activities involve the introduction and use of new genetic materials in breeding programs to develop cultivars to increase or stabilize grain yields with desirable food quality.

New Opportunities

The Malian program has continued work on millet entomology, breeding, quality and cropping systems. Work to develop *Striga* resistant sorghums and photosensitive late maturing sorghums to escape the head bugs and molds was expanded. InterCRSP activities were initiated for breeding and selection for nutrient efficiencies during the 1992 cropping season by a Malian sorghum breeder who returned to Mali. A Malian Ph.D. soil scientist will return to Mali to collaborate in this program in late 92 or early 93.

Research Progress

Germplasm Enhancement

Striga Resistance and Breeding

F_2 seed and 40 F_3 selections of the cross (SRN-39*Malisor 84-7) were sent from Texas to Mali and evaluated in 1991 under natural *Striga* infestations. Ten F_3's were selected for further use based on *Striga* resistance and grain yields at Katibougou. The resistance of SRN-39 was expressed under natural *Striga* infestation in Mali.

A replicated *Striga* trial from Dr. G. Ejeta, Purdue University, containing resistant and susceptible progeny of SRN-39 and Framida was sent to Mali for planting in the 1992 crop year. Several local Guineense cultivars collected in southern Mali have a local name, Séguétana, which means *Striga* resistant in the local (Bamana) dialect. A few have been introduced into the USA for laboratory evaluation by Dr. Butler, Purdue University. They will be included in the *Striga* evaluation trials in 1992 in Mali.

International Food Sorghum Adaptation Trials (IFSAT)

Grain yields of the International Food Sorghum Adaptation Trials at Cinzana Mali were excellent in 1991 (Table 1). Again, as in 1990, the top yielding hybrids were crosses with Dorado with the top performer yielding 5.03 tons per hectare. However, the head bug-grain mold complex was

Table 1. Yield and quality of selected entries in the International Food Sorghum Adaptation Trials (IFSAT) grown at Cinzana, Mali in 1991.

	Mean				
Treatments	50% bloom (days)	Plant height (m)	Yield (t/ha)	Decort. yield (%)	T6 texture (mm)
ATX 631*Dorado	62bcdef	2.22b	5.02a	48.8	9.3
AArg 34* Dorado	60defgh	1.88d	4.84a	52.2	13.9
AVAR * Dorado	61cdef	1.94d	4.11ab	66.6	9.0
ATX 630* R 3338	60defgh	1.46mno	3.09bcde	63.7	15.9
AArg 34* R 8510	62bcdef	1.66efghi	2.82cdef	57.4	8.3
Sureño	66a	2.06c	2.27cdefghi	62.5	10.3
Dorado	65abc	1.47lmno	2.31cdefghi	76.1	9.3
ATX 631*CSC120*TX7000	56ijklm	1.61ghijk	2.11defghi	40.4	7.6
ATX 631* R8505	55jklm	1.53klm	2.31cdefghi	48.5	9.5
VG 153	66a	2.36a	2.73cdef	64.0	8.0
Malisor 84-7	65abc	1.48lmn	2.22cdefghi	70.0	8.0
ATX 631* RTX 435	59efghij	1.65e..j	2.28cdefghi	46.6	9.7
ATX 631* R 8504	59ef..j	1.47k..o	1.95defghi	55.8	9.3
Checks					
Malisor 84-1	61defg	2.24b	3.07bcde	66.8	8.2
Malisor 84-7	66a	1.33pq	2.04defghi	70.3	9.3
Mean	59	1.61	2.59	54.9	9.9
CV %	3.41	3.33	23.13		
sd				10.0	2.0

very severe and reduced the grain quality drastically for most entries, even for the tan plant entries. Sooty stripe was a serious problem also.

Only hybrids with Dorado and A-Var(Tx 635) had acceptable grain quality (Table 1), while only Dorado, A-Var, R3338 (waxy) and R-8510 had some resistance to sooty stripe. The major defect in quality was reduced decortication yields which is a major problem when head bugs and molds soften the endosperm. The color of porridges from the tan plant sorghums was far superior to that of purple or red plants.

Head Bug/Grain Mold Breeding Progress

Malisor 84-7 is an excellent source of resistance to head bugs. A large number of progenies from Malisor 84-7 have been identified as resistant to head bugs and have been entered into multi-location trials across Mali. The progenies have excellent agronomic, grain quality and disease resistance which should lead to a potentially useful variety. R-6078, a grain mold/weathering resistant type from Texas, was identified as tolerant to head bugs by Dr. Doumbia in Mali. It appears that the combination of head bug resistance with grain mold and weathering resistance is possible. Two ICRISAT-developed lines from Burkina Faso, ICSV 1079BF and ICSV 1089BF, possess useful head bug resistance along with desirable agronomic characteristics. Other sorghum lines identified as very useful in the breeding program based on performance of breeding progeny in Mali include: Dorado, Sureño, 86EON361, M50009, VG-15, E 36-1, S-34, ICSV 401, ICSV 1079 and ICSV 1002. The progeny of CE 151 perform very well in the dry, northern areas of Mali.

Head bug resistance appears to be quantitative and recessive in nature. Several Malisor 84-7 derivative breeding lines were selected for grain hardness and overall grain quality in Texas, and then evaluated in Mali in 1991. Only a few showed acceptable levels of head bug resistance, indicating that endosperm hardness alone does not result in head bug resistance. Other unidentified factors appear to be more important. To successfully select for head bug resistance, it is necessary to screen in the presence of heavy head bug pressure.

The combination of head bugs, grain molds and weathering, causes significant damage to the quality of the grain that is produced in addition to yield reduction. Even the local photosensitive types are attacked by head bugs with resulting pigmentation of the grain which gives food products an unattractive purple or red color. For food use in the more humid areas of Mali, the development of tan plant varieties, photosensitive, with straw colored glumes should be emphasized to minimize the color and avoid grain molds. Only then will sorghum be a high quality raw ingredient for processing value-added, shelf-stable foods that have an excellent chance of competing with rice, wheat and maize products. Grain yield, per se, is not the most important criteria for Malian breeding programs. Yield of high quality food products per hectare should be the major criteria for selection of sorghum in Mali.

Late Photosensitive Cultivar Development

Numerous crosses with the very late photosensitive Maicillo Criollo and improved Maicillo Criollo sorghums from Honduras (developed by Dr. Dan Meckenstock, INTSORMIL sorghum breeder, TAM-131) with elite high yielding and Guinea types were made to develop breeding material for the southern part of Mali which requires long season cultivars. Several F^2 populations were grown in Mali in 1991. Segregation for maturity was excellent with a wide range of maturities present from early, photo insensitive plants to late plants like the original Maicillo Criollo derivatives from Honduras. The Maicillos Criollos provide excellent sources of late maturity genes; but, the grain is attacked by head bugs and molds. Selections from the F^2 segregating populations were planted for selection/ increase/evaluation in southern Mali during the 1992 crop year. In addition, three trials were planted in 1992 in southern and central Mali consisting of sorghums with ultra late genes and normal comparisons to determine potential new methods of developing hybrid, photosensitive sorghums. This could lead to a major improvement in sorghum yields, and especially grain quality, because the photosensitive hybrids would mature after the rains.

Heterosis Studies of Guinea Sorghums

Relatively low yields of guinea sorghums have been a major obstacle for sustained progress in yield improvement of the race in West Africa. Several genetic analyses were completed on guinea and non-guinea forms of sorghum. From an evolution point, the guinea form apparently evolved differently from non-guinea types. During their evolution, adaptation and stabilization, these sorghums accumulated primarily genes which contribute to stability of grain yield and to such traits as hard grain with resistance to mold, weathering and insect damage which is useful in food grain quality rather than genes that contribute to high yield. Quality of Guinea sorghums can be improved dramatically by changing glume and plant color while retaining the other desirable characteristics. Such cultivars would provide grain of exceptionally high quality for processing into value-added products. Selections (F_3/F_4) of Guinea types with tan plant color will be evaluated in preliminary yield trials as soon as possible.

Pearl Millet Breeding

Downy mildew resistance in pearl millets is absolutely required in West Africa. U.S. pearl millets do not have acceptable downy mildew resistance. Therefore, crosses of elite U.S. millets with Malian millets are made in the U.S. and returned to Mali as F_1, F_2 or S_1 selections possessing the desired characteristics. Additional selection occurs in

Mali where downy mildew pressure is high. These methods provide new useful germplasm efficiently.

An effective level of drought tolerance is obtained by selecting millet lines that produce root systems that penetrate and extract moisture from soils with fine-textured, dense subsoil profiles. These types from the Kansas program have been sent for evaluation in Mali. Several S_1 lines derived from nine Malian varieties were screened in 1991 at Ft. Hays, Kansas under conditions where 200 mm of stored subsoil moisture was available to depths of 1.2 m in the soil profile. Only 157 mm of rainfall was recorded from planting to maturity. Using total biomass production and visual stress scoring as measures of drought response, highly significant phenotypic variation was found in the ability to extract stored soil moisture. A nursery of S_1 lines with drought response ratings ranging from poor to very good were selected from within four varieties and sent to Mali for drought stress evaluation in 1992. By limiting selection in Kansas to the S_1 generation, acceptable levels of downy mildew resistance should be retained.

Crosses between elite Kansas lines and materials from Mali have produced several excellent F_1 hybrids and F_2 families exhibiting good yield potential and drought tolerance. The best materials were sent to Mali for selection and advancement. Several F_2 families produce segregates with heights of 1.7 to 1.9 m suitable for intercropping with legumes.

Seed Exchange

Over 80 introductions of elite breeding lines and breeding progenies were introduced into the U.S. from Mali the past two years for use in the Texas/IER/INTSORMILcollaborative breeding program. These are useful for Texas and are crossed with other elite germplasm lines to generate new breeding material for use in the Malian program.

A large number of crosses involving drought and soil toxicity/acid soil tolerant sorghums, Bagoba, BabadiaFara, N'GaberiKimé and Gadiaba were made in Texas with elite sorghums from around the world with high yields, drought, disease and insect resistance and grain quality. F_2 seed was sent to Mali for planting in 1992. Other lines used extensively in these F_2's were SRN-39 (*Striga* resistance), Malisor 84-7 (head bug resistance), Ajabsido (drought resistance), as well as Sureño, VG-153, B Var1 (BTx635) and Dorado, which show some head bug resistance as well as grain mold resistance and improved grain quality.

Plant Protection

Sorghum Pathology

A major aspect of pathology research in Mali has been to examine the relations between head bug damage and molds on seed deterioration. It was observed that known mold resistant sorghums, such as SC748 and Sureño, develop extensive mold damage if the sorghum heads are not protected from head bugs. Protection from head bugs will be a requirement for evaluation of grain mold resistance. This is important because grain mold and head bug resistance is required in an improved sorghum cultivar for Mali. Fungi isolated from damaged sorghum seed in 1991 were predominately *Colletotrichum graminicola, Phoma spp.* and *Curvularia spp.* The infrequent isolation of *Fusarium spp.* may reflect the method or unique environmental conditions. Chemical control of grain mold using benomyl was ineffective.

Anthracnose has become a major concern; the level of disease remains high. Susceptible cultivars in 1991 were IS2057 and TX434. Both of these differentials are resistant at other locations, adding to the speculation that the isolates of *C. graminicola* in Mali are different from those in other regions of Africa and the Americas.

Seed Treatments for Pearl Millet Downy Mildew

Downy mildew, a major problem in millet production in West Africa, may be controlled by use of metalaxyl combined with carboxin and furathiocarb. The product called Apron® plus is produced by Ciba-Geigy and has been tested in Mali for several years at Cinzana and many other locations by M. Diourti and others. In 92 trials conducted over four years in Mali, mean pearl millet grain yield improvement was 21.3%. Part of the increase in performance can be attributed to increased stands, and seedling vigor, in addition to downy mildew control. Ciba-Geigy plans to market Apron® plus in Mali where the cost benefit ratio exceeds 1:5. Currently, extensive tests are being conducted in the 1992 crop year and Mr. O. Coulibaly, Ph.D. student at Purdue, plans to test the economic returns in summer of 1993.

This technology has the possibility of greatly enhancing millet production in Mali. However, there are potential toxicity and environmental problems which must be carefully evaluated prior to general use of the treatment. The technology may be a major break through in production of more grain in millet regions because the millet grows faster and makes more efficient use of all available moisture.

Head Bugs of Sorghum

Panicle Feeding Bugs of Sorghum

1991 was the third year of the collaborative sorghum entomology research program in Mali between Drs. Y.O. Doumbia and G.L. Teetes. The goals of the project are: 1) develop screening methods to find sorghum lines with resistance to panicle feeding bugs that are usable by plant breeders to evaluate progeny lines; 2) determine the relationship between bug abundance and damage and pathogen infection, grain deterioration and food quality; and 3) determine the relationship between resistance and glume, kernel and panicle characteristics. Research conducted included a preliminary screening trial, an advanced screening trial, an assessment of the interaction of panicle-feeding bugs with molds and determination of the most simple method to protect panicles from bug infestation and damage.

Preliminary Screening Trial

The trial involved 51 sorghum varieties from the National program, Texas A&M University and ICRISAT. These 51 varieties had been selected by screening 100 lines in 1989 and 1990. Bug abundance was recorded for 5 panicles and bug induced damage was rated. Other parameters measured included vitrosity, 1000 kernel weight, germination and flotation. Bug abundance was very high (mean of 140 bugs/5 panicles) as was bug damage ratings (mean = 2.4, range = 1.25 to 4.5).

Advanced Screening Trial

Nine sorghum varieties were tested for resistance to panicle-feeding bugs in an advanced trial. These had been selected based on screening experiments during 1989 and 1990. Based on multiple selection parameters, Malisor 84-7, R6078, B Var1 (BTx635), and '82selDur' Durra were the most resistant of the nine lines.

Interaction Between Bug Damage and Pathogen Infection

Panicles were protected from both bugs and molds using a combination of bags and fungicide (Benomyl) application. Damage to the grain was compared with grain from panicles unprotected from bugs or mold. Bugs were abundant (mean of 150/5 panicles). Both bugs and molds caused damage to sorghum kernels; the combination caused more damage than either one alone. Of the two, bugs caused more damage than mold, based on most damage parameters evaluated.

Grain Quality Studies

Additional work on parboiling of sorghum and millet confirmed that the variety was critically important for production of good quality, higher value, marketable products. The use of sorghum grain from the market resulted in products with high levels of dark, black or purple stained kernels that significantly lowered the appearance of the products. Good quality food products can be consistently made from only high quality sorghum. The best quality is obtained with grain from sorghum cultivars with white pericarp, without a pigmented testa, with tan plant color and straw color glumes. In the more humid areas of Mali, the grain must be photosensitive to escape serious damage from the head bug- mold complex. Thus, it is very important that plant breeders develop photosensitive tan plant cultivars that produce high quality, light colored kernels which will allow production of marketable processed foods such as large and fine grits, meal and flour. The yield of grain does not need to be increased drastically because the higher quality will enhance the value of the grain significantly for home use and for commercial production of value added products. Currently on the streets of Bamako, ladies sell processed corn grits and meal at premium prices because they are of good quality. Superior sorghum products could be sold in the same fashion. It is particularly ironic that a semiindustrial corn milling company, called CERECOM, produces dry milled corn products but cannot produce quality equal to that produced by the ladies.

There appears to be a niche market for good quality processed products sold at reasonable prices in Mali. But, the major hurdle is the lack of good quality sorghum for processing. The market samples of sorghum evaluated are blends of white sorghum with badly stained kernels that cannot be processed into top quality products. The obvious solution is to produce good quality grain and process it into a good quality product that is priced high enough to produce a profit; but significantly lower than rice. Products with potential are parboiled and nonparboiled decorticated sorghum of various sizes for use in traditional dishes. The technologies are available but the sorghum cultivars are not ready yet. The IER breeding program has a few photosensitive, white, tan, straw glume advanced sorghum lines in multilocation trials which could be useful if their yields are at least equal to local cultivars.

Laboratory Evaluation of Samples from the Crop Improvement Program

Research continues in Mali, in the Food Technology Laboratory, to improve methods of selecting sorghums and millets for tô quality. Sorghum and millet lines and varieties from the Malian breeding programs were evaluated for kernel characteristics, physical properties, decortication yield and the properties of fresh and stored tô. The tangential abrasive dehulling device effectively provides decorticated grain for tô tests. When only small quantities of grain are available, a mini tô test is performed on the flour. Potential new cultivars are compared with local cultivars for porridge texture and keeping properties. For advanced materials, larger samples are milled, cooked into tô, and evaluated in larger cooking trials as needed.

Milling and tô properties of grain from the IFSAT trial, grown at the Cinzana station in 1991, showed that head bugs and mold softened the grain and significantly reduced the yield of decorticated grain although a few cultivars had acceptable milling properties (Table 1). Only selected, illustrative data are presented; but, a few cultivars, especially Dorado and its crosses, had acceptable dehulling properties with high grain yields. The waxy hybrid, ATx630*R3338, had good milling properties; but, the porridge quality as expected was poor with a very unacceptable color because of its purple plant color. The cultivars with tan plant color, even though badly damaged by head bugs, had acceptable tô color. Parboiling the damaged kernels from tan plants enhanced milling yields significantly and still produced acceptable color tô. The presence of head bugs and molds create very serious problems limiting the use of high yielding sorghums in Mali. Processing the damaged grain could be one possible alternative or it could be used for poultry feed. Ultimately, there will be sorghum grown for food and lower quality, higher yielding sorghums will be grown for livestock feeds.

Millet Grain Evaluation

Grain of 11 varieties of millet grown at Cinzana was parboiled using a soak-boil procedure and the processing properties of the raw and parboiled samples were compared. The information showed that parboiling increased the decortication yields significantly and enhanced the texture and yield of the cooked decorticated grain but cooking time was also increased. The greatest response to parboiling was with soft kernels.

The food technology laboratory conducted several demonstrations of various food products prepared from sorghum, millet, maize and various grain legumes to distribute information to potential users. Popped sorghum, noodles and other products were made.

Agronomy Studies

Agro-Physiology

Previous research showed that treatment of sorghum seed prior to planting with abscisic acid (ABA) increased the drought tolerance of seedlings grown from this seed. It was also found that seed produced in Bema, Mali produced more drought tolerant seedlings than those grown from seed produced at Cinzana, Mali. Recent research involving seed analysis for free and conjugated-ABA, found that generally there was a greater accumulation of conjugated-ABA in seed produced in a stressful environment (Bema) than in seed (from the same source) produced in a less stressful environment (Cinzana). There were no differences between the locations in free ABA.

In further research on proline accumulation in sorghums, there were significant differences between genotypes in quantities of proline accumulated in roots, stems and leaves. Those sorghums accumulating high amounts of proline had significantly greater heat and desiccation tolerance than those that accumulated less proline. Landraces obtained from Mali had high heat and desiccation tolerance.

Soil Toxicity Studies

Several field experiments were implemented to alleviate soil chemical properties associated with nutrient deficiencies/toxicities in sandy soils of the Cinzana station as well as to test contrasting sorghum genotypes in these soils. These experiments were conducted for 2 consecutive growing seasons (1990 and 1991) in the same experimental units. Sorghum genotypes tested included Babadia Fara, CSM 63, Malisor 84-5 and ATx631 x Dorado. The genotypes were tested in combination with low levels of both N and P.

The symptoms of poor early sorghum growth (leaf yellowing and purpling followed by seedling death) were displayed at a lower percentage in 1990 by Malisor 84-5 (susceptible control) in comparison with previous data. In addition, leaf purpling (typical symptom of P deficiency in sorghum seedlings) was displayed by each of the above genotypes except Babadia Fara. Soil conditions strongly affected the different genotypes in 1991 (Table 2). Leaf purpling was displayed by seedlings of Babadia Fara, but rates of survival were significantly higher.

Table 2. Genotype growth and yield in 1990 and 1991 (control plots only) genotype affected seedlings

Genotype	Affected seedlings (%)	Grain yield (kg ha^{-1})
	1990 Growing Season	
Babadia Fara	0	1038
CSM 63	0	1275
Malisor 84-5	2	601
ATx631 x Dorado	0	1346
	1991 Growing season	
Babadia Fara	25	554
CSM 63	45	455
Malisor 84-5	69	147
ATx631 x Dorado	91	0

The effect of different N and P levels were significant on sorghum growth. Combining the two nutrients significantly enhanced growth over applying either nutrient alone.

A common feature of each experiment was the high variability within and between experimental units. In addition, large variabilities were observed in the response of the different genotypes from growing season to growing season (Table 2). Average coefficients of variation were 58% in 1990 and 94% in 1991. Definitive conclusions cannot be made; however, it is clear that Babadia Fara is the best sorghum for soils with severe nutrient stress.

Cropping Systems

Two long-term cropping system studies were established in 1990. At the higher rainfall site at Samanko, cropping systems were sorghum-peanut based, while at the lower rainfall site at Cinzana, pearl millet-cowpea based systems were used. Randomized complete block designed experiments with split plot treatment arrangement and 4 replications were used. Continuous sole crop, continuous intercrop, and rotational systems were included as whole plot treatments, with N fertilizer rates as subplots. Data collected included grain and stover yields and yield components.

Three studies on crop residue management were initiated in 1990. The objectives of these studies are to determine variety (improved versus unimproved) interactions with crop residue level at different N rates, and effect of residue removal, residue incorporation and residues on the soil surface upon grain yield and soil properties. At present, only preliminary results are available.

Nitrogen (N) Levels and Cropping Systems

In both 1990 and 1991, no interaction between cropping systems and N rates occurred for either study. Application of 80 kg ha^{-1} N greatly increased the yield of sorghum, while pearl millet did not respond to levels of nitrogen above 20 kg ha^{-1} (Table 3).

Table 3. Influence of N rate on grain and stover yields of sorghum and pearl millet in 1991.

Sorghum yield			Pearl Millet yield		
N rate	Grain	Stover	N rate	Grain	Stover
		kg ha^{-1}			
0	1195a	3161a	0	970a	2545a
40	14[illegible]8b	3819b	20	1144b	3380b
80	17[illegible]4c	4544c	40	1048b	3528b

Means within each column followed with the same letter are not significantly different at $P < 0.05$.

The rotation of sorghum with peanut and pearl millet with cowpea increased both grain and stover yields (Table 4). When sorghum-peanut intercrop was the previous crop, sorghum grain and stover yield was increased over that of continuous sorghum, but not as much as following a peanut crop. In contrast, the previous millet-cowpea intercrop resulted in no improvement of either the succeeding pearl millet grain or stover yield. Sorghum showed a greater response than pearl millet to N application and the previous legume or cereal-legume intercrop than did pearl millet. Sole-cropped sorghum following peanut produced a yield equivalent to continuous sorghum with 80 kg ha^{-1} N application, while sole-cropped millet produced yield equivalent to 40 kg ha^{-1} N application. Analysis of intercropping efficiency using Land Equivalent Ratios (LER) indicated that the pearl millet-cowpea system was superior to the sorghum-peanut system (LER of 1.50 versus 1.15).

Table 4. Influence of previous crop on grain and stover yield of sorghum and pearl millet in 1991.

Previous crop	Present crop	Grain yield kg ha^{-1}	Stover yield kg ha^{-1}
		Samanko	
Sorghum	Sorghum	1393a	3138a
Sorghum-Peanut Intercrop	Sorghum	1961b	4887b
Peanut	Sorghum	2435c	6865c
		Cinzana	
Pearl Millet	Pearl Millet	1131a	3657a
Pearl Millet-Cowpea Intercrop	Pearl Millet	1144a	3175a
Cowpea	Pearl Millet	1350b	4422b

Means with identical letters have no significant differences among them at $P < 0.05$. Mean separations done within each experiment.

Nitrogen Use Efficiency in Sorghum

Experiments continued to determine the effect of nitrogen management on sorghum grown under different rainfall and soil conditions in Mali. A local genotype was compared to an improved type at each location in the test. The experiment was modified to use the Bema Station site which is characterized as a sandy soil area with rainfall of 350-400 mm. At the drier Bema site, there was no response to applied N in terms of grain or stover yields, although there was a tendency for the improved genotype to respond to N for stover production. The results were not surprising since the rainfall was low, and a severe post flowering drought occurred. There was a significant grain and stover yield response to applied N at the Samanko location which had better soils and higher rainfall. The improved genotype produced nearly double that of the local type, and responded to applied N at higher rates.

A new experiment was initiated at N'Tarla and Sotuba to compare local and improved sorghums for response to applied N. The sites have different soil characteristics and the N'Tarla site generally receives about 200 mm less precipitation per season than the Sotuba site.

In this experiment, all genotypes responded well to N application. At Sotuba, the maximum yields were obtained at the 120 kg ha^{-1} rate while at N'Tarla, the yield response was linear through 160 kg ha^{-1}. The local types outyielded the improved types because the poor seed quality of the improved types caused very poor stands. Yield stability from improved sorghums will occur most rapidly if seed quality and disease resistance is incorporated. Thus, head bugs/mold damage of improved sorghums affects subsequent stand establishment and grain yields as well as grain quality.

In Mr. A. Coulibaly's studies of sorghum growth rates and tillering, tiller number per plant was linearly related to growth rate during the first growth stage as determined under controlled temperature and light conditions for a number of genotypes at a range of plant densities. Genotypic differences were found for growth rate per tiller and response to temperature. Use of these results in model systems greatly overestimated field tillering response.

Institution Building

INTSORMIL has built and equipped a physiology agronomy laboratory at the Cinzana Agricultural Experiment Station to provide support for the expanded activities in agronomic and drought research being conducted by IER scientists. A new vehicle was purchased for cooperative programs in cropping systems and other activities conducted at Cinzana. Support to purchase supplies, labor and equipment for sorghum and millet breeding, entomology, pathology and grain quality enhanced the ability of IER to expedite those research programs.

Several students are training at INTSORMIL institutions. Mr. M. Doumbia, Soil Fertility, has nearly completed his Ph.D. thesis on the soil toxicity problem at Cinzana. This work is funded jointly by TROPSOILS and INTSORMIL.

Dr. A. Touré, Ph.D. in sorghum breeding at Texas A&M returned to Mali in May 1992, where he is a sorghum breeder and Malian INTSORMIL Coordinator located at Sotuba. Mr. Abdoul W. Touré completed his M.S. in agronomy at the University of Nebraska and returned to Mali in April 1992. Mr. O. Coulibaly continued studies for a Ph.D. in agricultural economics with Dr. J. Sanders at Purdue and will be conducting field research in Mali in 1993.

Mr. Adama Coulibaly completed his M.S. in agronomy at Kansas State University and returned to Mali. Mr. Sidi B. Coulibaly and Mr. S. Dioné finished M.S. degrees at the University of Nebraska and returned to Mali. Mr. S.B. Coulibaly is located at the Cinzana Research Station working on high temperature stress and soil-water relationships. Mr. S. Dioné is chief of the seed laboratory at Sotuba.

Networking

The research accomplishments in Mali are immediately and directly transferable to most countries in West Africa. The work on sorghum and millet food technology applies to Africa and many areas of the world. Head bug and drought research are common to West African areas. CIRAD has a research project funded by the EEC in the Food Technology Laboratory on grain quality. The effective working relationship between the Food Technology Laboratory and the Malian breeding and agronomic programs continues to provide useful information.

Dr. M. Traoré and Dr O. Niangado serve as Chairmen of the Steering Committee of the West and Central African sorghum and millet research networks, respectively.

Progress to develop an effective network of sorghum and millet scientists in West Africa continues. A key element is the leadership, spirit, and enthusiasm for collaboration shown by returning scientists trained in INTSORMIL institutions. These scientists have seen the benefits reaped by U.S. scientists through association/interaction in the sorghum improvement committee of North America. SAFGRAD has been very instrumental in promoting strong interactions among regional sorghum/millet workers which has been critically important.

Collaboration with the ICRISAT West African sorghum improvement program for Africa (ICRISAT/WASIP), located at Samako, on insects, disease, and quality has been excellent. For example, the IER Food Technology Laboratory annually evaluates WASIP samples for dehulling and tô quality. Excellent cooperative research on the relationship of head bugs and grain quality has been conducted.

Training

Thesis and dissertations completed during 1991-92 were:

Coulibaly, Adama. May 1992. Relationship between growth rate and tiller number in sorghum. M.S. Thesis, Kansas State University, Manhattan, KS. (advisor - R. Vanderlip).

Coulibaly, Sidi Bekaye. August 1991. Physiological characteristics of drought resistant sorghums. M.S. Thesis, University of Nebraska, Lincoln (advisor, C.Y. Sullivan).

Dioné, Siaba. October 1991. Influences of abscisic acid on sorghum growth and stress resistance. M.S. Thesis, University of Nebraska, Lincoln (advisor, C.Y. Sullivan).

Touré, Aboubacar. May 1992. Heterosis, combining ability and breeding potential studies for grain yield and yield components in guinea sorghums (sorghum bicolor L. Moench). Ph.D. Thesis, Texas A&M University, College Station, TX. (advisors D.T. Rosenow and F.R. Miller).

Touré, Abdoul W. May 1992. Effect of rate on time of application on pearl millet response to nitrogen. M.S. Thesis, University of Nebraska, Lincoln (advisor J. Maranville).

Mr. Abdoulaye Traoré initiated studies for a Ph.D. in agronomy in June 1992 at University of Nebraska, Lincoln.

Dr. A. Touré spent two months at Lubbock, Texas working with Dr. Rosenow's breeding program with visits to several commercial hybrid seed company research programs. INTSORMIL research on *Striga* screening and breeding at Purdue was evaluated and plans made to initiate additional research in Mali to obtain *Striga* resistance.

Travel

INTSORMIL travelers to Mali, included: Drs. L.W. Rooney, food scientist (twice), Dr. D.T. Rosenow, sorghum breeder, G. Teetes, entomologist, and R.A. Frederiksen, pathologist from Texas A&M University; Drs. C. Sullivan, physiologist, J. Maranville, agronomist, and S. Mason, agronomist from the University of Nebraska. Mr. William Stegmeier, millet breeder, Kansas State traveled to Mali to review and plan pearl millet breeding research.Dr. M. Traoré, physiologist, participated in the International Crops Symposium at Ames, Iowa and interacted with INTSORMIL PI's at the University of Nebraska in Lincoln.

Research Accomplishments

INTSORMIL has been in Mali informally since November of 1979. A formal Memorandum of Understanding was signed with IER in 1984. The program has interacted with ICRISAT-WASIP, TROPSOILS, IER and Ciba-Geigy.

Table 5. Malian scientists trained by INTSORMIL PI's

Name	Year graduated	Degree sought	Discipline
Moussa Dossolo Traoré	85	PhD	Physiology
Sidi Bekaye Coulibaly	91	MS	Physiology
Siriba Dioné	91	MS	Physiology
Abdoul W. Touré	92	MS	Agronomy
Adama Coulibaly	92	MS	Agronomy
Osman Coulibaly	*	PhD	AgriEconomics
Karim Traoré	90	MS	Millet Breeding
Minamba Bagayoko	90	MS	Agronomy
Aboubacar Touré	92	PhD	Sorghum Breeding
Abdoul A. Sow	*	PhD	Soils
Mamadou Doumbia	*	PhD	Soil Fertility
Assa Kanté	87	MS	Food Technology
Mamourou Diourté	88	MS	Pathology
Abdoulaye Traoré	*	PhD	Agronomy

* = currently studying, MS completed in Soil Fertility, supported by TropSoils.

USAID-Mali has supported the program morally and financially over the years. Some accomplishments are:

Training

INTSORMIL has provided graduate training for 14 key Malian scientists (Table 5).

Short term training in the USA for Malian PI's in physiology, breeding, soil fertility, food technology and entomology

Infrastructure

- Designed and equipped food technology laboratory at Sotuba
- Built and equipped physiology laboratory at Cinzana
- Provided computers/word processors for DIAL-COM and laboratories
- Short-term technical assistance on soil fertility/agronomy, entomology, pathology, physiology, food technology
- Physical and chemical analysis of soil profiles of Cinzana station
- Established and installed sprinkler systems to initiate screening procedures for drought tolerance at Cinzana.

Germplasm Enhancement

- Elite sorghums from all over the world have been incorporated into Malian breeding programs.
- Testing in Texas and Mali has demonstrated the drought response in Mali is similar to that in West Texas.
- Elite U.S. pearl millet lines crossed to Malian pearl millets have been introduced into Mali.
- Seven improved sorghum lines from the Malian program have been released.
- These Malisor lines (84-1 to 84-7) have different maturities and characteristics for the various regions of Mali.
- Malisor 84-7 has shown some advantages in multiple cropping systems.
- Malisor 84-7 has excellent tolerance to head bugs which can be genetically transferred to its progeny.

CSM 388 and CSM-219, improved local photosensitive Malian sorghum cultivars, are grown by farmers on a significant area.

Utilization

- Sorghum and millet postharvest technology systems in Mali were documented in 1979 and subsequent years.
- Strategies for evaluating the quality of cereals, especially sorghum, for thick porridge (tô) were devised.
- Equipment for the new Food Technology Laboratory was provided.
- Personnel were given short term training programs in the U.S.
- Mini tests for evaluating milling and tô properties were developed.
- Sorghum dehulling properties were defined by combined village trials and laboratory research in Mali.
- Sorghums with hard endosperm and thick pericarp were definitely required for efficient traditional hand pounding.
- Pearl millet quality is affected most by variation in kernel size and shape which significantly affects dehulling properties.

- Pearl millets with long, thin kernels (souna types), have drastically reduced yields of decorticated grain.
- Tô quality of millet cultivars does not vary as much as it does among sorghums.
- The combination of cowpea and millet flour (1:3) significantly improved the nutritional status of young children.
- This technology has been transferred to villages, especially in the Cinzana area.

Plant Protection

- The adverse effect of head bugs on the grain/food quality of introduced sorghums across West Africa was first recognized and documented in Mali.
- Head bugs and molds combine to cause devastating losses in grain yield and quality of most introduced types.
- Inheritance of head bug resistance is quantitative and primarily recessive.
- Head bug damage reduces sorghum milling yields.
- The damaged grain is difficult to dehull because the endosperm is partially degraded and the kernel disintegrates when pounded.
- The tô has unacceptable texture, color and keeping properties.
- Parboiling can convert sorghum and millet into acceptable shelf-stable products.
- Parboiling improves dehulling yields, especially for soft grains.
- The cooked milled products can be eaten like rice.
- Good quality sorghum (white, without stained kernels) is required to produce good quality shelf-stable food products.
- The development of photosensitive sorghums with tan plant and straw color glumes is required to produce high-quality, value-added products.

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 partially determined through joint INTSORMIL/TROPSOILS collaboration.
- Some Durra varieties from Niger and northern Mali show tolerance to soil toxicity.
- A soil crust breaker designed at ICRISAT has effectively enhanced the stand establishment of sorghum and millet. Millet and sorghum genotypes vary in ability to emerge through soil crusts.
- The poor seedling emergence of improved sorghums is caused by inferior seed quality caused by headbugs/molds.

Publications

Clark, R.B., G.N. Al-Karaki, and C.Y. Sullivan. 1991. Genotypic responses in sorghum to drought stress and phosphorus nutrition. p. 124,Agron. Abstracts, Am. Soc. Agron., Madison, WI.

Touré, A., F.R. Miller, L.W. Rooney, and C. McDonough. 1991. Grain filling rates in some genotypes of sorghum (Sorghum bicolor (L.) Moench). International Sorghum/Millet Conference. Corpus Christi, TexasJuly 8-12.

Touré, A., F.R. Miller, and L.W. Rooney. 1991. Grain filling rates among different genotypes of Sorghum bicolor (L.) Moench. Proceedings of 17th Biennial Grain Sorghum Research and Utilization Conference. Lubbock, Texas.

Bagayoko, M., S.C. Mason and R.J. Sabata. 1992. Effects of previous cropping systems on soil nitrogen and grain sorghum yield. Agron. J. 84:862-868.

Niger

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Coordinators

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Mrs. Katy G. Ibrahim, Administrative Assistant, Purdue University, West Lafayette, IN

Collaborative program

Organization

There are several interdisciplinary activities involved in the INTSORMIL/INRAN/Niger Collaborative Research Program. They include Sorghum and Millet breeding, agronomy, pathology, physiology, food quality and economics.

The INRAN Director General, and INRAN scientists are in agreement that more of the collaborative research support will go directly to INRAN scientists with collaborative ties to U.S. based INTSORMIL principal investigators. This proposal, involving INTSORMIL, INRAN, and USAID/Niamey, has been negotiated for 1993.

Collaboration with Other Organizations

Institut National des Recherches Agronomiques
du Niger (INRAN)
TROPSOILS
ICRISAT Sahelian Center
Agricultural Research Corporation (ARC), Sudan
University of Nebraska
Texas A&M University
Mississippi State University
Purdue University

Developing Collaborative Research Plans

U.S. INTSORMIL principal investigators develop research plans and budget with INRAN collaborators on an annual basis. Each plan is then translated into French and submitted to the INRAN Director General for his approval. INRAN has appointed Dr. Ouendeba Botorou as host country coordinator for this project. Dr. Moussa Adamou has been nominated as scientific director for INRAN.

Sorghum Breeding

- Breeding Sorghum Cultivars Possessing Good Resistance to Drought, Striga, and Acceptable Grain Quality

I. Kapran, G. Ejeta, and J. Axtell

The overall objective of this joint project is to select high yielding stress tolerant sorghum varieties/hybrids with good grain quality for use in Niger. Our efforts in 1992 were concerned with the following four trials.

In general, the 1992 crop season was characterized by late coming and erratic rains, and a serious midge infestation; as for the past few years we noticed that late planted materials suffered the most.

Trial 1 - A Yield Trial of Advanced Selected Progenies from Purdue: Trial 1 was planted at Maradi on July 9, on a sandy soil like all our trials at this location. There were 126 test entries selected on the basis of productivity and resistance to stress, contributed by Dr. G. Ejeta; to these we added four checks including varieties Mota Galmi (earliness), Mota Maradi (earliness and local adaptation), SEPON-82 (productivity) and NAD-1 F1 (productivity). The trial had four replications, each made of two ranges, and the checks were planted after every 20 test entries and at the beginning and the end of each range. After emergence, vigor scores were given and many entries were at least as vigorous as the checks. Unfortunately the trial suffered from a combination of soil problems and panicle insect damage. The soil problem was observed as a general yellowing of all sorghums in the field, five to six weeks after planting, and caused a severe reduction in plant growth as observed later on the checks. A poor seed set characteristic of midge attack was observed and percent grain loss was assessed for all plots.

Trial 2 - A *Striga* Resistance Trial from Purdue: Trial 2 was planted on July 12 at Konni under natural *Striga* infestation. There were 20 entries including SRN-39 and many of its derivatives. The trial had four replications and three row-plots; *Striga* plants were counted on each side of the middle row, twice during the crop season. *Striga* appeared in the trial and was counted but, in general, there were less *Striga* plants in this trial than in neighboring "regular" yield trials, our assumption being that resistance was expressed. Agronomic and yield data were also recorded. As in other sorghum and maize trials on this station, a vascular disease was noted on some entries of this *Striga* trial. It appeared as a reddening of the stalk and leaf blade vessels and ultimately lead to plant death. This disease was the subject among others of a trip to Konni by the INTSORMIL pathologist Dr. R. Frederiksen, together with the INRAN pathologist, Issoufou Kolo, and breeder, I. Kapran. In addition to the vascular disease, the two pathologists noted the presence of foliar diseases on some of the entries of this trial. Overall, we concluded from this trial that SRN-39 continues to confirm its unique *Striga* resistance and has passed it on to a good number of its progenies. Resistance to weathering and improved grain yield should, however, remain on focus.

There is a common rationale behind Trials 3 and 4: over the past four years, the INRAN sorghum breeders noticed that head bug and midge cause more serious damage to sorghum than it appears, and that improved materials were usually more susceptible than locals even though their yield potential was higher. Upon request, we obtained from INTSORMIL/TAMU the materials tested there for their potential tolerance of the two insect pests. After seed increase in Niger in 1991, we decided to put them in a group of trials in collaboration with the INRAN sorghum entomologist, Mr. Kadi Kadi. The goal is to identify the best in each case and use them in various intercrosses at a later period. The entomologist conducted his tests at Maradi, Konni, and Bengou, with two to three planting dates for each trial at each location and the breeder made his observations in these trials. The breeder had the two trials planted at Maradi for the gathering of agronomic data and the entomologist had access to those.

<u>Trial 3 - A Head Bug Resistance Collection Using Lines Provided by Texas A&M</u>: This trial was planted with two replications at Maradi on July 14 and contained 20 entries, including 18 from TAMU, and two checks (MOTA MARADI and NAD-1). Most of the entries had poor seed set due to midge attack. A few were noticed that had clean white seed, comparable to that of MALISOR 84 -7 or DORADO (also included in the test and parental sources for many entries); in addition, some had a relatively good seed set indicating they were probably enough early maturing to escape midge damage.

<u>Trial 4 - A Midge Resistance Collection Using Lines Provided by Texas A&M and ICRISAT</u>: Equally planted on July 14 at Maradi, this trial contained 31 entries in two replications. Twenty-five entries were from INTSORMIL/TAMU, four from ICRISAT/WASIP (Kano, Nigeria) and two were checks (MOTA MARADI, SEPON-82). The ICRISAT entries were not received in time, so were not included in the entomologist's trials at Konni and Bengou; however, they had a perfect seed set in this trial and showed good agronomic traits including earliness, medium height, good panicle size and creamy white grain. Most of the entries from INTSORMIL/TAMU at least escaped midge attack, but most are agronomically poor. Except for TX623, TX430 and M8108, their seed set varied from 70% to 100%, whereas, our checks had low seed sets of about 10% (SEPON-82) and 30% (MOTA MARADI); however, this visual quick estimate was obtained from only one replication for all the entries, and we noticed that MOTA MARADI had about 90% seed set in the other replication. We also noticed that the entries in this trial had by far the best seed set compared to any material planted at any other time in the field. The entomologist has obtained numerous data from all the trials and will be able to help, but these results are very encouraging for a first time and suggest solutions may be envisioned for the midge problem.

Another activity, that required INTSORMIL's collaboration, was a relatively large scale hybrid seed production experiment. Rather than an actual yield trial, this was the logical step after the successful performance of an improved breeding material developed through the joining efforts of INRAN and INTSORMIL sorghum research groups. NAD-1 (INRAN's designation for TX623AxMR-732) was the best adapted, best yielding hybrid that came out of two theses' research conducted in 1986 in Niger, by students working under Drs. Ejeta and Axtell. NAD-1 has showed similar performance since then in INRAN's yield trials and even in the West African Sorghum Hybrid Adaptation Trial (WASHAT). NAD-1 has been the farmers' first choice in all INRAN demonstration plots since 1989 and, especially, in 1992 when this activity expanded. NAD-1 received good acceptation by rural people in tuwo food preparation and taste panels across four sorghum producing areas of Niger. The INRAN breeders have successfully demonstrated that seed production of this hybrid is feasible in Niger in isolated fields in a commercial manner; depending on the soil quality, the equivalent of up to 1500 kg/ha of hybrid seed has been obtained in experimental plots. Because of all this, the INRAN sorghum breeding project's immediate goal is to increase the number of demonstration plots so, eventually, NAD-1 will be grown in large areas of Niger, especially on irrigation perimeters where farmers pay rent to the government and have access to irrigation water in case of late season drought. NAD-1 has shown good tolerance of preflowering drought as it happened in 1990 at Maradi. The hybrid seed production activity in 1992 required larger amounts of female seed which was provided by INTSORMIL. During the rainy season we had one isolated field at the Maradi station and one at the Lossa seed production center managed by the National Seed Service. Two experimental off-season fields will be planted with irrigation at Konni and Maradi this winter, to obtain more hybrid seed and check on the feasibility of off-season seed production. It should be obvious that the input of INTSORMIL will continue to be needed, not only because it participated from the starting point of this activity, but also because technical help from experienced researchers is required especially on how to maximize seed production and methods of communication. As a technical background, we know that the female parent (TX623A) is very susceptible to long smut and this certainly reduces seed set. Crop homogeneity and productivity may also be affected in fields of the hybrid because of fertile plants observed in the female rows. The relative earliness (2-3 days in the flowering) of the female parent over the male parent (MR-732) could reduce fertilization, although we have not quantified this in a significant manner. In our search for a better seed production in 1992 at Maradi, we increased the planting ratio from 2R:4A to 2R:6A and thinned to two plants per hill in the female row. This was based on our knowledge that the male parent is a very good pollen provider. Unfortunately, our hybrid seed production was reduced to the equivalent of 865 kg/ha, which could result from the influence of many factors, including soil quality and the already mentioned long smut problem. The field planted on July 7 did not suffer from midge attack.

General Comments

The INRAN sorghum breeding project has made a significant progress in its own organization and in the results obtained over the years. INTSORMIL is recognized within INRAN as a great contributor to all of that success. Among other things, INTSORMIL researchers have provided professional assistance in the field and in academic training to many INRAN workers. The improved sorghum varieties SRN-39, NAD-1 (in pre-extension) and SEPON-82 (adopted by a large number of farmers) are clear examples of what this collaboration has yielded to farmers in Niger. This needs to be continued and strengthened. Our breeding project is still a young one, like INRAN itself, so experienced advice will be needed for a long time. Better and more adapted breeding methods and procedures can be learned from INTSORMIL collaborators' field visits to our nurseries. 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*. With crucial needs in these areas and the only sorghum breeder absent for Ph.D. training, INTSORMIL as the top collaborator, should bridge the gap and tighten its support. The best that could be done is to station an INTSORMIL breeder in Niger, at least during the crop season, or have one make regular trips at harvest to insure that the breeding material is advanced.

Millet Breeding

• Diversity, Combining Ability and Heterotic Patterns among African Pearl Millet Landraces

O. Botorou, G. Ejeta, W. Hanna and A. Kumar

Collaborative INRAN/INTSORMIL program for 1992 - preliminary report of the millet breeding project

I. Genetic study of Millet varieties

1. Evaluation of crosses between 2 varieties Ex-Bornou (Nigeria) and P3 Kolo (Niger)
   - number of entries: Ex-Bornou x P3 Kolo = 124
     P3Kolo x Ex-Bornou = 120
   - planting was done on 6m rows
   - spacing 1m x1m
   - planting date: 5 June 92 at N'Dounga (Kollo)

2. Activities
   - first weeding: 22 June 92
   - thinning and first urea application (50 kg/ha): 23 June 92
   - second weeding: 15 July 92
   - days to half bloom
   - Ex-Bornou x P3 Kollo:65 days = 95 entries/124
     85 days = 27 entries/124
   - P3 Kollo x Ex-Bornou 65 days = 94 entries/120
     85 days = 26 entries/120
   - Phytosanitary sprays against Dysdercus were done at heading period: three sprays with Lindane and Dimethoate EC (1 litre/ha)
   - Bird chasing

3. Constraints noted during the crop season
   - sandy winds covering young seedlings following the rains
   - dysdercus damage at heading
   - bird damage
   - head girdler worm damage at maturity

4. Results
   - Number of entries selected:
     * Ex-Bornou x P3 Kollo: 28
     * P3 Kollo x Ex-Bornou: 19

   These entries will be used to make composites.

5. Remarks
   - In general all entries from both crosses reached final maturity about the 25 August 1992.

II. Diallel Crosses

CIVT, ZATIB, GR-P1, HKB-P1 = Niger
Mansori = Sudan
Ex-Bornou = Nigeria

1. Evaluation of the crossing plots
   - plots measured 40 mx6m=240m^2; 6 plots=1440m^2
   - planting date: 7 June 92 at Goungobon
   - spacing: 1m x 1m

2. Activities
   - first weeding: 5 July 92
   - thinning and first urea application: 25 June 92
   - second urea application: 5 July 92
   - second weeding 20 July 92
   - crossing began early in August (06-08-92) and ended on August 17
   - three phytosanitary sprays with Lindane and Dimethoate EC (1 liter/ha) were done against dysdercus at heading.

3. Results

   Crosses made:
   - HKB-P1 x CIVT
   - HKB-P1 x Mansori
   - Mansori x HKB-P1
   - Mansori x GR-P1
   - Mansori x CIVT
   - CIVT x Mansori
   - CIVT x ZATIB
   - GR-P1x Mansori
   - Ex-Bornou x GR-P1
   - CIVT x GR-P1
   - CIVT x X (34) [mixed pollen from the 6 varieties]

   Unsuccessful crosses
   - CIVT x Ex-Bornou
   - Ex-Bornou x HKB-P1
   - Ex-Bornou x CIVT
   - ZATIB x Ex-Bornou
   - ZATIB x GR-P1
   - ZATIB x HKB-P1
   - Ex-Bornou x ZATIB
   - Mansori x ZATIB
   - HKB-P1 x ZATIB, will be made during the offseason of 1993.

III. Field Isolations

Plots were planted in the Kollo valley soil where sorghum and maize are produced. The strategy is to use sorghum plants as natural barriers and to be able to irrigate in the event of late season drought. Plots were planted at different periods and scattered between sorghum/maize trials and seed increase plots.

- Planting dates:
  - *Ex-Bornou x Mansori: 09-07-92
  - *Mansori x Ex-Bornou: 09-07-92
- spacing: 1m x 1m
- first weeding 22/7/92
- thinning and first urea application (50 kg/ha:6-8-92)
- second weeding and second urea application (50 kg/ha/: 27-08-92)

Results

This first cycle produced the following amount of seed:
- Ex-Bornou x Mansori: 31.8 kg
- Mansori x Ex-Bornou: 18.0 kg

IV. Collection trips of late maturing millet varieties

The objective is to add genetic variability to the existing material; trips were organized in the southern point of the Dosso and Tillabery departments to obtain late maturing millet varieties grown there, especially in the regions of Boboye, Dosso, and Gaya where 35 samples were obtained. In the department of Tillabery, 18 samples were obtained in the regions of Kollo and Say.

A genetic study of these late millets will start in 1993 at the Bengou and Tara stations, with the hope of obtaining an improved genetic material that suits the climatic conditions of the zone.

• Cereal Quality

M. Oumarou, A. Aboubacar, I. Kapran,
B. Hamaker and J. Axtell

New projects were initiated in 1992 on utilization of millet and sorghum in Niger. A study was begun to identify the grain attributes and consumer preferences related to millet and sorghum based couscous. The long range objective of this project is to produce a commercialized millet or sorghum couscous product that could compete with imported wheat couscous in urban areas. The emphasis will be on small scale couscous processing operations in semirural areas which could market their product to nearby urban centers. A second project was planned on composite flours using the new good food quality, high yielding sorghum varieties developed from the INRAN/INTSORMIL breeding program. This is projected to be a short term project where the best varieties and optimal concentrations are determined and demonstrations of bread, made from 203 composite flours, are made to processors and government officials.

• Plant Pathology

Issoufou Kollo and Richard Frederiksen

Long Smut

Screening

In 1992 only 35 entries were screened at our Kollo nursery. The entries originated from ICRISAT, Kano and India. Only three entries received good scores and they are included in the off season nursery.

Genetic study of resistance to long smut

During the 1992 crop season we made several crosses [resistant x resistant (R) x susceptible (S); S x R; S x S]. Eight crosses were actually successful. F2 seed will be produced during the off season and the screening will take place during the next crop season.

Effect of planting date

This was the last year for the study. Results are being analyzed.

Charcoal Rot (Macrophomina phaseolina)

During the crop season we studied the physiological specialization of *M. phaseolina*, using three sorghum and three millet varieties together with a cowpea check variety. The experiment was conducted on a heavily infected soil. Some of the plants were inoculated, others were not. In general, only inoculated sorghum and millet plants showed some symptoms of charcoal rot after maturity while all cowpea plants were killed. We later found nematodes on cowpea roots, which may explain their rapid death.

Striga

The experiment about the influence of soil fertility on millet *Striga* emergence was conducted at Kollo. The data is getting ready for statistical analysis.

Sooty Stripe (Ramulispora sorghi)

A field survey was conducted to assess the importance of sooty stripe on sorghum. This widespread search in the country shows that sooty stripe is not a constraint for sorghum in Niger.

We were able to isolate *in vitro* the two strains of *R. sorghi.*

• Niger Pathology Report

R. Frederiksen and I. Kollo

Considerable progress has been made in both the inoculation of sorghum with the long smut pathogen and on being able to store the fungus from season to season. Inoculation with cultures of sporidia produced high levels of the disease, whereas inoculation with teliospore cultures was ineffective. While these inoculation treatments differ from the observations made in Sudan, they support the concept that infection can be made from cultured isolates of the pathogen and that infection takes place in the boot prior to emergence. Mr. Kollo also observed that injury to the plant reduced the level of infection. Other studies on the long smut organism indicated that it survived for nearly two years when stored under dry conditions in a desiccator. Control spores lasted only about a year when stored under more natural conditions.

Acremonium wilt, oval leaf spot, charcoal rot, and head smut are other diseases of importance to sorghum in Niger. These diseases were all severe at the Konni Research Station in 1992, suggesting that this facility will make another excellent sorghum disease screening nursery.

Preliminary trials with Apron Plus® indicated that it will be important to continue the evaluation of this product where every stand establishment and downy mildew is a problem in pearl millet. Data from trials in Mali have shown a 20% or greater improvement in yield.

• Economics Program in Niger

B.I. Shapiro, J.H. Sanders, K.C. Reddy,
O. Coulibaly and T.G. Baker

This past year the Economics program continued publishing results on new technology introduction into Niger. The impact of new early cultivars of millet and cowpeas was evaluated. This research evaluated in which regions and under which policy or technical condition changes, chemical fertilizer would be utilized.

Implications for research management and public policy were drawn (Shapiro et al., 1992a, 1992b; Shapiro and Sanders, 1992).

• INRAN/INTSORMIL Collaborative Research Program Production Systems- 1992 Activity Report

T. Abdoulaye, M. Abdoulaye
and J. Lowenberg-DeBoer

A study concerning the use of sorghum byproducts was started in the 1992 rainy season. The general objective of this study was to determine the role of byproducts (forage, bran, etc.) in sorghum production decisions in the Birni N'Konni region. This study will provide information concerning the varieties grown in the area and the reasons, other than grain yield, that explain the choice of these varieties.

The specific objectives of the study are to determine:

1) the proportion of sorghum production income from byproducts,
2) the principal uses of the byproducts, and
3) the byproduct characteristics of the varieties grown.

The study is being conducted in the villages of Dagarka and Kaku in the Birni N'Konni arrondissement. Eleven farmers are participating in Dagarka and 12 in Kaku, for a total of 23 participants. All farmers are sorghum producers and all are volunteers.

Seventy-six sorghum fields are being followed. Both pure crop and intercropped sorghum fields are included. The distribution by cropping system is:

Millet/Sorghum/Cowpea	64.5%
Monocrop Sorghum	13.0%
Sorghum/Cowpea	12.0%
Millet/Sorghum	10.5%

In the sample, sorghum is most frequently grown intercropped with millet and cowpea. In this intercrop, the density of millet and sorghum is much greater than that of cowpea. The planting density of the millet and sorghum intercrop depends on the soil type, but in general, there is one row of sorghum for each row of millet. The sorghum and cowpea intercrop is similar to the commonly grown millet/cowpea intercrop in that the cereal component (sorghum) is planted first and at a density much greater than that of the cowpea.

The following are the sorghum varieties found in the sample:

Matcha da Kumia (MDK)	50 fields
El Zahi	15 fields
El Ceidawa	6 fields
Janjaré	2 fields
Mota Maradi	1 field
El Eka	1 field
Bagofa	1 field

All varieties can be considered local, with the exception of El Eka, which was introduced by ONAHA on the Konni perimeter. The variety MDK is the most frequently used. It has a long cycle. The others are intermediate maturity varieties.

The survey shows that the sorghum stalks are used for animal feed, construction and fuel. The bran is used only for animal feed. The grain and forage yields have been collected, but they have not yet been analyzed because some late maturing sorghum fields were harvested only in early December.

Proposal for the 1993 crop season - A second season of yield and crop use data will be needed to draw reliable conclusions. In addition, there may be some changes of byproduct use over time. As a consequence, it is proposed to continue the study during the 1993 season. Budgets will be estimated. Additional data will be collected on labor time need to harvest and process byproducts, with the intention of including byproduct activities in the Konni linear programming model analysis.

Senegal

D. J. Andrews
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Country Coordinators

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Collaborative Program

Support to ISRA in the third year of the collaborative program with INTSORMIL, funded by the Senegal Agricultural Research Project II from AID/Dakar managed by Michigan State University, continued in the areas of dryland sorghum and millet breeding, and millet pathology at CNRA Bambey, irrigated sorghum and millet breeding and millet agronomy in the Senegal River Valley at Fanaye in the summer (July-October) and at Fanaye and Thiago in the dry season (sorghum, November-March; millet, February-May). The supported research forms part of ISRA's total sorghum and pearl millet research program.

Production and Utilization Constraints

Pearl millet and sorghum production in Senegal suffer from the same general farm and market constraints as in other west African countries. Pearl millet and sorghum are the countries' major food cereals with pearl millet accounting for about 70% of the total area planted to dryland cereals (0.8 to 1.1 million ha). Yields are limited primarily by variable rainfall, poor cultivation practices, low soil fertility and no fertilizer use, diseases and pests (principally downy mildew, smut and the pearl millet head worm - *Raghuva*) and poor markets with a narrow range of end-uses.

Opportunities

There is a long history of agronomic research in Senegal on problems of soil fertility, cultivation, animal traction, residue management, fertilizers, pest and diseases and crop breeding which form an excellent basis for collaborative research. Because of soil degradation due to the increased frequency of cropping and removal of all crop residues, research into finding economic solutions to maintaining soil productivity are paramount. More stable cereal grain markets are needed for the adoption of technologies such as new varieties, fertilizers, rotations, and residue management which will increase and stabilize production. Following the construction of large dams on the Senegal River, the Government of Senegal has directed research into evaluating irrigated sorghum and pearl millet as alternatives to rice monoculture in the new irrigation areas.

Research Progress

Plans were jointly developed with ISRA researchers to meet two objectives: (1) to evaluate sorghum and pearl millet germplasm, both existing and introduced, in the Senegal River Valley under irrigated conditions in both the summer season and the dry season, and (2) to supplement the ongoing dryland sorghum and pearl millet breeding and pathology programs at the central research station (CNRA) of ISRA at Bambey. The off-season (winter) nursery at this location is also used to generate seed in support of the tests in the Senegal River Valley

Superior varieties, hybrids, and parental lines supplied from Texas A&M (TAM-121 and 122) and Nebraska (UNL-115 and 118) were retained for retesting in 1991-92 on the Senegal River Valley. Some sorghum seed parents and selections from segregating populations were retained for rainfed conditions. Sorghum genotypes are screened for long smut, and pearl millet for ergot and downy mildew. Dwarf pearl millet varieties and new hybrids from Nebraska (UNL-118) and Kansas State University-Hays (KSU-101) were tested in the Senegal River Valley and selections from segregating populations retained in 1989 for rainfed conditions were retested. Fertilizer levels and frequency and amount of irrigation were investigated in agronomic tests with pearl millet in the hot, dry season in the Senegal River Valley.

Pearl Millet

Rainfed

A high natural level of downy mildew incidence at Bambey and Nioro in 1991 permitted adequate selection for resistance in tests and nurseries. The check cultivar, Souna 3, averaged 29% incidence. One hundred and sixty eight selections were made from F_3's involving UNL-118 parents and further F_2's were produced. Synthetics can now be made from F_5 lines retained from the first crosses made in the project. In national variety tests in 1991, no new varieties, either from Senegal or West Africa, yielded significantly more than Souna 3, despite its higher downy mildew incidence.

Irrigated.

Three variety tests were conducted in the Senegal River Valley at Fanaye (clay soil) during the rainy season, and two more tests at Thiago (sandy soil) in the hot part of the dry season (planting February). Two agronomy tests were also conducted at Thiago.

At Fanaye in the rainy season the yields averaged 2600 kg/ha for tall varieties and 3200 kg/ha for the early dwarf genotypes, where the best hybrid gave 40% more than the best variety. These hybrids matured in 75 days. Stemborers and irrigation breakdowns reduced yields.

Yields were higher in the hot, dry season at Thiago averaging 3700 kg/ha in the dwarf genotype test compared to 3150 kg/ha in the tall varieties which, however, took 10 days longer to mature. The highest yielding dwarf entry was variety IBMV 8401, but this also flowered 10 days later and was taller than the best hybrid, 68A x 086, which took 70 days to mature and was 1.07 m tall. In 2 years tests, this hybrid and 23DAE x 086, have both given averages of over 5000 kg/ha (Table 1). Unlike the rainy season, there were no pests or diseases. Bird damage was noted to be less of a problem on the dwarf genotypes which are more easily defended.

The agronomy tests separately compared fertilizer levels and irrigation rates and frequency using an early dwarf hybrid, 68A x MLS. Yields without fertilizer were 3300 kg/ha. With 100 kg of 21-21-21 of NPK + 100 kg urea yields were increased 47% to 4870 kg/ha, though this difference was not significant. The four treatments in the irrigation test were based on 100% and 75% of calculated weekly evapotranspiration needs given once or twice a week. There were no significant differences between yields produced by these treatments (which averaged 4100 kg/ha) but the highest yield came from the least frequent irrigation at the lowest rate, totalling 526 mm of water for the season (Table 2).

Conclusions

Pearl Millet

Rainfed

Good progress has been made in introducing new parental genetic diversity into the Senegal breeding program and selecting downy mildew resistant derivatives. These will form the basis of new synthetic varieties.

Irrigated

The Senegal River Valley project contains several specialized growing environments, one of which, the hot dry season offers good conditions for cultivating very early maturing dwarf pearl millet, using moderate fertilizer levels and about 500 mm of irrigation. In this season rice and maize

Table 1. Mean yields, plant height, and days to stigma emergence of early dwarf pearl millet hybrids and varieties at Thiago, Senegal, in hot summer seasons of 1991 and 1992.

Hybrid/ variety	Days to 50% bloom	Plant height (cm)	Grain yield (kg/ha)
23DAE x 086	45	115	5220
68A x 086	41	111	5020
PV379A x 57028	46	114	4960
23DAE x 57028	45	117	4870
PV263A x 57028	44	109	4530
CL pop.	46	116	4390
NCD2	51	144	4270
68A x MLS	42	113	4180
GAM 8201	51	123	4110
IBMV 8401[1]	51	144	4305
2068A x 89-0083[1]	41	122	4050
T90DAE x 8677[1]	46	121	3990
Mean 1991-92	46	117	4837
Mean 1990-199[1]	44	118	3744

[1] Data from 1990-91 only.

Table 2. **Effect of rate and frequency of irrigation on grain yields (kg/ha) of the dwarf pearl millet hybrid 68A x MLS at Thiago, February-April 1992.**

Frequency of irrigation	100% need (693 mm total)	75% need (526 mm total)	Mean
1x week	3818	4683	4250
2x week	3576	4389	3982
Mean	3697	4536	SE ± 482 (NS)

Table 3. **Days to bloom, height, and grain yield of the top five entries and the check in the 1991 Bambey dryland sorghum hybrid trial.**

Hybrid/ variety	Days to 50% bloom (cm)	Plant height (cm)	Grain yield (kg/ha)
N96A x 75-1	53	170	4550
N94A x Tx430	55	150	3540
ATx631 x 2673	67	170	3510
N96A x 75-2	58	135	2840
CE 310-11A x 75-1	56	145	2650
612A x 75-1 (check)	55	150	2630
Mean (30 entries)	56	138	2420

Table 4. **Days to bloom, height and grain yield of the top five entries and the check in the 1991 Fanaye irrigated sorghum hybrid trial.**

Hybrid/ variety	Days to 50% bloom (cm)	Plant height (cm)	Grain yield (kg/ha)
1287-2A x 1271-2	63	160	5990
ATx631 x R8505	62	130	5550
N737A x M90378	64	185	5260
ICS35A x 1271-2	58	170	5260
N336A x R8505	56	145	4970
612A x 73-208 (check)	52	160	5000
Mean (30 entries)	62	148	3790

cultivation is not practical due to their higher water demand, and maize is also sensitive to the very high temperatures that can occur. Three to 4 t/ha of grain have been obtained in 80 days. Hybrids do not have to be used, as 4 t/ha has been produced from a slightly later maturing dwarf variety, IBMV 8401. However, several earlier maturing hybrids, e.g. 68A x 086, have produced yields 20% higher than varieties in previous tests. So far in this hot off-season, no pests or diseases have been noted. Birds remain a problem, as they are on rice, but damage is greatly reduced on the short statured millets.

Sorghum

Rainfed

INTSORMIL stocks have been used as parents in generating new diversity, and as hybrid parents in the ISRA early genotype breeding program for central-north Senegal (75 to 90 days to maturity). The 1991 rainfall was again low (347 mm at Bambey) and good selection was possible both for drought tolerance, foliar diseases, and grain mold. The lines provided by INTSORMIL which have contributed the most as parents in crosses with Senegal varieties, as indicated by selections retained from F_2 to F_4, are Dorado, LL34, DR10, DR290, 1275-1, 13019, WSV387, N96B, BVG1, BTX631 and Segaolane. The most advanced of these selections will enter yield tests. One hundred and thirty new lines and populations were provided in 1991 including 15 new seed parents. Of more immediate impact has been the hybrid parents retained from the many sent. Those giving the best hybrids in test have been N94A, N96A, and ATX631 which with the Senegalese pollinator 75-1 have given yields up to 70% more than the check hybrid, made with the same pollinator (Table 3). Male parents RTX8505 and M90378 have also contributed to high yielding hybrids. These hybrids have generally been earlier than varieties recommended for the same region. A test comparing hybrids to varieties showed that under conditions of drought stress hybrids can give up to twice the yield (1360 kg/ha) of the adapted variety.

Irrigated

As with dryland variety breeding, progress has come from crosses with adapted parents. However, introduced line SDS 3813 has now, over 2 years, given about 10% better yields than the established variety CE 151-262. The collaborative testing program has shown that CE 151-262 is the best variety for the rainy season and 75-14 (which is also a good male parent for hybrids) is best for the post-rainy season. In 3 years multilocation tests on farmers' fields, CE 151-262 has given yields of 2.8 to 6.3 t/ha while hybrid 612A x 73-208 has averaged 14% more. In the cool dry season, yields from variety 75-14 have averaged 3 to 4 t/ha while hybrid 612A x 75-14 has given 25% more. Recently INTSORMIL seed parents and restorers have given hybrids with substantially higher yields than the existing check hybrids above. These are ATX631, AVAR, AVG-1, N96A, N336A, N737A, 1287-2A, RTX430, RTX8505, 80C2241, 1272-1R, and M90378R (Table 4).

The collaborative project has broadened the useful genetic variability in the variety breeding programs for the rainfed and irrigated environments through the introduction of new hybrid parents. Substantially, better hybrids have been identified for both rainfed and irrigated conditions. Through the provision of the parental lines, hybrid seed can now be made in Senegal.

Research Accomplishments

An important objective at the outset of the collaborative project was to quantify possible yields from irrigated sorghum and pearl millet in the Senegal River Valley, as cropping alternatives to rice monoculture. In sorghum, good varieties and hybrids have been identified for both the summer and post-rainy seasons and their yield levels established. Varieties can yield 3 to 4 t/ha and hybrids 14-25% more. Experimental yields of over 7 t/ha have been obtained. In pearl millet, INTSORMIL dwarf varieties and hybrids were successful and gave 30% higher yields than tall varieties and mature earlier. Yields of 4 t/ha in 80 days were demonstrated and experimental yields of 6 t/ha recorded. There is a unique opportunity for pearl millet to be cultivated in the Senegal River Valley in that it grows best on light sandy soils unsuited to rice and at a time (February-April) when temperatures are above the optimum for other crops.

Fertilizer responses and water requirements have been determined which, with the cultivar yield information, will enable some partial budgeting to be performed to determine the economic feasibility of cultivating sorghum and pearl millet in the Senegal River Valley.

Travel

Dr. Demba M'Baye, pathologist and ISRA coordinator for INTSORMIL, visited the USA in July 1991 to participate in the INTSORMIL International Sorghum and Millet Conference in Corpus Christi, Texas, and to work in Dr. Larry Claflin's laboratory at Kansas State University, Manhattan.

Mr. Emmanuel Sene, agronomist, and Gilles Trouche, sorghum breeder, visited the USA in September 7-26 to see sorghum agronomy and breeding research at the University of Nebraska-Lincoln, Kansas State University-Manhattan, Texas A&M University-Lubbock, and Pioneer and DeKalb research and seed production facilities in Texas.

Dr. Larry Claflin visited Senegal in August 1991 to work with Dr. Demba M'Baye on disease nurseries and laboratory techniques at CNRA, Bambey.

David Andrews visited Senegal in November 1991 to participate in a review of ISRA research and discuss results and future plans with the breeders.

Reports

Fofana, A. Selection Mil. Rapport Analytique 1991. ISRA/CNRA Bambey, Avril 1992. pp. 26

Fofana, A. Selection Mil. Raport contre-saison 1992. ISRA/CNRA Bambey. September 1992. pp. 7.

Diangar, S., and T. Ba. Agronomie Mil. Results des essais agronomiques en contre-saison 1992 - Thiago. ISRA/CNRA Bambey, October 1992. pp. 13.

Trouche, G., S. Sall, and O. Hann. Amelioration varietale du sorgho pluvial. Rapport Analytique Hivemage, 1991. ISRA/CIRAD Bambey, Avril 1992. pp. 92.

Trouche, G., and M. Cissokho. Amelioration varietale due sorgho region due Fleuve, Senegal. Rapport Analytique Hivemage, 1991. ISRA/CIRAD Bambey, March, 1992. pp. 23.

Trouche, G. Synthese de trois annees de recherche sur l'amelioration varietale due sorgho. Project SAR II-ISRA-MSU-USAID, Bambey, 1992. pp. 12..

South America (Colombia/CIAT)

Guillermo Muñoz
Mississippi State University

Coordinators

Dr. Guillermo Muñoz, In-country Sorghum Breeder, CIAT, Apartado Aéreo 6713, Cali, Colombia
Dr. Manuel Torregroza, ICA, Director of Cereals, Apartado Aéreo 151123, Bogotá, Colombia (Host-country Coordinator)
Dr. Lynn Gourley, Department of Agronomy, Mississippi State University, Mississippi State, MS

Institutions Involved

Mississippi State University (MSU)
Instituto Colombiano Agropecuario (ICA)
Fundación El Alcaraván
Federación Nacional de Cultivadores de Cereales (FENALCE)
Centro Internacional de Agricultura Tropical (CIAT)
Universidad Tecnológica de los Llanos (UNILLANOS)
Universidad Nacional de Palmira
Universidad del Tolima
EMBRAPA, Brazil
IDIAP, Panama
FONAIAP, Venezuela
Private sector, including national and multinational seed enterprises

Collaborative Program

Memorandum of Understanding

The collaborative research site in Colombia operates under four formal and several informal agreements which facilitate the project's involvement in a broad range of research activities. In 1981, a Memorandum of Intention was signed by the Directors of INTSORMIL, ICRISAT, and CIAT. Research started in 1982 through informal cooperation between scientists from ICA, EMBRAPA, and INTSORMIL. In Colombia, a Memorandum of Understanding was finally organized and formalized in 1988 through a Memorandum of Agreement among the Colombian National Research Program (ICA), INTSORMIL, and CIAT. Since then, CIAT has significantly helped the program to achieve established goals. In 1988, research was initiated in the acid savannas of Arauca through a Memorandum of Agreement between INTSORMIL and the El Alcaraván Foundation—a consortium of petroleum companies (Shell, Ecopetrol, and Occidental de Colombia), managed by Occidental. Informal agreements and very strong links have been established with nonprofit organizations such as FENALCE—a production/extension-oriented organization—and three Colombian universities. The INTSORMIL collaborative research site project, MSU-111, is managed through the Office of International Programs at MSU, under the direction of Dr. Ronald Brown.

Interdisciplinary Research

Collaborative research on germplasm enhancement was originally established to help solve problems related to sorghum and pearl millet production on acid soils. Even though this is the Program's primary research objective, emphasis is being placed on other activities, largely because of the diversity of institutions involved. For example, FENALCE's main interest is to develop lines for semi-arid areas (e.g., drought tolerance - Project TAM-122) and lines resistant to grain mold diseases. ICA aims to develop drought-tolerant lines, adapted to acid soils and resistant to grain mold diseases (TAM-124). The universities' main objective is research in agronomy and physiology (UNL-114), and entomology (TAM-125 and MSU-105). The El Alcaraván Foundation aims to develop germplasm adapted to acid savannas and slightly acid soils ("vegas"). This institution is also increasingly interested in grain quality and utilization (TAM-126 and PRF-103B).

Most of the above mentioned research activities are conducted by undergraduate students, depending on the specific goals of each institution, under the scheme of thesis research.

Mr. David Andrews (UNL-115) and Dr. Lloyd Rooney (TAM-126) are to be involved in two new areas: pearl millet production and sorghum utilization, respectively. Pearl millet production will become more important for the project, initially as a forage and later as a grain crop.

CIBA-Geigy, ICI, PROSEGRA, FEDEARROZ, and ICA have received A and B Al-tolerant pairs and are to develop new hybrids for the Latin American acid-soil savannas.

Financial Inputs and Management

Colombia does not have a USAID Mission, only a representative. Operational funds for Project MSU-111 are transferred to CIAT from MSU and are accounted for as an externally funded project. CIAT also manages the El Alcaraván account for INTSORMIL. From the financial viewpoint, the main accomplishment was the establishment of strong cooperation among the participating institutions. Even if the amount of real money provided by these institutions is small, a large part of fixed costs are absorbed by them, resulting in considerable cost reductions.

Because of CIAT's new interest in sorghum production, especially its potential to be an important component of sustainable agricultural systems in savanna ecosystems, new resources are being found to back sorghum research in Latin America.

INTSORMIL and ICRISAT have begun negotiations with the InterAmerican Development Bank (IDB) to obtain resources for sorghum research in Latin America. These new resources will help establish a Latin American sorghum network and support specific research projects under the supervision of NARS that have the scientific capability to conduct such projects.

The El Alcaraván Foundation supplied almost U.S. $100,000 to support INTSORMIL's collaborative research in the Territory of Arauca on the condition that the full amount be spent in that region. FENALCE contributed an agronomist (B.S.) for the La Libertad Project and another for the drought project at Motilonia, Atlantic Coast. ICA provides all the infrastructure for experimental activities in the acid-soil area of Meta.

The sum of all additional support (land, equipment, human resources, miscellaneous facilities) provided by the Colombian organizations represents four times INTSORMIL's support.

Collaboration with Other Institutions

Because of scarce resources, much interinstitutional cooperation for Latin America has been, and will have to be, developed in Colombia. CIAT has been supporting the program in several ways; administratively, establishing relations with other scientists, and opening alternatives for new areas of research. Land, laboratories, equipment, and transport are only some of the facilities that CIAT has made available to INTSORMIL's project in Colombia. CIAT is also increasing basic seed of INTSORMIL lines for release in Colombia.

Private Sector

For the last three years, establishing relations with private sector enterprises has been a priority. INTSORMIL has supported the evaluation of specific germplasm of interest to both INTSORMIL and the private sector. For example, CIBA-Geigy is increasing A and B Al tolerant pairs and developing hybrids in isolated plots, using as male lines some of their own lines, IA 28, ICA-Nataima, and TX 430. Half of the product will be for CIBA-Geigy and half for INTSORMIL.

Most of Latin America is in the process of privatization and opening up the economy. The NARS involved in the above-mentioned research have also been part of this process and in many countries, such as Colombia and Peru, future public research will become the responsibility of the private sector or "mixed" companies which are owned both privately and publicly and which are profit accountable. According to USAID's new definition, a NAR would be any organization related to agricultural research, whether public or private.

To support research in Latin America, INTSORMIL has supplied the following germplasm:

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

In Colombia, FENALCE provides technical support to farmers through an agronomist (B.S.) stationed in each sorghum growing region. ICA provides farms and scientists for all projects involving both institutions. The El Alcaraván Foundation fully supports research in Arauca under the leadership of INTSORMIL's scientists.

The Planning Process

The complexity of relationships among the institutions involved in sorghum research in Colombia has made the planning process very important. The goal is that such research is coordinated, with results being published each year and distributed among those involved. Specific short and long-term goals have been developed jointly with ICA, El Alcaraván, FENALCE, and the universities. Annual planning meetings are being held formally in Colombia. Specific experiments, organizational funding, and individual responsibilities are discussed at these meetings.

Research on Sorghum and Millet Constraints

The main constraint to sorghum production in Colombia is the high production costs of the average yield (2.6 t/ha). Most sorghum is grown on valuable lands, making production unprofitable. A means of reducing production costs is to incorporate marginal lands. However, production constraints of these low-cost lands include, for example, poor distribution of water, soil acidity and high Al saturation, pests and diseases (especially head mold), and periods with excessive rainfall and high relative humidity. Sorghum production in these areas therefore requires the development of varieties or hybrids adapted to the specific ecological problems prevalent in each region.

Despite the constraints encountered in these marginal areas, the amount of land available is such that the acid, well-watered savannas of Latin America constitute, potentially, a major region for sorghum production and, thus, a logical focus for future work. These savannas account for more than 10% (76 million ha) of land in Latin America and the Caribbean. Of course, work can also be developed in other regions, such as the forest margins where grain mold diseases are the main constraint or the semiarid zones where drought is prevalent.

Wherever farmers grow sorghum in Latin America they require low-input technology and invest considerable effort to prevent resource degradation. Research on sustainable agricultural systems therefore becomes a mandate.

Research Methods

Characterization and determination of ecological areas for sorghum production in Latin America

Mechanized agriculture

Ecosystem 1. Soils without toxicity limitations, either salinity or Al saturation. More than 600 mm of rain, high relative humidity. For example, Atlantic Coast (Montería, Colombia).

Ecosystem 2. Soils with toxicity limitations, either salinity or Al saturation. More than 600 mm of rain, high relative humidity. For example, Llanos Orientales (Arauca, Colombia).

Ecosystem 3. Soils with toxicity limitations, either salinity or Al saturation. Less than 600 mm of rain, relative humidity may be high or low. For example, Cerrados (Brazil).

Ecosystem 4. Soils with pH limitations, but no Al toxicity. Less than 1000 mm of rain, relative humidity may be high or low. For example, El Tigre (Venezuela).

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

Ecosystem 6. Soils with normal pH, neither Al toxicity nor salinity is a production constraint. Drought is not an important constraint. Less than 1500 mm of rain, humidity may be high or low. This is an excellent ecosystem for sorghum production. High technology and good infrastructure are available. For example, Cauca Valley (Colombia).

Nonmechanized agriculture.

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

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

Breeding/germplasm Improvement

Standard research methods are used for all the breeding related activities in Colombia. Early generation breeding material is received each year from Project MSU-104 and is evaluated in each level of Al saturation and screened in several locations by all participating institutions. A full set of germplasm was sent to ICA and the El Alcaraván Foundation for screening in both acid and nonacid soils. Low-input technology was used in all locations (using 60-60-60 N-P-K fertilization).

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

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

Thus, for example, a grain yield of 2.5 t/ha will be satisfactory for level 3, whereas at least 3.5 t/ha is expected for level 1. TAM-128 breeding lines and hybrids for drought tolerance have been increased at CIAT.

Research Progress

Breeding/germplasm Improvement

A major accomplishment of the INTSORMIL project in Colombia will be the possible release of a variety (from the world collection) for the Department of Arauca. Lines have been under evaluation since 1988 and ICA is now evaluating the possibility of their release, using information generated by INTSORMIL, under the El Alcaraván/CIAT/INTSORMIL agreement. The genotypes IS 3071, IS 8577, and IS 6944 may be released for levels 1 and 2 of Al saturation. 156-P5 Serere-1 (Sorghica Real 40) and MN 4508 (Sorghica Real 60), INTSORMIL lines released in Colombia for soils with 40% and 60% Al saturation, respectively, are used as checks.

In Year 13, several experiments at Arauca aimed to complete the agronomic package for these new lines, including planting densities, fertilization levels, stability analysis, and planting dates.

Evaluation in the Field

Not all lines have been found to perform equally at different levels of Al saturation. Some crosses are excellent for vega soils (low levels of Al saturation), but do not perform well at high levels of Al, even if one parent is tolerant.

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

At levels above 60% Al saturation, hybrids may provide a possible alternative in the increase of grain yield. A full set of hybrids is being tested in Arauca and ICA-La Libertad at the three levels of Al saturation.

Both semesters A and B have been used for evaluating Al-tolerant lines. Some lines performed better in the first semester and the height of all lines decreased in the second semester. Also, compared with commercial hybrids, these lines show less incidence of head fungus diseases.

Mutual Research Benefits

National and multinational seed companies will use the technology from this collaborative project to produce acid soil tolerant varieties and hybrids in Latin America. As well as being tolerant of Al toxicity, these lines show little incidence of grain mold diseases, which makes them an excellent alternative for these production regions. The release of A and B, Al-tolerant lines, will expand the agricultural industrial market in the United States.

Institution Building

An agreement with INTSORMIL was signed on March 23, 1988. Some of INTSORMIL's contributions have been:

Short visits to Colombia by scientists with ample experience in sorghum production.

Long visits to Colombia by scientists with ample experience and by support personnel.

ICA scientists received an opportunity to conduct postdoctoral research and make use of sabbatical leave.

Jobs for research assistants (graduate students) chosen from Colombian personnel.

Donations of germplasm and supply of equipment for use by both parties.

Recent literature to support collaborative research projects being conducted in Colombia.

Supplies, equipment, and travel expenses for INTSORMIL's employees.

Trips for ICA personnel to the United States or to other countries.

Organization of periodic work meetings that benefit INTSORMIL's collaborators in Colombia and enhance the exchange of information among researchers.

Support of work meetings planned and organized by both parties.

International Committee for Sorghum (CIS)

CIS is developed as a result of joint economic and research efforts among ICA, FENALCE, INTSORMIL, and the private sector. CIS's objectives for Latin America are to:

Promote integration among institutions and persons related to sorghum research and production.

Provide orientation and enhance development of research and technology transfer programs on sorghum production.

Serve as a mechanism whereby personnel involved in sorghum research, transfer, and development can seek advice and orientation.

Promote and sponsor the organization and conduct of research and transfer activities related to sorghum production, and to diffuse information through publications and other documents.

Establish liaison with international institutions having similar objectives.

Research support funds for ICA have been limited because of a constrained operational budget. Host country capabilities have been strengthened through supplies and some labor for field work. Furthermore, the program has collaborated with ICA to make available equipment, literature, trained staff, seed storage facilities, and to distribute germplasm.

Dr. Guillermo Muñoz (Ph.D. - MSU), Associate Senior Staff with headquarters at CIAT, was appointed INTSORMIL PI for MSU-111 (Colombia) in July 1988 but since 1987 has been acting as PI and made possible all the activities in which the program is now involved. He coordinates research, especially in plant breeding, soil science, and seed technology, and training activities with collaborating organizations in Colombia and with INTSORMIL projects in the United States.

Mr. Javier Bernal (M.S. - University of Nebraska) is the principal sorghum breeder at ICA's main acid-soil research station at La Libertad (Villavicencio, Colombia).

Agronomist Alfonso González, a B.S. student trained by INTSORMIL, is working in sorghum research for the ICA/FENALCE Agreement and has strengthened ICA's sorghum program at La Libertad. He has been in charge of specific experiments and the semicommercial fields at La Libertad, Meta. He is currently coordinating all students' research activities in that region.

Agronomist Adolfo Gasca, another B.S. student trained by INTSORMIL, is the coordinator for the El Alcaraván/INTSORMIL cooperative PROGRAM.

Agronomist Walter Rendón, a B.S. student previously trained by INTSORMIL, is working as Director of ICA/CRECED in Arauca and has strengthened both ICA's sorghum research program at La Libertad and the El Alcaraván Foundation activities. He is in charge of specific experiments and the semicommercial fields and has made selections in the field with the INTSORMIL PI, strengthening the genetic variability for the future development of varieties in Arauca and the Llanos Orientales. He has been involved in the screening of sorghum lines for poorly drained savannas.

Annual meetings have been conducted in Colombia with INTSORMIL's support; the objective was to share results of experiments done in the country. Following a recommendation from the last meeting, the report entitled, "Informe de las Actividades de Investigación Realizadas en Colombia en el Cultivo de Sorgo, 1990-91," is being published—the third of a series of publications prepared each year.

Considerable research was done through B.S. degree students to increase the research capability of the program. Ten B.S. degree students from the National University of Palmira, the University of Tolima, and the Technological University of the Llanos are working on their thesis research in collaboration with INTSORMIL.

Networking

Colombia is the only Latin American country where universities, the private sector (El Alcaraván), national research institutions (FENALCE and ICA), and an international center (CIAT) collaborate with INTSORMIL to accomplish research and training goals. In contrast, networking activities in other Latin American countries are very weak.

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

CIS (ICA, El Alcaraván, FENALCE, and INTSORMIL) is organizing the second international sorghum meeting for Latin America for January 1993. The main themes of the meeting will be crop protection and the further strengthening of relationships, especially with the private sector, in the area of joint research.

CIAT has included INTSORMIL's results in sorghum and pearl millet research in its dissemination efforts to reach farmers and scientists in the region.

Research Accomplishments

Significant advances have been made in the breeding program at ICA through collaboration with INTSORMIL and the El Alcaraván Foundation. Research conducted by

INTSORMIL, in collaboration with ICA and other organizations in Colombia, has attracted private-sector funds, furthering long-term research goals in Colombia. The El Alcaraván Foundation has provided substantial operational and training funds for research conducted in the Department of Arauca. This research is oriented toward plant breeding for both acid and nonacid soils, agronomy, phytopathology, and sorghum utilization.

Three new lines are being evaluated for release in Arauca as a result of significant advances in the ICA/El Alcaraván breeding program, thanks to collaboration with INTSORMIL and the El Alcaraván Foundation. Research conducted by INTSORMIL has developed specific varieties for the poorly drained savannas of Arauca.

Selections were made for different ecosystems from 500 F_4 lines sent by Project MSU-104; short lines with good yield capacity are being evaluated in regional trials. These lines, considered as second generation, are of a better agronomic type than the world collection lines.

Twenty F_2 populations from Mississippi were screened in different environments (both vega and savanna), resulting in promising breeding material available for future work. The lines selected are short, with good yield potential. These selections are the third generation.

As previously mentioned, the principal accomplishment of the program has been the release by ICA of two first-generation, Al-tolerant sorghum lines from the world collection. To back up this accomplishment, the program has planted a 10-ha area for basic seed multiplication.

SUDAN

Gebisa Ejeta
Purdue University

Country Coordinator

Gebisa Ejeta, Country Coordinator, Purdue University, West Lafayette, IN 47907
Katy G. Ibrahim, Administrative Assistant, Purdue University, West Lafayette, IN 47907
El Hilu Omer, Host Country Coordinator, Agricultural Research Corporation, Gezira Research Station, Wad Medani, Sudan

Collaborative Program

Organization

The INTSORMIL/U.S. principal investigators develop their scope of work jointly with ARC scientists. These workplans are reviewed and approved by 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 the INTSORMIL Management Entity at the University of Nebraska and then are disbursed in Sudan to each ARC scientist to carry out his research program.

Dr. Ejeta and Katy Ibrahim coordinate the management of this program with the 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, INTSORMIL.

Economic Program - Hamid Faki, 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

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 the 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.

Sorghum Breeding
Osman El Obeid Ibrahim

The sorghum breeding program has focused greatly on synthesis and evaluation of hybrids primarily for the irrigated Gezira scheme. A number of experimental hybrids have emerged as being superior in several multilocational testing sites conducted both at GRS and in farmers fields in the Gezira. A number of seed parents have emerged as being promising for use in hybrid seed production. Hybrids developed with seed parents, BON34, BON23, and BON44 have been the best both in yield expression and seed quality. Some of these seed parents have been shown to segregate for waxy endosperm and hence its effect or kisra quality needs to be evaluated. Parental lines developed for enhanced drought tolerance have also been evaluated in hybrid combination. Evaluation of these hybrids showed that many of these lines posses superior combining ability and express their drought tolerance in hybrid combination as well. Currently a large and extensive experiment is underway to evaluate the performance and stability of many of these parental lines.

Striga Research
A.G.T. Babiker and A.M. Hamdoun

Effects of Chlorosulfuron and Urea on Striga Infestation and Growth of Two Sorghum Varieties

Two sorghum varieties Dabar and SRN-39 were used in this experiment. Nitrogen as urea and chlorosulfuron were applied at sowing.

Dabar invariably sustained more *Striga* than SRN-39. Nitrogen as urea at 80kg/feddan had a moderate suppressive effect of *Striga* populations SRN-39, but had a negligible effect on emergence of the parasite in Dabar. Chlorosulfuron reduced emergence of the parasite in both varieties and was more effective at the high rates. Herbicide-fertilizer combinations were more efficient than either treatment alone. *Striga* considerably reduced sorghum height, number of heads and straw yield. Chlorosulfuron, in absence of urea, increased sorghum height by 9-35% and 9-13% in Dabar and SRN-39 respectively. Urea at 80 kg/fed increased sorghum height by 106% in Dabar and by 55% in SRN-39. However, when chlorosulfuron was used in combination with urea sorghum height was always less than that attained with the fertilizer alone. In absence of urea Dabar did not form heads. However, in the urea treated plots heading was considerable. Chlorosulfuron/urea combination gave fewer heads than the fertilizer alone. SRN-39 produced heads in all treatments. The lowest heading (49%) was obtained from plots which received no treatment. Urea alone increased heading to 100%. In comparison to the untreated control chlorosulfuron at 1.05 and 1.25 g, when applied in absence of urea, increased heading. The number of plants which showed distinct heads at harvest time was 63-67%. Chlorosulfuron/urea combination gave similar number of heads to the urea alone. Straw yield showed high variability. *Striga* caused considerable reduction in straw yield of both varieties and Dabar was the most sensitive. Moreover, the adverse effect of *Striga* was mitigated by urea. Chlorosulfuron, in absence of urea, had negligible effects on straw yield of Dabar. However, in plots planted to SRN-39 the herbicide increased straw yield and at 1.05 g a twofold increase was achieved in comparison to the untreated plots. Chlorosulfuron/urea treated Dabar gave slightly less straw yield than the corresponding urea treatment. However, with SRN-39 chlorosulfuron/urea combination had no adverse effects.

Effects of Urea and Goal on Striga Incidence and Sorghum Growth

Sorghum cv. Dwarf White Milo was tested under two levels of urea and one level of goal. Urea at 0 or 80 kg/fed was applied at planting. Goal at 0.12 kg was used as post-emergence directed spray at different stages of crop growth. Sorghum stand was adversely affected in plots where no fertilizer or herbicide was applied and in plots sprayed with Goal 15 days after planting. The other treatments had no adverse effects on crop stand. Plots treated with urea showed higher number of heads than those which did not receive the fertilizer. Goal, in absence of urea, increased heading by 2-3 fold. However, when applied to urea treated plots its effects on heading were influenced by application time. Applications at 15 days after planting had a depressive effect on heading while those made at more advanced growth stages had no effect. Regarding straw yield, the differences between treatments were not significant. However, urea treated plots tended to give more yield than the untreated ones. Furthermore, goal had negligible effects when applied to urea treated plots. Application of the herbicide in absence of urea gave slightly higher yields than the corresponding plots which received no herbicide treatment.

Effects of Trap Cropping and Ethephon on Striga Incidence in Subsequent Sorghum

This experiment was started during the previous season. Plots were either left uncropped or cropped with groundnuts (cv. Ashford), cotton (cv. Barakat), sunflower (cv. Perdovic) or *Dolichos* beans (cv. Brazile). The plots were either treated with ethephon or left untreated. The crops were harvested and their residues were removed. The plots were sown to sorghum (cv. Dabar) and the treatments; effect on *Striga* were evaluated as described above. *Striga* population displayed large variability between plots. Nevertheless, emergence of the parasite in sorghum seemed to be dependent on the preceding crop. In comparison to the control *Striga* population density was extremely high in plots previously cropped with sunflowers. Conversely emergence of the parasite was extremely low in plots where sorghum was preceded by *Dolichos* beans. Trap cropping with cotton did not affect emergence of the parasite early in the season, but late season emergence was somewhat curtailed. Plots previously planted with groundnuts had the same *Striga* infestation as the control plots. Ethephon applied alone had no adverse effects on *Striga* population density, plots treated with the low rate of the stimulant had a higher level of infestation than the control. Ethephon in combination with trap crops displayed variable effects. The combination had inconsistent and negligible effects when the trap crops were cotton and groundnuts. Ethephon in combination with sunflower had a depressive effect on *Striga* emergence when compared to sunflower alone. However, the infestation level was still severe particularly at the low rate of the stimulant. Plots previously planted to *Dolichos* beans and treated with ethephon showed higher *Striga* population than the corresponding *Dolichos* beans plots. However, the level of infestation was still below that in the control plots or plots treated with ethephon alone. Sorghum growth and yield differences between treatments were not always significant. However, among all treatments, trap cropping with *Dolichos* beans tended to give the tallest sorghum plants and the highest number of heads and straw yield. Conversely, sorghum preceded by sunflower or Ethephon at 0.4 kg exhibited the poorest growth.

Effects of Mixed Cropping on Striga Incidence in Different Sorghum Varieties

Four sorghum varieties (SRN-39, N-13, IS-9830 and Dabar) were planted as described before. *Dolichos* beans, cowpeas and groundnuts (cv. Ashford) were planted (two seeds) each with individual sorghum variety in the same hole. Treatment effects were assessed as before. The highest *Striga* infestation among the sorghum varieties was shown in plots planted with IS-9830, while the lowest infestation occurred in plots sown to SRN-39. Within each sorghum variety, *Striga* population density was highest in the sole crop. Mixed cropping, invariably, lowered infestation. In the crops used in the system, *Dolichos* beans was the most effective, while groundnuts was the least. *Dolichos* beans suppressed *Striga* for the whole growing season. On the other hand, groundnuts suppressed emergence of the parasite early in the season, but late season infestation was relatively high. With respect to sorghum growth, the differences in the parameters measured were not always significant. However, sorghum in mixed cropping tended to be taller, produced more heads and straw yield than the sole crop. Furthermore, *Dolichos* beans and cow peas were more efficient than groundnuts in alleviating the adverse effects of *Striga* on sorghum growth.

Sorghum Pathology

El Hilu Omer

Effect of Cytokinin Application on Leaf Senescence and Charcoal Rot (Macrophomina phaseolina)

The experiment was conducted on cultivar Tx623 at the GRS under irrigation. Sowing was, deliberately, delayed until August to minimize rain interference at post-flowering time. Spacing was at 15 cm between single plants along ridges 60 cm apart. The crop received nitrogen in the form of urea at the rate of 85 kg/ha and two sprays with Danitol-S for insect control. Irrigation was applied when necessary until the time of 50% flowering when it was stopped from the stress treatments. The stress treatments were separated from normally irrigated plots by a marginally stressed plot seven meters wide.

The treatments were as specified in the work plan.

1. Stress + Benzylaminopurine (BAP) spray.
2. Stress + DW spray.
3. Normal irrigation + BAP spray.
4. Normal irrigation + DW spray.

Spraying with BAP was started at the time of water stoppage and repeated once every three days for a period of 36 days. Only the upper leaf surface of the bottom half number of green leaves received the spray. At the end of the spraying period individual leaves were rated for green leaf score on a scale of 1-5, where 1 was dry or completely senescent leaf.

One week later the crop was harvested and the stalks examined for presence or absence of charcoal rot. BAP showed some delay in leaf senescence which was significant in the stress treatment. However, the charcoal rot data showed marked reduction in natural incidence of the disease as a result of BAP spraying under stress conditions. Negligible incidence of the disease occurred in the irrigated unsprayed treatment. Crop yield was affected by the stress, but BAP does not seem to have influenced crop yield.

Long Smut (Tolyposporium ehrenbergii)

The superiority of sporidia as a source of inoculum, compared to teliospores stored for one year has been amply testified in previous seasons. In this season, the efficacy of fresh teliospores was compared with sporidia. Both sources were prepared as suspensions in water to which a trace of tween 80 has been added.

Inoculum injection was at the boot stage on susceptible cultivar Tx623. Disease assessment was at the time of maturity on a scale of 1-4.

Sporidia sources gave successful infections in 62% of inoculated plants, whereas the sporeballs resulted in 98% successful infections. Similarly, the number of smutted kernels was much higher in sporeball inoculated heads compared to sporidia inoculum.

Screening Fungicides Against Covered Smut (Sphacelotheca sorghi)

Only a few products are registered against smut diseases on sorghum in Sudan. This experiment was conducted to compare the efficacy of two unregistered chemicals; Monceren Combi DS 70 and Heptasan 50, with the standard product Fernasan D, for the control of covered smut. Seeds of hybrid sorghum (HD-1) were contaminated with the chlamydospores collected from previous season and stored at room temperature. A rate of 1:900-spore/seed (wt/wt) was used. The seeds were shaken with the spores to uniform coverage and the contaminated seeds were then treated with the test products at various rates. The subplot size was 2 rows 7 m long and planting was on ridges 15 cm between single plants and 60 cm between ridges. The plot received standard rate of urea and sprayed with sorgoprim for weed control. All products were evaluated for their effect on germination and protection against smut was assessed at maturity. Seed germination was good (80%) in all treatments, including the control, and none of the treatments showed smut infection except the control which gave 21% smutted heads.

Entomology

Chemical Control of Stem Borers on Sorghum

Nasr Sharaf Eldin

Screening of insecticides for the control of stem borers on sorghum has been underway for the last decade. Nevertheless, the only insecticide, so far approved and registered for commercial use in the Sudan, is carbaryl. The reason for this is that natural infestation is normally too low to give consistent and reliable data, especially with optimum sowing dates. The chemicals under test have been upgraded from a long list of chemicals tested in the last few years.

The experiment was conducted in a whole howasha (five feddans) to roughly simulate farmers' fields, and was planted on August 23rd, about 45 days later than the optimum sowing date to induce higher natural infestation. Planting was effected by hand on rows of 60 cms apart and 20 cms between plant holes.

Four chemicals, plus Sevin as standard and an untreated control, were screened in a field of sorghum (variety Dwarf White Milo) and laid out in a randomized block design with two replications. The insecticides tested and their dosage rates per feddan were as follows: Furadan 10 G at 15 kgs., Lannate 90% WP at 250 gms., Sevin 85% WP at 1.5 lb a.i., Evisect 90% SP at 400 gms., Sumithion 50% EC at 1.0 lit. and Control (Untreated). The granulated Furadan was applied by hand in a small furrow along the length of the ridge beside the plants and then covered and irrigated. The other formulations were applied with knapsack sprayers. Two applications were applied on September 21st and October 11th with the first appearance of the adults in the field.

Evaluation of efficacy was based on the level of damage to the plants, and the number of larvae and their entry-holes. Weekly surveys were undertaken. Data collected were from a row section about one meter long along the ridge. The plants showing the "dead heart" effect and those showing no damage symptoms were recorded. Also a number of plants from each treatment were taken to the lab where larvae-entry-holes were counted and the plants split open and the inside living larvae recorded. At the end of the season, the number of heads in each treatment and the grain yield were determined. Data were subjected to the appropriate transformation before analysis of variance for comparison between the different means.

Six counts were made to determine the percentage of plants showing the "dead heart" effect. The count on October 3rd showed that Furadan significantly reduced the number of damaged plants compared with Lannate, Evisect and the control. All treatments, except Evisect, were better than the control. The count three days later indicated that all treatments were similar in efficacy and were significantly better than the control. Thirty-eight days after the second application, Furadan maintained significant reduction of percentage damaged plants, compared with all other treatments, which sustained similar damage. The overall average of the six counts showed that Furadan was significantly better than Sevin, Evisect and the control; the other treatments, Sumithion and Lannate, were similar to Sevin.

Data on the larvae and their entry-holes showed that all treatments were similar in efficacy and that they significantly reduced the number of larvae and their entry-holes compared with the control. The number of heads and the grain weight under Furadan treatment was greater than the other treatments, though the difference was not significant. Grain yield showed considerable differences. The highest yield was produced with Furadan treatment, followed by Lannate and Sumithion and the lowest by Sevin, Evisect and the control.

The results clearly indicated that the insecticides tested significantly reduced the damage inflicted on the plants compared with the control. This is reflected in the lower percentage infested plants, and the lower number of the living larvae and their entry-holes. However, differences within the chemical treatments as compared with Sevin were insignificant, although Furadan showed slightly better performance.

The grain yield was generally low because of the late sowing and the attack of birds. However, yield produced under Evisect treatment was extremely low, possibly due to the heavy scorching caused to the plant by this chemical.

In light of the results presented and the discussion above, the following 3 chemicals at the specified dosage rates are recommended for release for the control of stem borers on sorghum: Furadan 10 G at 15kgs/fed., Lannate 90% WP at 250 gms/fed., and Sumithion 50% EC at 1.0 lit/fed.

Evaluation of Sorghum Food Product Quality

S.M. Badi, P.L. Bureng, L.Y. Monawar and Y.M. Abdalla

Collaborative studies are continuing between FRC and sorghum breeders in Central and Eastern Regions. These investigations have been conducted according to the objectives agreed upon between FRC, ARC breeders and the INTSORMIL team of scientists. The parameters investigated were the physical characteristics of various hybrid sorghums. The performance of the new hybrids under dehulling and milling processes has been determined according to AACC and ICC approved methods. The sorghum flours produced as whole meal and decorticated were evaluated for kisra preparation. Some of the parameters measured for kisra production were pH, total acidity and color of batter before and after fermentation, and Kisra product. The Kisra produced was subjected to laboratory taste panel. The organoleptic parameters investigated were taste, texture and color or appearance.

The physico-chemical analysis of nine hybrids, plus control samples, along with pH and total acidity (as lactic acid) of the flour was determined. The milling characteristics of sorghum grain were determined as well. The hardness of the grains was expressed in terms of brokens and overtails of sieving tests. Two types of sorghum flours were used to test the suitability and acceptability of the new sorghum hybrids in kisra productions. These flours are whole meal (100%) and 80% extraction rate type of flour.

Our results do not show any pattern to indicate direct relationship between the milling characteristics of the grains and Kisra quality. The variety which produced less acceptable Kisra was the dark red variety, PB 815. The process of fermentation improves the color of Kisra especially on those varieties with creamy/orange-yellow colors. The dark brown/red varieties are not greatly improved. The dark colored varieties of Gadam El Hamam, with different treatments gave less acceptable Kisra. The fermentation process did not improve the color of Kisra, especially brown flours. Nutritionally the brown/red varieties have high protein values. The fat content are comparable. The ash content of Gadam El Hamam (brown/red variety) is slightly lower than the creamy varieties.

The results obtained in these investigations will be repeated in the program. Detailed screening of the hybrid varieties, including the traditional varieties, will be carried out this year. The functional properties and physical characteristics of these grains will be considered in greater detail in order to establish the definition and parameters of the grains for a good quality Kisra.

Economics

John Sanders

In the summer of 1990, Mohamed M. Ahmed and John H. Sanders did fieldwork in the Gezira irrigation project to estimate the returns to research from investment in HD-1. HD-1 is in the early stage of diffusion there on approximately 17,000 ha, or 9% of the sorghum crop area. Even at this early stage of diffusion, there is a reasonable financial rate of return of 23 to 31%. Eliminating the price and exchange-rate distortions gives an economic return of 16 to 21%. Measures to eliminate these distortions, especially the overvalued exchange rate, would encourage sorghum exports by increasing their competitiveness and would enable the market rather than the governmental sector and foreign-aid donors to allocate the critical input of chemical fertilizer.

Institution Building

The INTSORMIL/Sudan program, as in the past, continued to provide direct allocation of funds to the Agricultural Research Corporation. This support contributes important operational backstopping for sorghum breeding, millet breeding, physiology/agronomy, pathology, *Striga*/weed control, entomology, food quality, economics, library improvement and administrative support. This strengthens the overall capability of ARC to address the important issues for improved production and utilization of sorghum and millet.

INTSORMIL Scientists Travel

Drs. Darrell Rosenow, Gary Peterson and Gebisa Ejeta traveled to Sudan from November 4 to November 16, 1991 to work on the Sudan Sorghum Collection Growout.

Drs. El Hilu Omer, Sitt M. Badi, and M.B.A. Salecm attended the INTSORMIL International Conference, Corpus Christi, Texas on July 9-14, 1991. A Sudan country program meeting was held at this time.

Dr. A.G.T. Babiker, ARC pathologist arrived at Purdue in January 1992 for a one year sabbatic to work with Drs. Gebisa Ejeta and Larry Butler.

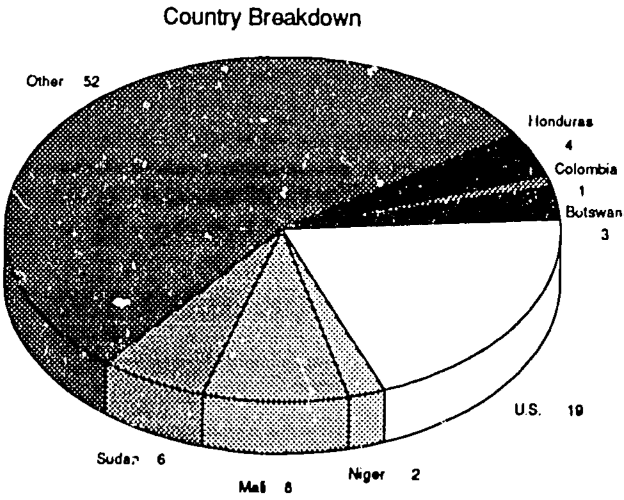
Training

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.

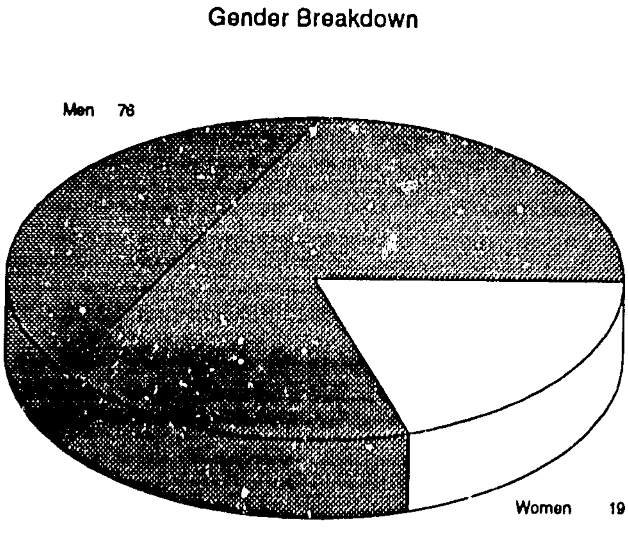
The most frequently used mode of training is graduate study for advanced degrees, with the students' research forming an integral part of an INTSORMIL project. During the year covered by this report, 95 students from 35 different countries were enrolled in an INTSORMIL advanced degree program. Approximately 80% 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. 1992 INTSORMIL Training Analysis.



Country Breakdown

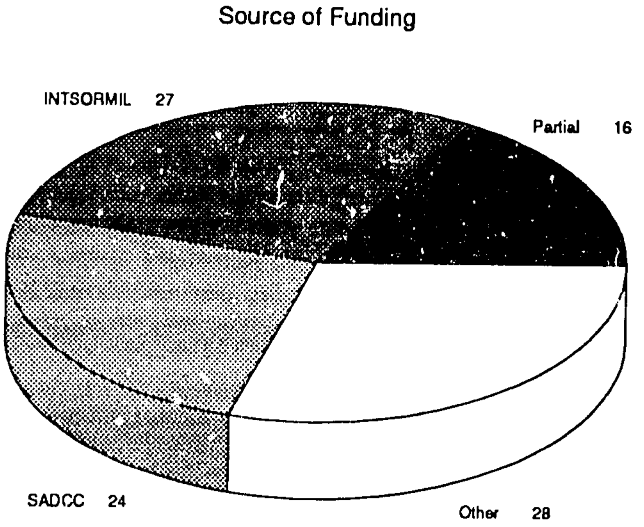
Figure 2. INTSORMIL Training Analysis.



Gender Breakdown

INTSORMIL also places a high priority on training women which is reflected in Figure 2. In 1992, 20% of all INTSORMIL graduate participants were women. Twenty-seven of the total 95 students received full INTSORMIL scholarships. An additional 16 students received partial INTSORMIL funding and the remaining 52 students were funded from other sources as shown in Figure 3.

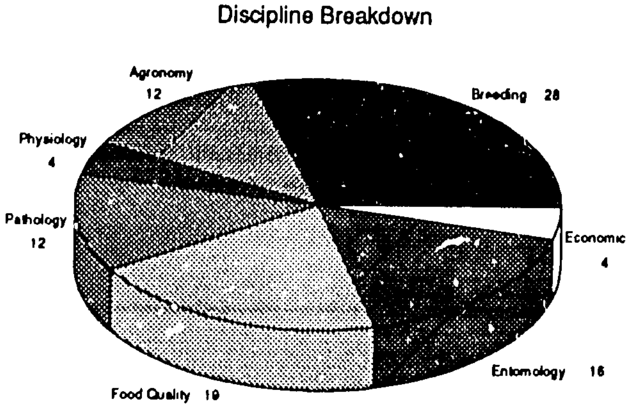
Figure 3. 1992 INTSORMIL Training Analysis.



Source of Funding

All 95 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. 1992 INTSORMIL Training Analysis.



Discipline Breakdown

Total student numbers increased slightly in 1991-92 as compared to 1990 and 1991. However, the number of INTSORMIL funded students has decreased by 21% from 1988. This also represents a decrease of 43% in the number of INTSORMIL funded students as compared to 1987. This decrease is partially due to an equivalent increase in the number of students supported through other sources, i.e., A.I.D. Missions, ICRISAT, etc.

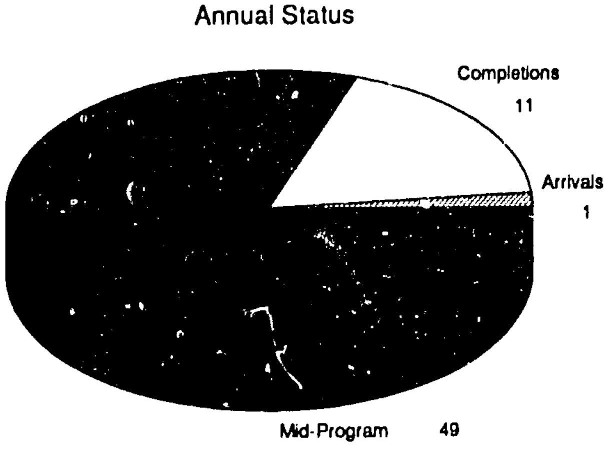
In addition to graduate degree programs, short term training programs have been designed and implemented on a case by case basis to suit the needs of host country scientists. Several Host Country scientists were provided the opportunity to upgrade their skills in this fashion during 1992.

INTSORMIL cooperates with ICRISAT on a ten year special training program for the Southern African Development Coordinating Countries, SADCC. The SADCC/ICRISAT regional Sorghum and Millet Research Program was designed to respond to the need of the 10 member states of SADCC, the Southern African Development Coordination Conference, to initiate research on sorghum and millets in the marginal rainfall areas of the region. The program is implemented by ICRISAT and funded by USAID, CIDA and GTZ.

A major component of the program is Training and Staff Development. The objective of this component is to strengthen the scientific and technical research capability of National Research Programs through advanced degree and technical training. In order to accomplish the objective, ICRISAT has sub-contracted the advanced degree training element to INTSORMIL, the International Sorghum and Millet Collaborative Research Support Program, where the necessary linkages and institutions exist.

In 1992, INTSORMIL placed one additional scientist from Zimbabwe into a graduate program in Canada. This brought the total number of active SADCC students to 61 for 1991-92. (Figure 5)

Figure 5. 1992 SADCC Training Analysis



The scientist who arrived in 1992 was placed at Guelph Univeristy in Ontario. This student is funded by the Canadian International Development Agency, CIDA, but administered by INTSORMIL in the same manner as our AID funded students.

The SADCC/ICRISAT Southern African training program continues to hold a high profile in INTSORMIL training activities. Of 49 students matriculating in the U.S., Canada and Brazil, 24 are studying under INTSORMIL scientists while the remainder are with subject matter specialists not covered by INTSORMIL scientists. There were 11 degree completions in 1992.

The following table is a compilation of all INTSORMIL training activities for the period covered by this report, July 1, 1991 through June 30, 1992.

Year 13 INTSORMIL Training Participants

Name	Country	University	Discipline	Advisor	Degree	Gender	Funding*
Coulibaly, Adama	Mali	KSU	Agronomy	Vanderlip	MSC	M	I
Gono, Lawrence	Zimbabwe	KSU	Agronomy	Vanderlip	PHD	M	S
Heiniger, Ronnie	U.S.	KSU	Agronomy	Vanderlip	PHD	M	I
Lele, Etani	Botswana	KSU	Agronomy	Vanderlip	MSC	M	S
Madulu, Ruth	Tanzania	KSU	Agronomy	Vanderlip	MSC	F	S
Gutierrez, Patricio F.	Ecuador	UNL	Agronomy	Clegg	MSC	M	I
Maliro, Charles	Malawi	UNL	Agronomy	Clegg	PHD	M	S
Mohamed, Mirghani S.	Sudan	UNL	Agronomy	Clegg	PHD	M	I
Masi, Cassim	Zambia	UNL	Agronomy	Maranville	PHD	M	S
Sirifi, Seyni	Niger	UNL	Agronomy	Maranville	MSC	M	O
Toure, Abdoul	Mali	UNL	Agronomy	Maranville	MSC	M	I
Traore, Abdoulaye	Mali	UNL	Agronomy	Maranville	PHD	M	I
Goggi, Susani	Argentina	MSU	Breeding	Gourley	PD[1]	F	I
Zake, Vincent	Uganda	MSU	Breeding	Gourley	PHD	M	O
Mushonga, Joe	Zimbabwe	PRF	Breeding	Axtell	PHD	M	S
Peters, Paul	US	PRF	Breeding	Axtell	PHD	M	O
Botorou, Ouendeba	Niger	PRF	Breeding	Ejeta	PHD	M	O
Cisse, N'Diaga	Senegal	PRF	Breeding	Ejeta	PHD	M	O
Grote, Ed	US	PRF	Breeding	Ejeta	PHD	M	O
Ibrahim, Yahia	Sudan	PRF	Breeding	Ejeta	MSC	M	O
Johnson, Richard	US	PRF	Breeding	Ejeta	MSC	M	O
Vogler, Renee	US	PRF	Breeding	Ejeta	MSC	F	I
Weerasuriya, Yohan	Sri Lanka	PRF	Breeding	Ejeta	PHD	M	O
Dahlberg, Jeffrey	US	TAM	Breeding	Miller	PHD	M	P
Gouveia, Sergio Jeremias	Mozambique	TAM	Breeding	Miller	MSC	M	S
[illegible]uzzah, Bill W.	Uganda	TAM	Breeding	Miller	PHD	M	O
Ombakho, George	Kenya	TAM	Breeding	Miller	PHD	M	P
Palma C., Alejandro	Honduras	TAM	Breeding	Miller	MSC	M	O
Tenkouano, Abdou	Burkina Faso	TAM	Breeding	Miller	PHD	M	O
Toure, Aboubacar	Mali	TAM	Breeding	Miller/Rosenow	PHD	M	P
Gorman, Chris	US	TTU	Breeding	Rosenow	MSC	M	I
Isbell, Verne	US	TAM	Breeding	Rosenow	PHD	M	P
Mkhabela, Milton	Swaziland	TTU	Breeding	Rosenow	PHD	M	S
Doumbia Mamadou	Mali	TAM	Breeding	Peterson	PHD	M	P
Chirwa, Rowland	Malawi	UNL	Breeding	Andrews	PHD	M	S
Chungu, Chibwe	Zambia	UNL	Breeding	Andrews	MSC	F	S
Jeutong, Fabien	Cameroon	UNL	Breeding	Andrews	PHD	M	O
Kiula, Barnabas	Tanzania	UNL	Breeding	Andrews	MSC	M	S
Mahama, A. Assibi	Ghana	UNL	Breeding	Andrews	MSC	M	O
Muza, F.R.	Zimbabwe	UNL	Breeding	Andrews	PHD	M	S
Ahmed, Mohamed	Sudan	PRF	Economics	Sanders	PHD	M	I
Coulibaly, Ousmane	Mali	PRF	Economics	Sanders	PHD	M	I
Nichola, Tennassie	Ethiopia	PRF	Economics	Sanders	PHD	M	I
Salih, Ali	Sudan	PRF	Economics	Sanders	PHD	M	O
Ching'oma, Godfrey	Malawi	MSU	Entomology	Pitre	MSC	M	S
Lopez, Julio	Honduras	MSU	Entomology	Pitre	MSC	M	I
Portillo, Hector	Honduras	MSU	Entomology	Pitre	PHD	M	I
Bayoum, Imad	Lebanon	TAM	Entomology	Gilstrap	PHD	M	I
Behle, Robert	U.S.	TAM	Entomology	Gilstrap	PHD	M	P
Ciomperlik, Matthew	U.S.	TAM	Entomology	Gilstrap	PHD	M	P
Monroy, Jose	Honduras	TAM	Entomology	Gilstrap	VS[2]	M	I
Rao, Asha	India	TAM	Entomology	Gilstrap	MSC	F	I
Rojas, Edgar	Costa Rica	TAM	Entomology	Gilstrap	PHD	M	P
Roque, Javier	Mexico	TAM	Entomology	Gilstrap	PHD	M	P

Name	Country	University	Discipline	Advisor	Degree	Gender	Funding*
Jimenez, Nora	Colombia	TAM	Entomology	Teetes	MSC	F	I
Jost, Douglas	U.S.	TAM	Entomology	Teetes	MSC	M	I
Magallenes, Ricardo	Mexico	TAM	Entomology	Teetes	PHD	M	P
Manthe, Chris	Botswana	TAM	Entomology	Teetes	PHD	M	S
Paliani, Anderson	Malawi	TAM	Entomology	Teetes	MSC	M	S
Pendleton, Bonnie	US	TAM	Entomology	Teetes	PHD	F	O
Lelong, Dolly Bell	Tanzania	PRF	Food Quality/Util	Butler	PHD	F	O
Siame, Anthony Bupe	Zambia	PRF	Food Quality/Util	Butler	PHD	M	S
Tarimo, Thadeo	Tanzania	PRF	Food Quality/Util	Butler	PHD	M	S
Weerasuriya, Yohan H.	Sri Lanka	PRF	Food Quality/Util	Butler	MSC	M	O
Aboubacar, Adam	US	PRF	Food Quality/Util	Kirleis/Hamaker	MSC	M	O
Mohamed, Abdel-Mageed	Sudan	PRF	Food Quality/Util	Kirleis/Hamaker	VS[2]	M	I
Oria, Maria P.	Spain	PRF	Food Quality/Util	Kirleis/Hamaker	PHD	F	O
Shull, Jeanette	US	PRF	Food Quality/Util	Kirleis/Hamaker	PD[1]	F	I
Anderson, Brian	US	TAM	Food Quality/Util	Rooney	MSC	M	P
Beta, Trust	Zimbabwe	TAM	Food Quality/Util	Rooney	MSC	F	S
Clegg, Chally	US	TAM	Food Quality/Util	Rooney	MSC	M	P
Corujo, Juan	Spain	TAM	Food Quality/Util	Rooney	MSC	M	P
Cruz y Celis, Laura	Mexico	TAM	Food Quality/Util	Rooney	MSC	F	P
Hugo, Leda	Mozambique	TAM	Food Quality/Util	Rooney	MSC	F	S
Islas-Rubio, Alma	Mexico	TAM	Food Quality/Util	Rooney	PHD	F	P
Lekalake, Rosemary	Botswana	TAM	Food Quality/Util	Rooney	MSC	F	S
Mrema, Greyson	Tanzania	TAM	Food Quality/Util	Rooney	MSC	M	S
Suhendro, Elly	Indonesia	TAM	Food Quality/Util	Rooney	MSC	F	O
Wright, Lee	US	TAM	Food Quality/Util	Rooney	MSC	M	P
Kedera, John	Kenya	KSU	Pathology	Claflin	PHD	M	O
Xu, Jin-Rong	China	KSU	Pathology	Leslie	PHD	M	O
Casela, Carlos	Brazil	TAM	Patholgy	Frederiksen	PHD	M	O
Esele, Peter	Uganda	TAM	Pathology	Frederiksen	PHD	M	O
Mansuetus, Anaclet	Tanzania	TAM	Pathology	Frederiksen	PHD	M	S
Naidoo, Gnanambal	South Africa	TAM	Pathology	Frederiksen	PHD	F	O
Oh, B.J.	Korea	TAM	Pathology	Frederiksen	PHD	M	O
Rosewich, Ute L.	Germany	TAM	Pathology	Frederiksen	PHD	F	I
Guthrie, Phillip	Great Britain	TAM	Pathology	Odvody	PHD	M	I
Kunene, Innocentia	Swaziland	TAM	Pathology	Odvody	PHD	F	S
Alexander, John	US	TAM	Pathology	Toler	PHD	M	O
McClelan, Eddie	US	TAM	Pathology	Toler	PHD	M	I
Gandoul, Gandoul I.	Sudan	UNL	Physiology	Eastin	PHD	M	I
Nyakatawa, Ernson	Zimbabwe	UNL	Physiology	Eastin	MSC	M	S
Coulibaly, Sidi Bekaye	Mali	UNL	Physiology	Sullivan	MSC	M	I
Dione, Siriba	Mali	UNL	Physiology	Sullivan	MSC	M	I

* I = Completely funded by INTSORMIL
P = Partially funded by INTSORMIL
S = SADCC/ICRISAT funded
O = Other source

[1]PD = Post Doctoral
[2]VS = Visiting Scientist

KSU = Kansas State University
MSU = Mississippi State University
PRF = Purdue University
TAM = Texas A&M University
TTU = Texas Tech University
UNL = University of Nebraska - Lincoln

Year 13 SADCC/ICRISAT Training Participants

Name	Country	University	Discipline	Advisor	Degree	Gender
Alfredo, Manuel	Angola	Vicosa	Pathology	Ferreira da Silva	MSC	M
Chitengue, Jone	Angola	Vicosa	Breeding	Vieira	MSC	M
Domingos, M'panzo	Angola	Vicosa	Agronomy	Nogueira Fontes	MSC	M
Jose, Joao	Angola	Vicosa	Breeding	Cardosa	MSC	M
Emmanuel, Willie	Botswana	MSU	Seed Technology	Vaughan	BSC	M
Lekalake, Rosemary	Botswana	TAM	Food Science	Rooney	MSC	F
Lele, Etani	Botswana	KSU	Agronomy	Vanderlip	MSC	M
Makhwaje, Ernest	Botswana	KSU	FSR/Econ	Norman	MSC	M
Malepa, Dollina	Botswana	UNL	Plant/Soil	Walters	PHD	F
Manthe, Chris	Botswana	TAM	Entomology	Teetes	PHD	M
Molapong, Keoagile	Botswana	N. Carolina St.	Plant/Soil	Cox	PHD	M
Moroke, Thebeetsile	Botswana	So. Illinois	Plant/Soil	Chong	MSC	M
Khalema, Ticiso	Lesotho	Texas Tech	FSR/Econ	Ervin	MSC	M
Mofolo, Moea	Lesotho	UNL	Agronomy	Sorensen	BSC	M
Mokhoro, Cyprian	Lesotho	UNL	Food Science	Jackson	MSC	M
Ranthamane, Matla	Lesotho	KSU	Breeding	Bramel-Cox	MSC	M
Sefika, Phakiso	Lesotho	UNL	Forages	Anderson, B.	MSC	M
Ching'oma, Godfrey	Malawi	MSU	Entomology	Pitre	MSC	M
Chintu, Edmund	Malawi	Guelph	Breeding	Kannenberg	PHD	M
Chirwa, Rowland	Malawi	UNL	Breeding	Andrews	PHD	M
Luhanga, Jeffrey	Malawi	MSU	Seed Tech	Andrews, C.H.	PHD	M
Maliro, Charles	Malawi	UNL	Agronomy	Clegg	PHD	M
Paliani, Anderson	Malawi	TAM	Entomology	Teetes	MSC	M
Brito, Rui	Mozambique	CSU	Agronomy	Dumford	PHD	M
Gouveia, Sergio	Mozambique	TAM	Breeding	Miller	MSC	M
Hugo, Leda	Mozambique	TAM	Food Science	Rooney	MSC	F
Maposse, Inacio	Mozambique	UNL	Forages	Anderson, B.	MSC	M
Mucavele, Firmino	Mozambique	Florida	FSR/Econ	Spreen	PHD	M
Pereira, Luiz	Mozambique	UNL	Agroclimatology	Weiss	MSC	M
Kunene, Innocentia	Swaziland	TAM	Pathology	Odvody	PHD	F
Mabuza, Khanyisile	Swaziland	Guelph	Food Science	Gullet	MSC	F
Malaza, Millicent	Swaziland	Penn St.	FSR/Econ	Warland	PHD	F
Matsebula, Sebenzile	Swaziland	Saskatchewan	Biometrics	Baker	PHD	F
Mkhabela, Milton	Swaziland	Texas Tech	Breeding	Rosenow/Nguyen	PHD	M
Felix, Joel	Tanzania	PRF	Agronomy	Vorst	MSC	M
Kaganda, Suleiman	Tanzania	UNL	Forages	Anderson/Moser	MSC	M
Kiula, Barnabas	Tanzania	UNL	Breeding	Andrews	MSC	M
Madulu, Ruth	Tanzania	KSU	Agronomy	Vanderlip	MSC	F
Mansuetus, Anaclet	Tanzanaia	TAM	Pathology	Fredriksen	PHD	M
Matowo, Peter	Tanzania	KSU	Agronomy	Pierzwnski	PHD	M
Mbuya, Odemari	Tanzania	Florida	Agronomy	Boote	PHD	M
Mgema, William	Tanzania	UNL	Agronomy	Clark	MSC	M
Mndolwa, Samuel	Tanzania	KSU	Agronomy	Moshier	BSC	M
Mrema, William	Tanzania	TAM	Food Science	Rooney	MSC	M
Mtwaenzi, Hamis	Tanzania	MSU	Weed Science	Coats	MSC	M
Tarimo, Thadeo	Tanzania	PRF	Bird Control	Butler/Weeks	PHD	M
Chisi, Medson	Zambia	KSU	Breeding	Bramel-Cox	PHD	M
Chungu, Chibwe	Zambia	UNL	Breeding	Andrews	MSC	F
Hikeezi, Doreen	Zambia	KSU	Food Science	Walker	MSC	F
Masi, Cassim	Zambia	UNL	Agronomy	Maranville	PHD	M
Mwale, Moses	Zambia	UNL	Plant/Soil	Walters	MSC	M

Name	Country	University	Discipline	Advisor	Degree	Gender
Ngulube-Msikita, Rachel	Zambia	UNL	Breeding	Moser	BSC	F
Siame, Anthony	Zambia	PRF	Food Science	Butler	PHD	M
Beta, Trust	Zimbabwe	TAM	Food Science	Rooney	MSC	F
Gono, Tigere Lawrence	Zimbabwe	KSU	Agronomy	Vanderlip	PHD	M
Mahuku, George	Zimbabwe	Guelph	Pathology	Hall	PHD	M
Makaudze, Ephias	Zimbabwe	TAM	FSR/Econ	Fuller	MSC	M
Mazhangara, Edward	Zimbabwe	PRF	FSR/Econ	Masters	MSC	M
Muza, Figuhr	Zimbabwe	UNL	Breeding	Lee	PHD	M
Nyakatawa, Ermson	Zimbabwe	UNL	Agronomy	Eastin/Schilling	MSC	M

CSU = Colorado State University, Fort Collins, Colorado
KSU = Kansas State University, Manhattan, Kansas
MSU = Mississippi State University, Mississississippi State, Mississippi
PRF = Purdue University, West Lafayette, Indiana
TAM = Texas A&M University, College Station, Texas
UNL = University of Nebraska, Lincoln, Nebraska

Florida = University of Florida, Gainesville, Florida
Guelph = University of Guelph, Ontario, Canada
N. Carolina St. = North Carolina State University, Raleigh, North Carolina
Penn St. = Penn State University, University Park, Pennsylvania
Saskatchewan = University of Saskatchewan, Saskatoon, Canada
So. Illinois = Southern Illinois University, Carbondale, Illinois
Texas Tech = Texas Tech University, Lubbock, Texas
Vicosa = Universidad Federal de Vicosa, Brazil

Appendices

INTSORMIL Buy-Ins

University/ Project No.	Buy-In	Year	Life of Buy-In	Annual Amount	Total
KSU-106	SADCC/ICRISAT Training	1989	2 years	23,200	46,400
	SADCC/ICRISAT Training	1990	3 years	40,000	120,000
	AID/Mauritania Training	1989	2 years	2,520	5,040
	Kansas Agric. Exp. Station	1991	3 years	19,000	57,000
	Kansas Agric. Exp. Station	1989	3 years	19,000	57,000
	Kansas Agric. Exp. Station	1988	3 years	13,333	40,000
	Kansas Grain Sorghum Commission	1985	6 years	17,500	105,000
	EPA/University of Nebraska	1990	2 years	32,518	65,036
					$ 495,476
KSU-107	USAID/Gaborone	1988	5 years	50,000	**$ 250,000**
KSU-108	Kansas Corn Commission	1988	3 years	16,845	50,535
	Kansas Grain Sorghum Commission	1989	1 year	13,666	13,666
	Kansas Corn & Sorghum Commission	1985	9 years	18,482	166,338
	Kansas Agric. Exp. Station	1991	3 years	19,000	57,000
	EPA	1990	3 years	39,523	118,569
					$ 406,108
MSU-104	MIAC	1990	2 years	115,725	231,450
	MIAC	1992	1 year	142,000	142,000
	El Alcaravan Foundation	1991	1 year	200,000	200,000
	FEDEARROZ	1990	5 years	10,000	50,000
	FENALCE	1991	1 year	5,000	5,000
					$ 628,450
MSU-105	SADCC	1992	1 year	4,210	4,210
	FAO	1992	3 years	2,245	6,735
					$ 10,945
MSU-111	El Alcaravan Foundation	1990	2 years	200,000	400,000
	FEDEARROZ	1990	5 years	10,000	50,000
					$ 450,000
Kenya	MIAC-USAID/Nairobi	1991	26 months	130,000	200,000
	MIAC-USAID/Nairobi	1992	1 year	120,000	120,000
					$ 320,000
PRF-103A	AID/Program Support Grant	1988	1 year	10,000	10,000
	AID/Program Support Grant	1989	1 year	5,000	5,000
	Agric. Exp. Station	1988	2 years	7,000	14,000
	McKnight Foundation	1989	3 years	229,368	688,104
	McKnight Foundation	1992	3 years	250,000	750,000
					$ 1,467,104
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	1 year	5,000	5,000
	USAID PSG	1990	3 years	10,000	30,000
	Rockefeller Foundation	1989	3 years	24,500	73,500
	USAID/PSTC	1990	4 years	50,000	200,000
	Purdue Research Foundation	1991	1 year	2,800	2,800
	Pioneer Seed Company	1991	3 years	60,000	180,000
					$ 491,300
PRF-105	USAID PSG	1989	3 years	5,000	15,000
	USAID PSG	1991	1 year	5,000	5,000
	USAID/Bean-Cowpea CRSP	1990	1 year	22,000	22,000
	USAID/PSG				**$ 42,000**

INTSORMIL Buy-Ins

University/ Project No.	Buy-In	Year	Life of Buy-In	Annual Amount	Total
PRF-107	USAID PSG	1989	1 year	16,500	16,500
	USAID PSG	1990	2 years	14,000	28,000
	McKnight Foundation	1989	3 years	20,632	61,896
	State of Indiana	1990	1 year	8,200	8,200
	Pioneer Seed Company	1991	2 years	15,000	30,000
					$ 144,596
PRF-109	USDA Grant	1990	2 years	30,000	**$ 60,000**
PRF-111	USAID/Khartoum-PL480	1990	3 years	80,000	**$ 240,000**
TAM-121	Rockefeller Foundation	1992	1 year	18,724	**$ 18,724**
TAM-122	USAID/TAMU	1989	1 year	24,000	24,000
	USDA	1989	3 years	13,333	40,000
	State of Texas Grant	1989	2 years	28,000	56,000
	USAID/TAMU	1990	3 years	18,000	54,000
	State of Texas Grant	1990	2 years	20,000	40,000
	State of Texas Grant	1991	2 years	7,000	14,000
	Texas Higher Coordinating Board	1991	2 years	27,000	54,000
	USAID/TAMU	1991	1 year	13,000	13,000
	USAID/TAMU	1991	1 year	15,000	15,000
					$ 310,000
TAM-123	Texas Grain Sorghum Producers	1990	5 years	50,000	250,000
	USAID/TAMU	1990	1 year	17,000	17,000
	USAID/TAMU	1991	1 year	28,000	28,000
					$ 295,000
TAM-124	USDA	1989	3 years	10,000	30,000
	Texas Advanced Research	1989	1 year	75,000	75,000
	Texas Advanced Research	1990	3 years	15,000	45,000
	Rockefeller Foundation	1990	2 years	30,000	60,000
	TAES (ERA)	1990	2 years	32,000	64,000
	Rockefeller Foundation	1992	1 year	7,000	7,000
					$ 281,000
TAM-125	TAMU/Program Support Grant	1989	3 years	24,000	72,000
	Texas Grain Sorghum Producers	1989	5 years	10,000	50,000
	USDA/APHIS	1989	2 years	15,000	30,000
	USDA/APHIS	1990	3 years	23,734	71,202
	USDA/APHIS	1990	1 year	28,200	28,200
	USDA/CSRS	1990	2 years	29,910	59,820
	TAMU/Program Support Grant	1990	2 years	18,638	37,276
	TAMU/Program Support Grant	1990	2 years	30,000	60,000
	SADCC/ICRISAT Training	1989	1 year	21,000	21,000
	USDA/APHIS	1991	1 year	13,200	13,200
	TAMU/Program Support Grant	1990	3 years	27,000	78,000
					$ 520,698
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	31,500	63,000
	HATCH	1990	3 years	35,000	105,000
	Sorghum/Wheat Producers	1990	1 year	15,000	15,000
	Grain Sorghum Producers	1992	3 years	51,973	155,919
	TAES/ERA	1991	2 years	12,500	25,000
	TAES/ERA	1991	2 years	19,000	38,000
					$ 696,419
TAM-131	AID/Honduras - PL480	1990	3 years	120,000	**$ 360,000**
UNL-113	SADCC/ICRISAT Training	1989	3 years	18,000	54,000
	USAID/ICRISAT Training	1989	3 years	18,000	54,000
	Rockefeller Foundation	1989	3 years	8,333	25,000
	Ministry of Science (Leave)	1991	1 year	25,000	25,000
					$ 158,000

INTSORMIL Buy-Ins

University/ Project No.	Buy-In	Year	Life of Buy-In	Annual Amount	Total
UNL-114	SADCC/ICRISAT Training	1991	2 years	18,485	**$ 36,970**
UNL-115 & - 118	Michigan State/Senegal Agric.	1989	4 years	48,350	**$ 193,400**
UNL-116	USDA/OICD	1989	3 years	14,667	44,000
	Elliott Grant	1989	4 years	17,250	69,000
	Nebraska Sorghum Board	1990	3 years	24,400	73,200
	Nebraska Sorghum Board	1992	3 years	56,000	168,000
					$ 354,200
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
	Social Science Research	1991	1 year	31,600	31,600
	Adaptation of Plants to Soil Stress Workshop	1992	1 year	25,000	25,000
					$ 526,783
Total Buy-Ins					**$ 9,226,298**

INTSORMIL Sponsored and Co-Sponsored Workshops 1979 - 1992

	Name	Where	When
1.	International Short Course in Host Plant Resistance	College Station, Texas	1979
2.	INTSORMIL PI Conference	Lincoln, Nebraska	1/80
3.	West Africa Farming Systems	West Lafayette, Indiana	5/80
4.	Sorghum Disease Short Course for Latin America	Mexico	3/81
5.	International Symposium on Sorghum Grain Quality	ICRISAT	10/81
6.	International Symposium on Food Quality	Hyderabad, India	10/81
7.	Agrimeteorology of Sorghum and Millet in the Semi-Arid Tropics	ICRISAT	1982
8.	Latin America Sorghum Quality Short Course	El Batan, Mexico	4/82
9.	Sorghum Food Quality Workshop	El Batan, Mexico	4/82
10.	Sorghum Downy Mildew Workshop	Corpus Christi, Texas	6/82
11.	Plant Pathology	CIMMYT	6/82
12.	Striga Workshop	Raleigh, North Carolina	8/82
13.	INTSORMIL PI Conference	Scottsdale, Arizona	1/83
14.	INTSORMIL-ICRISAT Plant Breeding Workshop	CIMMYT	4/83
15.	Hybrid Sorghum Seed Workshop	Wad Medani, Sudan	11/83
16.	Stalk and Root Rots	Bellagio, Italy	11/83
17.	Sorghum in the '80s	ICRISAT	1984
18.	Dominican Republic/Sorghum	Santo Domingo	1984
19.	Sorghum Production Systems in Latin America	CIMMYT	1984
20.	INTSORMIL PI Conference	Scottsdale, Arizona	1/84
21.	Primer Seminario National Sobre Produccion y Utilizacion del Sorgo	Santo Domingo, Dominican Republic	2/84
22.	Evaluating Sorghum for Al Toxicity in Tropical Soils of Latin America	Cali, Colombia	4/84
23.	First Consultative and Review on Sorghum Research in the Philippines	Los Banos, Philippines	6/84
24.	INTSORMIL Graduate Student Workshop and Tour	College Station, Texas	6/84
25.	International Sorghum Entomology Workshop	College Station, Texas	7/84
26.	INTSORMIL PI Conference	Lubbock, Texas	2/85
27.	Niger Prime Site Workshop	Niamey, Niger	10/85
28.	Sorghum Seed Production Workshop	CIMMYT	10/85
29.	International Millet Conference	ICRISAT	4/86
30.	Maicillos Criollos and Other Sorghum in Middle America Workshop	Tegucigalpa, Honduras	12/87
31.	INTSORMIL PI Conference	Kansas City, Missouri	1/87
32.	2nd Global Conference on Sorghum/Millet Diseases	Harare, Zimbabwe	3/88
33.	6th Annual CLAIS Meeting	San Salvador, El Salvador	12/88
34.	International INTSORMIL Research Conference	Scottsdale, Arizona	1/89
35.	INTSORMIL Graduate Student Workshop and Tour	College Station, Texas	7/89
36.	ARC/INTSORMIL Sorghum/Millet Workshop	Wad Medani, Sudan	11/89
37.	Workshop on Sorghum Nutritional Grain Quality	West Lafayette, Indiana	2/90
38.	Sorghum for the Future Workshop	Cali, Colombia	1/91
39.	INTSORMIL PI Conference	Corpus Christi, Texas	7/91
40.	Social Science Research and the CRSPs	Lexington, KY	6/92

Acronyms

AAA/SFAA	American Anthropological Association/Society for Applied Anthropology
ABA	Abscisic Acid
ADC's	Advanced Developing Countries
ADIN	Nursery for Disease and Insect Resistance
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
ARS	Agricultural Research Service
ASA	American Society of Agronomy
ATIP	Agricultural Technology Improvement Project
BIFAD	Board for International Food and Agricultural Development
CARE	Cooperative for American Remittances to Europe, Inc.
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
CIAB	Agricultural Research Center of the Lowlands, Mexico
CIDA	Canadian International Development Agency
CIAT	International Center for Tropical Agriculture, Colombia
CILSS	Interstate Committee for Drought Control in the Sahel
CIMAR	Centro de Investigación en Ciencias del Mar y Limnologia, Costa Rica
CIMMYT	International Maize and Wheat Improvement Center
CIRAD	Centre de Coopèration Internationale 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
DAR	Department of Agricultural Research, Botswana
DR	Dominican Republic
DRI-Yoro	Integrated Rural Development Project, Honduras-Switzerland
EAP	Escuela Agricola Pan Americana, Zamorano, Honduras
EARSAM	East Africa Regional Sorghum and Millets
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
ERS/IEC	Economic Research Service/International Economic Development
EZC	Ecogeographic Zone Council
FAO	Food and Agriculture Organization of the United States
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
GOB	Government of Botswana
GOH	Government of Honduras
GTZ	German Agency for Technical Cooperation
IAN	Institute Agronomia Nacional, Paraguay
IANR	Institute of Agriculture and Natural Resources
IARC	International Agriculture Research Center
IBM	International Business Machines
IBSNAT	International Benchmark Soils Network for Agrotechnology Transfer
ICA	Instituto Colombiano Agropecuario/Colombian Agricultural Institute
ICARDA	International Centre for Agricultural Research in the Dry Areas
ICRISAT	International Crops Research Institute for the Semiarid Tropics
ICTA	Instituto de Ciencias y Technologia Agricolas, Guatemala
IDIAP	Agricultural Research Institute of Panama
IDRC	International Development Research Center
IER	Institute of Rural Economy, Mali
IFPRI	International Food Policy Research Institute
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
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
ISC	ICRISAT Sahelien Center
ISRA	Institute of Agricultural Research, Senegal
ITA	Institut de Technologie Alimentaire, Senegal
JCARD	Joint Committee on Agricultural Research and Development
KARI	Kenya Agriculture Research Institute
KIRDI	Kenya Industrial Research and Development Institute
KSU	Kansas State University
LDC	Lesser Developed Country
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
NARS	National Agricultural Research System
NSF	National Science Foundation
NSP	National Sorghum Program
NSSL	National Seed Storage Laboratory
NU	University of Nebraska
OAU	Organization of African Unity
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
PSTC	Program in Science & Technology Cooperation
PVO	Private Volunteer Organization
SACCAR	Southern African Centre for Cooperation in Agricultural Research
SADCC	Southern Africa Development Coordination Conference
SADCC/ICRISAT/SMIP	SADCC/ICRISAT Sorghum and Millet Support Program
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
SICNA	Sorghum Improvement Conference of North America
SIDA	Swedish International Development Agency
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
UNILLANOS	Universidad Technologica de los Llanos
UNL	University of Nebraska - Lincoln
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
WASAT	West African Semi-Arid Tropics
WASIP	West Africa Sorghum Improvement Program
WSARP	Western Sudan Agricultural Research Project