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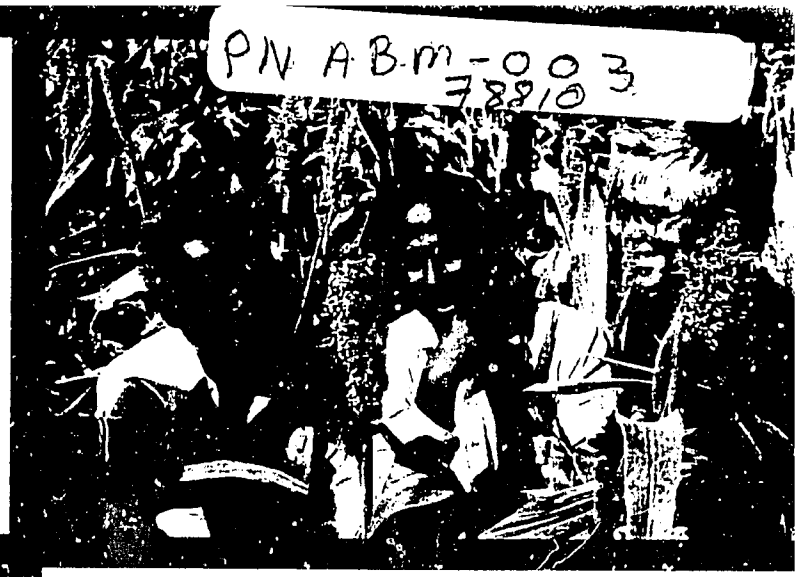
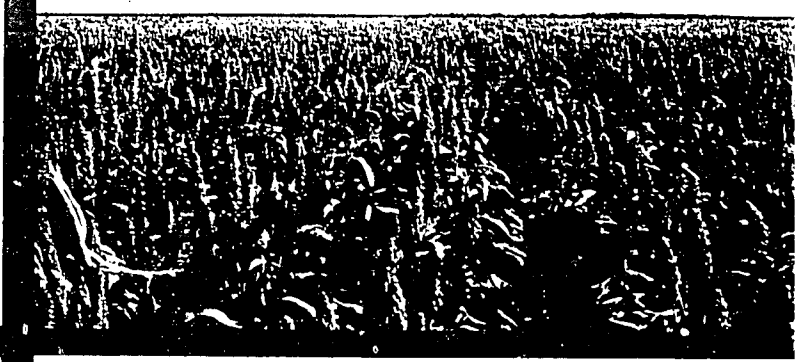


INTSORMIL

Annual Report 1991

SORGHUM/MILLET COLLABORATIVE RESEARCH SUPPORT PROGRAM (CRSP)



Fighting Hunger with Research ... a team effort

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Cover Photographs
(top to bottom)

1. Dr. Omer Hilu, ARC Sudan and Dr. R.A. Frederiksen, Texas A&M University, examine long smut in a Sudanese farmer's field. (Photo courtesy of Dr. Gebisa Ejeta.)

2. Honduran farmer transports sorghum harvest from hillside farm. (Photo courtesy of Dr. Dan Meckenstock.)

3. American sorghum field planted in new white 'food type' hybrid. (Photo courtesy of Dr. Lloyd Rooney.)

4. Young Nigerian boy helps mother prepare nutritious mix of millet and cowpea flours. (Photo courtesy of Dr. John Yohe.)

INTSORMIL

Annual Report 1991

Fighting Hunger with Research . . . A Team Effort

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

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

INTSORMIL INSTITUTIONS

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

INTSORMIL Institutions are affirmative action/equal opportunity institutions.

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EXECUTIVE SUMMARY

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 Bureau for Research and Development. Over the past twelve 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 six american universities with over 100 international scientists in six 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 five 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 concert 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, 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.

1990/91 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 1990/91 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 was awarded a new five year Grant from A.I.D. in September, 1990. This extends the life of the INTSORMIL program from July 1, 1990 to June 30, 1995.

- 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 was awarded a three year grant from USAID/Egypt to conduct collaborative research with the Egyptian Agriculture Research Center and the USAID/NARP project on "Water Use Efficiency on Sorghum" and "Sorghum Stalk Rot Research". The two subgrant institutions in INTSORMIL are the University of Nebraska and Kansas State University". This new grant is effective July 1, 1991.

- Developed the INTSORMIL Five Year Calendar with dates of all INTSORMIL major activities to provide more orderly and efficient annual planning. In addition, annual EEP reviews have been incorporated in order to keep the panel abreast of project activities and to allow input from the EEP on a yearly basis as required by USAID guidelines.

- INTSORMIL/Mississippi State University organized the first ICA/INTSORMIL Sorghum Workshop in Colombia. The Workshop was held at CIAT near Cali, Colombia. Two hundred were in attendance. The Colombian Minister of Agriculture was present when two new sorghum varieties, Sorgo Real 40 and Sorgo Real 60 were released. These were joint releases between INTSORMIL and the Instituto Colombiano Agropecuaria (ICA).

- Dr. Gebisa Ejeta, INTSORMIL Sudan Country Coordinator, Purdue University, in conjunction with Sudan INTSORMIL counterpart scientists and USAID/Khartoum developed a proposal for local

currency funding from PL480 generated funds to support local currency costs for INTSORMIL collaborative research in Sudan. This proposal was submitted to USAID/Khartoum, the Sudan Ministry of Agriculture and the Sudan Ministry of Finance and Planning in early 1990. This proposal was funded at 1.7 million Sudanese pounds per year in October, 1990. This is equivalent to about $100,000 per year.

- INTSORMIL was awarded $100,000 from A.I.D. to support identification of Cross CRSP opportunities. This grant was made to INTSORMIL in September, 1990. Participating CRSPs are Bean/Cowpea CRSP, Fisheries Stock Assessment CRSP, Nutrition CRSP, Peanut CRSP, Pond Dynamics CRSP, Small Ruminants CRSP, Sorghum/Millet CRSP (INTSORMIL), and the Tropical Soil Management CRSP (TROPSOILS).

- Initiated and awarded $25,000 grant from USAID/S&T to co-sponsor Sorghum Utilization Symposium with ICRISAT. This conference was cancelled for Bamako, Mali for reasons beyond INTSORMIL's control. It was rescheduled and programmed as part of the INTSORMIL International Sorghum and Millet CRSP Conference in July, 1991. The Symposium highlighted current state of the art technologies and focused on future research directions.

- The INTSORMIL Newsletter was re-initiated under a new format.

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 1990/91, 99 students from over 35 different countries were enrolled in an INTSORMIL advanced degree program and advised by INTSORMIL pincipal investigators. Over 80% of these students are from countries other than the U.S. which shows 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 1990/91 totaled 22. An additional 17 students received partial funding from INTSORMIL. The remaining 60 students are funded from other sources but are working on INTSORMIL projects.

Total student numbers remained constant with that of last year which has increased by 18% compared to 1988. However, the number of INTSORMIL funded students as compared to 1987 has decreased. This decrease is partially due to an equivalent increase in the number of students supported through other sources. An even more significant factor is that budget flexibility for supporting training under INTSORMIL projects has been greatly diminished because of inflationary pressures.

In addition, INTSORMIL also manages the SADCC/ICRISAT Southern African training program which placed an additional 22 scientists from nine southern African nations into graduate programs in the U.S., Canada, and Brazil. This brought the total number of active SADCC students to the record high of 67 and met our targeted cummulative total of 100 students since the program began in 1985.

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 TROPSOILS 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.

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, for 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 is writing his Ph.D. dissertation under the guidance of INTSORMIL entomologist, Dr. George Teetes. Mr. Manthe's work is 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.

- 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. Chris Manthe, Dollina Malepa, Rosemary Lekalake, and Etani Lele are completing their studies.

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.

New approaches have included establishing research relations with different South American countries, trying to develop a Latin American Sorghum Research Network which is to facilitate exchange of germplasm and informal cooperation among scientists from each country. During the 1990/91 period, a new organization was established in Colombia, the CIS (International Committee for Sorghum). This is 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.

- To provide orientation and enhance development of research and technology transfer programs on sorghum production.
- To serve as a mechanism where sorghum research, transfer, and development programs can seek advice and orientation.
- To promote and sponsor the organization and conduct of research and transfer activities related to sorghum production, as well as to diffuse information through publications and other documents on the subject.
- To establish a liaison with international institutions having similar objectives.

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.

Two new lines are under evaluation for release as a result of significant advances in ICA's breeding program, thanks to collaboration with INTSORMIL and the El Alcaravan Foundation. Research conducted by INTSORMIL in collaboration with ICA and other organizations in Colombia has attracted private sector funds to further long-term research goals in Colombia. The El Alcaravan 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.

Fourteen populations of aluminum-tolerant lines, obtained from the U.S. private sector, were evaluated under three levels of aluminum saturation. Selections were also made in the different ecosystems from 500 F_5 lines sent by INTSORMIL/MSU-104 project. These selections were short-stature lines with good yield capacity. They are being evaluated in regional trials. These lines, considered second generation, have better agronomic type than lines directly from the world collection.

Twenty F_3 populations from Mississippi were screened in both vega and savanna environments. Promising breeding material was identified and is available for future work. The lines selected have short stature and good yield potential.

Honduras

INTSORMIL works in conjunction with the National Research Institution, Recursos Naturales, the Pan American Agricultural School, EAP and The Soil Conservation Program, LUPE. 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 maicillos criollos, which are grown in association with maize by subsistence farmers on small hillside farms. Research is focused on the development of high yielding sorghum varieties and hybrids for the two major agroecological zones of Honduras. 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.

Screening of non-photoperiod sensitive hybrids and breeding materials from the INTSORMIL/Texas A&M International Sorghum Tropical Adaptation Trial (ISTAT) and the International Food Sorghum Adaptation (IFSAT) in 1990/91 showed excellent potential for use in Honduras of Dorado, 86EON361, 87EON366,SC1207-2, R8503, R8510, R8606 (male lines) and the best female lines were ATx626, A Var (ATx635), and ATx631.

An INTSORMIL/TAMU drought trial under low rainfed conditions at Rapaco, Honduras revealed that several Texas and international cultivars showed excellent adaptation and drought tolerance.

The sorghum-sudangrass forage hybrid, ATx623* Tx2784, performed well in pilot production and feeding trials, and is planned for release in 1991. It is resistant to pathotype one of downy mildew. The new hybrid will be called, "Ganadero".

Grain from two enhanced maicillos and their criollo (landrace) counterparts grown at two farm sites in Honduras were lime-cooked and processed into tortillas in the Cereal Quality Lab at Texas A&M University. They were compared with tortillas processed from Sureño (used as a positive control). Kernels from the criollos were less dense, softer, and required less cooking time than grain from the improved cultivars. Both improved criollos compared favorably with Sureño.

Disease ratings were made in on-farm trials and in the breeding trials with some of the improved maicillos showing high levels of disease resistance. 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, by three host country graduate students, on the langosta complex (a group of four lepidopterous larval insect pests) which causes extensive damage to sorghum and maize seedlings in Southern Honduras. A

new student has been identified to initiate research on a third predator of the langosta complex, paper wasps.

Farm level economic analysis of new technologies in Southern Honduras is continuing on the social returns to the introduction of new sorghum cultivars, Sureño and Catracho. At the present level of diffusion of the new cultivars on approximately 13% of the sorghum area, there would be an internal rate of return of 32% or, on an annuity basis, $700,000/year for the next 30 years. Use of new cultivars should include the cost of the expensive soil-conservation techniques (SCT) (rock terraces) to prevent soil erosion. With moderate policy changes and the new technologies including the SCT, farm income can be increased by 58%.

Six Honduran and 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.

Mali

INTSORMIL works with the National Research Institute, IER, and uses a strong interdisciplinary approach to sorghum and millet improvement as mandated by the very complex nature of the constraints in both sorghum and millet production in Mali. 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.

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.

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 millets 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.

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 drought resistance is a major concern. Major activities involve the introduction and use new genetic materials in breeding programs to develop cultivars to increase grain yields with desirable food quality.

Germplasm from U.S. breeders and the INTSORMIL/Texas A&M University/USDA sorghum conversion program has been incorporated into the Malian breeding programs. Testing in Texas and Mali has demonstrated that the drought response in Mali is similar to the drought response in west Texas. In general, sorghums identified at Lubbock, Texas as preflowering drought tolerant performed better than other varieties. The material identified in these trials is being used in crosses in Mali and the U.S. to enhance the drought resistance in sorghums for use in both countries.

Sorghum and millet postharvest technology systems in Mali have been documented and strategies for evaluating the quality of cereals, especially sorghum, for thick porridge (tô) were devised. Mini tests for evaluating milling and tô properties were developed and currently are used in the laboratory. Equipment for the new Food Technology Laboratory has been purchased and personnel have been provided short term training programs in the U.S.

Sorghum dehulling properties were defined by combined village trials in Mali and laboratory work in the U.S. This research showed that sorghum with hard endosperm and thick pericarps is definitely required for efficient traditional hand pounding.

Parboiling can convert sorghum and millet into acceptable products. A processed food product called 'sori' was developed to add value to sorghum grain produced at the farm level and is in the early stages of consumer acceptance testing. If acceptable, 'Sori' has the potential to offset shifting consumer preference to imported, more convenient grains, especially rice and wheat, which drain foreign exchange. The increase in volume of parboiled sorghum is an important factor because a given weight of parboiled sorghum could feed significantly more people than nonparboiled sorghum. The preparation of couscous is time and energy intensive. Production of couscous via parboiling could be economically feasible and could diversify available sorghum products.

Collaborative sorghum entomology research in Mali has a three-fold objective: (1) to develop screening methods for evaluating sorghum lines for resistance to panicle feeding bugs that are usable by plant breeders to evaluate progeny

lines and make selections; (2) to determine the relationship between resistance and glume, kernel and panicle relationships; (3) and to determine the relationship between bug abundance and damage, pathogen infection, grain deterioration and food quality.

The severity and persistence of the adverse effect of head bugs on food quality of introduced sorghums was first generally recognized in Mali. Head bugs reduced sorghum and milling yields and gave tô, a local thick porridge, an unacceptable texture and keeping properties.

F_4 progenies with excellent tolerance to head bugs were identified and seed was increased in the off season for entry in advanced trials across Mali in 1991. Malisor 84-7 and other lines were the source of resistance. ICSV 1079 and ICSV 1089 also possess useful head bug resistance. Many of the Malisor 84-7 crosses were made in Texas by A. Toure, a Malian Ph.D. candidate. These improved types, in general, have improved yields and good food quality properties.

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 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 being used.

INTSORMIL has provided short term and graduate training for several key Malian scientists. Scientists trained in food technology, pathology, breeding, physiology and agronomy have returned to Mali and collaborate in the program. Six graduate students are currently training in INTSORMIL universities to provide personnel to continue the programs. The programs include agronomy, breeding, physiology, economics and soils.

Technical assistance to develop the Cinzana station, to map the soils, and obtain detailed physical and chemical analysis of the soil profiles has been provided. Equipment and short term consultants were supplied to establish and install sprinkler systems and screening procedures for drought tolerance and research at Cinzana.

Niger

In collaboration with the Institute of National Agronomic Research, INRAN, INTSORMIL has developed strong programs in the areas of sorghum/millet breeding, agronomy, physiology, pathology, and food technology. The program has developed an effective laboratory screening technique for *Striga* resistant sorghums. This method could be important to resolving the problem of the parasitic weed, *Striga*, in Africa and India.

Innovative disease screening techniques were developed in collaboration with INRAN and are being employed in several other countries. Dr. Omer El Hilu from ARC/Sudan, working with Richard Frederiksen and John Clark continues to explore an initiative to set up an All Africa Long Smut Disease Nursery. This nursery will serve to screen all advanced breeding material for Long Smut, a major disease of sorghum in Africa. Most recently research in Niger has identified 11 cultivars to be resistant or moderately resistant to long smut. The most resistant cultivars were Terra, SC326-6, SC630-11E, BTx2775, Tx378, B8106, RTx7078, QL3, R9188, 87L3450 and 84C9408. The relationship between date of flowering and incidence of disease was high, suggesting that all lines flowering early are subject to escape.

Field research in farm production economics has made important contributions to the INRAN economics and on-farm testing programs. One study indicates that farmers have other more favorable alternative investments rather than most types of crop technologies. Hence, further development of technologies and policies is necessary for development of sustainable agricultural systems.

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. Issoufou Kapran, working with Gebisa Ejeta, identified five experimental sorghum hybrids with excellent adaptation and yield potential in Niger. These hybrids yielded much higher than local varieties both under rainfed (149%) and irrigated (161%) locations in Niger.

Experiments are in progress by Dr. Paresh Verma and Dr. Jerry Eastin which will provide information needed to optimize water-use efficiency of the millet/cowpea intercropping systems. Once the water extraction patterns of the two crops and the optimum shade level needed to maximize photosynthesis, but minimize transpiration for maximum water-use efficiency in cowpea are known, we will be able to alter the time of cowpea planting and hence shading level, to increase overall production of the intercropping system.

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 not fertilizer use, diseases and pests (principally downy mildew, smut and the 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.

Progress to date has resulted in superior varieties, hybrids, and parental lines supplied from INTSORMIL/Texas A&M University and INTSORMIL/University of Nebraska being retained for retesting in 1990/91 on the Senegal River Valley. Some sorghum seed parents and selections from segregating populations were retained for rainfed conditions. Yield potential of varieties in irrigated summer or cooler winter season were demonstrated to be 4 t/ha. Hybrid yields are significantly higher. The best hybrid yields are from INTSORMIL hybrids or INTSORMIL seed parents with existing pollinators. Dwarf pearl millet varieties and new hybrids from INTSORMIL/Nebraska and INTSORMIL/Kansas State University-Hays were tested in the Senegal River Valley and selections from segregating populations retained in 1989 for rainfed conditions were retested. Plant population levels and alternatives to flooded bed irrigation were investigated in agronomic tests with pearl millet in the hot winter season in the Senegal River Valley. The best opportunity for irrigated pearl millet production in the Senegal River Valley, vis-a-vis other crops, is in the hot season, planted in February. Use on lighter sandy soils is indicated, where water control is less of a problem. Optimum fertilizer levels may be much less than expected. Future tests should concentrate on comparing irrigation frequencies and moderate levels of fertilizer application. Grain yields of 4t/ha of pearl millet were obtained from three separate tests in the hot winter season (February-May) using dwarf cultivars taking 80 days to mature. This is clearly the most advantageous period in which dwarf pearl millet varieties and hybrids can best realize their potential. Yields at other times or locations, or with tall varieties are 50-60% of this. Palatability tests showed that the grain of dwarf varieties is acceptable.

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 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. 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 at the Gezira Research Station continues to develop well. The ICRISAT/INTSORMIL sorghum hybrid, 'Hageen Dura-1' was released in 1984 and the Sudan Gezira Board projected 55,000 hectares to be grown in 1991. This technology is in its initial stage of diffusion and has already shown a high rate of return to society of 32%. The ARC is currently considering the release of two INTSORMIL/ARC developed open pollinated varieties, namely M90303 and SuCr38:17, for use in the irrigated area, particularly in the Gezira.

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.

An array of other collaborative *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, will grow the international Sudan sorghum collection at ARC in 1991. The purpose of this is to provide proper documentation of this valuable germplasm for the benefit of Sudanese, U.S. and other international sorghum scientists.

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 world-wide 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 program utilized for U.S. agriculture.

Future Directions

Over the past 12 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

Xanthomomas campestris pv. *holcicola*, the causal agent of bacterial streak of sorghum (*Sorghum bicolor*) was found to be borne both on and inside the seed coat of sorghum seeds. *X. c.* pv. *holcicola* was isolated from surface-sterilized and unsterilized seeds from sorghum plants that were inoculated in the field. This pathogen was also isolated from leaf, lemma and palea tissue on seeds. Concentration of bacterial cells in the seed decreased gradually from 8.4×10^5 at harvest to 4.4×10^3 after 24 months of storage. The number of bacterial cells decreased from 8.8×10^6 and 4.1×10^6 at harvest to 5.0×10^3 and 3.3×10^3 cfu for leaf and glume/lemma/palea tissue, respectively, after being in storage for 24 months. The effect of seedborne inocula on bacterial streak development was determined by planting sorghum seed that was vacuum-infiltrated with different levels of *X. c.* pv. *holcicola* inoculum and assessing symptom development under greenhouse conditions. Plants from seed with low inoculum levels (10^1 cfu/ml) had lower incidence and a delayed onset of symptoms compared to a high inoculum density (10^8 cfu/ml). Sorghum plants inoculated at seven weeks or younger with *X. c.* pv. *holcicola* developed distinct bacterial streak symptoms whereas maize plants inoculated after five weeks developed no or barely discernible symptoms. Selected antibiotics were screened for *in vitro* efficacy in inhibiting growth of *X. c.* pv. *holcicola*. Doxycycline, streptomycin and vancomycin were effective against all tested strains.

Objectives, Production and Utilization Constraints

Objectives

To ascertain the prevalence and importance of *Pseudomonas avenae* and *Xanthomonas campestris* pv. *pennamericanum* in pearl millet production areas in West Africa.

To develop an antisera bank for LDC scientists for the purpose of diagnosing bacterial diseases of pearl millet and sorghum.

To identify and characterize *Fusarium moniliforme* isolates from LDC's with respect to mating type and vegetative compatibility group.

To determine if techniques developed for *Fusarium* spp. for placing fungal isolates into vegetative compatibility groups can be applied to other fungal pathogens of sorghum and millet such as *Claviceps* spp. and *Acremonium* spp.

Constraints

Laboratory facilities in LDCs are usually poorly equipped and have limited chemicals or other scientific supplies for disease diagnosis. When equipment is available, often it is not functional due to a minor problem such as a bulb that is burned out in a microscope. In this context, researchers may evaluate germplasm accessions in a screening program based solely on disease symptoms. With some diseases such protocols may be more than adequate, but with diseases that are difficult to diagnose, such as those often incited by bacteria and viruses, the results may be erroneous. In those instances where the causal agent is seedborne, a definitive diagnosis is very important since many countries require a phytosanitary certificate stating that the seed or feed grain is free of specified disease causing organism(s).

Since it is prohibitively expensive to set up laboratory facilities for disease diagnosis with the accompanying highly trained personnel in each developing country, alternatives to this process need to be seriously considered. One alternative would be to develop diagnostic kits that utilize immunological procedures developed from biotechnological research such as the dot-immunobinding assay. This procedure is simple, inexpensive, and requires very limited equipment, such as a refrigerator. The limiting factor in this technique is the availability of specific antisera to the major diseases. A bank of high-quality antisera available to LDC researchers could permit researchers with limited training and/or poorly equipped laboratories to apply this powerful technique to their local conditions.

Monoclonal antibodies incorporated into such assays could resolve most, if not all, of the bacterial disease diagnostic problems. They are expensive to develop, however, and the screening methodologies are laborious, but once developed the antisera is of high quality and available in copious quantity.

Stalk rots of sorghum and millet are a continuous problem wherever these crops are grown and losses usually range from 5-10% annually. Some of these fungi can also cause other disease problems such as grain mold and are essentially endophytes that coexist with the plant from seed to harvest. 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 study of 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 using simple techniques 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 could be useful in identifying particular races and/or strain types for use in resistance breeding programs.

Research Approach and Project Output

Research Methods

The specificity of monoclonal (versus polyclonal) antisera in detecting bacterial and fungal organisms has been widely reported. Development of monoclonal sera involves a hybridoma technology in which mice are injected with a purified antigen from the bacteria. We will utilize a selected protein from the bacterial cell wall that was identified as unique to the target organism via sodium dodecyl sulfate-polyacrylamide gel electrophoresis. A selected strain of mice (BALB/c) will be immunized with the protein for three weeks. The mice will then be sacrificed and their spleen removed. Spleen cells will be fused with myeloma cells (cell line NS-1) to produce the hybridomas. Myelomas are essentially malignant cells that secrete antibodies and provide the "immortality" needed for continuous antibody formation. The spleen cells impart the specificity of the serum.

The causal agents of bacterial diseases will be identified primarily by the dot- immunobinding assay. Cooperating scientists will be sent 3 x 5 cm strips of nitrocellulose paper. Leachate from suspected diseased tissue will be applied to the paper. After soaking the paper in ethyl alcohol and acetic acid to fix the bacteria, these scientists will return the nitrocellulose paper to the project locations for completion of the test. It is advisable to complete the technique at the project locations because of refrigeration requirements, availability of antisera, and the ease in purchasing and storing the protein A-alkaline phosphatase conjugate for the enzyme reaction. In cases where LDC laboratories are suitably equipped and personnel adequately trained to complete the entire procedure, we will provide antisera and the enzymatic reagents for the cooperating scientists. Permits for importing plant materials or microbial cultures are not required because the analysis process requires that the nitrocellulose strips be soaked in ethyl alcohol and acetic acid prior to shipment (USDA-APHIS, personal communication).

Upon receipt of the nitrocellulose paper containing the unknown bacterial pathogen, approximately 24 hours will be required to finish the test. The test results will be mailed, faxed, or telexed (if possible) to the cooperators. Previous research has shown that successful results can be obtained up to three months after the bacterial pathogens have been placed on the nitrocellulose paper. The only equipment needed by the LDC cooperator will be pipettes, small test tubes, 5 µl glass capillary pipettes, and several liters of acetic acid and ethyl alcohol. Total costs of supplies for each

cooperating scientist should not exceed $50 and should be sufficient for approximately 100 tests.

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 a vegetative compatibility test. The diversity in the population as measured by these tests can indicate the amount of genetic recombination that is occurring with the pathogen population and the ease with which new pathogenic combinations may arise.

VCG testing usually involves the generation of nitrate-nonutilizing mutants to be used in the forcing of heterokaryons. These mutants can be generated spontaneously at high frequency in a number of different fungal species, including many *Fusarium* spp. We will attempt to apply these techniques to other important fungal pathogens of sorghum.

Research Findings

Pseudomonas andropogonis is the causal agent of bacterial leaf stripe in sorghum. Research is in progress to develop a complementary DNA specific probe for this organism. The vector pBluescript, and genomic DNA from *P. andropogonis* have been isolated. Only limited success has been accomplished with ligation and transformation of the DNA, but a protocol for a more efficient transformation system is being investigated. Research on a selective or semiselective medium for isolating *P. andropogonis* from plant tissue is in progress. Approximately 50 chemical compounds have been tested at a variety of concentrations and in numerous combinations. In addition, approximately 25 antibiotics have also been tested. Of these, sodium acetate and silver nitrate appear to be the most promising.

The PCR (polymerase chain reaction) techniques is a recent biotechnological development and preliminary studies by others have shown that detection protocols including a PCR as the primary detection component can detect even a single bacterium within a seed lot. DNA was extracted from five pathovars of *Xanthomonas campestris* and two strains of *X. campestris* pv. *holcicola* (causal agent of bacterial leaf streak in sorghum). This DNA was tested for strain-specific amplification with ten-mer oligonucleotide primers. Differences were noted between the pathovars and the *X. c.* pv. *holcicola* strains, however the banding patterns were not always reproducible. Attempts to identify cells *X. c.* pv. *holcicola* from infested sorghum seed and the control (healthy seed) were unsuccessful. The banding patterns in these experiments were nearly impossible to interpret and the reactions were not reproducible. Additional experiments designed to remedy these technical difficulties, including a program with a "slope" for temperatures in the denaturation and reannealing phases were terminated due to a lack of funds and to the departure of a student from our program.

PCR experiments with *Fusarium* spp. were more successful. A screening protocol in which a number of bands could be identified repeatedly and unambiguously was delineated, and primers potentially suitable for discriminating different mating populations as well as for measuring genetic variability within a mating population were identified. In some cases, the genetic variability of these banding patterns was also checked. Work in this area will be continued during the coming year when a replacement for the postdoctoral researcher who had been working in this area is hired.

The second year of an experiment to determine the overwintering of cells of *X. c.* pv. *holcicola* in infested grain sorghum debris is in progress. Bacterial cells were found to overwinter in leaves, stems and seeds of grain sorghum during the tests conducted in 1990-1991. In addition, volunteer seedlings from overwintered seed also were found to be infested with *X. c.* pv. *holcicola*.

Studies of an extensive collection of over 1200 isolates of *Fusarium* from sorghum, maize, banana, and rice in Thailand during October 1989 were continued. The diversity observed in this population is being used to determine if the same pathogen can be recovered from rice, banana, maize, and sorghum. Preliminary evidence from Kansas collections suggests that there is one population that predominates on sorghum ("F"), and two other populations that predominate on maize ("A" and "D"). Southeast Asia would be expected to have large numbers of the "C" population, but the ability of these strains to cause stalk rot in sorghum and millet is unknown. Collections from the United States, Southeast Asia, and Africa all need to be made because the fungal populations may have evolved with the ancestral host in each region (United States - maize, Southeast Asia - rice, and Africa - sorghum and millet). It is important to establish if the differences detected in U.S. populations are the result of host preference or geographical distribution. All of the isolates collected from Thailand have now been purified through a uninucleate microconidium via micromanipulation and preserved in 15% glycerol for long-term storage at -80°C and analyses of mating populations and VCG diversity have begun. We have found that isolates belonging to both the "A" and the "F" populations can be recovered from banana and suggest that intercropping may provide an important refuge for these pathogens during times when the susceptible crop is not present.

We continue to develop testers for both sexual and vegetative compatibility testing and to identify possible trouble spots in the applications of our techniques not only to isolates of *Fusarium* from sorghum and millet, but also from other hosts and for other fungal species as well. At this time we have established a working set of standards that have been made available on request to researchers doing these types of identification. Two SADCC students are planning to incorporate these techniques into their thesis studies and Dr. Gary Odvody has been exploiting these techniques for the analysis of strains recovered from his field populations.

Dr. W. A. J. deMilliano had been planning a sabbatical with us beginning in August 1991 for approximately one year and was going to work on the application of these techniques to other fungal pathogens of sorghum and millet. With Dr. de Milliano's departure from the SADCC/ICRISAT/SMIP program however, these studies have been shelved for the present. We have done some testing of strains of *Acremonium* from Egypt to determine if the VCG testing can be applied to these pathogens. Unfortunately of the ten isolates that we examined, no nit mutants could be induced and we were unable to proceed further with our tests. Additional strains from different locations should be tested before concluding that this technique will not be applicable to *Acremonium* spp., however. Similar studies with *Colletotrichum* spp. have been successful.

As part of a joint research effort with USDA scientists we have begun studies of the fumonisin toxins produced by some strains of *F. moniliforme*. These toxins are of potential importance in both human and animal nutrition and are associated with serious toxicological problems, cancer and death in horses, donkeys, swine, laboratory rats and monkeys, and humans. We anticipate further work in this area to determine if these toxins pose a threat of the same magnitude to sorghum utilizers as they now appear to pose for maize utilizers.

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Presentations

Dr. Leslie made invited presentations or seminars as follows during 1990: American Phytopathological Society Annual Meeting, Grand Rapids, Michigan. Fourth International Mycology Congress, Regensburg, Federal Republic of Germany. Norwegian Society for Plant Pathology, As, Norway. Station de Pathologie Vegetale, INRA, Montfavet, France.

Networking Activities

Workshops

Dr. Leslie attended the Seventh Regional Workshop on Sorghum and Millets for Southern Africa in September 1990 in Manzini, Swaziland, and followed this meeting with several days at the SADCC/ICRISAT center in Bulawayo Zimbabwe discussing potential research projects with *Fusarium* spp. and the application of techniques developed for *Fusarium* to other fungal plant pathogens.

Dr. Leslie also participated as an invited speaker in a session on "Problems in *Fusarium* Systematics" held at the 1990 annual meeting of the American Phytopathological Society. His talk focused on techniques related to mating

populations and how the techniques developed for the study of *Fusarium* populations from maize and sorghum can be used to approach other difficult problems in *Fusarium* taxonomy.

Research Investigator Exchanges

Dr. Demba M'Baye, Plant Pathologist, ISRA/CNRA, Bambey, Senegal worked in Dr. Claflin's laboratory from July 12-20, 1991. Dr. M'Baye conducted experiments for identifying bacterial diseases of sorghum and pearl millet. He also utilized library facilities and reprint collections to further strengthen his background and resources on diseases of millet and sorghum.

Dr. J. R. Reddy, Plant Pathologist, Plant Quarantine Unit, ICRISAT, is presently developing a monoclonal antibody to the bacterial streak pathogen (*Xanthomomas campestris* pv. *holcicola*) in Dr. Claflin's laboratory. He is also studying several epidemiological parameters of bacterial diseases of sorghum.

A consulting trip to Kenya was made by Dr. Claflin to determine disease incidence on sorghum and pearl millet. Activities included training in-country plant pathologists and breeders, and recommending protocols for screening germplasm to long smut, covered kernel smut, downy mildew of sorghum, and smut of pearl millet. This visit was sponsored by MIAC (University of Missouri)/Kenya Agricultural Research Institute/INTSORMIL

Dr. Ibrahim Mansour, from the Institute of Plant Pathology, Agricultural Research Council, Giza, Egypt visited in both Dr. Leslie's and Dr. Claflin's laboratories from April 6 - June 22, 1991. Dr. Mansour also visited Plant Pathology Departments at Texas A & M University, Virginia Tech and University of Nebraska - Lincoln, and attended a workshop on fumonisin toxins sponsored by North Carolina State University. His visit was sponsored through a training project of the Egyptian National Research Project (NARP/USAID) via San Diego State University. Other long- and short-term visitors are expected during the next two years.

Low Input Ecologically Defined Management Strategies for Insect Pests on Sorghum

Project MSU-105
Henry N. Pitre
Mississippi State University

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Summary

A principal constraint to sorghum and maize intercropping in Honduras is a lepidopterous pest complex (referred to as langosta) damaging or destroying the crops early in the growing season. Current entomological investigations center on aspects of the biology and ecology of the four principal insect species in this complex. Particular attention is given to identification of noncrop host plants and the role of this vegetation in the establishment of infestations and dynamics of each species in the population. With knowledge of seasonal occurrence of the pests and availability of suitable noncrop plants, insect populations can be monitored closely for pest outbreaks.

Insect feeding studies reveal that sorghum and maize may be a sink habitat for two of the species in the langosta, whereas the fall armyworm utilizes the crops as source habitat to increase population. The net population of the other two armyworm species decreases in the sink habitat, i.e., survival and population increase may depend on nearby noncrop source habitats.

Egg laying preferences for noncrop vegetation by the three main species in the langosta have been investigated. Specific weed grasses have been identified as preferred hosts for two of the armyworm species, whereas fall armyworm prefers sorghum and maize. This information, along with larval feeding preference and performance on noncrop host plants, is useful in sampling to determine infestation levels in areas with known suitable host noncrop vegetation, and in predicting potential for infestation of the grain crops.

In host plant resistance studies larval mortality, pupal weight, generation time, intrinsic rate of increase and relative fitness were used to make inferences about antibiosis to fall armyworm. Antibiosis resistance appears to be widespread in landrace populations. The selected landrace San Bernardo III is combined with TAM428 (with some resistance to fall armyworm) to produce an enhanced level of antibiosis. Studies reveal that sources of resistance to fall armyworm in Honduran native sorghums may be polygenic and should be stable over time.

Objectives, Production and Utilization Constraints

Objectives

1. Study the biology and population dynamics of insect pests responsible for destruction of sorghum and maize seed and seedlings.

2. Evaluate sorghums for resistance to specific insect pests.

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

Constraints

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 and function 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. This project has a principal objective to work with insect pest problems encountered by low income, subsistence farmers in developing countries and to investigate the principal insect pests in Mississippi for development of pest control methods which do not rely entirely on chemical insecticides. These control methods have emphasized host plant resistance, cultural control tactics, biological control, and selective use of insecticides. Investigations of root, foliage, stalk, and panicle feeding insect pest biology, ecology, behavior, population dynamics and reactions to insecticides have contributed to our understanding of insect ecology, migration and development of insecticide resistance in pest outbreaks in specific host countries and in the southeastern United States. This program provides assistance to farmers in the 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.

Many of the insect pest constraints to sorghum and maize production in Honduras are recognized. Some insects in the soil that damage and/or destroy sorghum seed, lepidopterous larvae that damage or destroy seedling plants, stem and stalk borers that weaken and/or kill maturing sorghum and head feeding bugs and caterpillars that destroy the seed have been identified; all are important in reducing crop yields. Therefore, a range of insect pest management tactics have been evaluated to determine the effective practices that have application in the developing countries in the Central American Ecogeographic Zone. Principal emphasis has been on development of nonchemical pest control practices that may or may not include minimum use of insecticides. This is important in production areas where financial investment in crop production must be held to a minimum. These insect pest control methods have emphasized host plant resistance, and cultural and biological control tactics.

Insect pests common to the Americas have been investigated in the United States to elucidate the biological and ecological relationships of populations and the 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

1. Pest Biology and Population Dynamics

A lepidopterous pest complex, collectively referred to as "langosta" by subsistence farmers, is an important constraint to sorghum and maize production in southern Honduras. Four species, the fall armyworm, *Spodoptera frugiperda*, two other armyworms, *S. latifascia* and *Metaponpneumata rogenhoferi*, and the grass looper, *Mocis latipes*, were previously identified as the principal insect species in the langosta complex. *Spodoptera frugiperda* was the predominant species on intercropped sorghum and maize from May to August. *Spodoptera latifascia* and *M. rogenhoferi* were present only early in the crop growing season. *Mocis latipes* was present in mid-season.

The recent emphasis in MSU-105 in the langosta studies has centered on aspects of the biology and ecology of the four above-mentioned insect species. Particular attention has been given to identification of noncrop host plants and the role of this vegetation in the establishment of infestations and population dynamics of each pest species. The suitability of the noncrop grasses and other vegetation for insect development was emphasized in studies in 1991. With knowledge of the seasonal occurrence of the pests and availability of suitable noncrop host plants for the langosta, insect populations can be monitored closely for pest outbreaks. Some evidence may be obtained for identifying "source" and "sink" habitats for the species. This can be helpful in the application of pest management tactics in these specific habitats. Whereas the fall armyworm can usually be found in all stages in grasses growing in and along irrigation ditches (source habitat) on the plains in southern Honduras during the day season, no information has been obtained to identify source habitats for the other species in the langosta complex. However, these insects may also survive in this or similar habitats during periods when suitable host plants are not present in dry areas before the rainy seasons in this region. It is possible that when these insects leave their dry season niches at the onset of the rains, there is sufficient noncrop vegetation to sustain the populations in sorghum and maize production areas (sink habitat).

In laboratory feeding performance studies with *S. latifascia* and *M. rogenhoferi*, sorghum and maize were found to be less suitable as hosts than some broadleaf weeds occurring in southern Honduras. This suggests that sorghum and maize may be a sink habitat for these two species. A sink habitat is defined as the area where the net pest population decreases, and survival and population increase may depend on nearby noncrop source habitats. Changes in the agroecosystem (i.e., intercropped sorghum and maize) which do not confer stability similar to the insect's original ecosystem (i.e., the source habitat) have forced the pests(s) to temporarily feed on the crops. But these two species disappear after about four to five weeks even when sorghum and maize and a great variety of noncrop vegetation are available as potential hosts.

Although many farmers spray their crops after these insects arrive early in the season, benefits of insecticide applications on the core population of these two pests is very limited. The two species appear to have only one generation in the area, and it seems that they are unable to complete or have difficulty completing their life cycle on sorghum and maize.

An explanation for the disappearance of *S. latifascia* and *M. rogenhoferi* from the sorghum and maize production fields in southern Honduras has not been elucidated. Parasites (predators were not evaluated) were shown to be an important mortality factor in the field, but there is insufficient evidence to indicate that they are key to the disappearance of the two species.

Field studies showed that populations of *S. latifascia* were higher in plots with weed control, whereas *M. rogenhoferi* was not affected. However, the influence of crops and noncrop vegetation on the biology and population dynamics of these two insects is still not fully understood.

Three areas of study are being investigated in order to assist in the development of an efficient program for management of these two insect species, 1) oviposition and feeding preferences and their modification, considering host plant species and phenology, 2) the possibility that *M. rogenhoferi* can diapause (aestivate), and 3) identification of sex pheromones and their use to monitor these two insect species to determine their presence during mid- to late-season and/or migration from other areas.

Noncrop Host Plants

The most common weeds found around and in production fields in the hills (La Coyota) and plains (El Conchal) were collected and identified before the production fields were planted and during the early growing season of sorghum and maize in the summers of 1990 and 1991. As soon as the noncrop vegetation flourished after the rains began, whole plants (n=200) of each species were sampled biweekly in three fields on the plains and three in the hills. The plants were searched in the field for *S. latifascia*, *M. rogenhoferi*, and *S. frugiperda* eggs and neonates. No eggs of *M. rogenhoferi* or *S. latifascia* were collected on any of the samples taken on crop or noncrop vegetation, but neonates were observed on sorghum and maize seedlings more than on noncrop vegetation. *S. frugiperda* eggs were commonly collected from the grass weed *Ixophorus unisetus* as well as sorghum and maize seedlings. These observations will continue in 1992. Knowledge of the preferred ovipositional host plants, especially if these turn out to be weeds present early in the season when sorghum and maize are planted, may provide the basis for specific recommendations for management of these plants in such a way that the crops are least affected by insect pests. On the other hand, if crops are preferred as ovipositional hosts, sampling for eggs and neonates would have to be emphasized.

Host Feeding Performance

Field collected broad leaf weed species (n=4), sorghum, maize, and a grass weed species in two phenological growth stages (seedlings and older plants) were evaluated as feeding hosts for *S. latifascia*. Mortality throughout development was recorded, larval weight was measured 15 days after hatching, pupae were weighed on day two, and sex ratio was determined. Time (days) from larvae to pupae, pupae to adult and adult to death was also recorded.

Pupae from each treatment, subtreatment and replication were kept separately for emergence. Newly emerged female moths were mated, allowed to lay eggs and eggs were counted. Adult male and female life spans were recorded.

The differences in fitness of insects fed seedlings and mature plants might explain the population decrease of *S. latifascia* and *M. rogenhoferi* as the season progresses. Preliminary feeding studies proved sorghum and maize to be unsuitable hosts. These studies have not been completed, but show that observations confirm the same and also indicate that plant phenology may influence fitness of the insects.

Host Preference Studies

S. latifascia and *S. frugiperda* were randomly selected from an egg mass and placed individually in petri dishes 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. Results observed from this study will elucidate the importance of vegetation around the crops as they are preferred or not by neonate larvae. This information then will be used in a pest management program for the incorporation of adequate weed management as this relates to the insect's behavior.

Determination of Larval Feeding Induction

S. latifascia and *S. frugiperda* neonates were reared for 15 days on diets as in the feeding performance study. Sorghum and the other plants were offered one at a time within petri dishes to larvae reared on each of two hosts. Larvae were starved for 24 hours and tested for three hours. The sequence of hosts visited, time spent, and dry weight consumed was recorded, initial weight of each host was estimated by using dry-weight to fresh-weight ratios obtained from similarly sized oven-dried foliage samples. A mean consumption index (MCI) will be calculated by subtracting dry weight sorghum or maize consumed from dry weight of

the other host with which sorghum or maize is compared. These values (MCI) will be analyzed using ANOVA.

The ability to discriminate among hosts based on host quality may be important in *S. latifascia* and *S. frugiperda* especially because we know that noncrop plants are more suitable hosts than sorghum and maize for *S. latifascia*. However, if larvae can get induced to feed on a nonhost plant (i.e., sorghum and maize) they are more likely to continue feeding on a selected plant than moving to look for a more suitable host. Likewise, if larvae are feeding on a weed plant and can get induced to it, they may be expected to stay there resulting in lower crop damage. These and other results related to oviposition preference and neonate preference will elucidate the importance of weed management for management of these two insect species in the langosta. These studies will be expanded in 1992.

Host Oviposition Preference

S. latifascia and *S. frugiperda* moths (five days old) reared in the laboratory on a meridic diet were tested for ovipositional preference for weed plants in the presence of sorghum and maize inside a field cage. Although the data have not been analyzed at this time, observations reveal that eggs were laid only on a grass weed *I. unisetus*, maize, sorghum and a broad leaf weed, *Amaranthus hibridus*. This study was conducted separately for the two insect species and will be repeated in 1992.

A no choice oviposition test was also conducted in 1991. Results of this test indicated that *S. latifascia* may lay eggs on *Melampodium divaricatum* and *Ipomoea* sp., however, it did not lay eggs on *Portulaca oleracea*. In the case of *S. frugiperda* eggs were laid only on *I. unisetus* and *Ipomoea* sp. Interestingly no eggs were laid on maize or sorghum.

Observations

The occurrence of the lepidopterous pest complex on sorghum and maize creates the biological illusion that the component species coexist conjointly. Actually, the complex is the product of a fine-grained mosaic of different microhabitats, each supporting a well-adapted successful species. Except for *S. frugiperda*, sorghum and maize apparently serve as a sink habitat where the net lepidopterous population decreases, and survival and population increase depend on nearby noncrop source habitats.

Because of the geographical and biological diversity involved by the complex, controlling the langosta is a formidable challenge. Although many farmers spray their crops after the langosta has arrived, this has no effect on the core population of at least two of the species, nor does it reduce their subsequent generations since these species are unable to complete or appear to have difficulty in completing their life cycle on maize and sorghum.

More effective control measures would include management of noncrop vegetation or source habitats. Monitoring source habitats and synchronizing planting dates to follow migration would be a low cost control measure that could be employed by subsistence farmers. Likewise, destruction of relatively small source habitats before planting could lead to local population extinction of some pest species. These tactics are within the means of resource-poor farmers since they primarily involve investment of their own labor. Insecticide applications could contain the insect pest in the source habitat but it is unlikely that subsistence farmers will be willing to invest in spraying weeds.

The diversity of the lepidopterous pest complex ensures that sustaining adequate control of the langosta will depend on an array of integrated pest management practices. Because manipulation of a niche may affect one species adversely only to benefit another, as in the case with weed control which reduced the population of *M. latipes* but increased population size of *S. frugiperda*, a greater understanding of the ecology behind each species is required before a technological control package can be developed. Other areas of additional needed research include host oviposition preference of moths, additional studies on feeding preference including young and old plant tissues, and parasitization of larvae.

2. Host Plant Resistance

Plant resistance is one of the most effective and ideal methods for controlling crop pests. The uses of a resistant cultivar for management of pests by itself or in combination with other components of IPM are biologically, ecologically, economically, and socially feasible. Plant resistance is the most environmentally safe component of IPM. The National Research Council reported that classical plant breeding to develop new varieties is the most successful biological method of pest control. Genetic engineering promises to accelerate breeding for pest resistance. It has been predicted that resistant cultivars in American agriculture would have a major role in pest control until 1992 and that a demand for their use beyond that time would sharply increase. In sustainable agriculture, or any agricultural system, the use of a resistant cultivar should be the foundation or hub of any crop protection scheme where damage from insect pests is a major concern.

Some levels of plant resistance to insects has been reported in sorghum for at least 17 insect and mite species. MSU-105, in collaboration with TAM-131, has emphasized research on the tropical landrace sorghums called maicillo criollo, which are widespread in Central America. Their greatest concentration is in El Salvador and Honduras. These sorghums are more sensitive to photoperiod than other known photosensitive sorghums, require shorter day lengths to initiate flowering than other known photosensitive sorghums, and are adapted to intercropping with early maturing maize.

Since the fall armyworm appears to be the principal lepidopterous pest in the langosta complex, this species was emphasized in MSU-105/TAM-131 sorghum host plant resistance investigations during the past two to three years. Studies have been conducted in Honduras and in the United States 1) to determine if insect resistance is present in commonly used sorghum cultivars as well as improved lines, and 2) to determine types and levels of resistance (particularly antibiosis, i.e., adverse effects on the insect). Deployment of resistant genes into sorghum cultivars would reduce producer insecticide inputs and provide a sustainable insect pest management control alternative that would be persistently effective, ecologically compatible, and safe to humans.

In these studies larval mortality, pupal weight, generation time, intrinsic rate of increase and relative fitness were used to make inferences about antibiosis to fall armyworm. Sorghums with evidence of insect resistance were used in initial antibiosis studies. The selected landrace San Bernardo III suppressed fall armyworm population density increase and showed that its resistance could be combined with that of TAM428 (with reported resistance to fall armyworm) to produce an enhanced level of antibiosis. Further studies revealed that antibiosis may be widespread in landrace populations. Cohorts of larvae raised on several landrace accessions attained significantly lower pupal weights than those raised on a recognized fall armyworm resistant variety. Antibiosis resistance to fall armyworm was also detected in the accessions Hilate-179, Pina-61, and Lerdo-104.

A reduced fecundity as suggested by smaller pupa size induced by maicillo sorghums and inability of survivors to overcome maicillo's antibiosis to produce larger pupae suggests that this resistance in these genotypes is polygenic. The maicillos resistance should be stable over time and furthermore the traditional practice of growing sorghum landrace mixtures in Honduras increases the probability that antibiotic genes are widespread within the maicillos population. These hypotheses require confirmation.

In expanded antibiosis studies, 15 landrace sorghums common to production areas in southern Honduras were evaluated in laboratory screening tests. In one study fall armyworm larvae fed Pompom-170 had the shortest developmental time, but the longest time in the pupal stage; insects on Porvenir had the longest time in the pupa stage. The landraces Catura-68, Porvenir, Paquete, Peloton-99, and Pompom-170 did not influence generation time, fecundity, intrinsic rate of increase, net developmental rate, or total mortality compared with a sorghum having some insect resistance.

In a second study, lower pupal weight and fecundity were observed for insects fed Variedad Blanca, and lowest intrinsic rate of increase and developmental rate were observed for larvae fed Variedad Blanca, Angel de Limon, Corona-195, and Norteno-72. Larvae raised on Cola de Caballo-159, and 845 cm experienced the shortest time for development to pupae, whereas insects on 845 cm had the lowest pupal weight, fecundity, intrinsic rate of increases and net developmental rate. In a fourth test larvae fed DMV-143, Gigante Pavana, Porvenir, and DMV-197 had the longest generation times; DMV-197 and Porvenir resulted in low pupal weights and fecundity; and DMV-143, DMV-197 and Gigante Pavana, resulted in low intrinsic rates of increase and net developmental rates. These studies reveal the presence of various levels of antibiosis resistance in the landrace sorghums planted by subsistence farmers in Honduras. The characteristic expression of resistance varies in type of influence on the insect. Although the levels of resistance varies among sorghum genotypes and may be low, the host plant resistance observed can be used in breeding programs to increase levels of antibiosis.

The large number of lepidopterous larvae feeding on intercropped sorghum and maize (exerting feeding pressure on plants) influences plant selection through indiscriminate attack during the early growing season. Insect feeding may or may not kill the crop plants, but surviving plants are weakened. Differential selection may have resulted in maicillos accumulation of antibiotic alleles which appear to confer a broad level of intermediate resistance through reduced fecundity. The inclusion of these traits into conventional cultivars not only will enhance productivity and make the environment safer by reducing dependency on insecticides, but it will also conserve these genes *in situ* where evolutionary processes can continue.

Studies presently completed revealed that sources of resistance to fall armyworm in the maicillo sorghums may be polygenic and should be stable over time. A study was conducted to determine if maicillo sources of fall armyworm resistance are stable and are not lost or reduced in magnitude over time (e.g., several generations). A series of five tests to evaluate antibiosis resistance to fall armyworm in San Bernardo III was conducted over five successive generations. Results from this study were inconclusive. Studies will be repeated.

3. Development of Pest Management Systems

The MSU-105 Project has emphasized research on the fall armyworm, an insect that annually migrates into the southern United States where it causes economic injury to a large number of crops, including sorghum and corn. This pest shows a desired preference for plants in the grass family. The literature reports conflicting views on egg laying behavior on sorghum and maize in relation to age (size) of the plants. Since this insect is a migratory species and may immigrate into areas at different times during the crop growing season, when the crops can be in different stages of plant development, MSU-105/TAM-131 research is investigating stage of maturity of the grain crops as a factor influencing plant acceptability by fall armyworm for oviposition.

The objectives of this research are 1) to determine oviposition preference by fall armyworm moths of different ages for sorghum plants at various stages of maturity, and 2) to assess the effect of light on oviposition by fall armyworm moths of different ages on sorghum plants at various stages of maturity. This research is incomplete and will be continued in 1992.

Publications

Portillo, Hector E., Henry N. Pitre, Dan H. Meckenstock and Keith L. Andrews. 1991. Langosta: A lepidopterous pest complex on sorghum and maize in Honduras. Florida Entomologist. 74: 287-296.

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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 rainfed 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 in providing information for pest control recommendations. Accordingly, only Sevin remains as 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 will be continued.

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.

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 by most programs in Third World countries. An INTSORMIL graduate student in MSU-105 obtained training in these new host plant resistant methods and is utilizing them in research in Honduras. This technology is being disseminated into Honduras.

Assistance Given

One binocular microscope was hand-carried to the Panamerican School of Agriculture in May, 1991 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 School in May, 1991 included five 6x6x6 foot saran screen cages for use in field studies, ten 2x2x2 foot metal and wire cages for holding insects in laboratory tests, one hypothermograph for recording temperature and humidity in planned studies, and a thermal box for holding insect and plant materials at cool temperatures for short term preservation.

Routine research and office supplies are shipped each year to Honduras to assist the students and collaborators.

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

Project PRF-104B
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Summary

1. Water soluble root exudate compounds similar to strigol, rather than sorgoleone, control *Striga* seed germination in the field. The simple agar gel assay we devised using *S. asiatica* seed to screen sorghums for low stimulant production gives excellent correlations with resistance to *S. hermonthica* in infested fields in Africa (Sudan and Niger). Low stimulant production is a simply inherited recessive trait. We have transferred this resistant trait to agronomically elite sorghums and shown that they are both productive and resistant to *Striga* in Sudan and Niger.

2. Sorghum genotypes differ by up to a billion-fold in the amount of this *Striga* germination stimulant they produce. Sorghums which produce the most stimulant and which are the most susceptible to *Striga* are from China, where they have developed in the absence of *Striga*. Genotypes capable of producing relatively large amounts of stimulant produce approximately a million fold more when the seedlings are grown with only 2 hours of light per 24 hours than if they have 16 hours of light. Low stimulant genotypes produce the same low amount regardless of the light regime.

3. The sorghums tested, both high and low stimulant producers, all produce the same three active stimulant compounds readily separable by HPLC. The single pearl millet cultivar tested does not produce stimulant active toward our *S. asiatica* seeds. The single proso millet cultivar tested produces even higher amounts of stimulant than high stimulant producing sorghums. The proso millet produces the same three stimulant compounds as sorghum, although there is a difference in which of the three is most abundant. These stimulants have not yet been identified. At least some cowpea cultivars produce root exudate compounds which stimulate our *S. asiatica* seeds to germinate, although cowpeas are a host for *S. gesneroides* and not *S. asiatica*. We may be able to screen for low stimulant production in cowpeas using our *S. asiatica* seed.

4. Both *S. hermonthica* and *S. asiatica* produce, in their vegetative tissue, readily extractable toxins with the former showing greater virulence. Sorghum genotypes differ greatly in their susceptibility to this toxin, especially when the toxin is present in *in vitro* sorghum cultures. We are using the *Striga* toxin as a selecting agent to screen out susceptible sorghum cells in culture. We have over 30 sorghum plants regenerated from the few clones which were developed from the survivors rescued after long exposure to the toxin. We will be testing their progeny for enhanced resistance to *Striga*.

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 *Striga* in much of Africa, grain molds and weathering in India, and grain-eating birds and weathering in the southeastern U.S. Accumulated evidence indicates that phenolic components of these plants (including tannins in the case of sorghum) correlate to some degree with resistance to the above constraints, with the possible 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

All of this research is coordinated closely with that of Dr. Ejeta. We have found that a fully integrated interdisciplinary program, with the breeding done by Dr. Ejeta and the laboratory work done here, can be quite productive.

The general approach we use 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 identify superior sources of resistance (to birds, mold, *Striga*, etc.), establish in the laboratory the biochemical mode of resistance, develop a simple method of screening for the resistant trait, screen genotypes in the laboratory for the trait, confirm their resistance in the field, and use them in breeding improved sorghums. The major emphasis we place on developing pest resistant sorghums (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: The major antinutritional effects of high tannin sorghums are decreased weight gains and diminished feed utilization efficiency. We have previously shown that the major underlying basis for these effects is not inhibition of digestion of dietary proteins, which is largely overcome by the specialized salivary tannin-binding proteins. The basis for the antinutritional effects of high tannin sorghum appears instead to be systemic (in bodily tissue, not just in the intestinal tract) inhibition of the metabolic utilization of digested and absorbed nutrients.

In this past year, Lilian Jimenez-Ramsey, a Brazilian PhD student under Dr. John Rogler, poultry nutritionist in Animal Sciences, has in our laboratory metabolically labelled developing sorghum seeds with $^{14}CO_2$ and isolated several polyphenol fractions, including condensed tannin, labelled with ^{14}C. On feeding these materials to chicks Lilian found that none of the tannin fraction was absorbed from the digestive tract, and thus the systemic effects could not be due to tannin. On the other hand, Lilian found that nontannin polyphenol fractions associated with tannins and presumably absent in low tannin sorghums, were readily absorbed from the digestive tract. Significant levels of ^{14}C were found in liver, kidney, serum and bone. Thus, these tannin-associated materials could be responsible for the systemic effects of high tannin sorghum. Lilian is now preparing large amounts of these various polyphenol fractions, including tannin, so that they can be fed individually to determine which are responsible for the antinutritional effects.

If we can identify the tannin-associated component responsible for the antinutritional effects of high tannin sorghum, we will 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. We have been selecting for bird resistance in the F_2 and F_3 generation of the hybrid material and have three selections with useful resistance, although they may not be as resistant as the hybrid. We have a PSTC/USAID grant to characterize these sorghums with Kenyan and Brazilian collaborators. Thadeo Tarimo, a SADCC-supported PhD 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 when given a choice, the sparrows prefer Pioneer 8333, a bird-susceptible sorghum hybrid with brown-colored seed but no tannin, about 3 to 1 over the tannin-free Arkansas line. This test was done with mature grain, and shows that it is not necessary to utilize immature grain to get bird repellency. Tarimo will be looking at extracts of the grain to see if the repellent factor can be extracted, purified and characterized. It may be useful as a natural and safe bird repellent for other crops. This repellent characteristic will certainly 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, postdoctorate from Ethiopia, has continued his studies on this problem at a low level while he works on the sorghum RFLP map in Dr. Bennetzen's laboratory. He is now joined by a new PhD student under Dr. Ejeta, Richard Johnson, who is supported by a grant from Pioneer Seed Co. Although the data are incomplete, it is clear that the new studies agree with our earlier work which showed that resistance is more highly correlated with occurrence of flavan-4-ols than with tannins or with 3-deoxyanthocyanidins.

Coincidence and significance of observations that the biological activities (bird repellency, mold repellency and antinutritional effects) considered to be due to "tannins" are instead due to nontannin materials which occur with tannins: We have shown that sorghum tannins in the diet of rats and mice induce production of proline-rich salivary proteins which strongly bind tannin and effectively minimize its antinutritional effects. With Dr. Nicholson, we have shown that at least one of the mold fungi on sorghum (*Colletetrichum graminicola*) also produces tannin-binding proteins that seem to play a role in protecting against tannin which would otherwise prevent spore germination. And now we have shown that tannins are not responsible for the major antinutritional effects, but that tannin-associated phenolics are probably responsible. These findings explain the reasonably good correlations of repellency and antinutritional effects with tannin content, because the nontannin components responsible appear to occur exclusively with tannin. The results indicate, however, that observation of a high correlation of a biological activity with the occurrence of tannin is not sufficient proof that tannin is actually responsible.

The results must now be followed by identification of the active nontannin material(s) in each case: bird and mold resistance, and antinutritional factors.

Tissue culture: In this past year our tissue culture program has mainly emphasized development of high quality suspension cultures suitable for transformation with exogenous DNA using a particle gun, and selection in what we call liquid culture for resistance to *Striga* toxin. Cai Tishu, visiting scientist from PRC, now has fast growing, stable suspension cultures of several sorghum genotypes. So far, she has not been able to regenerate these, although we continue to refine the system in hopes of obtaining regeneration. Meanwhile, we utilize "liquid" cultures, in which the cells are not finely divided but are in somewhat larger clumps. These cultures are readily established and are readily regenerated. Cai has used these liquid cultures to screen for resistance to *Striga* toxin. She now has over 30 plants regenerated from clones of cells which survived exposure to *Striga* toxin. We are collecting selfed seed from these greenhouse-grown plants. Their progeny will be evaluated for resistance to the *Striga* toxin, and those that appear to be resistant will be evaluated in collaborators' *Striga*-infested fields. In this way we hope to develop new sources of resistance to *Striga*.

Striga: The simple laboratory assay using sorghum seeds germinating in agar gels in Petri dishes that we developed for screening sorghums for low stimulant production has now been run on over 1000 entries by R. Vogler, graduate student under Dr. Ejeta, and M. Alkire, technician. Many low stimulant producers have been identified. Previous results assure that low stimulant producers are resistant in *Striga*-infested African fields. I assume Dr. Ejeta's report will describe these results and their significance.

We have confirmed that sorghum SRN-39, identified by Dr. Ejeta as a superior source of broadly expressed resistance to *Striga*, is resistant at least partially because it produces extremely small amounts of water soluble stimulant required to trigger germination of *Striga* seeds. Yohan Weerasuriya, graduate student from Sri Lanka, has shown that under our defined laboratory conditions, the amount of this stimulant produced by a highly susceptible cultivar such as IS4225 can be as much as a billion-fold greater than that produced by SRN-39 under the same conditions. On the other hand, both these cultivars and all others tested produce equivalent amounts of sorgoleone regardless of whether they are resistant or susceptible to *Striga*. Sorgoleone does not appear to be a controlling factor in *Striga* germination, so we no longer work on it. From now on "stimulant" refers to the water soluble stimulant measured by the agar gel assay, and not to sorgoleone.

Characterizing the production of the stimulant, Yohan has shown that in our conditions using glass wool as the substrate, high stimulant producing sorghums such as IS4225 are quite sensitive to light, producing at least a million-fold more stimulant when light is limited to two hours a day than they do in 16 hours of light/day. Low stimulant producers such as SRN-39 do not respond to light; they produce the same low amount regardless of the light regime. Under our conditions (growing in pure water with no minerals added) most cultivars begin stimulant production within two days after the radicle emerges from the germinating sorghum seed. Production is maximal around seven days and essentially ceases around 14 days when the seedling has exhausted its stored energy.

The one cultivar of pearl millet we have analyzed produces virtually no stimulant to which our *Striga asiatica* seeds respond, but a cultivar of "white" (proso?) millet produces even more stimulant than sorghum IS4225. The stimulant is so active and occurs in such small amounts that we can detect it by its stimulant activity at concentrations at least 12 orders of magnitude lower than by any chemical assay. It is extremely difficult to obtain enough pure sample to chemically characterize this material. Bupe Siame, graduate student from Zambia, has developed methods for con-

centrating and purifying the stimulant a thousand-fold, but we have not yet been able to identify it. The purified stimulant from sorghum and from proso millet can be separated by HPLC into the same three active fractions. Sorghum cultivars such as low stimulant producer SRN-39 and high stimulant producer IS4225 do not differ in the nature or proportion of the three active fractions, only the amount. The major fraction from sorghum is one of the minor fractions from proso millet. The major fraction from proso millet, which corresponds to one of the minor fractions from sorghum, chromatographs on HPLC and TLC (several solvents) with strigol, the water soluble *Striga* germination stimulant previously identified from the root exudate of cotton, a nonhost. Bupe's results indicate that the water soluble germination stimulants produced by sorghum and proso millet may be strigol and strigol analogs.

We have observed that some sorghum genotypes produce in their root exudates inhibitors of *Striga* seed germination. For genotypes which are high stimulant producers this inhibition is not significant. We have found two classes of synthetic compounds effective as inhibitors of *Striga* germination at concentrations which do not affect sorghum germination or growth. Simple nonsubstituted phenols are inhibitory; catechol is the most inhibitory. These phenols are not sufficiently stable to be utilized in the field as *Striga* control agents. However, Yohan has found that certain synthetic nonionic detergents strongly and specifically inhibit *Striga* germination and are stable enough for use in the field. We are considering using inhibitory detergents as a crop seed treatment, much as fungicides are used, in order to at least delay the onset of *Striga* infestation. This seed treatment approach is more feasible for subsistence farmers than the formerly proposed soil treatment with synthetic germination stimulant to clean up infested fields.

Yohan has developed rabbit antibodies to surface antigens on *Striga* seed. These antibodies can distinguish between *Striga hermonthica* and *Striga asiatica*, between the seeds of *Striga* and those of other plants of the *Scrophulariacea* family, and between *Striga* seeds which have been preconditioned, germinated or devitalized and those which have not. Yohan also has chicken antibodies which inhibit germination of *Striga* seeds, suggesting they may be specifically bound at the receptor site for the germination signal, permitting its recognition and manipulation by the methods of molecular biology. We hope to obtain seed samples representing various populations of *Striga hermonthica* which vary in host specificity in different locations, and develop specific antibodies to them. This would permit development of a simple ELISA assay which could be used to determine the degree of contamination of crop seed or soil samples with *Striga* seed, and the proportions of the varying host-specific *Striga* strains within the sample and within any *Striga* seed sample. Knowledge of the local *Striga* strains is essential for breeding *Striga*-resistant sorghums for specific locations.

Publications

"Tannins and Lignins" (with A. Hagerman), in "Herbivores: Their Interaction with Secondary Plant Metabolites," G. Rosenthal and M. Berenblum, Eds., 2nd Edition, 1991, Academic Press, in press.

"Tannin in Betel Nut and Its Products Consumed in India: Comparison with High Tannin Sorghum" (with P. Pushpamma), J. Agric. Food Chem. 39: 322-326 (1991).

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"Tannin Mediated Induction of Proline-rich Protein Synthesis" (with H. Menhansho, T. N. Asquith, J. C. Rogler and D. M. Carlson), J. Agric. Food Chem., in press.

"Accumulatin of Sorghum Phytoalexins at the Infection Site" (with B. A. Snyder, B. Leite, and R. L. Nicholson), Physiological and Molecular Plant Pathology, in press.

"Biotechnology Research on *Striga*", in S. K. Kim (ed). Combating *Striga* in Africa: Proceedings, International Workshop organized by IITA, ICRISAT, and IDRC, 22-24 August, 1988. IITA, Ibadan, Nigeria, pp. 42-47 (1991).

"The Nature and Amelioration of the Antinutritional Effects of Tannins of Sorghum", Proceedings, International Conference on Sorghum Nutritional Quality, Purdue University, Feb. 26-March. 1, 1990, pp. 191-205.

"Use of ^{15}N-Labeled Protein to Determine the Effect of Dietary Tannin on the Relative Abundance of Endogenous and Dietary Protein in Feces" (with S. Mole and J. Rogler), Proceedings, 15th International Conference of the Groupe Polypehnols, 9-12 July, 1990, Strasbourg, France, pp. 121-123.

"Tissue Culture of Sorghum" (with T. Cai), Proceedings of Sorgo Para El Futuro, Jan. 16-18, 1991, CIAT, Cali, Colombia.

"The Role of Tannin in Nutritional Quality", Proceedings of Sorgo Para El Futuro, Jan. 16-18, 1991, CIAT, Cali, Colombia.

"Some Novel Approaches to the *Striga* Problem" (with G. Ejeta, D. E. Hess, B. Siame, Y. Weerasuriya and T. Cai), Proceedings, 5th International Symposium on Parasitic Weeds, June 1991, Nairobi, Kenya, pp. 539-544.

"Genetics and Breeding Strategies for *Striga* Resistance in Sorghum" (with G. Ejeta, D. E. Hess and R. K. Vogler, Proceedings, 5th International Symposium on Parasitic Weeds, June 1991, Nairobi, Kenya, pp. 539-544.

"Research Into Germination of *Striga* Seed by Sorghum Root Exudates" (with D. E. Hess and G. Ejeta), Proceedings, 5th International Symposium on Parasitic Weeds, June 1991, Nairobi, Kenya, pp. 217-222.

"Antinutritional Effects of Condensed and Hydrolyzable Tannins", Proceedings, 2nd North American Tannin Conference, June 1991, Houghton, Michigan.

"Several Approaches to the *Striga* Problem Being Developed at Purdue University" (with G. Ejeta), Proceedings of the 2nd Workshop of the Pan African Striga Control Network (PASCON), June 1991, Nairobi, Kenya.

Abstracts

"Somaclonal Variation in Sorghum", Rice Biotechnology Quarterly 5: 40-41 (1991)

"Absorption and Distribution of ^{14}C-Condensed Tannins and Related Sorghum Polyphenols in Chicks" (with L. M. Jimenez-Ramsey, J. C. Rogler, T. L. Housley, and R. C. Elkin), 2nd North American Tannin Conference, Houghton, MI, June 1991, and International INTSORMIL Conference, Corpus Christi, TX, July, 1991.

"Sorghum Suspension Cultures and Callus Formation from Suspension Culture Protoplasts" (with T. Cai), International INTSORMIL Conference, Corpus Christi, TX, July, 1991.

Inhibition of *Striga* Seed Germination" (with Y. Weerasuriya), International INTSORMIL Conference, Corpus Christi, TX, July, 1991.

"Water-Soluble Germination Stimulant for *Striga*" (with B. Siame), International INTSORMIL Conference, Corpus Christi, TX, July, 1991.

"Selecting Sorghum Genotypes for *Striga* Resistance Using an Agar Gel Assay" (with R. G. Vogler and G. Ejeta), International INTSORMIL Conference, Corpus Christi, TX, July, 1991.

Networking Activities

Workshops

International Workshop organized by IITA, ICRISAT, and IDRC, 22-24 August, 1988. IITA, Ibadan, Nigeria, pp. 42-47 (1991).

International Conference on Sorghum Nutritional Quality, Purdue University, Feb. 26-March. 1, 1990

15th International Conference of the Groupe Polyphenols, 9-12 July, 1990, Strasbourg, France

Sorgo Para El Futuro, Jan. 16-18, 1991, CIAT, Cali, Colombia.

5th International Symposium on Parasitic Weeds, June 1991, Nairobi, Kenya

2nd North American Tannin Conference, June 1991, Houghton, Michigan

2nd Workshop of the Pan African *Striga* Control Network (PASCON), June 1991, Nairobi, Kenya

International INTSORMIL Conference, Corpus Christi, TX, July, 1991

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Research Information and Material Exchange

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

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

Disease Control Strategies for Sustainable Agricultural Systems

Project TAM-124

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Summary

Progress has been made in the development of tools to research plant pathogens. The sugarcane mosaic virus (SCMV) strains reported from various parts of the world have been uncertain taxonomically. Working as a team, INTSORMIL, American University, Australian and other national workers have demonstrated that the group attacking sorghum is composed of four distinct potyviruses. These are Johnsongrass mosaic virus (JGMV), maize dwarf mosaic (MDMV), sorghum mosaic virus (SrMV) and SCMV. The technique used required peptide digests of the virus protein coats. These data confirm previous findings of a classification of SCMV strains based on N-terminal serology. Considerable progress has been made on the methodology of genetic fingerprints of isolates of *Colletotrichum graminicola* using selected DNA isolation. These techniques will permit the evaluation of shifts in this pathogen within a season and between seasons. The technique will permit superior selection of sorghum with durable resistance to anthracnose as well as provide the basis for expanding the approach for monitoring the pathogen genetically. Generally only the phenotype of the pathogen could be observed through its reaction on a host differential. By genetically characterizing the pathogen the work can be done directly in the laboratory. Progress has been made in the application

of other DNA technologies to defining species of the downy mildew fungi and the smut fungi. Some of these techniques now permit identification of pathogens to species by their DNA profiles directly.

Research Objectives

Sudan

Long Smut
- Identify sources of resistance.
- Identify plant traits leading to disease escape.
- Collaborate with All African Long Smut Nursery.

Striga
- Begin studies on histopathology of resistant sorghum.

Honduras

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

Brazil

- In 1990/1991, we will continue our collaborative work on anthracnose, particularly in the area of dilatory resistance. The possibility of holding a major conference on anthracnose to consider the worldwide threat of this disease is seriously being considered. Such a conference was recommended at the global conference in Zimbabwe.

India

- A proposal was prepared for collaborative work on long smut and ergot. Status uncertain.
- Collaborate with Dr. T. B. Garud on virus problems in India.

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.
- Inoculate and evaluate long smut nurseries at Kollo and Tillabery.

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 phaesolina* using both natural hot spots and laboratory approaches.

Venezuela

- Evaluate 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.

Zimbabwe

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

Tanzania

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

Mr. A. Mansuetus will be traveling to Tanzania sometime during the next 12 months to survey the diseases of sorghum caused by *Fusarium* spp. The diseases include: seed rot, head blight, small seed, pokkah boeng, and grain mold. Much of the actual research will be done in Tanzania by Mr. Mansuetus over the next 2-3 years for a doctoral dissertation. Co-chairing his committee will be Dr. Odvody. It is also proposed to invite Dr. John Leslie, Kansas State University, to assist in the development of Mr. Mansuetus' research.

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 (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. Produce 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 to 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

Research Methods

Currently we combine several approaches to controlling diseases of sorghum and millet. Our system of networking includes the growing of several uniform nurseries in locations where certain diseases are important, such as the 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. Based on the ISAVN, for example, Mr. Diourte in Mali believes that he has isolates of *Colletotrichum graminicola* different from those that are present in the U.S. Based on field trials, this appears to be true and would be expected. By combining field data with that of the laboratory, Dr. R. W. Toler and colleagues have characterized the sugarcane mosaic virus subgroup into four distinct potyviruses. We expect to reduce the number of significant pathotypes of *C. graminicola* to a smaller more useful number using RFLP, and PCR/RAPD technologies. Last year we reported on the progress in characterizing the different species of tropical downy mildews utilizing the combination of field and laboratory data. Similar progress is being made for the fungus causing head smut; however, it has been much more difficult because of the unique biotropic relations between the host and pathogen and difficulties in isolating DNA. The project has 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 there is hope that sorghum will 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 the durability of the resistance. 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 deploy a cultivar susceptible to a damaging disease. Most of the work is interdisciplinary and involves specialists from many disciplines. The wide acceptance of germplasm developed from INTSORMIL institutions and the use of this germplasm in national programs demonstrates the importance of this approach.

Research Findings

Sorghum Smuts

Long Smut

Long smut caused by *Tolyposporium ehrenbergii* Pat. is prevalent and severe on sorghum in the drier regions of Mali and Niger. Little is known about the disease and its epidemiology. In Mali, we have looked at date of planting as a means of determining aspects of the epidemiology and possible control of the disease from the various dates of planting in 1989-1990. At Bema, where long smut is generally more severe, later plantings have had less disease.

In Niger, work has been focused on long smut because it is important in Niger. Most of the work is being done at the Kollo Station because the disease is endemic in the area.

In 1990, 75 sorghum accessions were evaluated in a nursery with susceptible spreader rows. Data were collected on the basis of a 0-4 scale as follows:

0 = Resistant	0 sori/head
1 = Moderately resistant	0 sori/head< 5
2 = Moderately susceptible	5 sori/head< 10
3 = Susceptible	10 sori/head < 20
4 = Very susceptible	20 sori/head

Based on these ratings the following entries were found to be moderately resistant: Terra, SC326-6, SC630-11E, BTx2775, BTx378, B8106, Tx7078, PL3, R9188, 87L3450 and 84C9408. Since many of these are early maturing lines, a regression of long smut on maturity was done. A coeffi-

cient of determination R^2 was 0.55. This means that 55 percent of the variability is due to maturity. All early maturing lines with a low score will need to be evaluated under controlled conditions to eliminate the possibility of escape.

A date of planting experiment was done using four cultivars. This experiment was done to test the hypothesis that there is a probability that the incidence of disease will increase as the season progresses. These data appear to support the hypothesis (Fig. 1). El Mota, an early maturing cultivar, had an increase in disease with each planting date. Disease increased between dates of planting 1 and 2 but the 3rd date of planting did not differ from the second.

Head Smut

There is currently little information available on the genetics of *Sporisorium reilianum*, the causal agent of head smut of maize and sorghum. This is partly due to the lack of naturally occurring phenotypic mutants and the difficulty in generating auxotrophic mutants. RFLP's and RAPD's are being sought which will be useful as genetic markers. One of the limiting factors has so far been the efficient extraction of fungal DNA. Commercially synthesized RAPD primers are being screened for their usefulness in differentiating between the host specialized isolates of *S. reilianum*. Decreasing the annealing temperature of the PCR demonstrates that RAPD markers are a very quick and easy way of differentiating between the different pathotypes using minute amounts of template DNA. However, their validity with larger sample sizes has yet to be confirmed. Pulse field gel electrophoresis (PFGE) and southern hybridizations are being employed to describe the karyotype. Southern hybridizations are being used to localize the *ura3*, *tpi1* and *leu2* genes from *Ustilago maydis* on individual *S. reilianum* chromosome-sized fragments. Nine discrete chromosome-sized fragments were separated using PFGE. The width and densities of the bands suggest that there may be as many as 15 such fragments. This was substantiated using CHEF which also serves to differentiate between the host specialized isolates (Fig. 2). Fifteen chromosomes were seen in smut samples isolated from infected maize plants while only 13 chromosomes were found in isolates from sorghum. This difference seems to be very consistent. Using *Saccharomyces cerevisiae* as a standard, preliminary estimates indicate that the genome size ranges between 18 and 27 Mbs. Flow cytofluorometric measurements of nuclear DNA reveal a genome size of 30 Mbs.

Downy Mildew

Dr. I. Kunene completed her work on biological control of sorghum downy mildew. Her dissertation was on the role of the chytrid, *Gaertneriomyces longispore*, as a hyperparasite of oospores of *Peronosclerospora sorghi*. The hyperparasite was demonstrated to reduce levels of the disease under field conditions and the organism would survive in the soil. There was a linear relation in the level of chyrid in the soil and disease control. Mr. Chenlin Yao continued to characterize downy mildew fungi genetically. Cloned DNA fragments have been used to identify downy mildew infected seeds of maize as to species. This is particularly

Fig. 1. Effect of three weekly plantings on incidence of long smut in four sorghum cultivars at Kollo, Niger.

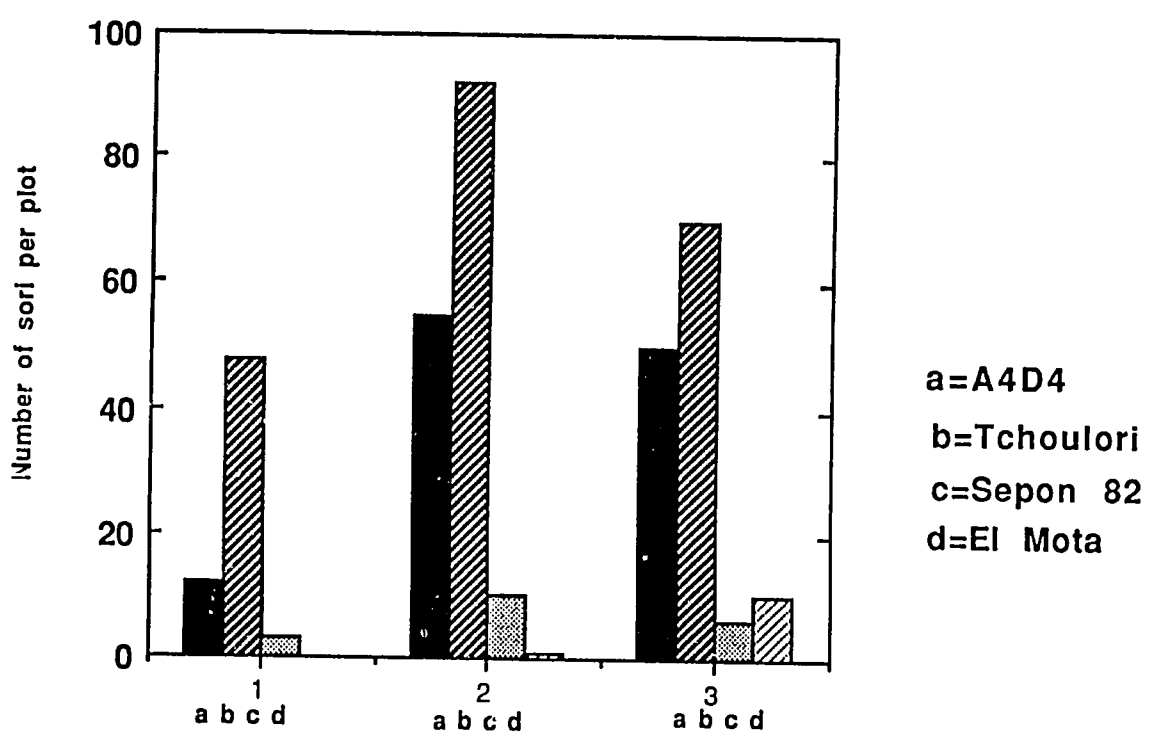
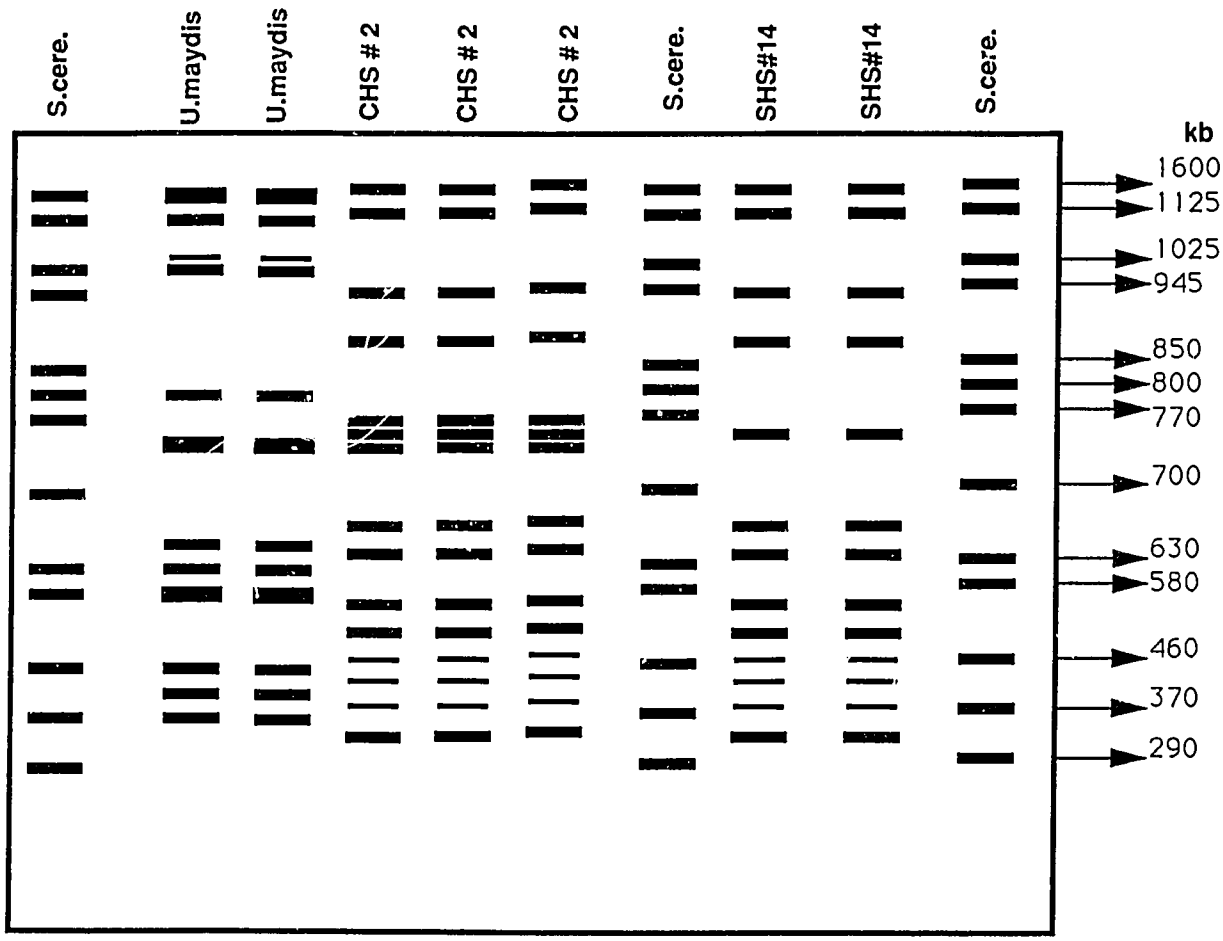


Fig. 2. **CHEF separated chromosomes. Run conditions: Pulse time 60s for 15 hr and 90s for 9 hrs at 200v. Samples from L-R, Lanes 1, 7 & 10 Saccharomyces cerevisciae; 2&3 U. maydis; 4,5&6 CHS (different isolates); 8&9 SHS (different isolates).**



significant in that the species of the organism could not be identified by conventional means and by the fact that the organism was never grown or alive during the analysis. It is now possible to characterize species of these fungi from their DNA alone (Note Phytopathology 81:901-905, 1991) and not introduce living pathogenic agents.

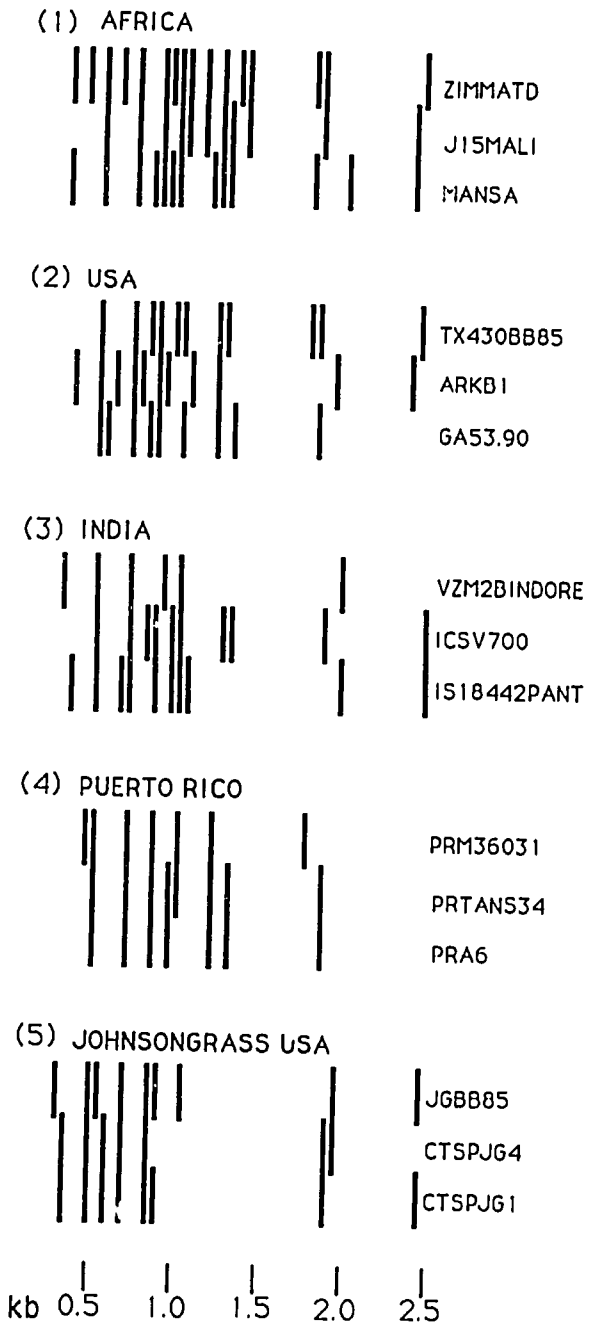
Anthracnose

Several projects are under way in our study of anthracnose. Under field conditions, we have demonstrated that there is evidence for dilatory resistance to *Colletotrichum graminicola*. Based on field evaluations of ten selected genotypes, significant differences in dilatory resistance were observed. In addition, the resistance was closely correlated with latent period. Mr. Casela and Mr. Collins also evaluated the role of sclerotia of *C. graminicola* on the epidemiology of anthracnose. They found that 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.

RAPD markers are a tool with which we can quickly and easily characterize differences among isolates of *Colletotrichum graminicola*, the causal agent of sorghum anthracnose, and so begin to map diversity within the pathogen population of any given area, and follow the effects of different cultivar deployment strategies upon pathogen genotype distribution. Preliminary data have been obtained for 15 isolates, consisting of three each from Africa, U.S., India, Puerto Rico, and three Johnsongrass (*Sorghum halepense*) isolates collected from Texas. DNA from each isolate was amplified in three separate reactions using three different 10-base primers, and the resulting fragment size data were combined to yield the accompanying chart, showing the composite signature of DNA fragment sizes for each isolate (Fig. 3). Although the sample size is low, analysis of these data shows, perhaps not surprisingly in view of the isolated nature of the habitat, that the greatest homology within groups occurs among the Puerto Rican isolates. Analysis of percentage of alleles shared between three-isolate groups again shows that the Puerto Rican isolates lie at the greatest distance genetically from the others, followed in genetic distance by the U.S. Johnsongrass isolates. The characteristic of the DNA signatures of certain groups of isolates permits RAPD-based technique not only for ge-

netic studies but also in applications such as tracking down the possible source of a sudden disease outbreak, and detecting quarantine violations.

Fig. 3. RAPD signatures - composite chart.



Mr. C. Casela observed variability in pathogenicity among monoconidial isolates from individual lesions and from monoconidial cultures. Fifteen monoconidial isolates were obtained from one lesion each of the sorghum cultivars TX623 (Griffin, Georgia), called L-1, and SC748-5 (Brazil), called L-2. Fifteen monoconidial subcultures were further obtained from each of two original monoconidial cultures, L-1.1 and L-2.1, respectively, followed by a second generation of 15 monoconidial isolates from each of two monoconidial subcultures, L-1.1, 11 and L-2.1, 13. Virulence tests were performed on a group of five differential cultivars, TX378, SC326-6, SC414-12E, TX2536, and SC748-5.

From the 15 monoconidial isolates of L-1 and L-2, seven and three pathogenic races, respectively, were identified. The 15 monoconidial cultures from L-1.1 and from L-2.1 were separated into two and four races respectively. Finally the second generation of monoconidial isolates from L-1.1, 11 and from L-2.1, 13 produced six and four different races, respectively. These data demonstrate the high variability existing in *Colletotrichum graminicola* and raises questions about the mechanisms responsible for such variation.

Sorghum anthracnose is generally more prevalent and severe in southern Mali. Recent surveys have demonstrated the importance of the disease at Sotuba and Samako. The growing of the international sorghum anthracnose virulence nursery has not provided convincing evidence for differences among isolates in Mali as of yet. The reactions however, have unique differences from those produced in the U.S. Differences probably are present in Mali, however until there is genetic control of the disease these differences will not present agronomic problems.

Grain Mold

Grain mold damages sorghum through actual loss in yield and reduction in quality and nutritional value of the grain. *Fusarium moniliforme* and *Curvularia lunata* are the most important fungi causing grain mold.

The only practical methods for controlling grain mold are avoidance or escape and the use of grain mold resistant sorghum cultivars. Development of resistant cultivars should be based on knowledge of the genetics of the disease resistance. So far, little information is available on grain mold resistance. Research has been done by J. Peter Esele at College Station, Texas, U.S., and at Serere and Namulonge in Uganda. Mr. Esele studied the effects of the testa (B_1-B_2-), red pericarp (RRYY), purple plant color (P-Q-), thin mesocarp (ZZ) and the intensifier gene (II). The presence of a pigmented testa was the single most important character conferring grain mold resistance. Although not as significantly as a pigmented testa, the effect of red pericarp color in conferring resistance is enhanced when the intensifier gene is present. Mesocarp thickness was found to have no significant role in grain mold resistance. Tan plant color confers grain mold resistance, purple plant color does not. The presence of the intensifier gene in the grain improves resistance to grain mold with either purple or tan plant color. Grain mold reactions at College Station and Serere were not significantly different and these sites could become excellent locations for grain mold resistance selection. Namulonge is not a suitable location.

Mr. Anaclet Mansuetus is studying the mating populations of *F. moniliforme* section *liseola* on sorghum and pearl

millet from Tanzania to find the vegetative compatibility groups in which they fall. Mr. Mansuetus collected specimens from Tanzania in June 1991 from entries in the sorghum grain mold resistant nursery and from pearl millet variety trials at Ilonga and Ifahara. Additional collections were made from local sorghum cultivars grown in fields of traditional farmers. Mr. Mansuetus is also isolating these fungi from sorghum grown in Texas. *Fusarium* spp. were collected from heads of sorghum cultivars differing in grain mold resistance and grown at College Station, Corpus Christi, Beeville and Victoria. Isolates of *F. moniliforme* section *liseola* accounted for 35% of the isolates, but none were obtained from black seeded sorghum. Forty-five isolates from this section were crossed with standard mating tester strains (A-F) to determine the mating population of the isolate. All six mating populations were found but not all from each site. Dr. John Leslie, Kansas State University, provides materials, guidance and leadership for Mr. Mansuetus' research program.

Sorghum Virus

Sorghum yellow banding virus (SYBV) was observed in one county nonadjacent to and seven counties contiguous with the initial site of observation near Floresville, Texas in 1984. SYBV occurred naturally only on sorghum x sudan grass hybrids except for one occurrence on grain sorghum tillers. No SYBV was observed on primary growth and initial or highest incidence was generally observed at field perimeters on basal rather than stem tillers. The virus can be detected in several infected plant tissues including roots. In an irrigated field, incidence of SYBV increased with each of two ratooned crops (< 1% and 10-30%). The slow recovery single ratoon crop of several dryland fields had a higher incidence of SYBV (10-25%) than the comparable irrigated ratoon crop. In greenhouse tests, SYBV occurred in the first (1991), third (1990), and subsequent ratoon crops of sorghum x sudan only when grown in soil from an SYBV-affected field. Wider row widths increased field incidence of SYBV in 1990. Aphids did not transmit the virus and vectors are yet unknown, but results indicate a soilborne mechanism for SYBV. Mechanically inoculated sudan grass and sorghum x sudan cultivars differed in resistance to the virus. Sorghum x sudan hybrid tissue of SYBV infected plants was analyzed serologically for the presence of SYBV. Virus was present in roots, leaves, culms, pedicels, stem exterior, flowers, and in the stem exterior but not in the pith. SYBV showed an apparent increase in incidence after ratooning, but the increase occurred only in new tillers of plants already infected. All plants with symptoms were tested serologically, and those testing positive were rated as susceptible. The percentage of infection and the mean disease incidence ratings of three replications for each entry were tested. Of the 51 entries tested, 22 were rated as susceptible, and 29 as resistant. A definite synergistic effect between SYBV and MDMVA on grain sorghum host exists. The multiple infected plants were more severely diseased than those with either virus alone. All plants doubly infected died after 17 days. The number of sorghum cultivars tested for susceptibility to sorghum yellow banding was increased to 516; 138 cultivars were susceptible to the virus and 378 were resistant. This is a 26.74% susceptibility. In total, more than 516 sorghum cultivars have been tested for host range to sorghum yellow banding virus.

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

Other virus related research included the distribution of the International Sorghum Virus Nursery, supplying antiserum from the International Sorghum Virus Antiserum Bank, and antiserum to sugarcane mosaic strain H was added to the Antiserum Bank. MDMV-B infected 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. In 1990, 150 commercial grain sorghum hybrids were evaluated for their reactions to MDMV-A under field conditions. Disease pressure was very high with about 99% of the plants infected.

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Networking Activities

Workshops

Dr. Frederiksen participated in the "Sorghum for the Future" Conference at Cali, Colombia, January 16-18, 1991. He presented a paper on "Diseases affecting the grain and panicle of sorghum". Drs. Toler and Frederiksen participated in the International Sorghum and Millet Conference at Corpus Christi, Texas. Dr. Frederiksen presented an invitational paper on the Role, Contribution and Direction of Biotechnology in a Sustainable Production Network.

During the past year we introduced 151 accessions of sorghum and pearl millet from Sudan, Mali, India, Zimbabwe, Zambia, and France. These items were grown under quarantine conditions and released to the breeder or individual requesting the service. Tx 2891, a multiple disease resistant sorghum breeding line, was released. Tx 2891 has excellent resistance to downy mildew and head smut in the U.S. The line was developed originally in a program to improve grain mold resistance in selected sorghum lines with resistance to downy mildew.

Twelve Sorghum Downy Mildew Virulence Nurseries, eight International Anthracnose Virulence Nurseries and five other related anthracnose nurseries were distributed to collaborators. Distribution of the International and All Sorghum Disease and Insect Nurseries were also distributed as part of the cooperative program with other TAMU projects. Essentially all of the TAMU projects collaborate on these nurseries. Several International Sorghum Virus Nurseries were also distributed. Sorghum antiserum was supplied to Venezuela, Zambia, India, and U.S. agencies.

Integrated Insect Pest Management Strategies for Sustainable Agricultural Systems

Project TAM-125
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Summary

Project TAM-125 is developing integrated pest management strategies for sustainable sorghum/millet production with concentration on plant resistance and biological control.

On-site collaborative research activities are in Honduras, Mali, and Niger. Research in Texas is used for technology development, graduate student training, and short-term training. Insects on which major effort is made for development of insect resistant cultivars are sorghum midge, yellow sugarcane aphid, greenbug, and panicle feeding bugs. Insects of major focus for biological control are sorghum and millet stalk borers, millet head caterpillar, fall armyworm, and aphids.

The collaborative research effort in Honduras has focused on biological control of fall armyworm in Honduras. This effort progressed to completion of a third Master of Science degree. The most recent degree program examined the suppressive impact and techniques for managing two of the three primary predators of fall armyworm. Plans were developed with collaborators Escuela Agricola Panamericana and SRN to continue research on biological control of fall armyworm with a fourth Master of Science to begin in 1992.

In Mali, a second 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 has 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 judgment decisions during progeny selection and line evaluation. This multidisciplinary program has been extremely successful, with the principal collaborator, Dr. Y. Doumbia, being recognized by SAFGRAD for outstanding research contributions.

In Niger, work plans were developed to continue the research program on biological control of millet stem borers and millet head caterpillar. Gilstrap visited Niger in the Fall of 1990, and the visit resulted in a proposal to INTSORMIL for additional funding to support a greater collaborative effort in Niger and Mali. The program seeks to place a Ph.D.

graduate student from Niger or Mali in the graduate training program at Texas A&M University. This graduate program is expected to begin in the fall of 1992. A work plan for the collaborative research on MHC was developed by Gilstrap and Dr. Youm (ICRISAT-S' 'hore) and consists of four objectives. A second initia' . was developed in 1991 to provide short term training to a Nigerian employed by INRAN. This plan has been submitted to INRAN for approval and action. If approved, the trainee is to arrive at Texas A&M University in January or February of 1992. The training seeks to prepare a continuing INRAN collaborator to work with Drs. Gilstrap and Youm on biological control of millet stem borers.

Graduate students from Colombia, Mexico, Malawi, Honduras and Botswana are being trained in entomology. Technology transfer has occurred through publications and exchange visitation. Collaboration with ICRISAT scientists has continued strong.

Objectives, Production and Utilization Constraints

Objectives

Botswana sugarcane aphid research: This collaborative project was dissertation research of Chris Manthe, a Botswanan graduate student. The research is completed and the dissertation is being prepared. The research results were reported in a previous report and will not be repeated here.

Mali sorghum panicle-feeding bug research: The objectives are 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.

Honduras fall armyworm and sorghum stem borer research: The objectives are to identify biological control agents and assess the efficacy of these agents on stem borers, fall armyworm and other pests of sorghum.

Technology development and student training research: The objectives of research conducted in Texas are to provide a mechanism for graduate student training programs, to identify and evaluate sorghums resistant to insect pests, determine resistance mechanisms, investigate plant-pest ecological responses and determine economic injury levels; and identify potential biological control agents for use against sorghum and millet insect pests, and integrate effective biological controls with local production practices. Individual student research program results are reported under Student Training in the section on Research Approach and Project Output.

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, stem borers, armyworms, the sorghum midge, and the millet head caterpillar in traditional farming systems is dramatically increased when improvements in agricultural production are attempted through breeding and changed 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 and millet vary geographically, and in intensity and persistence. Sorghum and millet 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 Sorghum/Millet Entomology project focuses on developing insect control technologies applicable to sustainable agriculture systems. The tactics developed and evaluated include plant resistance to insects, biological control, and manipulation of cultural practices. Each tactic is supported with ancillary insect pest biological and ecological research to ensure its 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 is on damage assessment and plant resistance to the sorghum panicle-feeding bug complex. Collaborative research in Honduras is on biological control of fall armyworm, and the collaborative research in Niger is on biological control of millet head caterpillar and millet stem borers. Research in the U.S. is for 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. Student training in the area of biological control involves recognizing, conceptualizing and defining functional ecosystems of key pests for biological control tactics; developing experimental methodologies for measuring the actual and potential impacts of natural enemies; and validating results of biological control studies by implementing research results in production agriculture systems.

Research Approach and Project Output

Mali sorghum panicle-feeding bug (*Eurystylus marginatus*) research: This collaborative research project continues to be extremely productive. At Sotuba during 1990, a number of experiments were conducted. One experiment related to developing and evaluating screening methods for breeders to use in making selections and testing materials for resistance to panicle feeding bugs. The objective of the study was to determine the level of damage of 89 sorghum

lines by the panicle feeding bug under conditions of natural infestation in an attempt to identify resistant lines. Genotypes with the best resistance are subjected to further testing. In 1989 the preliminary screening nursery consisted of 100 sorghum entries from the National Program with ICRISAT and Texas A&M University. In 1990 the number of entries was reduced to 89. Sorghum lines were evaluated using natural bug infestations, two replications, and two five meter rows per entry. Bug abundance was recorded from five panicles per plot. Two panicles of each entry were protected using bags over the panicles. Data collected included panicle shape, length of glumes, and grain color. Visual ratings were made of bug damage and grain mold. Also, vitrosity and weight (1000) of kernels, percent germination, and number of floating kernels were determined. Comparisons were made between kernels from protected and unprotected panicles. Sorghum lines tested in the preliminary screening nursery were damaged to different degrees. A study of the distribution of damaged lines showed that during 1989 and 1990 7-17% of the sorghum lines had an infestation level of 100 to 150 bugs per five panicles. The sorghum line S34 had an infestation level of 1185 bugs per five panicles in 1990. In 1989 15% of the entries rated low bug damage of 1 or 2, while in 1990 39% rated low damage, but this difference may have been due to differences in bug abundance. To determine the relationship between bug damage and pathogen infection, a correlation analysis was conducted using 72 lines in 1989 and 89 lines in 1990 (two replications). There was a positive correlation between the two parameters. The correlation was strongest using 1990 data. A similar positive relationship between bug abundance and grain mold was found using data from an advanced trial using 12 sorghum lines. Relative to 1000 kernel weight, vitrosity, flotation, and germination, a positive correlation existed between bug damage and these parameters. Bug feeding increased vitrosity, reduced kernel weight and germination, and increased the number of floating kernels. These relationships were especially positive when data from susceptible sorghum lines were used. After two years of screening, only nine sorghum lines were considered to have any level of resistance to panicle-feeding bugs. These sorghum lines were damaged less than or no more than Malisor 84-7, the resistant standard check. The sorghum lines were further tested for degree of resistance under artificial bug infestation. These sorghum lines including Malisor 84-7 are listed below with bug abundance and damage ratings for 1989 and 1990.

	# bug/5 panicles		Damage ratings	
Sorghum line	1989	1990	1989	1990
Malisor 84-7	27.5	79.0	1.7	2.3
87-SB-F4-54-2	37.5	188.5	1.7	2.0
IS16357	85.0	454.0	1.0	2.5
IS2074C	20.5	7.5	1.0	1.0
IS21468	16.5	22.5	2.0	2.0
IS21525	18.0	51.5	2.0	2.0
IS27477	15.0	138.0	1.0	2.0
R6078	32.5	110.5	1.5	2.3
BVAR1	6.5	89.5	1.7	2.0
1082 Sel dur	32.0	57.0	1.0	2.0

A second experiment was conducted to determine the relationship between bug damage to kernels and the degree of pathogen infection. Four replications of treatments were used including application of fungicide (Benomyl), protection from bugs using plastic bags, plastic bags plus Benomyl, and natural infestation and no fungicide. Bug abundance was determined from five panicles 14 days after anthesis, and at grain maturity. Bug damage and pathogen infection were visually rated. Also, kernel weight and flotation were determined. The level of bug infestation was uniform, but bugs per five panicles varied from 24 to 48. Fungicides did not appear to affect bug damage. Pathogen effects were greater on unprotected than on fungicide protected panicles. The correlation coefficient comparing bug damage to grain mold ratings was 0.313. The correlation was low due to low humidity levels. Kernels from panicles not protected from bugs were severely damaged based on flotation tests. A third experiment determined the level of bug damage using different methods of panicle protection. These treatments included natural infestation, protection from bugs using constructed cages, protection of panicles using paper pollinating bags, and protection of panicles using diazinon insecticide. Using these treatments in 1989 provided outstanding results that showed the high level of damage to kernels inflicted by bugs. In 1990, bug abundance was less than in 1989 and the magnitude of bug damage was much less. However, the general results were similar. Attempting to protect panicles using paper pollinating bags was time consuming and the bags often tore after much rain. The use of constructed cages was not practical for several reasons. Protecting panicles using an insecticide was practical and differences in protected and unprotected panicles were found. For example, protected panicles had higher seed weights. Bug infestation, damage, and grain mold, in general, were less in 1990 than in 1989. The level of the effect of bug damage was reflected in the lower infestation level between the two years.

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 supports international research collaboration.

Technology Development

The occurrence of a new greenbug biotype (biotype I) was confirmed using TAES developed biotype E resistant sorghum lines and the original released biotype E resistant line (Tx2783) compared to KS96, a biotype I resistant line. All TAES biotype E resistant sorghum lines are susceptible to the new biotype. Crosses to one biotype I resistant source were attempted. Those crosses, plus ones that will be made in Puerto Rico will be tested in greenhouse trials. To date, biotype I is most prevalent in southwest Kansas, but is also present in several northwest Texas areas. A major effort recently has been to evaluate TAES greenbug resistant sorghums at Beeville and College Station to select strongly

for adaptation to the harsh south Texas climate and prevailing diseases.

Sorghum midge resistant sorghum lines were advanced two generations; selections for resistance among agronomically improved segregating germplasm lines were made and elite sorghum midge resistant lines and parent lines in hybrid combination were tested at Corpus Christi, College Station, and Lubbock. Excellent progress in developing acceptable sorghum midge resistant hybrids continues to be made. In spite of this progress, the ultimate goal has not been reached. New converted exotic lines were screened and one line was considered to be a potential new source of sorghum midge resistance. We continue to introgress different gene sources to elevate the resistance level. Plans are to release another group of sorghum midge resistant R-lines in the near future. The problem in developing midge resistant hybrids is still with the A-line side of the F_1 hybrid. F_2 populations of TAM2566 sources by ICRISAT resistant lines were evaluated. Among these populations fairly high levels of resistance are found, but plant agronomics are not acceptable.

Student Training

Bonnie Pendleton, Ph.D. student from the U.S.: A simulation model of sorghum midge population dynamics based on developmental rate equations was developed and field tested for two years in the Texas Brazos Bottom. The model predicted the build-up of midge populations in mid- and late-planted fields very well. Early planted fields were not as well modeled, probably because sampling efficiency was so poor for early fields with low midge densities. In order to predict accurately the number of midges emerging from sorghum fields, a scalar was used in the model. The scalar was found to be strongly positively correlated with the size of the field studied. A dissertation on this research is being prepared and at least two journal publications will follow.

Doug Jost, M.S. student from the U.S.: The objective of this project is to validate a sorghum midge component of the sorghum crop growth model, SORKAM. Validation of the model requires sampling sorghum midge abundance and distributions as well as damage to the crop and loss of yield. Incorporation of such an element into SORKAM will help predict initial emergence of sorghum midge, abundance increases, and overall crop yield loss. Two years of data have been collected at two regions in the state. Early, normal and late planted sorghum fields were chosen and weather data collected at each site. The data in the table below represent the results of the validation effort. None of the data have been tested against the predicted results of the model, but will be the content of a thesis and subsequent publications.

Ricardo Magallanes, Ph.D. student from Mexico: Research was initiated to determine the differences in the habits, behavior and biology of sorghum midges within florets of resistant and susceptible sorghum lines. Research is being conducted in four general areas: life cycle length, egg laying, feeding site, and survivorship of sorghum midges infesting resistant and susceptible sorghums. The approach will be a life table analysis comparing sorghum midge development and survival of initial cohorts on the different host types. These data are being collected, and it is too soon to provide any results.

Nora Jimenez, M.S. student from Colombia: The objectives of this project are to determine the feasibility of using mixed planting of sorghum midge resistant and susceptible sorghum hybrids to exploit the sorghum midge nonpreference resistance mechanism and to determine the nature of the nonpreference of sorghum midge resistant cultivars. Relative to the first objective, per panicle yields were higher for the resistant hybrid than the susceptible hybrid. However, per plot yields showed no consistent pattern. Evidence of sorghum midge attraction to susceptible panicles resulting in increases in yield of the resistant hybrid was not apparent. The data suggest that other factors had greater effect than the attraction of midges to the susceptible panicles. Some of these factors include overall midge abundance levels, midge abundance during flowering, genotypic yield potential, and location of plots in relation to the source of sorghum midges. To further explore the nonpreference resistance mechanism, additional data were collected. These data included the time of day when actual floral anthesis

Maturing variety	Avg. sowing date	Avg. harvest date	Avg. # of midge collected (300 plants)	Avg. panicle damage (mature)	Avg. grain yield in kg/ha
Nueces County — 1990					
Early	2/25/90	6/17/90	8	11%	3,249
Normal	3/18/90	6/20/90	79	12%	1,561
Late	3/27/90	6/29/90	77	14%	2,328
Hill County - 1990					
Early	3/22/90	7/26/90	211	10%	2,601
Normal	3/28/90	7/28/90	225	16%	3,338
Late	4/28/90	8/5/90	357	17%	2,301
Nueces County — 1991					
Early	2/20/91	6/25/91	93	37%	3,677
Normal	3/2/91	6/26/91	17	34%	4,094
Late	3/11/91	6/26/91	4,558	67%	1,813
Hill County — 1991					
Early	3/10/91	7/25/91	322	23%	4,107
Normal	3/29/91	7/25/91	376	34%	3,338
Late	5/2/91	7/25/91	4,147	36%	3,331

occurred, numbers of midges on panicles from 8:30 a.m. and 12:30 p.m. (time when female midges are most abundant on flowering panicles), oviposition behavior in the field, actual proportion of flowering panicles of each genotype, and the distance of plots from the source of midge infestation. Preliminary review of the results indicated that there is a marked difference when spikelet anthesis occurs between the resistant and susceptible cultivars. The florets of the resistant cultivar opened starting at midnight while the florets of the susceptible cultivar began opening at about 8:00 a.m. causing floret opening to be synchronized with the presence of female midges. Female midges on the resistant cultivar showed no apparent nonpreference and attempted to oviposit, but the rate of successful oviposition was much less than on the susceptible cultivar. The value of this resistance mechanism is lower when midge abundance is very high. Female midges did not appear to recognize whether a floret was open or closed until oviposition was attempted by probing with the ovipositor. Midge abundance in plots appeared to be dependent on how close the plot was to the source of the midge infestation and how many midges the source was providing. This observation was supported by additional data using oil-coated solo cups to trap midges to determine abundance in time and space. Midges appear to have power of directional flight at least for short distances, and the insect appears to be phototactic toward the sun. Spatial distribution of midges appeared not to be uniform. Many midges were trapped on the flag leaf when it was oil coated. On close observation, midges appeared to lick the tip of the glumes and were adversely affected by the procedure. Also, in some cases the ovipositor of female midges got caught between the glumes because there was not sufficient room for the egg to exit the ovipositor. Additional experiments are planned to examine the effect of floral anthesis time on sorghum midge oviposition.

Anderson Paliani, M.S. student from Malawi: Visual damage ratings of seedling sorghum plants grown in flats in a greenhouse showed that sorghum lines PI457709 (rated 5.9) and PI453951 (rated 5.6) were moderately but significantly resistant to yellow sugarcane aphid compared to Tx430 (rated 7.8), and Tx2783 (rated 7.0), a greenbug biotype E resistant sorghum line. Based on two different designs of free choice tests, the aphid showed no preference for the susceptible sorghum lines over the resistant lines, indicating that antixenosis is not an important resistance mechanism. However, based on a measure of plant damage of susceptible and resistant plants including infested and noninfested plants, plant growth of the susceptible plants was more severely affected than growth of the resistant plants, indicating a level of tolerance to aphid feeding. These results are shown in the following table.

Sorghum Tolerance to Yellow Sugarcane Aphid

	Plant growth (cm)	
Sorghum line	Infested plants	Uninfested plants
PI457709	33.8a	35.9a
PI453951	29.3ab	30.4ab
Tx430	24.3b	27.4ab

Lorena Lastres, M.S. student from Honduras: This report summarizes studies conducted during 1988, and was submitted as a thesis in August 1990. The studies were conducted on sorghum and maize in central Honduras, and evaluated the impact of two key predators of fall armyworm (= whorlworm), *Spodoptera frugiperda* J. E. Smith. Predators evaluated were an earwig, *Doru taeniatum* Dohrn, and the tropical fire ant, *Solenopsis geminata* F. These are two of the three most common predators of whorlworm in central Honduras. The third common predator is of a species complex of predatory paper wasps, *Polybia* spp., and this group will be evaluated for predatory impact during 1992-93.

The suppressive impact of *Solenopsis* and *Doru* on whorlworms: An initial set of studies was conducted on naturally occurring populations of predators and whorlworms on primera and postrera maize. These studies used a selective exclusion procedure to establish four treatments, with *D. taeniatum* and *S. geminata* being absent from half of the plots. Each treatment was replicated four times. Treatments consisted of plots with 1) *Solenopsis*-absent and *Doru*-absent, 2) *Solenopsis*-absent and *Doru*-present, 3) *Solenopsis*-present and *Doru*-absent, and 4) *Solenopsis*-present and *Doru*- present. To measure the effects of the four treatments on phytophagous arthropods, destructive whole plant samples were taken weekly in all plots. Natural populations of *D. taeniatum*, *S. geminata*, aphids, whorlworm larvae, and *Listronotus* sp. were present in all plots soon after plant emergence. As previously reported for central Honduras, mean percent plants infested with whorlworm were greater in primera (80%) than postrera (37%). Numbers of whorlworms were nearly three larvae per plant in primera and only about one per plant in postrera. *Listronotus* sp. and *Agrotis* sp. occurred almost exclusively during postrera. Aphids were present during both growing seasons, but were never dense enough to cause economic damage.

Solenopsis geminata in *Solenopsis*-present plots averaged 2.44 ants per m^2 during primera, and 13.7 ants per m^2 during postrera. Numbers of fire ants in *Solenopsis*-present plots in both primera and postrera increased as the plants aged. A substantial increase in the postrera ant population occurred soon after the plots were cleared of plant debris from the primera plantings. Though *S. geminata* reportedly destroys sorghum seed in southern Honduras, it was not observed feeding on maize seeds after postrera planting despite high ant densities in the *Solenopsis*-present plots. Nests of *Solenopsis geminata* in primera were scarce and limited to plot borders, and densities of *S. geminata* varied greatly and never exceeded 6 ants per m^2. The scarcity of *S. geminata* may have been due to the studies being located on land that was in continuous cultivation during the previous several growing seasons.

Doru taeniatum densities in *Doru*-present plots averaged 0.04 earwigs per plant during the primera, and 0.18 during postrera. These densities did not significantly reduce densities of whorlworm or aphids when compared to densities in

Doru-absent plots. *Doru taeniatum* is naturally rare on early primera maize because the earwig is just coming out of a reproductive diapause on undisturbed weedy plants. To increase numbers of *Doru* in the *Doru*-present plots, 50 earwigs were released in each *Doru*-present plot during the second week of the study. The primera studies were on soil that was continuously cultivated during several previous growing seasons and was not densely populated by *S. geminata*; whereas, postrera studies were located on soil not previously cultivated and was densely populated by fire ants.

Solenopsis geminata and *D. taeniatum* did not consistently maintain whorlworm infestations at significantly lower densities in either primera or postrera maize. Postrera samples revealed neither a significant effect of *D. taeniatum* nor an interaction effect between *D. taeniatum* and *S. geminata* on densities of aphids or *Listronotus* sp. Numbers of whorlworm larvae per plant and percent plants infested with whorlworm were consistently greater in *Solenopsis*-absent than in *Solenopsis*-present plots. However, during the first four weeks after primera plant emergence, *S. geminata* at a mean minimum density of 10 ants per m^2 significantly reduced infestations of *S. frugiperda*. *Solenopsis geminata* in primera also significantly reduced seedling cutting by *Agrotis* sp., and reduced *Listronotus* sp. infestations during the third and fourth weeks after plant emergence. Being a ground predator, *S. geminata* caused greatest mortality to whorlworm and *Listronotus* sp. mortality during early crop stages when these prey were dispersing on the ground. As occurred in these studies, *D. taeniatum* typically colonizes primera crops as the season progresses. *Doru taeniatum* was also absent from all postrera plots until the third week of sampling, and earwig densities in the fourth week of sampling averaged only 0.38 per plant. The *Doru* that were present did not cause a significant reduction in whorlworms or aphids. The differences in percent postrera infestation and insect numbers in all *Doru*-present plots were due only to presence of *S. geminata*. Though *D. taeniatum* eventually occurred at a density of 0.18 earwigs per plant, it had no significant effect on densities of *S. frugiperda* or aphids. Neither *S. geminata* nor *D. taeniatum* adversely affected the abundance of parasites during primera or postrera.

Manipulating numbers of *Doru*. A second set of studies was conducted to examine prospects for manipulating densities of *D. taeniatum*. These studies sought to promote an increase in numbers of earwigs on plants in half of the plots by providing *D. taeniatum* with whorl-like paper refuges pinned to plants. Refuges were not provided on plants in the remaining plots. Effects studied included plant associations of *D. taeniatum*, and *D. taeniatum* abundance and location on plants. The study field contained 25 species of common Honduran weeds and was selected because of its weed abundance and diversity. Weeds present represented 12 plant families. On each sample occasion, plots were searched for earwigs for a total of 15 minutes. Results showed that numbers of *D. taeniatum* per unit area were increased by habitat manipulation. Provision of four refuges/m^2 resulted in a two fold increase in numbers of naturally occurring *D. taeniatum*. Earwig densities can apparently be managed, but success depends in part on the availability of suitable shelters. Artificial whorls were the most common refuges used by *D. taeniatum* in both gramineous and nongramineous plants. Apparently, the absence of such structures in nongramineous plants prevents *D. taeniatum* from occupying these plants. Paper refuges did not affect the seasonal naturally occurring 1:1 ratio of immatures to adults. Greater numbers of earwigs occurred on the plants as plants aged, and predation of whorlworm larvae by *D. taeniatum* also increased significantly as plants aged.

Publications and Presentations

Publications

Teetes, G. L., M. J. Scully, and G. C. Peterson. 1991. Partial Life table for corn earworm (Lepidoptera: Noctuidae) on compact- and loose-panicle sorghum hybrids. J. Econ. Entomol. (In press).

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Youm, O., F. E. Gilstrap and G. L. Teetes. 1990. Pesticides in traditional farming systems in West Africa. J. Agric. Entomol. 7: 171-181.

Peterson, G. C. and G. L. Teetes. 1991. Registration of 22 midge resistant sorghum germplasm lines. Crop Sci. 31: 498-499.

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Youm, O., F. E. Gilstrap, and H. W. Browning. 1990. Parasitism of stem borers (Lepidoptera: Pyralidae) associated with corn and sorghum in the lower Rio Grande Valley of Texas. J. Econ. Entomol. 83: 84-88.

Youm, O. and F. E. Gilstrap. 1990. A note on the bioecology of the millet stem borer, Coniesta (=Acigona) ignefusialis (Lepidoptera: Pyralidae) in Niger. Abstract. Proc. Entomol. Soc. Nigeria.

Gilstrap, F. E., and G. W. Brooks. 1991. Sorghum midge and midge parasitism on johnsongrass. Jour. Econ. Entomol. 84: 431-5.

Invited Presentations

Teetes, G. L. 1990. Insect Biotypes in Sorghum: The Challenge of Developing Resistance to Aphids. Entomological Society of America, Section F Symposium, The Challenge of Biotype to Insect Resistance in Cereals. New Orleans, LA.

Teetes, G. L. 1990. Integrated Pest Management. Licensed Pesticide Applicator Workshop, Texas Seed Trade Association. Dallas, TX.

Teetes, G. L. 1991. The development and use of insect resistant sorghums. 9th Biennial Conference on Plant Resistance to Insects: Toward a More Sustainable Agriculture, College Park, MD.

Teetes, G. L. 1990. The Role of Plant Resistance to Insects in IPM. Department of Entomology Seminar Series. College Station, TX.

Teetes, G. L. 1990. The Development and Use of Insect Resistant Sorghums in Integrated Management of Insect Pests. International Sorghum Conference, "Sorghum For The Future". Cali, Colombia.

Teetes, G. L. 1991. Sorghum Management Options to Reduce Insect Induced Stress. Seventeenth Biennial Grain Sorghum Research and Utilization Conference, "Directing the Decade." Lubbock, TX.

Teetes, G. L. 1991. Integrated Pest Management in Grain Sorghum. Texas Conservation Research Workshop. Temple, TX.

Gilstrap, F. E. 1991. Western Regional Coordinating Committee-66: "The Final Chapter for Russian Wheat Aphid Biological Control." Portland, OR.

Gilstrap, F. E. 1991. Biological Control Quarantine Workshop, "Routing and Customs Problems Importing Exotic Arthropods." Baltimore, MD

Gilstrap, F. E. 1991. Amarillo TAES Seminar Series, "Biological Control in Annual Crops." Amarillo, TX.

Gilstrap, F. E. 1991. North Carolina Strategies in the 90's Conference on Biological Control, "The Regional Impact and Use of Biological Control Facilities." Raleigh, NC.

Networking Activities

Research Investigator Exchanges

Fifteen LDC scientists visited the sorghum entomology program at Texas A&M University. Mrs. Niamoye Diarisso Yaro spent three months during the summer 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. A first draft of a results report was prepared and will be reported in next year's INTSORMIL annual report. This effort will likely result in Mrs. Yaro coming 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 an earlier section in this report, and is further described in the Mali Country report. A major effort is needed to get the Mali panicle-feeding bug research results published in a refereed journal.

Germplasm and Research Information Exchange

Seed requests were received from eight LDC scientists, and these were forwarded to Dr. Gary C. Peterson. Publication reprints or copies related to sorghum entomology were sent to 27 LDC scientists. Research supplies and equipment were sent to Mali to support on-site research activities. Material for cages, bags to cover panicles, insect-collecting supplies, insect-preservation supplies, computer software, and other research related supplies were provided.

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

Frank Gilstrap visited with collaborating scientists in Honduras to continue studies on biological control of fall armyworm on sorghum and maize in Honduras. Discussions showed that information on predation by tropical fire ant and earwig predator are essentially complete. This information is the product of work by previous M.S. students, R. Jones, R. Sequeira and L. Lastres. A decision was made to pursue the next step in this program, focusing on *Polybia*. *Polybia*, a complex of paper wasps, is the only unstudied predator of the three predator systems attacking fall armyworm in Central America. Gilstrap met and visited with two students at Escuela Agricola Panamericana, and will provide short term training to one of these students in the spring of 1992. The training will consist of a 2-3 month period during which the student will work in the Gilstrap laboratory. This training is a prelude to the student being admitted to Texas A&M University in the fall of 1992 to pursue a Master of Science degree. The student's graduate research will be conducted in Honduras, probably beginning in the spring of 1993.

Frank Gilstrap visited Niger in the fall of 1990, and began developing a work plan to continue the research of Dr. Ousmane Youm on biological control of millet head caterpillar (MHC) and millet stem borers. The visit resulted in a proposal to INTSORMIL for additional funding to support a greater collaborative effort in Niger and Mali. The proposal seeks to place a Ph.D. graduate student from Niger or Mali in the graduate training program at Texas A&M University. A work plan for the collaborative research on MHC was developed by Gilstrap and Dr. Youm (ICRISAT-Sadhore) and consists of four objectives.

OBJECTIVE #1: Determine the bionomics (= field biology) of the MHC at key locations in Niger. Activities will include taking samples of the MHC from fields of millet production and from noncultivated *Pennisetum* spp. Several kinds of samples will be taken, and will include 1) removal of MHC immature stages that are part of naturally occurring field populations of MHC, and 2) field exposure of MHC immature stages that were produced in the laboratory. Data recorded from samples will be used to construct life tables and survival budgets. These will be used for estimating the importance of MHC and its respective natural enemies in key regions of Niger. Samples will include data needed to estimate crop losses due to MHC damage.

OBJECTIVE #2: Identify and evaluate the natural enemies of MHC. Natural enemies identified in samples of Objective 1 will be the basis for this objective. Selected natural enemies will be cultured, and information sought from these cultures will include host stage attacked, host response to parasitization, adult enemy behavior and nutritional requirements, enemy immature developmental biology and enemy population growth estimates in response to selected environments (e.g., photoperiod and temperature). These studies will provide a basis for rearing procedures needed for Objective 3, and for using selected species of natural enemies in field efficacy studies of Objective 4.

OBJECTIVE #3: Develop laboratory rearing procedures for producing MHC and one or more of its natural enemies. This objective seeks to optimize rearing procedures to produce the natural enemies selected out of Objective 2 for further testing in Objective 4.

OBJECTIVE #4: Evaluate tactics for implementing biological controls of MHC, and establish procedures for delivering these to small farms in the sub-Sahel. Objective 4 will field test the impact of biological control tactics applied to fields on small farms. These studies will examine the costs and impact of several strategies for controlling field populations of MHC. Studies will use natural populations of MHC, and artificially increased populations. Control tactics for testing are 1) improving field survival of naturally occurring populations of natural enemies (= biological control by enemy conservation), and 2) augmenting naturally occurring natural enemy populations with additional laboratory produced natural enemies (= biological control by augmentation). The former tactic optimizes availability of essential

requisites needed to target natural enemies, and the latter optimizes a target natural enemy's population response to MHC.

A second proposal and work plan was developed in 1991 to provide short term training to a Nigerian employed by INRAN. This plan has been submitted to INRAN for approval and action. If approved, the trainee is to arrive at Texas A&M University in January or February of 1992. The training seeks to prepare a continuing INRAN collaborator to work with Drs. Gilstrap and Youm on biological control of millet stem borers.

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

Project TAM-128

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Summary

A chytrid parasitic to oospores of *Peronosclerospora sorghi* reduced incidence of sorghum downy mildew in field microplots and was detectable in soil after one year. Taxonomic studies identified the chytrid as *Gaertneriomyces semiglobiferum*. Isolates of *Fusarium* spp. section Liseola were predominantly of the A mating group on corn and A and F on sorghum as determined by standard tester isolates from other geographical locations. Successful intercrossing among local isolates of each mating group demonstrated the ability of local populations of section Liseola to maintain variability through sexual recombination. Eleven species of *Fusarium* were isolated from sorghum and pearl millet grain collected in Zambia, Zimbabwe, and Botswana. Predominant species were *F. chlamydosporum, F. equiseti, F. moniliforme*, and *F. semitectum*. Not all species occurred on both pearl millet and sorghum but *F. equiseti* was isolated from 90% of the samples from both hosts and *F. semitectum* from 60 and 75% of host samples, respectively.

Objectives

Characterize *Macrophomina phaseolina* from diverse hosts in Southern Africa.

Determine stability and sources of resistance to foliar diseases through use of field nursery evaluations.

Host:pathogen interaction of *Exserohilum turcicum* on sorghum cultivars with specific and general leaf disease resistance.

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

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.

Develop a race (pathotype) typing system for isolates of *Colletotrichum graminicola* from sorghum using RFLP analysis or related biotechnology.

Develop and deploy germplasm nurseries and germplasm screening for major diseases in the SADCC region.

Research Approach and Project Output

Characterization of Macrophomina phaseolina

Pure culture isolates of *M. phaseolina* were obtained from all host specimens collected in 1990 from gramineous (sorghum and pearl millet) hosts at Lusitu, Zambia and from gramineous (sorghum, pearl millet, and corn) and non-gramineous (sunflower, cowpea, peanut, and sesame) hosts at Sebele, Botswana. Isolates are being evaluated for host preference differences similar to those reported in U.S. isolates obtained primarily from corn and soybeans. Host preference differences are correlated with observed differences in ability to grow on potassium chlorate amended media. Our initial results with a small number of isolates collected in 1988 had indicated a differential growth response between isolates from gramineous and nongramineous hosts; however, repeated tests with those isolates, known standard isolates and selected isolates from the 1990 collection produced variable results indicating a need to refine and stabilize the cultural evaluation techniques.

Foliar Disease Resistance in Nursery Evaluations

Additional candidates for anthracnose screening in Southern Africa were identified in U.S. nurseries through collaboration with TAM-121, TAM-122, and TAM-124. Many have genetic relationship to sorghums (TX434, BTX631, SC326-6, SC414-14E, BTX378, SC748-5) previously displaying good adaptability and excellent resistance to anthracnose and other diseases at several locations in the SADCC region.

Exserohilum turcicum general and specific resistance

Return of E. Mtisi to Zimbabwe and the resignation of W. deMilliano have necessitated a revision of this objective to begin in 1992 with an increased field research approach in Zimbabwe.

Biological Control of Sorghum Downy Mildew(SDM)

I.S. Kunene completed her dissertation research on biological control of SDM using the chytrid, *Gaertneriomyces semiglobiferum*. She demonstrated in field microplot studies that the chytrid parasitized soilborne oospores, which reduced both soilborne inoculum and subsequent SDM in corn and sorghum planted into that soil. She determined that the chytrid could survive in detectable levels in the soil for up to one year after application. Using ultrastructure of the zoospore, morphology, nutrition, and development, she was able to identify the previously unclassified *Gaertneriomyces* spp. and the species *semiglobiferum*.

Identification and Characterization of Fusarium Species on Sorghum and Millet in the SADCC Region

A. Mansuetus traveled to Tanzania in June 1991 and collected sorghum and pearl millet specimens from nurseries in Ilonga and Ifakara and from local sorghums at Bukiriro/Kachiri. *Fusarium* species, including prominent grain mold fusaria (*Fusarium* spp. section Liseola), are being isolated from the specimens for identification and characterization through sexual crossing and vegetative compatibility group studies.

In related studies in south Texas, A.S. Ring showed that mating group A (*F. moniliforme*, pink) predominated on corn, and groups A and F (*F.moniliforme*, yellow) predominated on sorghum. All *Fusarium* species were low on cotton. The yellow *F. moniliforme* is widespread, occurs predominantly on sorghum, and may be a new species that is being described by J. Leslie of KSU-108. Initial characterization to mating group and type (+ or -) was done with standards provided by J. Leslie; this facilitated intercrossing of local isolates and further established the ability of the local population to sexually recombine.

P. Nelson completed final identification of *Fusarium* species isolated from sorghum and pearl millet grain collected in Zambia, Zimbabwe, and Botswana in 1989. Eleven *Fusarium* species were identified but those most predominantly isolated (of a total 71 isolates selected for identification) were *F. chlamydosporum* (11), *F. equiseti* (21), *F. moniliforme* (9), and *F. semitectum* (16). Numbers of *Fusarium* species isolated from each seed sample ranged from zero to five for pearl millet and one to seven for sorghum. Not all species occurred on both pearl millet and sorghum but *F. equiseti* occurred on 90% of samples from both hosts and *F. semitectum* on 60 and 75% of host samples, respectively.

Anthracnose

P. Guthrie, working with TAM-124 and TAM-128, has utilized RAPD (Random Amplified Polymorphic DNA) technology to characterize isolates of *Colletotrichum graminicola* collected from infected sorghum at diverse global locations. Analysis of the data from 15 isolates shows that there is genetic homology among isolates from specific geographic regions that distinguish them from those of other regions. But some regions (e.g., Puerto Rico) had more DNA homology among their isolate group than other regions which may be due to geographic isolation. See TAM-124 report for details.

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Invited Presentations

Odvody, G.N. 1991. Seed treatment to reduce disease. Oral presentation given during Discussion Session: Production Practices for Control of Seedborne Diseases, August 21, 1991 at national meetings of the American Phytopathological Society, August 17-21, 1991, St. Louis, MO.

Networking

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

Sustainable Production Systems

Modelling Millet and Sorghum Establishment and Growth and Sustainable Crop Production

Project KSU-106
Richard L. Vanderlip
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Summary

Consistent differences in kernel weights among sections of the sorghum panicle were found. Seed weights were highest at the tip of the panicle and progressively decreased to the base. These differences were due to differences in fill rate, not duration of fill. These trends were found irrespective of kernel numbers within each segment. These data suggest that within-head compensation cannot completely remove differences in growing conditions during the grain fill period. Causes for the differences in grain fill rates need to be determined.

Tiller number in eight widely different genotypes was linear early related to daily growth rate. The relationship varied among cultivars at low (20/15°C) day/night temperatures and at high (30/25°C) temperatures. No differences among cultivars were found at an intermediate (25/20°C) temperature. These results can partially explain differences in cultivar performance across planting dates and location where temperatures are likely to be different. Responses are of utmost importance in determining the compensatory ability of sorghum at low plant populations under relatively good growing conditions.

Objectives, Production and Utilization Constraints

Objectives

1. Determine the characteristics of yield components which allow sorghum to compensate for stress.

2. Determine under controlled and field conditions the interactions of tillering and environmental factors.

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.

Project Output

Current work at KSU is primarily aimed at strengthening the modeling of sorghum and pearl millet by both field and controlled environment studies.

Objective 1. Determine the characteristics of yield components which allow sorghum to compensate for stress.

Kernel weight is an important yield component of grain sorghum. The sorghum plant adjusts kernel weights to compensate for changes in the environment which occur late in the growing season. This mechanism of compensation is

particularly important in climates where rainfall is unreliable. The factors which influence kernel weight patterns within the panicle can provide important clues to the plant processes which determine final kernel weights. Intrapanicle kernel weights and the factors which influence these weights need to be investigated. Our objectives were to determine the pattern of kernel weights found in hybrid grain sorghums, to see if there are differences in kernel weight patterns between a closed panicle hybrid and an open panicle hybrid, and to determine whether the intrapanicle kernel weight relationships observed are the result of the rate of grain fill and/or the length of the grain fill period.

Approach

A dryland field study was conducted at Manhattan, Kansas to investigate intrapanicle kernel weight relationships for two sorghum hybrids: DeKalb DK 46, an open panicle hybrid, and Pioneer 8500, a closed panicle hybrid. The experiment was designed as a split-split plot with hybrids as main plots blocked over three bloom dates. Subplots consisted of harvest dates with sub-subplots of panicle sections. Hybrids were planted on 25 May in rows 12.2 m long and 0.76 m wide. Plots were thinned to 123,000 plants per hectare.

At first bloom, 200 panicles from either DeKalb DK 46 or Pioneer 8500 were randomly selected and tagged. This process was repeated on alternating days, first for 8500 and then for DK 46, for a total of three bloom dates for each hybrid (Table 1). Starting six days after the last group of heads were tagged, 10 panicles from each of the six bloom dates were harvested twice weekly. Sampling continued over a period of 6.5 weeks for a total of 13 harvests.

Table 1. Dates of first bloom and tagging for the hybrids tested.

Hybrid	DeKalb DK 46	Pioneer 8500
Block	Date of first anthesis	
Group 1	August 1	July 31
Group 2	August 3	August 2
Group 3	August 5	August 4

Heads from these samples were split into four equal sections by removing the branches from the rachis based upon the number of whorls present. Two whorls each went into the base, lower middle, and upper middle sections with the remaining whorls being placed in the apical section. Each section was hand threshed. Kernels were counted, dried at 65°C for at least two days, and weighed. Individual kernel weights were determined by dividing section weight by the total number of kernels within the section. Kernel weights and numbers for hybrids and for individual panicle sections were compared using analyses of variance.

Rates of grain fill and the length of the fill period were compared using regression analysis. Least squares, linear regression equations were fit to kernel weight as a function of growing degree days using a base of 5.7°C. For each hybrid and panicle section, regression equations were calculated using harvests containing kernel weights between 10% and 90% of final kernel weight. We defined the effective fill period (EFP) as beginning at the X intercept of the regression equation and ending when kernel weights reached 90% of the maximum weights observed. T-tests were used to determine differences in slopes (rate of grain fill) between hybrids and among panicle sections. The length of the EFP was calculated for each bloom date by hybrid by panicle section combination. The effective fill periods were compared between hybrids and among panicle sections using analysis of variance.

Results

Analyses of variance showed a hybrid by section interaction for both kernel weight and kernel number. Kernel weights were heaviest in the apical sections of both hybrids when compared to the base or middle sections. The middle sections of both hybrids were significantly heavier than the base sections, however, the two middle sections were not significantly different from each other. There were significant differences between the corresponding sections of the two hybrids. The lower middle and basal sections of DeKalb DK 46 were heavier than the same sections of Pioneer 8500. Conversely, the apical section of the Pioneer hybrid was heavier than that of DK 46 (Fig. 1). In both hybrids kernel weights increased from the base to the apex.

Figure 1. Comparison of seed weights for each of the four sections of DeKalb DK 46 and Pioneer 8500. Means with different letters are significant at p<.05.

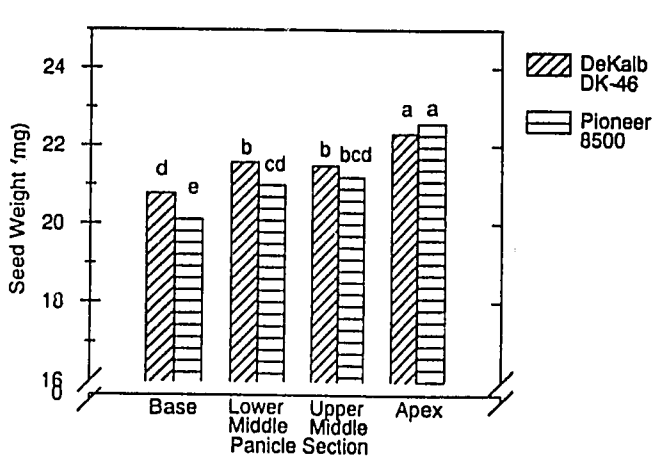


Figure 2. Comparison of seed numbers for each of the four sections of DeKalb DK 46 and Pioneer 8500.

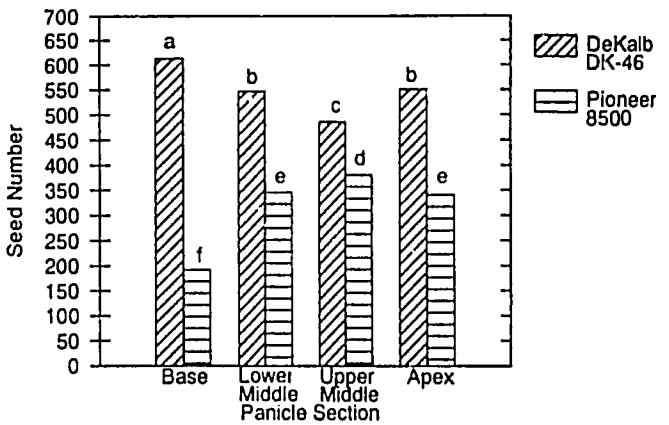
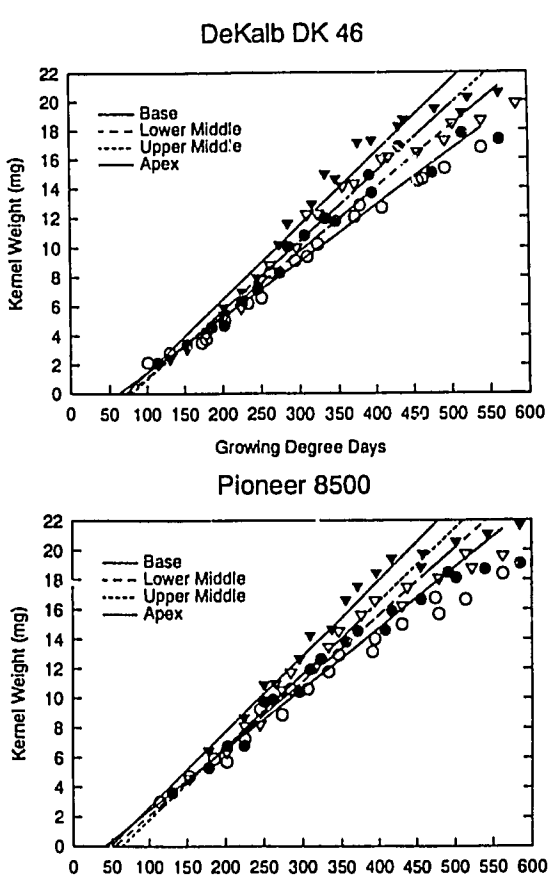


Figure 3. Rates of fill for the different panicle sections of DeKalb DK 46 and Pioneer 8500 as a function of GDD.



Kernel numbers were significantly greater in the upper middle sections of Pioneer 8500 than in the remaining sections. The lower middle and apical sections did not differ, but had more kernels than did the base section. In contrast, DeKalb DK 46 had the most kernels in the base section. The lower middle and apical sections did not differ but had more kernels than the upper middle section. DK 46 had significantly greater kernel numbers in each section of the panicle when compared to Pioneer 8500 (Fig. 2). It should be noted that the two hybrids had nearly opposite patterns of kernel numbers within the panicle.

Comparisons of slopes (rates of fill) among panicle sections using the t-test showed significant differences with the rates increasing from the base to the apex of the panicle. Within DK 46, rates of fill went from a low of 0.038 mg GDD^{-1} at the base section to 0.050 mg GDD^{-1} at the apex. All panicle sections within DK 46 showed significant differences in rates of fill at $p<0.1$. Within Pioneer 8500, rates of fill ranged from 0.041 mg GDD^{-1} at the base to 0.051 mg GDD^{-1} at the apex. All sections showed differences with the exception of the two middle sections and the apical and upper middle sections (Fig. 3). Between hybrids, Pioneer 8500 had a significantly higher rate of fill (0.040 mg GDD^{-1}) than DeKalb DK 46 (0.046 mg GDD^{-1}).

Analysis of variance for effective fill periods found significant differences between hybrids and among panicle sections. In both hybrids the base section had a significantly longer EFP than any of the remaining panicle sections. Between hybrids DeKalb DK 46 had a longer EFP than Pioneer 8500 (Table 2).

Table 2. Length of the EFP for individual panicle sections and hybrids.

Section	Hybrid: DeKalb DK 46	Hybrid: Pioneer 8500
	Length of the EFP period	
	GDD	GDD
Apex	402 a	384 ab
Upper middle	412 a	375 b
Lower middle	442 a	402 ab
Base	490 b	426 b
Total panicle	437	397

Means in the same column followed by the same letter are not significantly different at $p<.05$.

Discussion

In both the open panicle hybrid, DeKalb DK 46, and the closed panicle hybrid, Pioneer 8500, kernel weights increased from the base to the apex. This intrapanicle kernel weight relationship is not the result of kernel numbers within the panicle. Kernel numbers do not appear to influence the kernel weight relationship within the panicle. Differences in intrapanicle kernel weights are the result of the increased rate of grain fill from the base to the apex. In DK 46 there was a 25% increase from the base to the apex, while within panicles of Pioneer 8500 there was a 20% increase. The

length of the fill period did not change significantly among most panicle sections. Where differences were detected the base section always had the longest EFP.

There were no differences in kernel weights between the two hybrids. While Pioneer 8500 had a significantly higher rate of grain fill, DeKalb DK 46 had a longer EFP. The final yield of DK 46 was greater than that of Pioneer 8500, since DeKalb DK 46 had more kernels.

Objective 2. Determine under controlled and field conditions the interactions of tillering and environmental factors.

Tillering in grain sorghum provides the crop with the ability to compensate for poor stand establishment caused by adverse environmental factors (soil crusting, moisture stress, high temperature, diseases, insects, etc.), and this may prevent subsequent yield loss.

Genotypic variability in tiller production has been reported over a range of environmental conditions. Temperatures greatly influence tillering in sorghum. Recent studies on modelling sorghum growth and development suggest that the minimum dry matter accumulation rate required to maintain tiller growth depends upon cultivar and daily minimum air temperature

Our objectives were the following:

1. Determine the relationship between grain sorghum growth rate and tiller number for a range of temperate and tropical cultivars.

2. Determine the effect of temperature on these relationships.

3. To use field data to validate the established relationships.

Approach

Growth Chamber

Eight cultivars (Table 3) were grown in a growth chamber from seven days after emergence to growing point differentiation, at Manhattan, Kansas. Per plant dry matter was determined at the beginning of the growing period and dry matter and tiller number at the end.

Table 3. Cultivars used in the growth chamber and field experiments.

Brand	Cultivar	Adaptation	Maturity
DeKalb	DK 39Y	Temperate	Early
DeKalb	DK 46	Temperate	Late
DeKalb	DK 57	Tropical	Early
Pioneer	8500	Temperate	Early
	RS610	Temperate	Early
	ATx623XRTx430	Tropical	Late
	Segaolane	Tropical	Late
	CSM63	Tropical	Late

Temperature regimes were 20/15, 25/20, and 30/25°C, day/night. Combinations of light intensity, plant density, and nitrogen level were used to influence dry matter accumulation rate.

Growth rate was computed from initial and final plant weight. Daily growth rate was regressed on number of tillers to determine slopes which represent the daily assimilate flux required to maintain each tiller. Individual and combined regression analyses were performed to compare cultivars within a temperature regime. Assimilate flux required (slope) was regressed on daily minimum air temperature to determine the effect of temperature on tillering for each cultivar.

Field Environment

The field study was designed to provide a range of tillering responses and serve as validation data for the relationships obtained under controlled environments. The eight cultivars (as above), two planting dates (mid-May, early planting and mid-June, late planting) and three plant populations, (40,000, 80,000, 160,000 plants per hectare) were used to create growth environments that should influence sorghum growth and development, particularly tiller production. The experiment was conducted at two locations: Manhattan and St. John, Kansas. The design was a split-split plot with dates as main plots, densities as subplots, and cultivars as sub-subplots.

Results

Tiller number increased as growth rate increased. Regression analyses indicated a strong positive linear relationship ($R^2 > 0.70$) between dry matter accumulation rate and tiller number for most cultivars within each temperature regime (Table 4).

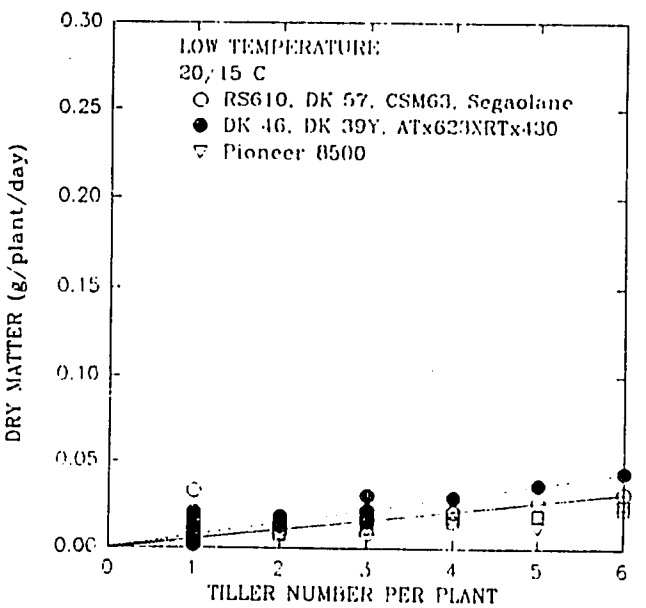
Dry matter required per growing point varied among cultivars at low temperature, 20/15°C (Fig. 4) and at high, 30/25°C (Fig. 6) temperature ($P<0.01$). No differences were found among cultivars at the intermediate temperature, 25/20°C (Fig. 5). Pioneer 8500 required the lowest amount of dry matter per tiller at the low temperature, while at the high temperature, CSM63 had the lowest requirement. At both temperatures ATx623XRTx430 was associated with the highest requirement. Requirement per tiller was not related to temperate or tropical adaptation ($P>0.05$).

Daily dry matter accumulation rate required per growing point increased as daily minimum air temperature increased. Although each cultivar showed a linear relationship between the requirement per tiller and the daily minimum air temperature ($R^2 > 0.75$), no significant differences in temperature response were found among cultivars. Combined response for all cultivars is shown in Figure 7.

Table 4. Slopes of the linear relationship between growth rate and tiller number at three day/night temperature regimes.

	20/15 C		25/20 C		30/15 C	
Cultivar	Slope	R^2	Slope	R^2	Slope	R^2
Pioneer 8500	0.0038 d	0.80	0.026	0.85	0.072 c	0.87
RS610	0.0058 c	0.47	0.034	0.93	0.081 bc	0.91
DK 46	0.0068 b	0.92	0.017	0.72	0.076 c	0.95
DK 39Y	0.0073 ab	0.83	0.024	0.95	0.062 c	0.87
DK57	0.0055 c	0.93	0.003	0.14	0.080 bc	0.48
CSM 63	0.0048 c	0.91	0.025	0.85	0.049 d	0.80
ATx623XRTx430	0.0076 a	0.86	0.025	0.95	0.091 ab	0.78
Segaolane	0.0050 c	0.86	0.024	0.85	0.097 a	0.84
			ns			

Figure 4. Combined regression analysis of growth rate and tiller number for cultivars of similar requirements.



The requirement per growing point was greatly increased at high temperature. However, a cultivar that produces less dry matter, regardless of temperature, will bear relatively fewer tillers. This can partially explain differences in cultivar performance across planting dates and location latitude and altitude which influence temperature.

Field results showed variation in tillering due to cultivar, plant population and date of planting with interaction among all factors. Date of planting which influences temperature had a significant interaction with cultivar at both locations ($P < 0.05$). At both locations, CSM63 and Pioneer 8500 produced the highest number of tillers, while RS610 was associated with fewer tillers. Although cultivars had differential responses to dates, tillers per plant diminished as planting date was delayed. Figures 8 and 9 show the comparison for all the cultivars across dates. These variations in tillering will be used as validation data for cultivar specific tillering coefficients obtained from the controlled environments.

Publications and Presentations

Mortlock, M. Y. Soil temperatures recorded at Sebele and Etsha six in the 1986/87 planting season. The Bulletin of Agricultural Research in Botswana 7:25-35.

Mortlock, M.Y., and R.L. Vanderlip. Germination and seedling establishment of pearl millet in Botswana. Twenty-first Anniversary Crop Production Congress, Crop Science Society of Zimbabwe, Harare, Zimbabwe, 1991.

Networking Activities

Only by long-distance as R. L. Vanderlip was on sabbatical.

Figure 5. Combined regression analysis growth rate and tiller number.

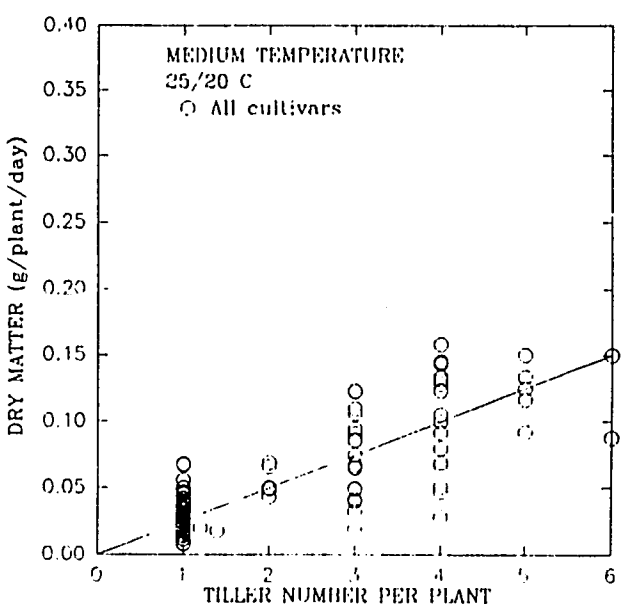


Figure 6. Combined regression analysis of growth rate and tiller number for cultivars of similar requirements.

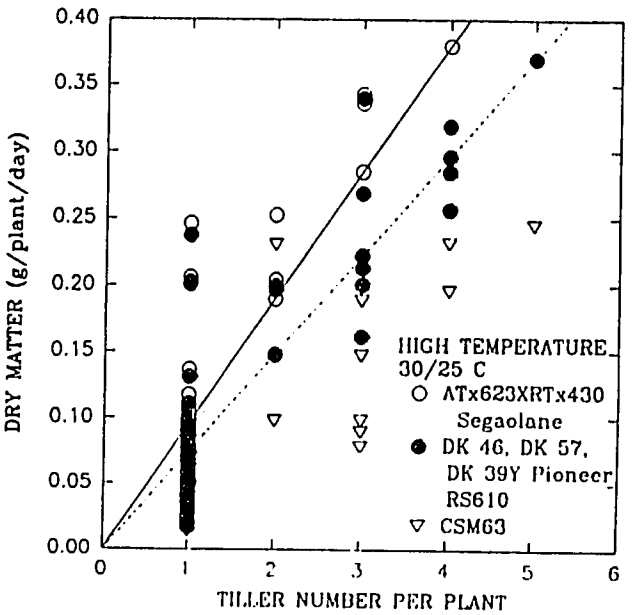


Figure 7. Relationship between dry matter required per tiller and daily minimum air temperature.

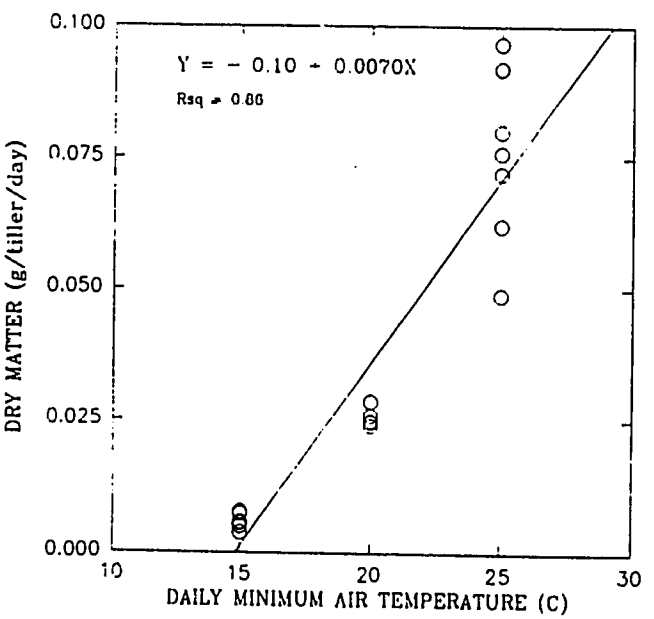


Figure 8. Sorghum tillering as affected by cultivar by date interaction, Manhattan, KS, 1990.

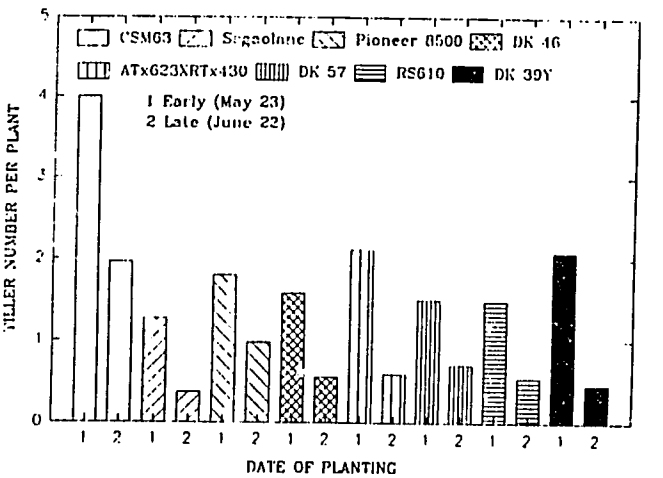
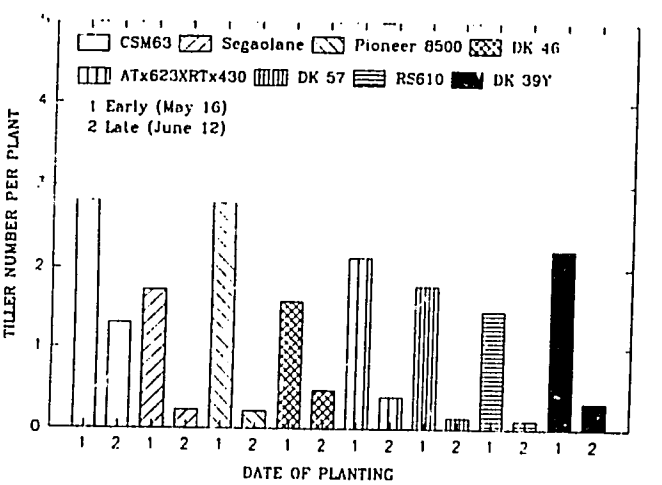


Figure 9. Sorghum tillering as affected by cultivar by date interaction, St. John, KS, 1990.



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

Project KSU-107
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Summary

Since 1983 INTSORMIL has participated in collaborative studies with Botswana's agricultural research scientists in their efforts to develop improved soil and crop management technology for dryland sorghum and millet production. In designing these studies, Botswana and INTSORMIL scientists recognized the need for practical and sustainable technologies to deal effectively with the twin primary constraints of soil-moisture and soil-fertility deficits. USAID/Botswana and the Ministry of Agriculture are supporting these efforts both financially and logistically.

Multilocational on-station and on-farm trials at nine sites were carried out during Year 12. 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 did not interact at any 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 showed significant response to P when the initial soil P levels by Bray 2, the standard laboratory method, were less than 10 mg/kg. A significant response to N was obtained only where rainfall was well distributed throughout the season.

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 12 objectives covered in this report were:

To evaluate, for various soils and for different rainfall conditions, the effect of several tillage practices, with and without fertilizer, on dryland sorghum production.

To evaluate the relative merits of animal versus tractor draught for tillage operations for dryland sorghum production.

To develop fertilizer response curves for dryland sorghum from field trials and to determine economically optimal fertilizer recommendations.

Constraints

Most of the cereal production in Botswana comes from traditional, smallholder, 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. Kraal manure, fertilizers, pest control, crop rotations, and crop residues are rarely used.

Most arable soils of Botswana fall into the FAO units arenosols and luvisols. They are relatively infertile. The arenosols have a relatively high sand content and are texturally classified as either sands, loamy sands, or sandy loams. The texture of luvisols can vary from sandy to clayey loams. These soils are "hard-setting", i.e, they are structureless and become compact, dense, and hard when dry. Their surface structure is unstable resulting in surface sealing and crust formation. Many of these arable soils are shallow, have a low moisture retention capacity, and are weakly developed. Soil moisture deficits are frequent because rainfall is low and unreliable over most of the country. All assessments of these soils agree that they are marginal for arable farming.

The single-furrow mouldboard plough is the primary tillage implement used by most Botswana farmers. Ploughing in of broadcast seed is the most prevalent planting method used in about 80-90% of the cropped area. Relatively few farmers row plant their crops. It takes about two to three days working about four to five hours per day to plough/plant a hectare with animal draught. Farmers therefore plough/plant their fields progressively in portions during the growing season whenever there is adequate rainfall, and whenever draught animals and time are available, until the entire field is planted. These tillage operations are the most costly inputs for dryland crop production in Botswana.

Tillage practices that can reduce soil and water losses compared to the traditional or conventional tillage methods used for dryland crops in Botswana have not been comprehensively evaluated. Previous tillage studies were done at the Sebele Research Station except for some trials initiated in 1978 on Kalahari sands at Motopi. No attempt was made to evaluate tillage systems and practices across soil types. Efforts were focused on comparing primary tillage using various implements with and without surface residues. Measurements were made of tillage and its residual effects on soil physical properties. In its entirety, this tillage research was oriented more towards engineering aspects of tillage than towards production agronomy and soil and water conservation. Much valuable information resulted; however, no definite and acceptable recommendations resulted that matched improved tillage practices to soil and crop needs and the environmental, economic, and social conditions of the farming systems in Botswana.

Currently farmers receive state subsidies through the Arable Lands Development Programme only for animal draught for tillage operations. Studies on the performance of various tillage practices implemented with animal draught are needed to enable ALDEP to effectively direct its assistance to the smallholder farmers in Botswana. Specifically, ALDEP needs to assess whether there is a significant economic advantage between animal versus tractor draught tillage operations. In addition, from a soil conservation perspective there may be longterm effects of tractor and animal draught on soil physical properties and productivity.

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. Previous fertilizer trials did not provide sufficient data to produce response curves for various soil types. More recent fertilizer studies have not shown significant response to applied P and N in inherently deficient soils when there was soil moisture stress and poor rainfall distribution. These results indicated a need for tillage research to include study of the interrelationships between tillage system and soil fertility and how these affect crop growth and crop yields. Parallel studies on soil fertility and its management are also needed to complement those on soil moisture conservation tillage for the following reasons:

The benefits of improved tillage practices can be more fully realized if soil fertility is not limiting production.

In semiarid climates a careful balance between soil moisture availability and soil fertility is needed because over-fertilization can result in profuse vegetative growth and thus induce moisture stress.

Research Approach and Project Output

INTSORMIL in close collaboration with scientists of the Department of Agricultural Research and the Department 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. Evaluation of tractor-implemented tillage systems with and without fertilizer.

E2. Evaluation of animal-implemented tillage systems.

E3. Development of fertilizer response curves from field trials to determine economically optimal fertilizer recommendations.

There were nine sites coded as follows: Mathangwane: F1 and F2, Mahalapye: M3 and M4, Sebele: S1, Palapye: M5, Tswidi: P2, Mushopa: P3, and Sese: J1. The locations of the three experiments on the nine sites were as follows:

	Sites								
Experiment	F1	F2	S1	M3	M4	M5	P2	P3	J1
E1	x	x	x	x	x	x	x	x	x
E2		x	x				x	x	
E3							x	x	x

The E1 trials were laid out in split plots in randomized complete blocks. At least two replications were laid out. Where space, time, and equipment permitted, third and fourth replications were added.

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 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 5 kg/ha followed by single mouldboard ploughing to 10-15 cm depth. This is the traditional method.

The main plot size was 40 x 15 m. To compare these treatments with and without fertilizer each main plot was split lengthwise and commercially available fertilizer 2:3:2 applied to one half of each plot. Fertilizer was banded at planting at a specified rate per linear metre of row, except for the deep ripping treatment, T3, where it was applied at various depths in the riplines at time of ripping, and for the broadcast/plough treatment, T6, where it was broadcast before ploughing.

Treatments for trial E2 were the same as T1, T2, T3, T4, and T6 for E1 but using animal draught implements. The deep ripping in trial E2 was done with chisels and was designated as T3 : precision chisel ploughing. Chiselling was done using a two-tined chisel plough drawn by an oxen or donkey team, to a depth of 25-35 cm on 150 cm centres at the onset of the early spring rains. This was followed by weed control between the chiselled strips. The crop was later row planted on the chiselled lines to obtain 20,000 plant/ha +/- 10%.

Plot size was 40 x 10.5 m. At F2, the tillage treatments were evaluated with and without fertilizers in the same manner as described for trial E1.

In the E3 fertilizer trials, nitrogen (N) x phosphate (P) factorial trials were carried out at three sites namely P2, P3, and J1. At each site 20 samples were taken evenly distributed over the field to detect any heterogeneity. Suitable locations for the experimental plots were then selected.

The same treatments were applied at all sites for the N x P trials, namely 0, 20, 40, 60 kg/ha N as lime ammonium nitrate (LAN) and 0, 10, 20, 40, 80 kg/ha P as single superphosphate (SSP). The treatments were combined factorially then replicated twice, giving 40 plots per site. In applying the treatments, the plots were ploughed then the fertilizer broadcast and disced in. The seed was then row planted to give 50,000 plants/ha. The plots 10 x 10 m. were laid out in randomized complete blocks.

Crop measurements for E1 and E2 were taken on ten 2m x 2m quadrats systematically sampled in the centre rows of each plot or subplot. Plant counts were taken at 3-4 weeks after emergence to assist in thinning, if needed, to the required plant population. At harvest, after threshing and recording the weight of threshed grain, samples were taken for determination of moisture content. An average head weight was calculated and this was used to adjust the yield from the quadrats, if necessary, for heads already harvested by the farmers, immature, or grazed heads. The moisture content was then used to calculate the adjusted grain yield at 10% moisture.

For E3, a 6 m x 6 m quadrat was sampled in the centre of each plot. All mature ready-for-harvest heads in the quadrat were then harvested. Moisture content of the grain from each plot was measured and used to express the grain yield as dry matter.

Field operations were done as the rainfall and other logistical factors permitted. All trials except those at M3 and M4 were planted prior to the end of December. At these sites planting took place in late January. Care was taken to ensure the operations at the nine sites were standardized.

At each site, two plastic rain gauges were appropriately installed and daily rainfall recorded. Table 1 summarizes the rainfall at the nine sites. It is notable that all sites received substantially below-average seasonal rainfall. Sites F1, F2, and S1 recorded approximately 100 mm below average. Others were 150 to 250 mm below average. Only two sites received more than 225 mm in the period between planting and physiological maturity. For Segaolane, the sorghum variety used in all the trials, this period varies from 100 to 130 days. All sites recorded a prolonged dry spell in the December/January period when temperatures and evaporative demand were at their maximum.

Table 2 presents the results for the effect of the six tillage treatments on grain yields for trial E1 at the nine sites. In these tables overall treatment means across the sites are reported including and excluding site F2. This was done because the crop in several treatments at F2 almost failed,

Table 1. Rainfall data summarized for the nine sites used for the trials E1 and E2.

	Site								
	F1	F2	S1	M3	M4	M5	P2	P3	J1
Rainfall[1]	360.0	369.0	433.0	271.5	270.5	309.0	328.5	394.5	267.0
Raindays	32	33	50	29	27	27	23	31	30
No. >10 mm	14	14	19	12	8	11	14	12	8
Mean depth	11.3	11.2	8.7	9.4	10.0	11.4	14.3	12.7	8.9
Ratio [2]x100	17.6	18.1	23.6	13.7	12.7	12.7	15.2	14.6	16.5
				Trial E1					
DEP to DOP									
Rainfall	116.5	158.5	30.0	58.0	56.0	92.0	75.0	16.5	49.0
Days	22	42	11	68	69	38	34	8	25
Raindays	7	12	3	6	7	5	6	2	5
DOP to DOP+100									
Rainfall	173.5	148	245	167	158.5	139	165.5	238.5	160.5
Raindays	18	15	26	18	14	16	12	17	17
DOP to DOP+130									
Rainfall	209.5	175.0	286.0	168.5	160.5	186.0	165.5	289.0	214.0
Raindays	23	18	37	19	15	19	12	21	24
				Trial E2					
DEP to DOP									
Rainfall	—	118.5	21.0	—	—	—	55.0	82.0	41.5
Days	—	21	12	—	—	—	33	23	36
Raindays	—	7	2	—	—	—	5	8	5
DOP to DOP+100									
Rainfall	—	176.5	251.0	—	—	—	165.5	185.5	167.0
Raindays	—	18	27	—	—	—	12	13	18
DOP to DOP+130									
Rainfall	—	215.0	286.0	—	—	—	165.5	241.5	172.5
Raindays	—	23	37	—	—	—	12	17	19

[1] Records F1, F2, J1 from October to March/ Records M3, M4, M5, S1 from October to April / Records P2 from November to March, P3 from November to May.
[2] Ratio = number of raindays divided by total days in period of record.
Note: DEP = date of early ploughing, DOP = date of planting.

due to poor crop establishment and stands, and the yields were very low compared to the other sites. It was considered useful to present both means in interpreting the results. The ranking in ascending order of the overall site mean yields were as follows:

1	2	3	4	5	6
F2,+f	F2,-f	J1,-f	M4,-f	F1,-f	M5,-f
7	8	9	10	11	12
F1,+f	M4,+f	P3,-f	M5,+f	J1,+f	P2,-f
13	14	15	16	17	18
P3,+f	S1,+f	M3,+f	M3,-f	S1,-f	P2,+f

From the results in Table 2 the following trends are apparent:

Overall yields of sorghum grain from the sites were three to five times the national average even in a year with less than average rainfall.

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

Tillage and fertilizer did not interact at any of the sites, indicating that their effects tended to be independent of each other.

A positive impact from early primary inversion tillage obtained in the previous year's trials was not as marked in these results. At F1 the yields from T2, the double plough, and T4, the plough + cultivate treatment, were higher compared to the other three treatments T1, T3, and T5. Where the overall mean site yields were between 300 to 1100 kg/ha, the double plough and plough + cultivate tended to perform better than the conventional treatment. From the yields presented in Table 2 it appears that there may be some yield benefit from the early inversion ploughing. However, effects were not statistically significant, and the data do not permit any definite conclusion to be drawn. With overall mean site yields above 1100 kg/ha, the conventional tended to perform as well as, or better than, the two early ploughing treatments.

The deep rip treatment performed poorly compared to the conventional and other treatments except at site F2.

The conventional with wide row spacing performed similarly to, or, at some sites better than, the deep rip treatment. At most sites the plant population at harvest for this treatment was much lower than those for the 75 cm narrow

Table 2. Grain yields kg/ha adjusted for already harvested, grazed, and immature heads and 10% moisture for E1 at nine sites used in 89-90 tillage trials.

	Site										
Treatment	F1	F2	S1	M3	M4	M5	P2	P3	J1	Mean F2 incl.	Mean F2 excl.
Conv.											
+fert	733	236	1190	1785	995	819	1743	986	868	1040	1141
-fert	831	44	1633	1445	9616	672	1019	911	508	853	954
Mean	782	140	1411	1615	806	745	1381	949	688	947	1048
DP											
+fert	1191	m	993	1121	1094	880	1739	1063	818	1112	1112
-fert	998	m	1326	1617	616	944	1338	891	462	1024	1024
Mean	1094	m	1160	1369	855	912	1539	977	640	1068	1068
Deep rip											
+fert	713	574	1282	564	587	m	979	991	1061	844	881
-fert	844	1561	1198	722	47	m	704	573	303	744	844
Mean	778	1067	1240	643	317	m	841	782	682	794	863
Plough + cult.											
+fert	1100	437	965	1519	1175	880	1514	1006	755	1039	1114
-fert	865	585	1237	1358	720	838	1374	1023	424	936	980
Mean	983	510	1101	1439	948	859	1444	1015	590	988	1048
Conv. + WRS											
+fert	684	2	1547	937	686	732	1350	629	833	822	925
-fert	682	62	1364	1675	1092	947	934	979	346	898	1002
Mean	683	32	1456	1306	889	839	1142	804	590	860	964
B/cast-plough											
+fert	m	11	m	1382	m	1480	1338	1497	1428	1189	1425
-fert	m	15	m	1098	m	932	491	1125	1127	798	955
Mean	m	13	m	1240	m	1206	914	1311	1277	994	1190
Overall mean											
+fert	884	252	1195	1218	908	958	1444	1029	961	993	1074
-fert	844	453	1352	1319	618	867	977	917	528	864	940
Tillage	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	ns		
cv main plot %	18.2	105.3	33.7	40.1	26.9	64.4	28.0	34.0	38.4		
cv subplot %	28.2	194.1	21.3	26.5	49.7	35.4	26.5	21.5	31.8		
SED_1	111	214	214	360	145	339	196	191	165		
SED_2	109	256	86	137	170	118	107	70	79		
df for E_a	4	8	12	5	4	8	10	10	10		
df for E_b	5	10	15	6	5	10	12	12	12		

**, *, and ns = respectively, highly significant P(>F) < .01, significant P(>F) >.01 and <.05, or not significant.
SED_1 = for comparing tillage treatments over all fert. levels, SED_2 = for comparing fert. treatments over all tillage levels, m = not implemented or failed or data lost.

spacing treatments. This may have contributed to the lower yields. However, it was not possible to conclude from the data that the lower yields from the deep rip and conventional with wide row spacing treatments were due to lower plant population.

There was a relatively weak response to fertilizer as applied in these trials except for the traditional broadcast/plough treatment. As shown in Table 2, for this treatment the broadcast fertilizer resulted in close to 50% increase in the overall mean yield taken across the sites. This probably indicates that uptake of the compound N:P:K fertilizer when banded adjacent to the seed may not have been optimal. Banding localizes the fertilizers relatively close to the surface. Access to nutrients is thus restricted to the roots growing in the vicinity of the fertilized zone. In addition, the surface layer remains relatively drier during the season, and this can possibly result in high soluble salt concentrations in the fertilized zone. These factors could reduce uptake and hence the effectiveness of the fertilizers. Broadcast fertilizers are more uniformly mixed in a greater volume of the rooting zone and this may promote greater access and uptake of the applied nutrients. It also probably explains why, for sites with overall site mean yields between 600 and 1200 kg/ha, the broadcast/plough treatment performed generally better than T1, the conventional treatment, and also, why it performed as well as, or better than, the early inversion ploughing treatments T2 and T4.

In general, but not always, higher yields resulted from those sites with the higher plant populations. Plant popula-

tions for most treatments at all sites were rarely higher than 30,000 plants/ha.

The soils at the nine sites where E1 was conducted can be grouped on the basis of texture and depth as follows:

Deep (>140 cm) sandy loam : M3, M5, P2, and J1

Shallow (<100 cm) sandy loam : F1, S1, and M4

Moderately deep (100-140 cm) clayey loam : P3

Shallow (<100 cm) clay soil: F2

Close examination of the yields for each tillage treatment with and without fertilizer across the nine sites presented in Table 2 does not show any consistent trends in response to either depth or texture. For example, yields at M3 and P2 were similar for some treatments but were much higher overall than both M5 and J1. The yield at S1 tended to be higher than both F1 and M4 and also M5 and J1. It seems reasonable to expect that in a deficit rainfall environment both soil depth and texture are likely to influence yields, because of their influence on capacity for storing moisture and nutrients. It is possible that management and other factors may be masking any possible effects of texture and depth. One possibility of making these effects apparent would be to use crop growth models in conjunction with land evaluation models that can simulate, and thus possibly separate, the effects of management differences from the effects of soil differences.

The results of yield for E2 are presented in Table 3. The yields at S1 were much higher relative to the other three sites. The ranking in ascending order of the overall site mean yields was as follows:

1	2	3	4	5
F2,-f	F2,+f	P2,-f	P3,-f	S1,-f

Across the sites, the chisel ploughing performed best at S1 where it outyielded the early inversion ploughing treatments by close to 50%. However, instead of chiselling only the planting rows 150 cm apart, as was done at the other sites, the whole plot was chiselled at S1. At F2, chisel ploughing gave the third best yield of the five treatments. However, at P2 and P3 yields from chisel ploughing were the lowest. These low yields at P2 and P3 were probably due to the low plant populations in the chisel ploughed plots. The broadcast/plough treatment gave the best yields at F2, P2, and P3. This is shown in Table 3 where treatment means across the sites are given excluding S1. The early inversion ploughing treatments tended to perform better than the conventional when the overall site mean yields were between 300 to 600 kg/ha. In this range, the traditional broadcast/plough treatment outyielded the conventional treatment. Except for the broadcast treatment, the means across the sites with S1 excluded were much lower than for the tractor implemented treatments.

Table 3. Grain yields kg/ha adusted for already harvested, grazed, and immature heads and 10% moisture for E2.

	Site					
Treatment	F2	S1[1]	P2[1]	P3[1]	Mean (S1 incl.)	Mean (S1 excl.)
Conv.						
+fert	113					
-fert	273	1996	269	406	736	316
Mean	193					
DP						
+fert	526					
-fert	138	1218	531	482	593	385
Mean	332					
Chisel plough						
+fert	320					
-fert	318	1704	103	235	590	219
Mean	319					
Plough + cult.						
+fert	294					
-fert	263	1136	735	520	664	507
Mean	279					
B/cast-plough						
+fert	369					
-fert	494	888	814	1157	838	821
Mean	432					
Overall mean						
+fert	324					
-fert	297	1388	491	560	684	449
Tillage	ns	**	**	*		
Fertilizer	ns	na	na	na		
Tillage x fert.	ns	na	na	na		

[1] No fertilizer treatment applied.
**,*, and ns = respectively, highly significant P(>F) < .01, significant P(>F) >.01 and <.05, or not significant.

The results from E1 and E2 in their entirety provide some indication that lower yields are obtained with animal versus tractor draught except under good management conditions as at the research station site S1, where a well trained team of oxen were always available and operations were done in a timely manner. In addition to this, other factors such as shallower depth of ploughing and planting may be the reasons for the generally lower yields with animal draught.

The results do not show strong trends that would permit definitive conclusions on the effect of the treatments on the various observations taken in these trials. It was hypothesized that mean grain yields for the various treatments would be related to either the total rainfall, or various partial rainfall totals, received after the date of planting. Correlations of grain yields for various treatments across the sites were made on such totals. No significant correlations were obtained that would support this hypothesis. Correlations between grain yield and the other components of yield, namely plant population and plant height, either singly or together, did not result in any significant and strong relationship between these variables.

The results for the E3 trials are presented in Table 4. A positive response was obtained for P at these sites where the soil level of P, determined by the Bray 2 analytical procedure, was less than 10 mg/kg. No significant interaction between N and P rates on yield was obtained for any site. The different responses to applied P at the different sites were directly related to the initial level of P in the soil. This implies that each merits its own fertilizer recommendations. A significant response to N was obtained only at site P2, Tswidi, where the overall mean yield was highest. At this site, the rainfall was well distributed and the crop management was much better compared to the other sites.

The economically optimum rate of application of P fertilizer can be calculated by plotting value of crop or cost of applied fertilizer vs P applied, then drawing a tangent to the value curve parallel to the cost line as detailed in FAO Soils Bulletin 18. The results of applying this procedure are also given in Table 4. This table summarizes the economics of applying P as single superphosphate or as 2:3:2. As would be expected, those sites with lower initial soil P and which gave the highest responses to applied P, gave good benefit to cost ratios. These ratios were higher for P applied as single superphosphate than as 2:3:2.

Table 4. Mean yields kg/ha for P treatments taken over all N rates and economics of applying fertilizer P as single superphosphate at three sites.

	Site		
Kg/ha P	J1	P2	P3
0	908	2421	1184
10	1599	2932	1529
20	1873	2884	1541
40	1603	3009	1624
80	2022	3548	1850
Mean	1602	2959	1546
SED	136	212	276
Error df	19	19	19
cv%	17.0	14.3	35.7
Initial P mg/kg	0.56	2.70	5.6
Rainfall mm after DOP	172	166	196
Opt. rate kg/ha	14.5	18.5	9.0
Yld. at 0 fert.	908	2421	1184
Yld. at opt. rate	1492	2881	1390
Cost fert Pula/ha	62	79	38
Extra yield kg/ha	584	460	206
Value[1] - cost fert	111	57	23
Ratio value:cost fert	2.80	1.73	1.59

[1] Value = value of extra yield.
1 kg P as SSP costs P4.25, 1 kg sorghum = PO.295.

This program has resulted in:

1. A comprehensive tillage research program involving a close working relationship between the Department of Agricultural Research and the Department of Field Services.

2. A model organizational structure for subject matter research and problem solving research. This model has been adopted for other research subject matter areas in the Department of Agricultural Research.

3. A clear indication that tillage and fertilizer management can increase yields and should be further studied.

4. Obligation of funds through ALDEP to cover equipment and operational costs of the program.

In addition to the foregoing program, INTSORMIL has continued where relevant to support the activities and interests of the national researchers. Support was provided to:

Meteorological Services researchers in a joint study to extract and interpret available autographic rain gauge data to obtain rainfall intensity-duration-frequency patterns over eastern Botswana.

Ms. Malepa's PhD. dissertation research on critical levels of macro and micronutrients for 12 soils of Botswana.

Publications

Carter, D. C. and N. Persaud. 1990. Manure and stover management for sorghum and millet production in eastern Botswana. Part 2 - The effect of manure, mulch, and soil-incorporated stover on the physical and chemical properties of two soil types. Bulletin of Agricultural Research in Botswana Vol. 8: 10-14.

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Persaud, N., K. Monageng, A. MacPherson, and K. Molapong. 1990. Conservation tillage and fertilizer practices for dryland cereal production in Botswana. Proceedings of the First Scientific Conference of the SADCC Land and Water Management Research Programme, SACCAR, Gaborone, Botswana.

Persaud, N., A. MacPherson, B. Sebolai, S. Beynon, M. Phillips, and N. Mokete. 1991. Tillage and Fertilizer Research Programme: Report on the 1989-90 tillage and fertilizer trials. 111 pages. Dept. of Agricultural Research, Gaborone, Botswana.

Networking Activities

INTSORMIL researchers in Botswana participated in:

The seventh annual workshop of the SADCC/ICRISAT Sorghum and Millet Program, Manzini, Swaziland, 17-21 September, 1990.

The first Scientific Conference of the SADCC Land and Water Management Research Programme, Gaborone, Botswana, 8-10 October, 1990.

International Workshop on Soil-Water Balance in the Sudano-Sahelian Zone, Niamey, Niger, 18-23 February 1991.

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 on tropical savanna soils.

Seed of 125 Al-tolerant A and B pairs is being distributed to three different programs: IDIAP (Panama), FONAIAP (Venezuela), and ICA (Colombia). Crosses of these 125 pairs had been evaluated using the Al-tolerant lines as females and two different pollinators (TX 430 and IA 28) as males.

A new set of advanced materials with better agronomic types than those of the world collection has been put together.

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 to low Ph tropical soils with phytotoxic levels of Al.

To develop minimum-input technology strategies for the evaluation of Al-tolerant lines grown on 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 to Al and Mn toxicities, and low P availability.

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

To distribute sorghum and pearl millet germplasm developed through INTSORMIL and ICRISAT projects 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.

To assist other INTSORMIL PI's in the conduct of research in Colombia

Constraints

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

Most sorghum in Latin America has been grown in high-cost lands, making production of this crop a nonprofitable enterprise under such circumstances. An alternative for reducing production costs is that of incorporating marginal lands into the production system. The most important constraint to increasing area planted to sorghum and pearl millet production in South America is soil acidity; South America has the largest acid soil areas in the world. These acid soils contain toxic levels of Al and sometimes Mn, enough to inhibit the growth of major cereal crops. This limiting factor could be avoided by the use of germplasm tolerant to high Al concentrations in the soil.

A second constraint, and maybe the most important, is the inadequate management of these highly fragile soils. The ecosystem could be easily destroyed not only at the 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 mentioned savanna areas could be incorporated into a sustainable agricultural system, the pressure for land on the Amazon area would decrease. Agriculture in the savannas can be easily mechanized and harvested products would be closer to population centers than in the Amazon region. Crop rotation, new fertilization and soil preparation practices, and integrated pest and disease management must become part of the research tools for the future.

The third most important constraint to sorghum and pearl millet production is drought. In many parts of the South American ecogeographic zone, drought due to variable rainfall patterns is a problem throughout the year. In addition to studying acid soils constraints, specific long-range research goals in Colombia will include research in pearl millet production and other factors affecting sorghum production such as tolerance to drought and diseases, and grain quality.

The fourth constraint for sorghum production is head mold diseases both in acid and nonacid areas. Since sorghum is not produced in very dry areas in South America, relative humidity becomes a problem in most production areas. This factor is related to the loss of quality and increase in the amount of aflatoxins in the grain.

Research on acid soil constraints could benefit both the LDC's and the U.S. in several ways. Al-tolerant germplasm would help increase sorghum production in acid soils in both regions with the use of less inputs; yet, the major benefit to the U.S. would probably be attained through commercial seed companies. Multinational seed companies could use the proven Al-tolerant germplasm for hybrids in their overseas operations. Spinoff improvement in U.S. hybrids would result if there is a large enough market demand for this product. The demand for improved varieties and hybrids should be ample in Latin America and Central Africa, considering these are food- and feed-grain deficient regions.

Research Approach and Project Output

Breeding and Institution Building in Colombia

In eight years of work in Colombia, a great deal of effort has been put into the evaluation of acid-tolerant lines from the world collection. As a result of this process, two lines: MN 4508 (Sorghica Real 60) and 156-P5 Serere-1 (Sorghica Real 40) were released for Al saturation levels of 40 to 60% and 20 to 40%, respectively.

While these lines were being evaluated, a set of 125 (A-B), Al-tolerant pairs was developed, using IS 7173 C as the main source of tolerance to Al toxicity. This set of A-B lines enables the release of germplasm entries for hybrid production.

Simultaneously, new lines for developing varieties with better agronomic types were obtained; screening sought to reduce plant height and days to flowering since the Al-tolerant lines from the world collection are tall (about 2 m) and have a long vegetative cycle (75 days). These breeding efforts have resulted in a new set of advanced lines developed in Arauca and La Libertad. This set was evaluated for yield capacity and tolerance to diseases, particularly anthracnose and head mold. The goal is to release a line every three years.

Since the concept of Al saturation levels was developed, the different nurseries are maintained independently for each level. Studies conducted have shown that lines of the F_2 or F_3 populations selected in nonacid soils would loose their tolerance to Al toxicity if only one of the parents was Al-tolerant.

In close cooperation with MSU-104, ICA and FENALCE, the main breeding and evaluation research was conducted for acid soils at CIAT-Palmira, CIAT-Quilichao, CIAT-Santa Rosa, ICA-La Libertad, ICA-Nataima, and the El Alcaraván Foundation (Arauca), and at Mississippi State University. ICA conducted its breeding activities at ICA-Nataima (its main sorghum station) and at La Libertad (a satellite station). Evaluation of selected lines was done at La Libertad and other acid soil sites in the region.

During the first two months of each year, joint annual work plans are developed among ICA, FENALCE, INTSORMIL, and El Alcarván, and become a formal part of the INTSORMIL collaborative effort. An operating budget is agreed upon among the parts, to be conducted as formalized in the work plans. This budget is administered by ICA, under CIAT's external control.

Most research this year dealt with developing better breeding techniques and objectives on the basis of each

Al-saturation level established. New sets of F_2 populations were sent by Dr. Bruce Maunder; these have been screened in each of the Al-saturation levels. One hundred heads of each population were selected for each level at La Libertad, for evaluation in the next generation. These populations were selected on the basis of their resistance to anthracnose and midge and tolerance to high levels of Al saturation. One population, sent by Dr. Duncan (University of Georgia), was evaluated in each of the Al-saturation levels. Segregating F_3 lines were evaluated in the following sites: Quilichao, La Libertad, and Arauca (Colombia); Santiago and David (Panama); and Venezuela (sites will be determined by national program staff).

In cooperation with other INTSORMIL projects, drought-tolerant sorghum germplasm (TAM-122) was evaluated in Motilonia (jointly with FENALCE), in the Atlantic Coast of Colombia (region known as the dry Caribbean), and at ICA's main research station (Nataima) (Table 1). Studies on sorghum as a raw material for food products were conducted with Dr. Rooney (TAM-126) and Dr. Butler (PRF-104B); the basic question was determining the proportions of sorghum and wheat flower that could be used to prepare bread and cookies. A new project is being developed to establish the possibility of using sorghum to manufacture beer and whisky.

Several nurseries have been sent to Colombia for evaluation in different localities. Some of the lines selected from the disease and insect nursery (ADIN) at the Nataima Experiment Station in 1989B-1990A are shown in Table 2. Table 3 shows the agronomic characteristics of the eleven most contrasting genotypes from the ADIN nursery, in terms of their performance under the attack of *Diatraea* sp. at the same center.

Class 1, 0-35%, Vega

Subclass 0-20%. A new set of materials is being evaluated for this environment. These new lines are earlier and shorter than the lines from the first generation (lines from the world collection). Two conditions prevail in this class: savanna soils that have been improved through the application of lime or by cultivating them. Studies conducted by INTSORMIL in Arauca and the Llanos Orientales have shown that each year that the land is cultivated, Al-saturation levels are reduced by 5-10%. On the other hand, the level of Mn was observed to increase each year.[1]

The genotypes under evaluation are no taller than 160 cm. Resistance to head mold has been an important evaluation factor.

Subclass 21-35%. Al-saturation in this subclass has had a strong negative effect and most commercial hybrids grown will show grain yield reduction. Most of the new lines evaluated in this subclass have shown good results; lines NB 9040, TX 430, ICA-Nataima, IS 7254C, IS 7542C, IS

Table 1. Best lines selected from each of the Drought Line Test (DLT), Disease and Insect (ADIN), and Drought Hybrid Test (DHT) Nurseries, and hybrids used in crosses for hybrids.

Nurseries			
DLT	ADIN	DHT	Lines A & B
82C5948	Tx 433	A1 x R6078	A1 - B1
B 8618	80C2241	A1 x Tx 433	A10 - B10
R 4244	MR 102 - 3LP	A8201-2 x R6078	ATx631 - BTx631
82BDM49	R - 8507	A1 x TAM 428	A8201-2 - B8201
Tx 7078	87BR6569		A35 - B35
Sc238-14	84c7730		
85V2022	87BB396		
860G4592	BT x 623		
87 DLON 327	R 8505		
87 DLON 416			
85L 7719 (B2-2B)			
B2 - 2B			

Table 2. Lines selected from the disease and insect nursery (ADIN) from INTSORMIL. Nataima Research Center, 1989B-1990A.

Genotypes	Days to flowering 1988B	Days to flowering 1990A	Plant height (cm)	Length of panicle (cm)
R-9188	49	47	110	25
R-3224	57	54	112	27
R-6078	64	66	118	26
Tx 433	60	60	127	30
R-8503	57	52	142	30

Source: ICA, Annual Report, National Cereals Section.

[1] Informe de las Actividades de Investigación Realizadas en Colombia en el Cultivo del Sorgo. 1989.

Table 3. Agronomic performance of the eleven most contrasting genotypes from the disease and insect nursery (ADIN), in relation to the attack of Diatraea sp. Nataima Research Center, 1990A.

Genotypes	Days to flowering	Plant height (cm)	Length of panicle (cm)	No. of eggs/ 30 plants	No. of larvae/ 30 plants	No. of pupae/ 30 plants
T x 2767	60	132	5	137	14	2
BT x 623	62	165	10	129	8	2
80R-2892	53	125	10	111	-	-
87L-3452	70	100	5	103	2	2
MB102-3	68	210	15	71	7	5
Sureño L.P.	59	110	10	6	-	-
87EON-115	59	110	10	6	-	-
8662802	56	130	5	4	-	-
T x 7078	50	100	15	3	-	-
MR103-3L.P	47	105	10	3	-	-
87LG-7060	51	140	7	2	-	-

Source: ICA, Annual Report, National Cereals Section, June 1991.

Table 4. Plant height and yield of Sorghica Real 60 and Sorghica Real 40 in comparison with eight other genotypes planted in acid soils with aluminum saturation levels between 40 and 60%. Average data for twelve sites in the Department of Meta.

Genotypes	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
PPQ-2	167	2984	2315	2649
IS-3522	183	2538	2143	2340
IS-8577	187	3312	2795	3053
IS-6944	189	2609	2283	2446
5D X 61/1/910	178	2428	2123	2275
ICA-Nataima	96	534	894	714
Icaima	151	712	2174	1443

Source: ICA, Annual Report, National Cereals Section, June 1991.

12666C, TX 415 are being used in crosses with IS 3071, IS 6944, IS 9084, MN 4508, IS 8577, IS 2765, SC 326-6, ICA-Nataima (79 Sepon 54)-27-1-2, and IS-7254C.

Class 2, 36-60%, Vegón

Subclass 36-45%. Most of the new lines in regional trials yield about 2.5 t/ha but have good agronomic traits. Lines like IS 9084, IS 3071, IS 3522, and IS 9084 performed well under these conditions. Several crosses using ICA-Nataima as one of the parents also performed well in this ecosystem. ICA-Nataima has intermediate tolerance to Al saturation but is a very well adapted line to tropical conditions. New F_2 populations are being screened for this Al saturation level.

Subclass 46-60%. Lines like MN 4508 (Sorghica Real 60) (Table 4) and IS 9084 performed well under these conditions. A new line, IS 6944, is being evaluated by the scientific staff of the El Alcaraván Foundation for possible release in Arauca. This line has always been the best yielding in the region but is one of the tallest lines among the Al-tolerant genotypes in the world collection. Genotypes appropriate for this subclass need to have more tolerance to Al toxicity. The lines of the first generation will present reduced plant height (below 170 cm) in this subclass, especially in the second semester. Grain yield for the first generation line, IS 6944, is about 2.5 t/ha in this subclass.

Class 3, 61-90%, Savanna

Subclass 61-75%. Only one of the first generation, IS 8577, will have profitable grain yields under these conditions. This line is being evaluated for possible release by El Alcaraván in Arauca. This is the most Al-tolerant line from the world collection and could be released for environments with 50-70% Al saturation. As well as all the lines from the world collection, IS 8577 is tall and late flowering, especially in the first semester. Most of these lines do not present much tolerance to drought. Therefore, they must be planted early in the cycle, usually before September 15.

Subclass 75% and above. None of the germplasm available to date will present profitable yields in this subclass. Recurrent selection is being used to obtain a bulk of the most Al-tolerant lines. This will be crossed with each of the 125 Al-tolerant female (A) lines. In the future, selection will be made both among the male and female germplasm.

Hybrids seem to present an alternative for this class. Three hundred combinations, using different Al-tolerant female lines, are being evaluated for their overall combining ability using IA 28 and TX 430 as the male parents. Fertilization did not include liming; a combination of 60-60-60 N, P, K has been applied. Table 5 presents results of some of the lines evaluated in this environment.

Table 5. Performance of hybrid combinations evaluated for aluminum-saturation levels of over 75%.

	Crosses of lines	Scale*	Yield (kg/ha)	Weight (g) of 100 grains
(AT2)-27-1-1-1-1	x 1 A28	6.5	2090	3.75
(AT2)-13-5-1-2-2	x 1 A28	5.0	1810	3.43
(AT2)-25-1-1-2-1	x 1 A28	6.0	1753	3.10
(AT1)-26-1-1-1-1	x 1 A28	5.3	1750	3.00
(AT2)-27-1-1-3-1	x 1 A28	4.5	1653	3.20
(AT1)-17-4-2-1-2	x 1 A28	4.7	1552	2.97
TX 623	x TX 430 x IS 8577-1-1-2-1	4.0	1532	3.55

*Overall performance, scale > 1-10, 1 = very poor and 10 = excellent.

Table 6. Differences between 1988 semesters A and B in yield, plant height, and days to flowering of various sorghum lines. Average of five sites in Arauca (Antioqueña, Raúl Ruíz, Alcaraván, Ismael Nuñez, and San Lorenzo).

	Plant height (cm)			Yield (kg/ha)			Days to flowering		
Line	Sem A	Sem B	Dif.	Sem A	Sem B	Dif.	Sem A	Sem B	Dif.
IS 10336	172.6	134.8	37.8	2313	1842	471	67.6	76.4	-8.8
IS 8577	215.4	159.6	55.8	2646	2256	390	72.5	71.2	1.3
IS 7151	221.6	255.0	66.6	2553	2173	380	74.5	70.8	3.7
IS 8933	221.7	159.8	61.9	2503	2146	357	73.7	73.4	0.3
IS 2765	220.9	161.0	59.9	2816	2492	324	76.2	73.8	2.4
IS 3071	227.2	149.0	78.2	2582	2290	292	73.7	74.2	-0.5
IS 9042	216.7	161.8	54.9	2686	2468	218	72.7	72.6	0.1
Serere	186.3	138.8	47.5	2327	2164	163	72.6	68.2	4.4
IS 8996	204.7	148.4	56.3	2026	2509	117	74.1	71.8	2.3
IS 3522	223.3	154.8	68.5	2614	2502	112	71.4	72.8	-1.4
MN 4508	221.6	162.0	49.6	2672	2561	111	75.1	72.2	2.9
IS 9084	223.6	160.4	63.2	2582	2516	69	73.1	72.4	0.7
IS 8959	222.4	159.0	63.4	2492	2447	45	74.3	73.4	0.9
IS 6944	230.8	160.0	70.8	2898	2858	40	74.5	72.6	1.9
5D x 61	223.8	140.6	83.2	2457	2526	69	73.9	67.2	6.7
IS 7132	206.3	152.8	53.5	1998	2076	-78	75.7	72.8	2.9
PPQ 2	162.7	136.4	26.3	2327	2800	-473	69.4	67.8	1.6
IS 9826	197.5	149.4	48.1	2217	2750	-533	71.0	70.0	1.0
IS 12152	221.2	165.0	56.1	1794	2608	-814	68.3	74.0	-5.7
IS 8931	216.3	158.6	57.7	2204	3130	-926	73.8	81.8	2.0
IS 9945	205.0	148.6	56.4	1481	2524	-1043	74.3	73.4	0.9
IS 9938	221.1	164.4	56.7	1440	2815	-1375	69.7	72.2	-2.5
IS 9109	228.6	173.0	55.6	986	2419	-1433	72.2	74.8	-0.6

The lines from the world collection have been found to perform better during the first semester (Table 6). Differences have also been found between the two semesters in terms of plant height, grain yield, and days to flowering. Plant height is usually greater during the first semester. Fifteen of the lines yielded about the same in both semesters, but eight of them yielded more in the first semester. Seventeen lines had a shorter growth cycle in the second semester.

Research Approach

Different approaches have been followed for research in Colombia. Since 1988, research has been conducted in Arauca in collaboration with the El Alcaraván Foundation, which provided all the funds for experiments in this region. Since ICA also has a scientist assigned to this region (Mr. Walter Rendón), all the work done in El Alcaraván is replicated in full in ICA-Arauca.

El Alcaraván provided support to 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 continues to be the main site for evaluating and selecting materials adapted to acid soil conditions. La Libertad is a well-drained savanna ecosystem, while Arauca has poorly-drained savannas. Arauca is a new research area in Colombia and both normal and acid-soil sites were used for sorghum and pearl millet evaluations. This enables the project to test selected advanced materials in both acid and nonacid soils.

Publications

Chacón, Mario. 1990. Descripción varietal de cultivares de sorgo, *Sorghum bicolor* (L.) Moench, en Colombia. B. Sc. Thesis, Agronomist, Universidad Nacional de Colombia, Facultad de Ciencias Agropecuarias, Palmira. 244 pp.

Fundación El Alcaraván, INTSORMIL, CIAT. 1988. Informe de investigaciones realizadas en Colombia en el cultivo del sorgo. Bogotá, Colombia. 233 pp.

Osorio, Javier. 1990. Evaluación de la estabilidad fenotípica del rendimiento de 24 genotipos de sorgo, *Sorghum bicolor* (L.) Moench, tolerantes al aluminio en Arauca. B. Sc. Thesis, Agronomist, Universidad del Tolima, Ibagué, Colombia. 250 pp.

Networking Activities

Each year a workshop is organized by ICA, El Alcaravan Foundation, FENALCE and the universities to share research results of experiments done in Colombia. El Alcaravan has been supporting the publication of the proceedings of this meeting.

The previous is a very important meeting since it enables researchers to update their knowledge and implement a work plan with the participation of all the institutions involved in research. In 1990, the private sector began to become involved in this idea; better results are expected for the future with their participation.

An international meeting ("Sorghum for the Future") was held at CIAT, Colombia, during the third week of January, with the participation of all the Latin American countries. This meeting provided the basis for a Latin American Sorghum Network. INTSORMIL supported this event to a great extent. Another result of the meeting was the strengthening of links between INTSORMIL and Latin American scientists; in turn these improved relations have resulted in better conduct of research in this area.

The most important result has been the establishment of an organization under CLAIS's umbrella for the development of networking activities in Latin America. Dr. Guillermo Muñoz was named president of this organization in the last PCCMCA meeting held in Panama, in February 1991. The main objective of this group will be to develop a research proposal to find resources for developing a strong networking program in Latin America, with CIAT as the pilot center.

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 Honduras, the social returns to the new sorghum technologies of new cultivars and improved agronomic techniques are substantial even though diffusion is still in the incipient stages, an estimated 9% of sorghum area. Nevertheless, the technology introduction already has a 32% internal rate of return, or an annuity value of $700,000. This calculation also includes the costs of the soil-conservation techniques to prevent the hillside farms from washing down into the valley.

An important next policy step for Sudanese agriculture will be the elimination of price and exchange-rate distortions. The HD-1 research investment will still be socially profitable, especially with continuing diffusion. These measures will improve the competitive position of Sudanese sorghum exports. Fertilizer imports will be more expensive but the market rather than governmental policies will allocate the fertilizer. There should be long-run benefits to a market economy from this shift.

Technology development should not be seen as a panacea for all resource-poor regions. To create a sustainable crop system, chemical fertilization will generally be necessary. For some regions, even with improvements in technologies and changes in policies, farmers are not expected to find this alternative profitable. Some research regional priority identification appears to be necessary in regions such as the Sahelo-Sudanian zone of Niger.

In a simple bargaining framework, female workers are better off with the technologies being introduced on the collective fields rather than directed specifically to them even when they are also able to expand the area of the private fields. This is due to the lower productivity of the private fields and the increased demand for labor on the collective fields resulting from new technology introduction. Some policies advocated to help women farmers can make both them and the entire family worse off. Land productivity and within-family bargaining processes are both important components of total family income determination and within-family income distribution during technology introduction.

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.

Constraints

Sudan

The impact of HD-1 in the Gezira scheme is an important success story for the INTSORMIL program. These estimates of the financial returns to research have been widely disseminated. Diffusion of HD-1 is expected to accelerate, especially with the recent droughts and disruptions of the civil war to normal cereal production. Financial analysis includes all the prices and costs faced by farmers and consumers. This analysis was redone, eliminating all the price- and exchange-rate distortions and subsidies. Sudan will be pushed to eliminate these price/exchange-rate distortions by funding agencies once the domestic situation normalizes. Eliminating all these distortions substantially reduces the profitability of these new technologies. Designing new technologies and policies for this environment will become an important challenge of postwar development.

Honduras

One principal factor in introducing the new sorghum cultivars and associated technologies on the hillside farms of southern Honduras is first implementing soil-conservation technologies. With the high labor requirements for terracing, the short-run profitability of these technologies is low. In the long run, the conservation devices stabilize the farms and allow other more intensive technology introduction, such as new cultivars. Stabilizing the resource base and raising small farmers' incomes are difficult endeavors. Complementary policies and incentives to increase the profitability of these long-run, socially-profitable technologies are necessary to facilitate this process.

Niger

In the Sahelo-Sudanian zone, introducing sustainable agricultural systems will often require chemical fertilizer along with the new cultivars. In some regions, even with further technology development and some feasible policy changes, there appears to be little potential for a profitable introduction of chemical fertilizer. The constraint here appears to be on the need for public planning to concentrate research investment where the potential returns are the highest rather than assuming that technological change is the appropriate instrument for even the most resource-poor environments.

Burkina Faso

Various policy measures to encourage general economic growth can benefit women farmers. However, aiming technology specifically at them or to the particular land resource they control may not be as efficient as just allowing new technologies to be utilized on the collective lands. Poor policy design could slow down the process of both technology introduction and income improvement.

Research Approach and Project Output

Sudan

The diffusion of HD-1 in the Gezira region is in its initial stages. HD-1 is presently being planted on approximately 17,000 ha or 9% of the sorghum crop area. Even at this early stage of diffusion, there is a reasonable internal rate of return of 23 to 31%, depending upon the level of fertilization employed. Over 30 years, this investment would pay approximately $1 million of annual benefits. As the diffusion process continues and higher fertilization levels are attained, these benefits increase considerably.

One problem in the near future is that these are financial benefits reflecting the present prices, costs, and exchange-rate structure. There are substantial price distortions in the Sudan, especially in the overvalued exchange rate. International agencies will begin pressuring Sudan to eliminate these distortions as soon as the domestic situation stabilizes. The overvalued exchange rate makes sorghum exports less competitive and reduces the value of the fertilizer imports. Also the overvalued exchange rate leads to import controls and rationing. Given the importance of these chemical fertilizer imports to HD-1 production, this overvalued exchange rate is an important constraint.

The extent of these distortions can be appreciated from comparing the Sudanese sorghum price at the official and street exchange rates with the price of sorghum delivered to the region (border price) (Table 1). At the official exchange rate, Sudanese sorghum was consistently above the world price. At the street rate, except for the drought year 1984-85, the Sudanese sorghum price was substantially below the world price.

By utilizing the sorghum price deflated by the fertilizer price, again the Sudanese real sorghum price is much higher than the world price. From 1985 through 1989, the Sudanese price ranged from 59 to 88% higher than the world price. Two unfortunate consequences result from these distortions:

1. The potential competitive position of Sudanese sorghum exports is eroded. If the other international marketing requirements could be met, sorghum exports would be increased by eliminating this exchange-rate overvaluation.

Table 1. Sudanese and world market prices for sorghum at official and street exchange rates.

Year	Sudanese sorghum prices ($/m.t.)		World price[a]	Sorghum/fertilizer price ratio	
	At official exchange rates	At street exchange rates		Sudan	World
1981-82	178	55	114	—	—
1982-83	171	61	114	—	—
1983-84	218	59	131	—	—
1984-85	930[b]	186	111	2.50	0.65
1985-86	142	37	95	0.97	0.59
1986-87	110	24	71	0.96	0.55
1987-88	197	74	81	1.18	0.63
1988-89	190	48	111	1.37	0.73

[a] Sorghum export prices delivered to U.S. Gulf ports.
[b] Note that 1984-85 was a severe drought season in Sudan.

Source: Official exchange rates are from IMF Year Trade Book, 1990. All sorghum and fertilizer prices are from Sudan Ministry of Agriculture, Agricultural Situation and Outlook, various issues.

Table 2. Income, coefficient of variation (C.V.) and sorghum-diffusion impacts of new technologies and policy changes in southern Honduras.

Description	Expected income (U.S.$)	C.V.	Expected grain production (kg)	% of new sorghums in crop plans
Traditional base case	$263	16	2,361	—
Technology introduction only:				
Farm with SCTs only	$282	15	2,066	—
Farm with SCTs and new sorghums	$303	14	3,894	53
Technology and policy changes:				
Changes in policy variables:[a]				
Farm with SCTs only	$374	6	2,735	—
Farm with SCTs and new sorghums	$415	14	4,439	81

[a] Available credit increased from $112.50 to $225. Interest rate decreased from 4.5%/month to 2%/month. Maize and sorghum minimum prices for good-rainfall years increased from 4 cents/kg and 2 cents/kg to 10 cents/kg and 7 cents/kg, respectively. The street exchange rate of 4 Honduran lempiras per U.S.$ in summer 1989 was utilized here. The street rate can result in a downward bias in estimating the real exchange rate due to the inclusion of a risk premium.

Source: Calculated from M. Lopez-Pereira and J.H. Sanders (1992), pp. 17-19.

2. Sudan rations chemical fertilizer imports and largely depends upon foreign aid for fertilizer imports. Chemical fertilizer is a critical input for Sudanese agricultural development, especially in the irrigated sector. The fertilizer prices will be increased by moving to real exchange rates. Then the market rather than the government or foreign-aid donors can do the allocation according to the value of fertilizer in production.

One immediate short-run consequence of eliminating the distortions and moving to economic rather than financial returns is to substantially reduce the returns to research. At the present levels of diffusion, the economic returns become almost marginal, internal rates of return of 16 to 21%. However, increasing the Gezira diffusion to 35% or 50% of the sorghum area raises these rates to more respectable levels of 23% to 31% (Ahmed and Sanders, 1991, p. 31).

Honduras

The introduction of new sorghum cultivars into Honduras has also begun. In 1989 an estimated 13% of the sorghum area in Honduras was planted in Sureño and Catracho, two new sorghum cultivars. Even if diffusion were to just stop at this level, then there has already been a substantial impact. The internal rate of return to this research was estimated to be 32% or, on an annuity basis, $700,000 (U.S. dollars) annually for the next 30 years. These annuities alone could finance a major part of all Honduran agricultural research. If diffusion proceeds and reaches 50% by 2002 or 2012, these annual benefits would range from $1.7 to $2.2 million (Gonzalez-Rey et al., 1990). So the sorghum research collaborative program with INTSORMIL and several Honduran public agencies has demonstrated substantial successes.

Moreover, this sorghum research program in southern Honduras has included the high costs of the soil-conservation program to first turn this hillside agriculture from itinerant farming to a permanent system. In the 1990 INTSORMIL Annual Report it was pointed out that many of those farmers adopting the SCTs were the same farmers who adopted the new cultivars and associated technologies. It is difficult to quantify all the long-term benefits of preventing the hillsides from washing down into the valley. Since only yield increases were included as benefits, these estimates here understate the social benefits.

By shifting to these new sorghum cultivars alone, yields were increased from 1.08 t/ha to 1.65 t/ha, according to farm-level testing in 1989. By also including moderate fertilization, a further yield increase to 2.55 t/ha was reached. Since the costing of new technologies also involved the very labor-intensive soil-conservation techniques, the combined profitability of these innovations was low. Without the SCT, the farming system with or without the new sorghum technologies will not be sustainable. The combination of these new technologies increases farm income only 15% in the farm-programming model. With some government policy support principally to eliminate the price collapse in good-rainfall years, the expected income increase would be 58% (Table 2). These simple policy changes also increase the utilization of the new sorghum

cultivars from 53 to 81%. One method to avoid these price collapses is to encourage increased feeding of small animals in adequate- or good-rainfall years when sorghum becomes a feedgrain. Another alternative is to facilitate on-farm or central cooperative grain storage to protect small farmers from annual postharvest price collapses. Honduras already has programs of this type but they do not presently function for small farmers.

The above results were for the profit-maximizing farm. Allowing for risk aversion in farmers' decisions had minimal effects on farm income or technology choices. The probable reason is that farmers were first allowed to satisfy subsistence objectives and this apparently adequately responded to their risk-avoidance characteristic.

Niger

The 1990 INTSORMIL Annual Report described the farm-level responses to new technologies and modified agricultural policies in two regions of the Sahelo-Sudanian zone in Niger. Early cultivars of cowpeas and millet are already being introduced into these systems. To make them sustainable systems, chemical-fertilizer introduction is required. Otherwise the soil-mining process accompanying the decline and disappearance of the fallow system will continue. The report then examined in some detail the technology modifications and policy changes to introduce chemical fertilizer. There were some feasible modifications in the higher-rainfall zone, resulting in fertilizer introduction, but not in the lower-rainfall zone.

Then income/ha comparisons were made for the two regions with traditional and new technologies. With or without the new technologies, incomes were twice as high in the higher-rainfall zone (Table 3). Decomposing income differences approximately 60% were due to yield differences and 31 to 38% to price differences.

Technology development is a powerful instrument for increasing farmers' incomes in resource-poor regions, such as the Sahelo-Sudanian zone. However, with slightly more resources, there is more response to new technologies. Strategies to focus crop technologies on areas with some potential for developing sustainable agriculture are necessary. In some regions the development of reforestation and improved grazing may be more appropriate. There already are movements in these resource-poor regions toward diversification as seasonal out-migration of most of the male workforce now occurs. Focusing crop technology on areas with more potential and facilitating the retreat from crop production in more marginal regions seems to be a more efficient strategy than trying to utilize crop technology development to resolve all low-income agricultural problems.

Burkina Faso

One of the most serious recent criticisms of the technological-introduction process is the within-family income distribution consequences. There is a particular concern that women or children may not benefit. However, there has been little evidence or systematic evaluation of the within-household income distribution process as technology is successfully introduced.

One of the zones of most rapid technological change has been in the cotton zone of southwestern Burkina Faso. In this region, new cotton and maize cultivars have been introduced. Chemical fertilization has been increasingly applied to both crops and onto sorghum. Other improved agronomic practices including cotton insecticide also have been introduced.

In the traditional system, there is joint family labor to provide for the subsistence cereal requirements. The adult family workers provide this labor on the collective fields for their share of the grain during the year and work their private plots for their own incomes. As the family moves beyond minimal grain subsistence, the household head needs to compensate adult family members for the increased labor on the collective fields. When new technology is introduced on the communal area, the household head must bid away additional family labor from the private fields to respond to the increased labor requirements. The adult workers can receive higher compensation by working more on the collective fields. The new technologies increase adult-equivalent incomes 129% (Table 4). Also with the new technologies, the incomes for the adult female (and male) worker more than double even with the decline in the income from the private plot (Table 4, cols. 1 and 2). If the technology is introduced only on the private fields, the female

Table 3. Comparison of expected net returns of dryland agriculture under different technologies at two sites in the Sahelo-Sudanian zone, Niamey region, Niger.

	Libore[a] (U.S.$/ha)	Kouka[b] (U.S.$/ha)	Ratio of net returns per ha
Current practices:			
Millet/cowpea intercrop	115	57	2.02
Improved cultivars (low density)	129	68	1.97
Improved cultivars (high density)	147	69	2.14
Improved millet/cowpea with fertilizer	175	76	2.30

[a] Higher-rainfall zone of 570 mm annually. Closer and better access to the principal urban market of Niamey. Supplementary irrigation available of 0.4 ha/farm generally in improved rice cultivars with chemical fertilization.
[b] Lower-rainfall zone of 430 mm. Only dryland agriculture. Further and poorer access to Niamey market.

Source: Shapiro, B.I., O. Coulibaly and J.H. Sanders, "Farm-Level Potential of Sorghum/Millet Research in Semi-Arid West Africa," Department of Agricultural Economics, Purdue University, West Lafayette, IN, 1991, p. 9.

Table 4. Adult-equivalent incomes and female family-worker incomes from new technologies and the availability of off-farm employment in the Solenzo region of Burkina Faso.

	Traditional technology	New technologies on collective fields[b]	New technologies only on private fields[c]	New technologies on collective and private fields
Farm income per adult - equivalent (U.S.$)[a]	125	222	115	202
Income of adult female worker:				
Private plot	36	14	68	68
Collective field compensation	—	71	—	45
Total: Female worker	36	85	68	113

[a] This is family income including the value of home consumption of food divided by the number of adult equivalents in the household. This includes only crop income from the collectives lands. Note that as technologies change so do family sizes. The traditional farm includes 5 adult equivalents. The farms with new technologies include 7.

[b] Here the new technologies are introduced on the more productive fields. The household head must pay more to the female worker for the increased labor on the collective field. The private field available is only 0.75 ha.

[c] Here the land available to the female worker is increased to 1.75 ha and the technology is introduced first on the private fields in spite of the lower productivity. This is done by forcing the model in the programming. It is equivalent to a preferential policy of directing the technology first toward the female farmer (and increasing her land area). These policy measures are frequently advocated in the women's literature.

Source: Ramaswamy, S., and J. H. Sanders, "Technological Change, Role of Women, and Intra-Household Distribution of Income in the Sahel," Department of Agricultural Economics, Purdue University, West Lafayette, IN, mimeo, 1991, pp. 29-31.

worker's income is $68 as compared to $85 with introduction only on the collective field (Table 4, cols. 2 and 3). This decline in income occurs even with an increase in the private land available to the female worker from 0.75 ha to 1.75 ha. Giving the female worker a larger land area, time to cultivate it, and concentrating the technology on her private fields makes both her and overall farm income lower. The explanation for this is the lower productivity of the private fields than of the collective fields. If the bargaining process within the household process works, she and the overall farm family would have higher incomes with the technology introduced on the collective fields.

In the final scenario, new technologies are introduced on both the private and collective fields. Again, the female cultivates 1.75 ha. Her private-plot income stays the same but she is also able to receive earnings from the new technology introduction on the collective field. Here the female would first work her private plot, which has lower productivity than the collective field. The household head has to pay more to obtain outside labor. Hence, family income declines from the case of introducing only new technology on the collective fields. The female worker is better off here but the family income is reduced for the seven adult equivalents. They would be better off by raising her wages and getting her to concentrate her attention on the collective fields. These are model results (Table 4) based upon assumptions about within-family wage bargaining. There is some field evidence for this type of wage determination but further field surveying is necessary on the within-family income distribution over time.

Publications and Presentations

Publications

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

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Sanders, J.H., 1990. "Agricultural Development," in V.W. Ruttan (ed.), Health Constraints in Agricultural Development, Dept. of Agricultural and Applied Economics, University of Minnesota, St. Paul, Staff Paper P90-74 published from a workshop, pp. 72-76.

Presentations

Ramaswamy, S., "Mobilization of Women's Labor From Within Large Farm Households in the Sahel—A Bargaining Analysis," paper presented at Annual Farming Systems Research/Extension Symposium, Michigan State University, Oct. 1990, based on his 1990 Ph.D. dissertation supported by INTSORMIL.

Ahmed, M.M., and J.H. Sanders, "The Impacts of Hageen Dura 1 in the Gezira Scheme, Sudan," paper presented at CRSP Seminar on Evaluating New Technologies, Detroit, MI, Nov. 1990.

Ahmed, M.M., and J.H. Sanders, "The Impacts of the Introduction of a New Sorghum Hybrid in the Gezira Scheme of Sudan," further extension of above paper, cited in text, Oct. 1991.

Gonzalez-Rey, D., M. Lopez-Pereira, and J.H. Sanders, "The Impact of New Sorghum Cultivars and Other Associated Technologies in Honduras," paper presented at CRSP Seminar on Evaluating New Technologies, Detroit, MI, Nov. 1990.

Sanders, J.H., "Farm Decision-Making on New Technologies: Does Risk Make a Difference?" paper presented at Departmental seminar on Risk Analysis, Dept. of Agricultural Economics, Purdue University, West Lafayette, IN, May 1991.

Sanders, J.H., "Impact of Agricultural Technology on Sub-Saharan African Women Farmers: Helpful or Harmful?" seminar presented to Women's Study Group, Purdue University, West Lafayette, IN, May 1991.

Networking Activities

Workshops

Sunder Ramaswamy presented a paper from his Ph.D. dissertation on the impacts on women of new technologies in Burkina Faso at the annual Farming Systems Research/Extension Workshop at Michigan State University in October 1990.

In November 1990, economists from four CRSP projects presented their results in a workshop on the economic evaluation of various projects. John Sanders participated in two planning meetings and received funding from this project. With this funding Mohamed Ahmed and John Sanders carried out field research in the Gezira project. Miguel Lopez-Pereira had done his Ph.D. dissertation on a related topic and briefly returned to Honduras. Two papers were presented on the impact of INTSORMIL research in Honduras and the Sudan (cited in Publications). These two papers were released as an INTSORMIL staff bulletin entitled "Host Country Impact Studies, Honduras and Sudan", Feb. 1991. This bulletin was distributed in Washington in spring 1991 as background on INTSORMIL impacts to USAID and Congressional representatives.

Research Exchanges

Collaboration was begun on a manuscript condensing and unifying the results from journal articles and theses in this project. Collaborators responsible for specific chapters or parts of chapters include Sunder Ramaswamy, Barry Shapiro, Kimsey Savadogo, Mohamed Ahmed, and Della McMillan (World Bank). The tentative title of this manuscript is "The Economics of Agricultural Technology Development in Semi-Arid Sub-Saharan Africa."

Resource Efficient Crop Production Systems

Project UNL-113

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Summary

Sorghum flowered 14 days earlier when 171 kg ha^{-1} N was applied to continuously grown sorghum as compared to no applied N. Of significance, sorghum grown in rotation with soybeans flowered 20 days earlier than continuously grown sorghum with no applied N and six days earlier than sorghum fertilized with 171 kg ha^{-1} N. This flowering difference suggests that there is possibly a P response. Shortening of maturity is very much like a growth response to applied P.

Sorghum leaf area duration was significantly influenced by a previous legume crop and applied nitrogen. Comparison of the forage legumes phillipesara and clitoria indicated sorghum retained leaf area better after phillipesara.

Sorghum genotypes for temperature and osmotic stress germination studies were from INTSORMIL Project PRF-107 and local Niger cultivars. Average germination for genotypes ranged from 52% to 87%. Lowest germination occurred at 45°C. Genotype P1058 consistently had a low germination where genotypes P1016, P1041 and P1044 tended to have higher percent gemination. Temperature gradient results indicated relative high germination from 25°C and 35°C. Germination decreased with increased osmotic stress. The genotypes that germinated best with no stress also germinated better with increased stress. These genotypes were P1004, P1006 and P1056. Seeds germinated best at 35°C at all levels of stress.

For Segaolane in Nebraska, resources (water, nutrients) were partitioned into weeds/grain/stover, with weeds making up as much as 42% of the total biomass in the treatment with the lowest management (no nitrogen or weed control). Sorghum grain yield was improved from 0.72 Mg ha^{-1} to 2.80 Mg ha^{-1} with complete weed control. However, sorghum grain yield was improved from 0.72 Mg ha^{-1} to 4.50 Mg ha^{-1} with the highest management of complete weed control and 114 kg ha^{-1} applied nitrogen. In all cases as the management of weeds and fertility improved, yield was increased.

Objectives, Production and Utilization Constraints

Objectives

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

Evaluate the nitrogen contribution of intercropped cowpea harvested for forage and grain to millet. In 1990 this four-year study will conclude by looking at residual contributions.

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

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

Long-term studies to determine pearl millet/cowpea cropping systems (monoculture, rotation, intercropping) by nitrogen fertilizer rate interaction effects will be initiated in Niger.

Evaluate the nitrogen by weed control on yield and water use of sorghum hybrids and local cultivars.

Evaluate stand establishment properties of grain sorghum lines used in the PRF-107 breeding program for stand establishment under drought, high temperatures and soil crusting conditions. Data collected during the past three years will be summarized and analyzed.

Evaluate short season lines and hybrids for agronomic characters and use in cropping systems.

Establish a collaborative research effort in Honduras and Mali.

Constraints

There are many constraints involved in 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. The importance of nitrogen 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) as monetary constraints for purchasing fertilizer occur in many developing countries. Improved nitrogen fertility also improves water use efficiency of grain crops.

Rotations

Grain sorghum-soybean rotation.

Research Methods

Sorghum and soybeans can be grown in rotation, a sustainable agricultural system. Although cereal yields are improved, other factors need to be considered when making management decisions. One of objectives of this study is to determine the influence of residue on nutrient cycling and plant growth and development. The experiment is a long term rotation. It 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} is applied as ammonium nitrate to the designated sorghum plots. Yield and yield components and agronomic data are taken from the two middle rows of six row plots.

Research Results

Research with maize indicated earlier flowering if it was grown after soybeans. Table 1 shows the time to 50% flowering of sorghum grown after soybeans and after sorghum (continuously) with the addition of varying levels of applied nitrogen. Sorghum flowered in 86 days if grown continuously to sorghum with no applied nitrogen. Application of nitrogen reduced the time of flowering by 14 days with the highest application rate. However, growing sorghum after soybeans resulted in a flowering period of 66-67 days. This is about 20 days earlier than the nitrogen stressed sorghum and even six days earlier than the fertilized sorghum. Applied nitrogen essentially had no effect. Both responses observed suggest that there is possibly a phosphorus response. Shortening of maturity is very much like a growth response to applied phosphorus.

Table 1. Days to 50 percent bloom as affected by nitrogen applied and previous crop.

Treatment		Days to 50% flowering
Continuous sorghum	0 kg/ha N	86
	56 kg/ha N	76
	112 kg/ha N	75
	168 kg/ha N	72
Sorghum after soybeans	0 kg/ha N	67
	56 kg/ha N	67
	112 kg/ha N	67
	168 kg/ha N	66

Bionitrogen availability and water use efficiency of grain sorghum grown in rotation with legumes in Sudan. (Mirghani S. Mohamed)

Research Methods

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 Vanderlip's criteria.

Research Results

Yield response to nitrogen and previous legume crop was previously reported (Annual Report, 1990). However, frequent sampling allowed for looking at the leaf area duration (LAD) as influenced by previous legume crop and applied nitrogen. LAD due to the previous legume crop was significantly different (P=0.05) for the growth intervals between the 2nd and 5th growth stages (Fig. 1). Grain sorghum following phillipesara tended to respond better than when it followed clitoria or sorghum. In general, grain sorghum tended to respond better with applied nitrogen (Fig. 2). The only significant difference (P=0.05) was between fertilizer and no fertilizer at the 3rd growth stage. At present, the growth data are being used in developing models to describe the various growth parameters.

Figure 1. The effect of previous legume crops on sorghum leaf area duration.

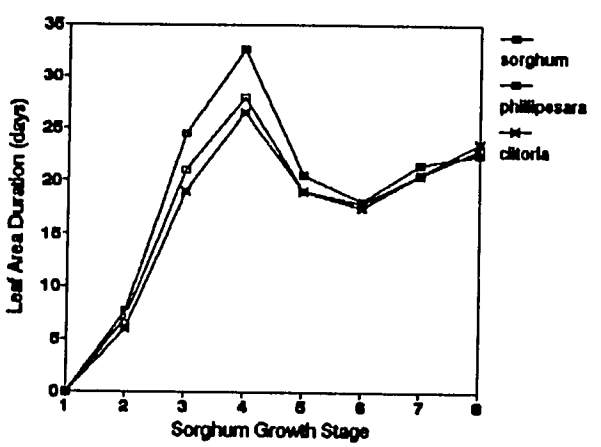
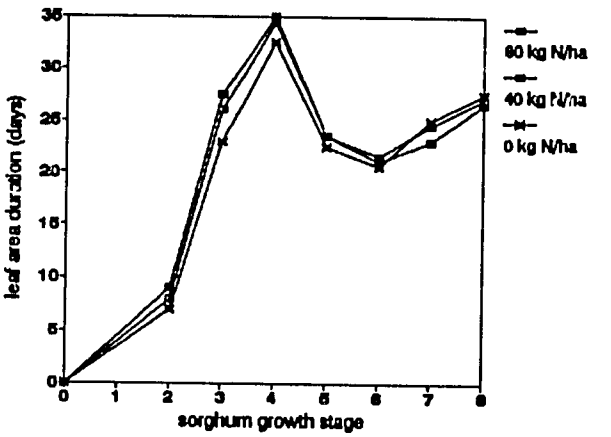


Figure 2. The effect of applied nitrogen on sorghum leaf area duration.



Grain Sorghum Germination Studies

Temperature and stress on germination.
(Helen Kasulu)

Research Methods

Studies to evaluate kernel weight, mesocotyl and coleoptile length, germination under varying temperature and osmotic potentials were conducted. Most seed (breeding lines and Niger cultivars) used was increased in Puerto Rico.

For temperature studies, a completely randomized experimental design with split plot treatment arrangement was used. Temperatures were 25/25, 30/30, 30/37, and 30/45 °C night/day and genotypes were subplots. A 12/12 hour night/day period was used. Seeds were germinated using moist germination towels. Also, a temperature gradient table was used to obtain temperatures over a large range (15, 20, 25, 27.5, 30, 35, 38 and 40°C). Temperatures were the main plots and sorghum genotypes were the subplots. Four replications were used.

For temperature x water potential studies, temperatures were 25, 30, 35, and 40 for 1989 and 25, 30, and 35 °C for 1990. Water potential was adjusted to 0, -0.4, -0.8 and -1.2 Mpa with 8000 molecular weight polyethylene glycol. The design was a randomized complete block with a split split plot arrangement. Temperature was the unreplicated main plot, osmotic potential as subplots, and genotypes sub-subplots. Seed was placed in petri dishes (four replicates) with about 1.5 mils of water or PEG solution and incubated for

nine days. A seed was considered germinated when the radicle length was 2mm.

The seed weight studies related the genotype seed weights or 100 seeds to germination and seedling emergence.

Research Results

The genotypes use in the studies are shown in Table 2. This material represents some of the lines from INTSORMIL Project PRF-107 and local Niger cultivars. The Niger cultivars are adapted to harsh environmental conditions.

Table 2. Genotypes used in the studies.

P1028	P1029	P1016	P1006	P1041
P898012	P1044	P1004	P967083	P1056
P1052	P1045	P1055	P1058	

Germination differences between sorghum genotypes to temperature occurred, but these were inconsistent over years. Average germination for genotypes ranged from 52% to 87%. Lowest germination occurred at 45°C. The genotype P1058 consistently had a low germination across years. Genotypes P1016, P1041, and P1044 tended to have higher percent germination, especially at higher temperatures. Temperature gradient results indicated relatively high germination from about 25°C to 35°C. Germination decreased quickly with temperatures lower or higher than these. In the genotype by temperature, most genotypes had the highest percent germination at 35°C and the lowest at 40°C. A unique event occurred for both years. Germination at 25 and 35°C was higher than 30°C.

Percent germination of most genotypes decreased with decreasing osmotic stress. Greater germination differences between genotypes occurred with no water stress. Variation in germination decreased as the osmotic stress was reduced from 0 to -1.2 Mpa. The genotypes that germinated the highest with no stress also germinated better with increased stress. These were P1004, P1006 and P1056. In all cases, as stress was increased germination was reduced. Seeds of grain sorghum germinated greatest at 35°C at all levels of stress.

Kernel weight varied with year. Genotypes P1016 consistently had one of the heaviest kernels, whereas, P1056 and 1055 had the lightest.

Present study - Studies to determine a physiological basis for seed germination and emergence under crust are being conducted in association by Dr. Stephen C. Mason who is on faculty improvement leave in Spain.

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, 57, and 114 kg ha^{-1} ammonium nitrate side-dressed three weeks after planting. Main plots were levels of weed control and subplots were nitrogen levels. Three replications were used. Samples were harvested from the middle two rows of six row plots.

Research 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 3. For Segaolane in Nebraska, both yield and total biomass were affected regardless of the fertility level. Resources (water, nutrients) were partitioned into weeds/grain/stover, with weeds making up as much as 42% of the total biomass in the treatment with the lowest management (no nitrogen or weed control). Sorghum grain yield

Table 3. The effect of applied nitrogen x weed control on sorghum stover and grain yield and weed yield and each as a percent of the total biomass.

Nitrogen (kg ha^{-1})	* Weed control	Stover (mg ha^{-1})	% of Total	Grain (Mg ha^{-1})	% of Total	Weeds (Mg ha^{-1})	% of Total
0	1	2.67	45	0.72	12	2.50	42
	2	4.23	57	2.25	30	0.96	13
	3	5.07	64	2.80	36	0.00	0
57	1	3.55	47	1.23	16	2.72	36
	2	4.50	51	2.54	29	1.75	20
	3	5.69	62	3.54	38	0.00	0
114	1	4.54	45	2.53	25	2.98	30
	2	4.96	50	4.06	41	0.97	10
	3	6.39	59	4.50	41	0.00	0

*1 = no weed control, 2 = one cultivation after three weeks, 3 = weed free; Maliro, unpublished.

was improved from 0.72 Mg ha^{-1} to 2.80 Mg ha^{-1} with complete weed control. However, sorghum grain yield was improved from 0.72 Mg ha^{-1} to 4.50 Mg ha^{-1} with the highest management of complete weed control and 114 kg ha^{-1} applied nitrogen. In all cases as the management of weeds and fertility improved, yield was increased.

Present studies - Greenhouse studies are being conducted to determine the nitrogen and water interaction when the stress (due to time of water application) may kill the plants. Some protocol is being developed.

Publications and Presentations

Publications

Clegg, M.D., 1991. Nitrogen removal by grain sorghum and soybeans as affected by rotation and applied nitrogen. 17th Biennial Grain Sorghum Research and Utilization Conference, Lubbock, TX.

Clegg, M.D., R.L Vanderlip, and S.C. Mason. Sustainable systems approach to sorghum/millet production, Sorghum Millet conference, Corpus Christi, TX.

Gutierrez, P.F., D.H. Meckenstock, and M.D. Clegg. 1991. Growth and yield of Honduran sorghum in pure stand and intercropping. Agron. Abst. p.61.

Mohamed, M.S., M.D. Clegg, and A.M. Parkhurst. 1991. Quantitative growth analysis and yield of sorghum as affected by nitrogen and previous legumes in Sudan. Agron. Abst. p.62.

Scoby, D.L., and M.D. Clegg. 1991. An economic analysis of sorghum cropping systems and nitrogen fertilization in east central Nebraska. Agron. Abst. p. 160.

Presentations

Dr. Max D. Clegg presented a paper "Sustainable systems approach to sorghum /millet production" at the Sorghum Millet conference, Corpus Christi, TX.

Networking Activities

Internship: African Internship, Rockefeller Foundation (Mirghani Mohamed, last year).

Faculty improvement leave: Dr. Stephen C. Mason is spending a year in Spain. He is studying mechanisms influencing emergence in crusting soils.

Assistance: Funding transfer to Mali and Niger.

Nutrient Use Efficiency in Sorghum and Pearl Millet

Project UNL-114

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Dr. Omar Niangado, Principal Millet Breeder, Cinzana, Mali
Mr. Abdoul Toure, M.S. student, University of Nebraska, from Mali
Mr. Cherif Oumarou, Agronomy Division, IRAN, B.P. 240, Niamey, Niger
Mr. Seyni Serifi, Agronomy Division, Maradi Research Station, INRAN, B.P. 240, Maradi, Niger (currently M.S. student, University of Nebraska)

Summary

Experiments were conducted in the greenhouse on pearl millet to better understand the influence of nitrogen (N) rate and timing on growth and water use characteristics. These experiments were part of research for two M.S. theses conducted by students from Mali and Niger.

The results of these studies showed that pearl millet responds to applied N when residual soil N is low. Since soils used in these experiments were similar to that of the Sahelian region where these crops are grown, it would be likely that these results can be translated in terms of field response. It has already been shown by collaborative work that pearl millet yields can be doubled in Niger by judicious use of N. The current studies also showed that the time N is applied can influence productivity as well. This has been shown in Mali for sorghum. The results did not show any appreciable influence on leaf water potential or stomatal conductance, but there was a tendency for applied N to reduce both of these parameters. Exactly how this translates into water use efficiency alterations is not yet clear.

A study conducted to investigate the variability of nitrogen use efficiency (NUE) in sorghum relative to available soil N and genotype source showed that genotypic variation in NUE was highly significant but largely dependent on the yield factor of interest, i.e., grain or total biomass. Genotype variability was also markedly influenced by soil N level and geographic origin. It was determined that simultaneous improvement of sorghum for plant N, grain N and NUE for grain or biomass should be possible.

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 semiarid 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

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.

A potential constraint to the UNL-114 collaboration in the next year may be that the current collaborator, Mr. Abdoulaye Traore, will start a graduate program at Nebraska, and this leaves an immediate void in the short run. It will take Mr. Abdoul Toure a little readjustment time to fit into the IER program as he returns this December, and he is the only person so far that will probably be involved with UNL-114 in the agronomic/physiological area.

Work in Niger has been pretty much on hold until Mr. Seyni Serifi completes his degree and returns.

Research Approach and Project Output

International

Two experiments were conducted in Mali by Mr. Abdoulaye Traore which were related to N management and subsequent influence on N use efficiency of selected sorghum genotypes. Complete data did not arrive in time to be included in this report, but the following summarizes this research.

The first experiment compared an improved and a local genotype over three levels of N fertilizer (0, 50, and 100 kg/ha N), applied either all at tillering or all at panicle initiation at two locations. The results showed that the local variety had a higher grain and dry matter yield when no N fertilizer was applied. This observed interaction confirmed earlier demonstrations that local types can outperform improved types under low management (See INTSORMIL 1990 Annual Report, pp. 27-34).

A second experiment was also conducted at multiple locations to compare a "local" variety to improved varieties S-34 and ICSU 1063 at four different N rates (0, 40, 80 and 120 kg/ha N). Similar to the former experiment, a variety by N rate interaction was detected. In this instance, the "local" variety produced more grain and total above ground dry matter at the low N rates, and also more total biomass at the high N rates because of the large amount of stalk material which this variety produces.

The results of the N chemical analyses are pending, but the experiments tend to support the contention that use of improved sorghum genotypes in Mali can only be effective if an improved management package is included.

Domestic

Study 1 - (Abdoul Toure, Mali, M.S. Thesis)

A greenhouse experiment was conducted as part of M.S. thesis research to supplement the field work previously reported (see INTSORMIL 1990 Annual Report, pp. 27-34). This work was conducted by Mr. Abdoul Toure of Mali.

The pot experiment consisted of a split-split plot arrangement with genotypes as the main plot. Genotypes used were the same as for the field experiment, i.e., ICTP-8203, an African type, and 68A x MLS, a selection derived from a cross between an adapted U.S. genotype and a population. Nitrogen level was the subplot and consisted of a low (0 N applied), medium and high treatment. The N was applied at 25 or 50 days after emergence (DAE) similar to the field experiment.

Table 1 shows that increasing N generally increased grain and stover yield of the genotypes studied as would be expected if residual soil N was low. The field experiment did not show a significant response to N, and this was assumed to be due to high residual soil N level (Toure and Maranville, 1991). There also appeared to be a relative disadvantage to delaying N application except for the genotype 68A x MLS. This might be expected since the young plants were under a severe N stress early and probably didn't fully recover when N was finally applied. There was no apparent difference in genotype response to N when averaged over all treatments although 68A x MLS had a very high yield at the medium N application applied 25 DAE.

The same trends were observed for N treatment with respect to total biomass and N uptake (Table 2). However,

Table 1. Grain and stover weight as affected by genotype, N rate and time of N application in the greenhouse experiment, 1990.

	Grain weight						Stover weight					
N	ICTP-8203			68A x MLS			ICTP-8203			68A x MLS		
rate	0	25	50	0	25	50	0	25	50	0	25	50
	---------- g/plant ----------											
L	6.1	7.5	8.2	5.9	5.7	6.0	11.6	8.8	14.3	9.0	8.6	8.8
M	33.5	38.5	25.3	25.1	84.3	13.8	54.5	48.4	25.9	31.5	30.2	20.1
H	65.8	39.4	11.7	30.9	34.1	10.1	69.1	52.5	33.7	29.3	36.9	20.2
Mean	35.1	28.5	15.1	20.6	41.4	10.0	45.1	36.6	24.6	23.3	25.2	16.4

Table 2. Biomass and N total uptake per plant as affected by genotype, N rate. Greenhouse experiment, 1990.

N rate	Biomass weight: ICTP-8203 0	ICTP-8203 25	ICTP-8203 50	68A x MLS 0	68A x MLS 25	68A x MLS 50	Plant N content: ICTP-8203 0	ICTP-8203 25	ICTP-8203 50	68A x MLS 0	68A x MLS 25	68A x MLS 50
	g/plant						mg/plant					
L	17.7	16.3	22.6	14.8	14.2	14.9	80	100	120	80	30	30
M	88.1	86.8	51.2	56.5	54.4	33.3	610	640	540	470	580	380
H	124.8	91.9	45.6	60.2	61.0	30.3	500	930	470	870	820	440
Mean	76.9	65.0	39.8	43.8	43.2	26.2	730	557	377	473	497	303

Table 3. Nitrogen efficiency as affected by genotype, N rate and time of N. Greenhouse experiment, 1990. NE_1 = 9 biomass g^{-1} N. NE_2 = g grain g^{-1} N.

N rate	NE_1: ICTP-8203 0	ICTP-8203 25	ICTP-8203 50	68A x MLS 0	68A x MLS 25	68A x MLS 50	NE_2: ICTP-8203 0	ICTP-8203 25	ICTP-8203 50	68A x MLS 0	68A x MLS 25	68A x MLS 50
	g/plant											
L	218	[illegible]	197	171	154	174	76	73	79	65	61	72
M	143	135	95	116	100	77	54	60	42	58	61	34
H	95	103	104	70	78	77	40	47	87	37	43	35
Mean	152	136	132	119	114	109	57	60	70	53	55	47

the taller African genotype produced significantly more biomass which was reflected in more total N accumulation as an average of all N treatments. This was accounted for primarily from the greater amounts of stover for ICTP-8203 rather than grain.

Nitrogen efficiency values for biomass or grain production (Table 3) indicated that higher soil N available reduced N efficiency. This is a general tendency often observed in other cereal crops (Maranville, et al., 1980). There appeared to be little influence of time of N application on N use efficiency in this greenhouse experiment.

The African Genotype ICTP-8203 had a higher N use efficiency for total biomass production than the improved type (Table 3). This is a common observation in low N soils. There was a tendency for this genotype to also have higher N use efficiency values for grain production which has not generally been observed in some field experiments (see INTSORMIL 1990 Annual Report, pp 27-34). The results support the general conclusion that pearl millet response to N fertilizer is dependent on the inherent soil N fertility or residual N available.

Study 2 (Seyni Serifi, Niger, M.S. Thesis)

A greenhouse study similar to the previous one was conducted to determine the influence of N on water use of pearl millet. Five genotypes were grown at four levels of N in a complete randomized design. Genotypes tested were MLS, ICTP-8203, 68A x MLS, HMP 559 and Dwarf PI185642, the first two being tall African types and the latter three being short types. Levels of N were 0, 50, 100 and 150 mg N per pot, each containing one plant, and replicated three times. Plants were grown at a water level of one-half field capacity determined once a week by weight. There were visible signs of water stress throughout the experiment, but not sufficient to stop plant growth and eventual seed set. Measurements included dry weight, tiller production, leaf water potential and leaf conductance. The following results are preliminary data.

Similar to Study 1, the results of Study 2 show that pearl millet responds to N application in low residual N soils. The greatest response to N was in the first increment (50 mg/pot) and may be an indication that the crop does not need as much N as other coarse grains (Table 4). There appeared to be little genotype difference in total growth with the shorter genotypes comparing favorably with the taller African types (Table 5). Very often in the field, the taller types produce

Table 4. Means of dry matter production and tillers per plant as influenced by N rate in a greenhouse experiment. Means are averaged over five genotypes and three replications.

N rate	Leaf wt.	Stem wt.	Head wt.	Total biomass	Tillers
mg pot^{-1}	g/plant				No. $plant^{-1}$
0	4.4	6.3	5.0	15.7	3.6
50	25.6	25.1	17.5	68.2	8.8
100	35.3	27.6	15.6	78.5	10.0
150	34.1	33.1	16.2	83.4	10.6

Table 5. Means of dry matter production and tillers per plant of five pearl millet genotypes grown in the greenhouse at four N levels. Average of three replications.

Genotype	Leaf wt.	Stem wt.	Head wt.	Total biomass	Tillers
	g/plant				No. $plant^{-1}$
MLS	27.5	20.4	17.2	65.1	7.8
ICTP-8203	38.6	30.2	6.6	75.4	8.8
68A x MLS	28.6	22.9	16.5	68.0	9.3
HMP 559	34.1	36.4	10.7	81.2	7.8
Dwarf PI 185642	37.3	16.2	17.6	71.1	7.8

more total biomass than the shorter ones due to more stalk production. This does not, however, always translate into more grain.

Nitrogen fertility tended to decrease the stomatal conductance in leaves at the vegetative and flowering stages but most notably at the vegetative stage (Table 6). There was also a tendency for N fertilizer to decrease total water potential at both growth stages. A decrease in leaf water potential from the vegetative stage to flowering was observed, and this was observed for all genotypes (Table 7). Little difference was observed among genotypes for leaf water potential at either growth stage, but stomatal conductance values were more variable (Table 7). Genotype 68A x MLS appeared to have a lower value at the vegetative stage for stomatal conductance than the others. However, the difference was not evident at flowering. At the flowering stage, genotype ICTP-8203 appeared to have a markedly larger stomatal conductance than other genotypes in the study.

Study 3 - (Youngquist, Bramel-Cox, Maranville)

Previous studies indicated that variation exists for N uptake and utilization efficiencies, but germplasm sources that have been evaluated were generally limited in numbers and origin. A study was conducted to study the variability of NUE in sorghum relative to available soil N and genotype source. The feasibility of improving NUE without sacrificing yield was also investigated.

Forty sorghum genotypes were evaluated with high and moderate N treatments. The germplasm included 10 adapted varieties, 10 sorghum conversion lines, and 20 exotics from three sources (Table 8). Two dual purpose sorghums with phenotypes similar to those of the source 1 exotics, Atlas and Ellis, were included in the exotic germplasm to complete a block of 10. Each set of the exotics was classified based on similar morphological characteristics. Source 1 had characteristics more closely associated with forage or world types whereas source 2 exotics had undergone some adaptation to domestic conditions. The experiment was conducted on a site having a natural residual soil fertility gradient. The moderate N fertility treatment had a residual 2 m soil nitrate level of 10 kg ha^{-1} to which was applied 80 kg ha^{-1} fertilizer. The high fertility treatment had a residual 2 m soil nitrate level of 30 kg ha^{-1} to which was applied 150

Table 6. Stomatal conductance and total leaf water potential (Ψ_w) of pearl millet as influenced by N rate in a greenhouse experiment at vegetative and flowering growth stages. Values are means of five genotypes and three replications.

	Vegetative		Flowering	
N rate (mg/pot)	Stomatal conductance (mm sec^{-1})	Ψ_w (MPa)	Stomatal conductance (mm sec^{-1})	Ψ_w (MPa)
0	307	-2.45	167	-2.19
50	107	-3.01	170	-2.15
100	118	-3.14	139	-2.70
150	153	-2.92	123	-2.67

Table 7. Stomatal conductance and total leaf water potential (Ψ_w) of five pearl millet genotypes at the vegetative and flowering growth stages in a greenhouse experiment. Values are means of four N rates and three replications.

	Vegetative		Flowering	
Genotype	Stomatal conductance (mm sec^{-1})	Ψ_w (MPa)	Stomatal conductance (mm sec^{-1})	Ψ_w (MPa)
MLS	144	-2.98	162	-2.43
ICTP-8203	150	-2.93	214	-2.14
68A x MLS	108	-2.71	143	-2.40
HMP 559	186	-2.82	141	-2.56
Dwarf PI 185642	157	-2.95	140	-2.48

Table 8. Germplasm type, genotypes and seed source.

Germplasm type	Genotype	Seed Source
Adapted varieties	N91	J. Eastin, Univ. of Nebraska
	IA28	P. Bramel-Cox, Kansas St. Univ.
	Martin	"
	TX430	"
	KX9	"
	TX7078	"
	TX2752	"
	KS18	"
	TX623	"
	Wheatland	"
Conversion lines	SC33-6	"
	SC599-6	"
	SC103	"
	SC642	"
	SC279	"
	SC566	"
	SC630	"
	SC414-12	"
	SC35-6	"
	SC303	"
Exotics (source 1)	Segaolane	"
	Atlas	"
	SanChiSan	"
	IS22201	"
	China 17	"
	N32	"
	DR144	D. Andrews, Univ. of Nebraska
	86M-11102	"
	Ellis	H. Gorz, Univ. of Nebraska
	M35-1	J. Maranville, Univ. of Nebraska
Exotics (source 2)	Dorado	D. Andrews, Univ. of Nebraska
	784	"
	1276	"
	1300	"
	DR14	"
	DR50	"
	1247-2	"
	IRAT 204	"
	IS1347	P. Bramel-Cox, Kansas St. Univ.
	N94B	J. Eastin, Univ. of Nebraska

kg ha^{-1} N fertilizer as ammonium nitrate. Two row plots 6 m long with 0.75 m row spacing were planted in a split-split plot design with three replications. Sprinkler irrigation was used as needed to prevent water deficit. Weeds were controlled by hand. Due to poor seed quality, plant densities were low for some entries. At maturity, three plants per plot were harvested from a section of the plot having good stand. The area from which they were harvested was measured and final yields were adjusted for differences in plant density of the harvested area. Panicles were harvested separately from stover. After oven drying, dry weights were measured and panicles threshed to determine grain yield. Nitrogen was determined on dried and ground sub samples by Kjeldahl.

Measured variables included stover dry weight (SDW), grain dry weight (GDW), stover N concentration (SN%) and grain N concentration (GN%). Calculated values from measured data included total above ground plant dry weight (TDW), total plant N (PN), total grain N (GN), utilization efficiency of whole plant production as TDW/PN (NE_{TDW}), utilization efficiency of grain production as GDW/PN (NE_{GDW}), and harvest index as GDW/SDW (HI). Analyses of variance were calculated for each N level, and treatment means subsequently adjusted using the co-variate of row length harvested. Combined analyses of variance over both N levels were calculated on adjusted means, and pooled error terms were used to test significance.

The components of N use efficiency were defined as follows:

TDW/SN=(PN/SN)(TDW/PN) and TDW/PN=TDW/GDW) (GDW/PN)
where TDW/SN = N use efficiency of total dry matter production
PN/SN = N uptake efficiency
TDW/PN = N utilization efficiency of dry matter production
TDW/GDW = ratio of total plant dry weight to grain dry weight, the inverse of harvest index
GDW/PN = N utilization efficiency of grain production
Similarly,
GDW/SN = (PN/SN)(GDW/PN) and GDW/PN = (GDW/GN)(GN/PN)
where
GDW/SN = N use efficiency of grain production
GDW/GN = grain produced per unit of grain N
GN/PN = fraction of total plant N translocated to the grain, often referred to as nitrogen harvest index (NHI)

The multiplicative factors become additive upon conversion to log such that $Y_k = \Sigma_i X_i$ where Y_k is the log of N use efficiency and $\Sigma_i X_i$ the sum of logs of the multiplicative factors contributing to N use efficiency. For instance,

$$\log(TDW/SN) = \log(PN/SN) + \log(TDW/PN).$$

The proportion of sums of squares attributable to the X_i component is:

$$\Sigma X_i y/\Sigma y^2 = (r_{yxi})S_{xi}/S_y$$

where r_{yxi} is the correlation coefficient and S_y and S_{xi} are the standard deviations for the log of N use efficiency and the X_i the component.

Significant variation in yield and N parameters are found both among germplasm type and among genotypes within germplasm type. Effects of soil N level were generally significant and contributed more to total variation than did germplasm type for all traits except HI. N level also contributed more to total variation than genotype within germplasm type for GN, PN, NE_{GDW}, and NE_{TDW}. The lack of significant interactions indicated that relative performance of genotypes was similar in both soil N treatments.

The contribution of genotypes of different germplasm types to the total variation of genotype within germplasm type varied depending upon the germplasm type. Adapted varieties had the lowest variation among genotypes. The use of adapted varieties in previous studies may explain the lack of difference often detected in N uptake in some of this research. The improvement of adapted material for N use efficiency traits should be enhanced through crossing with other sources. The highest variation in N uptake and NE_{TDW} were sorghum conversion lines and exotics. Exotic germplasm had the highest mean TDW and three times the variation in TDW among its genotypes than did the other germplasm types. Exotic sources also contributed a higher proportion of total genotype within germplasm variation than other germplasm sources for NE_{GDW} and HI. The highest variation for grain yield was found among sorghum conversion lines and source 2 exotics. Sorghum conversion lines and/or source 2 exotics had mean values as great as or greater than, and provided nearly as much or more variation in yield and N use traits as source 1 exotics with the exceptions of TDW and HI. Source 2 exotics had the highest mean grain yield of all types tested. The source 2 exotics '1247-2' and '1300' ranked in the top 20% for GDW, TDW, NE_{GDW}, and NE_{TDW}. Germplasm which has undergone some adaptation to domestic conditions, such as the sorghum conversion lines and source 2 exotics, could provide a good source of variation for N uptake and utilization traits and avoid some of the problems associated with trying to cross adapted material to exotic material.

The relative contributions of uptake and utilization efficiencies to genotypic variation in total N use efficiency varied depending upon soil N level, germplasm type and the yield factor of interest, i.e., grain or total plant dry weight. Uptake efficiency was the primary factor contributing to total dry matter production and grain yield differences, contributing more than 80% of the genotypic variation in both soil N treatments. Utilization efficiencies, NE_{TDW} and NE_{GDW}, tended have greater relative contribution in the high N soil. Within the high soil N treatment, N was not limiting and advantages associated with scavenging N were reduced as adequate N was probably available for all plants. Plants with high N uptake ability may be assimilating an abundance of N, but if the excess N cannot be utilized to produce more dry matter, there is no real advantage and N

efficiency is greatly reduced. Differences in plants' abilities to assimilate the N and produce dry matter is generally reflected as differences in their utilization efficiencies. In the moderate N soil, adequate plant N was available with aggressive uptake and this factor became the primary contributor to genotypic differences in N use efficiency as related to whole plant production.

Factors contributing to variation in utilization efficiencies were also influenced by germplasm and soil N. At each soil N level, TDW/GDW contributed substantially to variation in NE_{TDW} in the source 1 exotic germplasm while GDW/PN (or NE_{GDW}) contributed more for varieties and source 2 exotics. Except for the sorghum conversion lines, GDW/GN was at least as important as translocation of N to the grain (GN/PN) in contributing to genotypic variation in grain yield in both soil N treatments. The magnitude of the contribution of GDW/GN and GN/PN was greater in the high N soil treatment resulting in the greater relative contribution of utilization efficiency to the total sums of squares.

Although variation in N uptake and utilization efficiency traits among sorghums was shown, a knowledge of whether or not improvement in N uptake and utilization can be made without concurrent loss in yield potential is also of great importance. The results from this study indicated that simultaneous improvement of yield and N utilization efficiency should be possible. Plant N uptake and grain N content were highly correlated with both GDW and TDW for all germplasm types indicating that improvement in uptake efficiency and grain N content should occur simultaneously with improvement in yield. Utilization efficiencies, NE_{GDW} and NE_{TDW} had nonsignificant or negative correlations with GDW and TDW within the moderate soil N treatment. At the high soil N level, correlations between utilization efficiencies and yield were often positive and of higher magnitude.

Simultaneous improvement among N use traits PN, GN, NE_{GDW} and NE_{TDW}, should also be possible. The very high correlation of GN with PN indicates selection for high N content in the grain should generally result in plants with greater N uptake from the soil. Correlations of GN and PN with NE_{TDW} were consistently negative in the moderate soil N treatment, but nonsignificant or positive in the high soil N treatment. Correlations between the utilization efficiencies NE_{GDW} and NE_{TDW} tended to be positive in both soil N treatments. Given the lack of genotype x soil N interaction and the smaller, or even negative, correlations among traits in the moderate soil N treatment, greatest gains would most likely be seen in a breeding program where selections were made in high soil N, and then testing at varying levels of soil N. These results may be applicable only to production environments where N is not severely limiting and other environmental parameters are conducive to plant growth. In very low soil N environments, or in environments where stress severely inhibits plant growth and development, the relationships found in this experiment between yield and N use efficiencies may or may not hold true. Further investigations under these severe stress conditions would be needed to clarify this point.

Publications

Youngquist, J.B. and J.W. Maranville. 1990. Relative contributions of component traits for N use efficiency to genotypic variation in sorghum. p. 7. *In* R.R. Duncan (ed.). Sorghum Newsletter. Univ. of Georgia - Griffin.

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Networking Activities

UNL-114 supplied $9000 to Mali for collaborative research in nitrogen agronomy and physiology. In addition, training was provided to Mr. Abdoulaye Traore of Mali for three months at UNL in the area of English language and data management.

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

Project UNL-116
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Summary

Our midseason stress resistance screening model testing continued through 1991 and results remain encouraging. A mostly tan plant population generated from stress screening has been random mated three times and is in a winter nursery grow out to check for wild outcross contamination. If the grow out is satisfactory, the population will be submitted for release in the spring of 1992. No further testing of the midseason stress screening model is anticipated but a number of selections from the population are being hybridized and tested for possible release. Physiological characterization of stress resistant lines is underway.

Future germplasm manipulation will revolve mostly around incorporating larger seed size into our midseason (preanthesis) stress resistant population which has a generally high seeds m^{-2} number (and consequently small seed size). While high seed number is associated with preanthesis stress tolerance (and high yield), seed size capacity appears to be a significant factor in postanthesis stress tolerance. Landraces from limited yield stress areas tend to have larger seeds. Whether that relates more closely to stress tolerance or consumer preference for large seed is not known. 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 (possible length of grain fill indicator or controller) is being evaluated.

Studies to optimize nitrogen fixation and water use efficiency by legumes in sorghum/millet based cropping systems will be continued. Heavy pubescence in stress environments appears to enhance photosynthesis and water use efficiency.

Objectives, Production and Utilization Constraints.

Objectives

1. Develop and apply practical sorghum stress screening in the U.S. and LDC's.

2. Continue sterilization of new stress resistant B lines and produce new hybrids.

3. Continue cultural practice/cropping system/physiological/research in Niger, Sudan and western Kansas.

4. Develop canopy photosynthesis/transpiration/water use efficiency (WUE) measurement techniques. Also a

more reliable method to measure soil CO_2 flux and soil evaporation is being developed. It involves instrumentation development.

5. Cooperate on USDA/OICD Dryland Agriculture projects in India.

Constraints

Drought and low WUE, Nitrogen, High temperatures, Low temperatures, LDC infrastructures

Research Approach and Project Output

Research Methods and Findings by Objective

Objective 1: Stress screening is continuing for midseason stress tolerance. A random mated population has been derived principally from stress screening at Garden City, KS. Stress was especially severe in 1988 when 900 S_2 families were screened and reduced to 100 families which were recombined and random mated three times since then. The population is in a winter grow out to check for wild outcross frequencies and will be released if the grow out is satisfactory. A number of lines developed from the original 1988 S_2 family selection are responding favorably in stress tests. Also some S_2 and S_3 families were sent to Dr. R. R. Duncan for a 1990 grow out in a pH 4.3 Georgia soil with 50% Al saturation and an organic matter content of 1 to 2%. U.S. hybrids will not grow and develop in this test site. However, Dr. Duncan was able to select a number of panicles in 1990, pooled them for a Puerto Rico winter nursery increase and replanted them (an S_3 and S_4 genotype mixture) in 1991 in the acid soil Georgia test site. Five plots (2 rows x 44 each) were subjected to gridded mass selection using SC283 as an Al tolerant check. Ten heads selected (best by eye) from each plot of about 100 heads gave mean g/panicle weights of 48.7 (range 31-65.7), 36.5 (20.4-54.9), 46.9 (34.2-65), 55 (39.3-72.6) and 35.2 (27-42.2). The overall mean was 44.5 g/panicle compared to a mean panicle weight for the SC283 checks of 24.2 g (25.6, 23.4, 28.2, and 19.7). The 44.5 g/24.2 g ratio = 1.84 or 84% superiority for the S_3 and S_4 panicle weights. The actual grain weight superiority is not as critical as the fact that the selected plants grew as well as SC283 which is not a particularly high yielder. It does, however, demonstrate that we have succeeded in putting improved yield capacity from Great Plains screening into plants adapted to low organic matter acid soils with moderate Al saturation. Furthermore, the base midseason stress resistant population from which the original S_1 and S_2's were selected to get the acid tolerant S_3 and S_4 genotypes was screened in pH 6 to 7+ soils for heat and drought responses. Screening for heat and drought tolerance appears to have resulted in concentrating genes for stress tolerance of a fairly broad nature.

Testing of the midseason stress tolerance screening methodology developed by us appears to verify that the screening model works satisfactorily and can be used by others interested in midseason stress. Our timing approach to stress pressure is similar in many respects to Dr. D. T. Rosenow's approach but perhaps pressure is more severe. Also we have consciously focused more heavily on analyzing yield components (especially seed number which correlates positively with yield). This focus has demonstrated that the net critical characteristic of midseason stress tolerant germplasm is that it produces a fairly stable seed number at a reasonably high seeds m^{-2}. Again, since seeds m^{-2} correlates positively with grain yield the stress tolerant genotypes capable of generating a high seeds m^{-2} are usually water responsive and give high yields in the good years. Looking for these characteristics has permitted developing genotypes which are both stress resistant and water responsive. These genotypes, however, tend to have small seeds because of their high seed numbers. Since those who use sorghum as a food grain generally prefer medium to large grain and since cattle feeders believe larger more uniform seed rolls (crushes) better to improve starch availability, there is a need to improve seed size in our midseason stress resistant germplasm pool. This improvement of seed size effort was initiated five generations back. Some early generation crosses with seed size potentially 10 to 25% larger than average U.S. hybrids will be tested in 1992. This project has substantive cooperation with industry breeders. Our goal is to find the level to which seed size can be increased without reducing seed number to the point which forces yield reductions in different yield level environments. This evolves into defining the utility of seed size expansion (compensation) capacity during grain filling after midseason stresses have reduced seed number. A second way of stating this goal is to evaluate the role of seed size and compensation capacity as stress resistance mechanisms or attributes where postanthesis stress is prevalent. Postanthesis stress is common in many of the world's developing countries and occurs periodically in the U.S.

Physiological research underway is aimed at trying to determine the most limiting physiological processes and/or stress resistance mechanisms operating in sorghum. While photosynthesis (PS) is essential, it rarely correlates very positively with grain yield. On the other hand, increasing night temperatures do reduce the seeds m^{-2} differentiated and consequently reduce yields. The night temperature effect implicates respiration (R) because the paces of respiration and coupled synthetic activities are controlled by temperature. Therefore, in view of the generally negative correlation between increasing night temperature and yield, experiments were set up at Garden City, KS to monitor field canopy PS and R in a stress resistant (DK46) and normal (RS671) sorghum during the vegetative, reproductive, and grain filling stages to see if differences could be related to grain yield.

No significant differences in canopy PS, R or transpiration rates were noted during vegetative development (prior to panicle initiation). However, during growth stage 2 (reproductive development), PS rates were from two to four times higher in stress resistant DK46 than in RS671 (Figure

1). The transpiration (T) rate in DK46 was double the T rate in RS671 during the warmest part of the day in keeping with comparative PS rates of about four times higher for DK46 during the same time period. Calculated instantaneous water use efficiencies during the warm part of the day were on the order of three times higher in DK46 compared to RS671. Respiration differences (Figure 2) appear to be insignificant.

Precipitation was received before measurements were taken during grain fill and no PS or R differences were noted. The R component was much larger due to grain filling. Despite the marked reduction in PS and transpiration during reproductive development, final yields for RS671 and DK46 were surprisingly not different (3551 and 3386 kg ha^{-1} respectively). Additional analyses and experiments will be required to develop meaningful explanations of these observations. Sorghum is obviously very plastic in response to environmental stresses which makes stress mechanism research rather challenging.

Objective 2. Backcrossing to sterilize stress resistant B lines is continuing on a small scale.

Objective 3. Continue cultural practice/cropping system research in Niger, Sudan and the U.S. Little research was done in Niger because our cooperators were out of the country most of the time. The research progress report which follows relates to fertility problems in Sudan. The work is being done in Lincoln by Mr. Gandoul I. Gandoul as part of his Ph.D. dissertation. Mr. Gandoul is an employee of the Agricultural Research Corporation (ARC) in the government of Sudan. Nitrogen availability is a serious limiting factor in sorghum production in the deep cracking clay soils in the Gedarif area near the Wad Medani ARC station. Mostly sorghum monocropping for over 50 years has seriously depleted soil N and N fertilizer is very expensive. A major task then for Mr. Gandoul is to evaluate several possible legumes when he returns home to develop economic rotation systems to improve sorghum yield by improving legume N fixation and yield. Learning techniques to do this is a major goal in his Ph.D. investigations. The experimental legume is soybean. Mr. Gandoul's analysis of the problem follows.

Soybean yield is dictated through the integrated effects of many physiological processes including photosynthesis (PS) and associated transpiration (TR), assimilate translocation and utilization through respiration (R) and many coupled syntheses. These processes are partially integrated through source-sink interactions and are influenced by environment and the individual morphological and physiological characteristics peculiar to individual plants. The balance between assimilated carbon and sinks (leaves, roots, nodules, stover and seeds) dictates yields of the various

Figure 1. Sorghum growth stage two (panicle development) CO_2 exchange, Garden City, 1991.

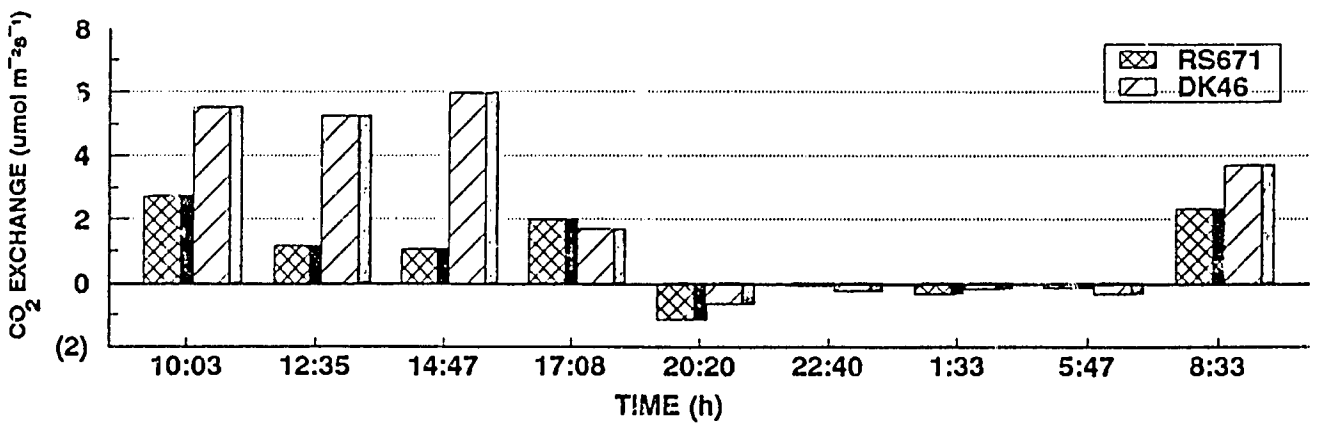
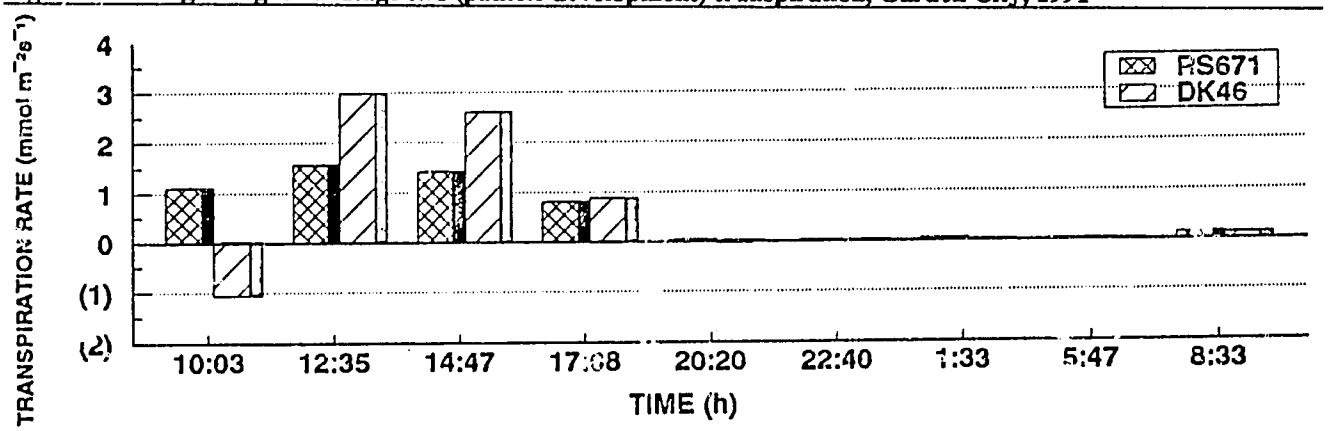


Figure 2. Sorghum growth stage two (panicle development) transpiration, Garden City, 1991



sinks. The amount of carbon retained as dry matter is determined by total photosynthesis and the efficiency of respiration and coupled synthetic processes producing dry matter. Legumes are commonly considered as source-limited rather than sink-limited and, therefore, photosynthate supply is an influential yield limiting factor to evaluate (Harrison et al., 1981; Buttery et al., 1981; Boerma and Ashley, 1988; Schultz, 1978). Energy requirements in developing seeds, roots and associated nodules of soybeans influence photosynthesis and final grain yield. There is, however, only limited information on whole plant or canopy photosynthesis and respiratory responses of crop plants in relation to energy costs of fruiting bodies and nitrogen-fixing nodules (Minchin et al., 1976). Therefore, more research is needed on photosynthesis and respiration to characterize assimilate partitioning among competing sinks (particularly nodule formation and function versus seed development) and at least partially quantify the energy receipts and expenditures in relation to yield differences.

Ongoing objectives are to (1) measure whole plant and canopy PS (assimilate supply) and TR, (2) measure canopy R and pod R at several periods to assess aerial assimilate requirements (sinks), (3) estimate soil CO_2 fluxes before and during pod development and (4) measure instantaneous water use efficiency (IWUE) - CO_2 uptake/H_2O transpired. Objectives 1 and 4 relate to maximizing efficient use of water in water limiting environments. Objectives 2 and 3 relate to N fixation and seed production. The division of assimilates between seed production and N fixation in different legumes is critical in that the value of seed versus N fixed for the following cereal takes on different meanings depending on the cost of N fertilizer, especially if foreign exchange is required to get it.

Methodology for gas exchange measurements is the same as for sorghum measurements above. A solid base (1.2 m x .9 m) is installed at ground level which supports a chamber (1 m long x .75 m wide x 1 m tall) to enclose the canopy for PS, R, and TR measurements using a LICOR 6200 system. Pod measurements were taken at four canopy heights (four pod maturities). An added twist to the general objectives stated above was to use two Clark (C) soybean isolines differing in pubescence level to evaluate the influence of pubescence mostly on PS and TR. Normal pubescence is CN and dense pubescence is CD. Plots were put on upland (drier) and lowland (wetter) conditions but both areas were dry late in the season. The upland soil is a Crete silt loam (an eroded soil) and the lowlands a fertile Kennebec silt loam. Soil moisture control (% wt/wt) during pod formation averaged 14.5% and 13.7% respectively in the upland and lowland soils with no differences between the CN and CD isolines. During pod filling, the upland soil moistures were 15% (CN) and 16% (CD) compared to lowland moistures of 18.4% (CN) versus 16.1% (CD). During both periods, the CD isoline was more vigorous, resulting in more leaf area and sometimes higher total water use. Three replicates in a RCB design were used.

Results

Gas exchange measurements for a 24 hour period at early flowering showed no significant differences ($P > 0.17$) between the isolines. The diurnal pattern of CO_2 exchange was quantified. Photosynthetic rate for both isolines reached its maximum level during the morning and noon hours and then fell gradually towards the evening hours. Respiration was generally lower at dawn (lower temperature) compared to night hours. Although differences were not significant, the CD isoline tended to fix more CO_2 at early flowering. There were no significant differences between the two isolines for transpiration or IWUE.

At pod formation the two isolines showed significant differences for the four attributes ($P > 0.001$) (Figs. 3, 4, and 5). The pubescent isoline exhibited greater photosynthetic rates and IWUE while maintaining lower leaf temperatures and transpiration rates. Averaged over water levels the dense pubescent isoline fixed significantly more CO_2 and used water more efficiently than the normal pubescent isoline under water limiting conditions, however, there were no significant differences under lowland conditions. Comparison between isolines at different moisture levels over 24 hour periods showed significant differences between isolines at each water level. The trend is always for higher PS and R rates under the higher water level (Fig. 6). Under the lower moisture, CD exceeded CN for PS and R.

Figure 7 shows significant differences between the two isolines throughout the day at the pod filling stage. The CD isoline showed higher PS and R rates and lower leaf temperatures. There were no significant differences between the two isolines for TR. There was a significant genotype X water supply interaction for PS where the rates were higher for CD under dry conditions but trends were not consistent for R, TR and IWUE.

Figure 8 shows mean pod respiration. There were significant differences among pods with the greater rates for the more mature pods and least in younger ones. Pod 2 did not differ from pod 3 but both were higher than pods 1 and 4 at 10:00 hr. Higher respiration in more mature pods reflected higher photosynthate demand by these pods compared to lower sink strength in the young pods. The CN isoline showed significantly lower pod respiration compared to CD. In general, pod energy demand will need to be evaluated more carefully in relation to root system demands for root expansion and N fixation activities.

In summary, the dense pubescent isoline tended to show greater photosynthetic rates, respiration rates and instantaneous water use efficiencies and lower transpiration rates compared to the normal isoline. Higher respiration rates probably may be attributed to the relatively higher PS and resultant supplies of assimilates. Leaf hairs and early stomatal closure are probably responsible for the sometimes lower CD transpiration rate. High pubescence legumes

Figure 3. Soybean photosynthesis (Ps) and respiration (R) during pod formation at Lincoln, NE, 1991. Numbers are leaf temperature (C).

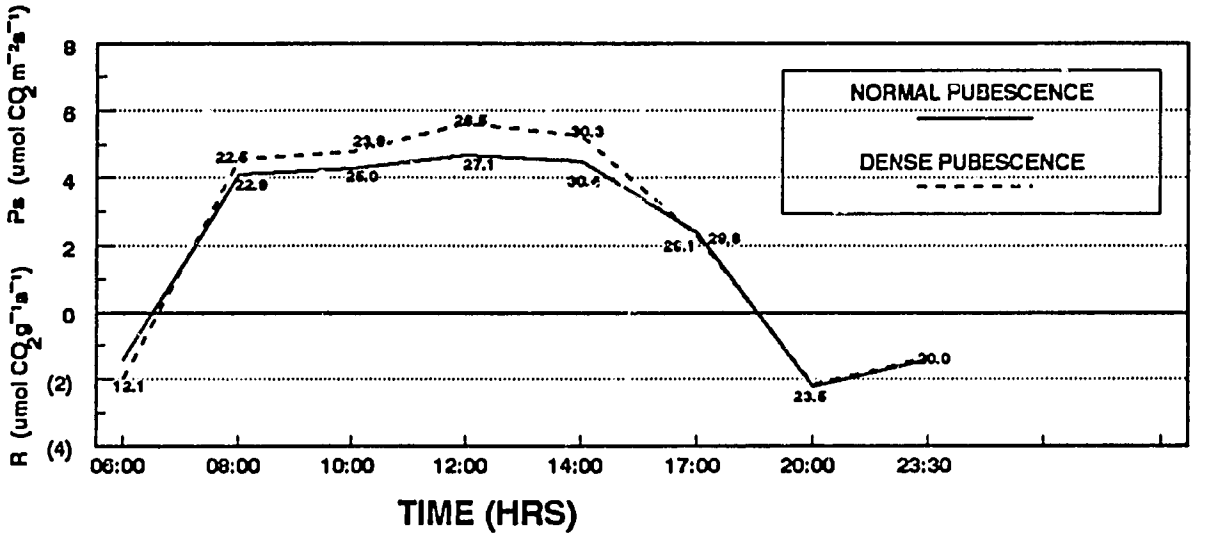


Figure 4. Soybean transpiration (TR) during pod formation at Lincoln, NE, 1991. Numbers are leaf temperature (C).

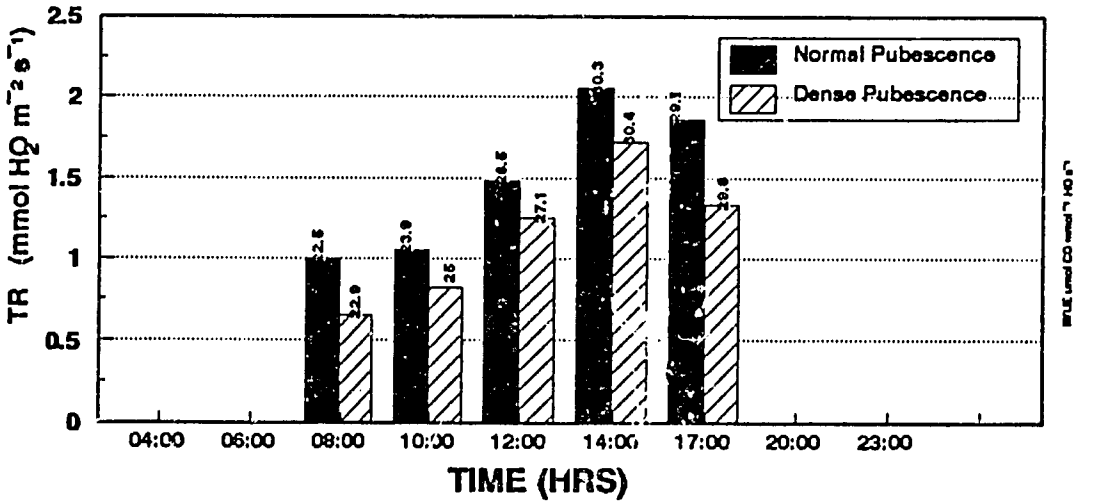


Figure 5. Soybean Instantaneous water use efficiency (IWUE) during pod formation at Lincoln, NE, 1991.

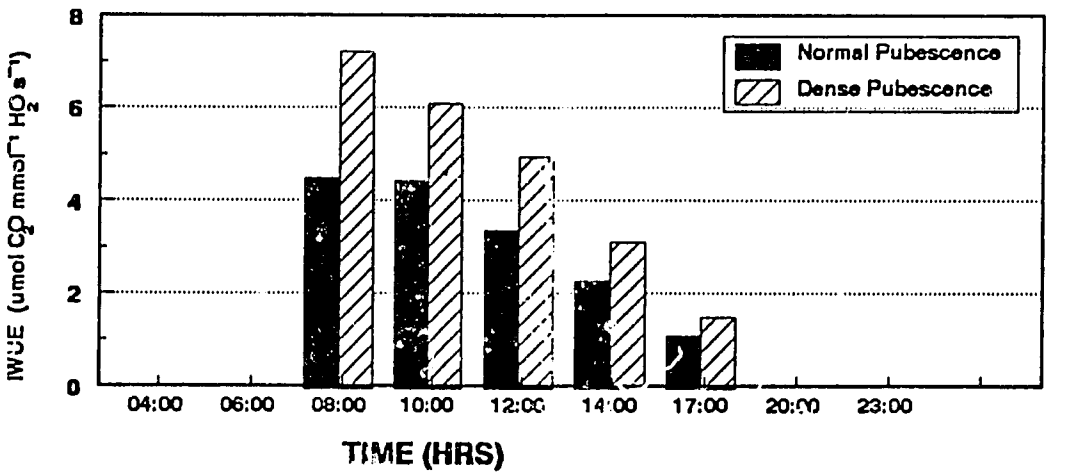


Figure 6. Upland and lowland soybean photosynthesis (Ps) and respiration (R) during pod formation at Lincoln, NE, 1991. Numbers are leaf temperature (C).

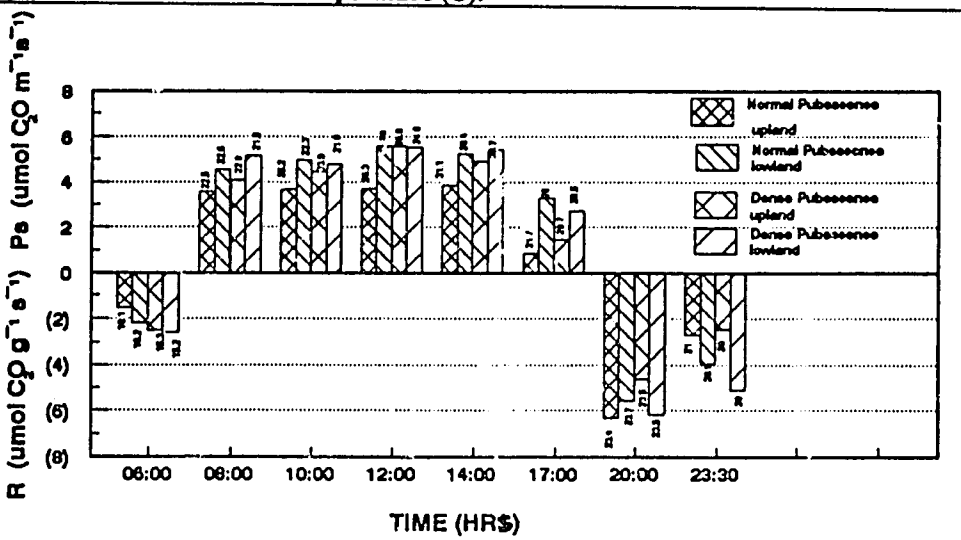


Figure 7. Soybean photosynthesis (Ps) and respiration (R) during pod filling at Lincoln, NE.

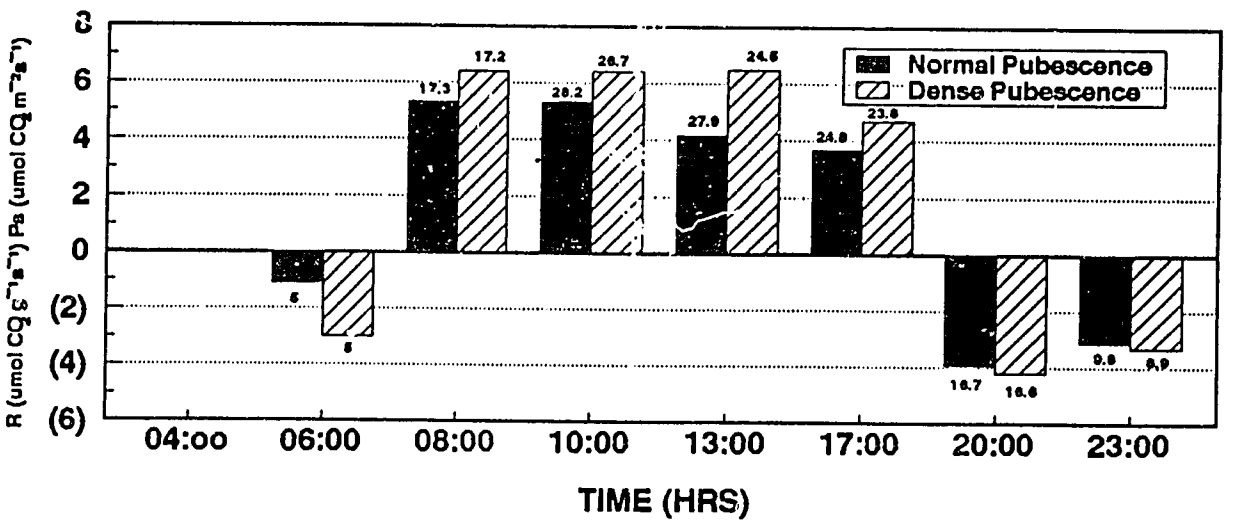
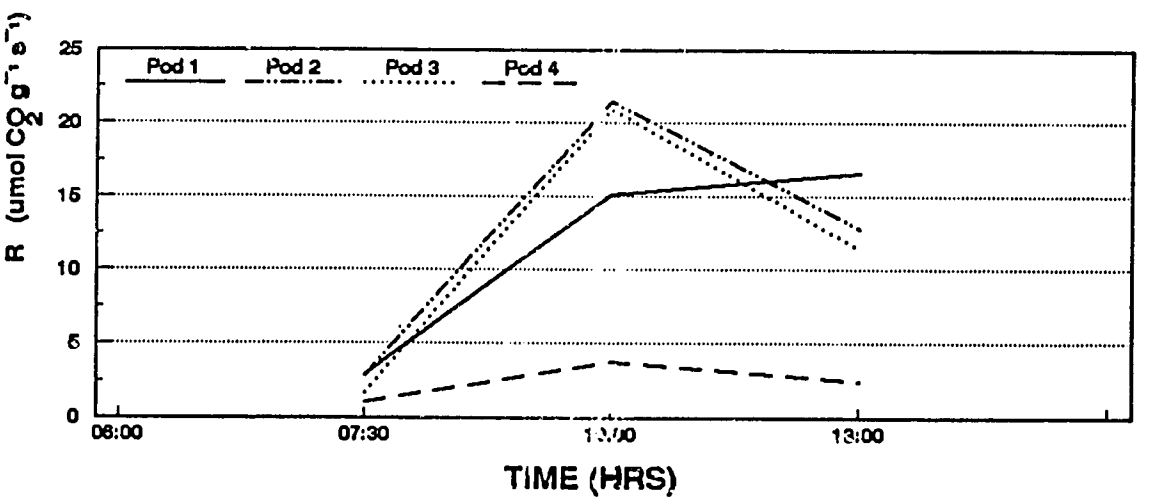


Figure 8. Soybean pod respiration (R) 37 days after flowering at Lincoln, NE, 1991.



should be useful in Sudan to maximize WUE in their limiting water conditions.

No attempts have yet been made to measure soil CO_2 and water fluxes. Methodology is still being developed. This is

a very early stage progress report and many more analyses are needed to evaluate temperature and soil moisture effects on physiological characteristics which control the balance between N fixation and seed production. The desired balance in any given location will depend on the relative value of the legume seed compared to the value of N fixation for the succeeding sorghum and millet crop.

Reports on Objectives 4 and 5 will be deferred to 1992.

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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. Increasing the efficiency of crop selection for unpredictable environments. Accepted for the January-February, 1992 issue of Crop Science.

Chapters in Books

Livera Munoz, M., J.D. Eastin and J.M. Norman. 1990. Microclima, temperaturas nocturnas elevadas, respuestas fisiologicas y rendimiento en sorgo. *In* A Larque-Saavedra (ed.) El Agua En Lasplantas Cultivados. pp. 95-104. Colegio De Postgraduados. Chapingo, Mexico.

Journal Abstracts

Verma, P.K., J.D. Eastin, and J.E. Partridge. 1990. Tissue specificity of heat shock response in sorghum. Agronomy Abstracts. p. 133. Am. Soc. of Agronomy, Madison, WI.

Verma, P.K., M. Nouri, A. Alou, J.D. Eastin and K.C. Reddy. 1990. Effect of crop residue on millet production in Niger. Agronomy Abstracts. p. 64. Am. Soc. of Agronomy, Madison, WI.

Zavala-Garcia, F., P.J. Bramel-Cox, J.D. Eastin and D.J. Andrews. 1990. Stability analysis of S_1 population derived from sorghum families. Agronomy Abstracts. p. 117. American Soc. of Agronomy, Madison, WI.

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.

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.

Invited 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 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.

Networking

Workshops

Program planning committee and a research session chair for the 1991 INTSORMIL Annual Meeting and Workshop at Corpus Christi, TX.

Both planning and presentation in an International Symposium on Global Climate Change, New Delhi, India, January 1991.

Research Investigator Exchanges

Four scientists from Egypt, one each from Senegal, Ethiopia and Mali.

Germplasm and Research Information Exchanges

Germplasm Conservation Use

169 large seeded accessions acquired for postanthesis stress work.

International exchange: Over 400 population derived R lines sent to Egypt. About 40 R lines to Texas A&M. Stress resistant population to Senegal and ICRISAT, India. Three A/B pairs and 10 R lines to Spain. A/B pair to Senegal.

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

Two LICOR 6200's and two infrared thermometers have been loaned to cooperators in India to work on stress mechanisms in sorghum plus PS and IWUE research on *Lucaena* (Subabal) and sorghum in intercropping systems in the rabi season.

Mechanisms of Environmental Stress Resistance in Sorghum and Pearl Millet Relative to Sustainable Production Systems

Project UNL-123

C.Y. Sullivan
University of Nebraska

Principal Investigator

Dr. C. Y. Sullivan, Professor of Agronomy and Plant Physiologist, USDA/ARS, University of Nebraska, Lincoln, NE

Collaborating Scientists

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Dr. John Leslie, Department of Plant Pathology, Kansas State University, Manhattan.
Mr. Sidi Bekaye Coulibaly, Agronomy Department, University of Nebraska, Lincoln, and IER, BP 258, Bamako, Mali.
Mr. Siriba Dione, Agronomy Department, University of Nebraska, Lincoln, and IER, BP 258, Bamako, Mali.

Summary

A temperature of 36/22°C (day/night) favored higher plant photosynthesis and growth compared to plants grown at 28/22°C. The Malian sorghum Gadiaba particularly responded positively to the higher temperature. The Malian local sorghums Gadiaba and CSM 228 tended to maintain their growth when water stressed.

All genotypes increased their cellular (membrane) heat tolerance when exposed to the higher temperature. There was a trend by the Malian sorghums to acquire greater heat tolerance.

Osmotic adjustment (OA) appears to be an important mechanism for adaptation to water stress. Particularly at the higher temperature, OA was significant for the Malian local sorghums, CSM 228, Gadiaba, and Malisor 5. Thus, OA appears to be one characteristic that could be selected for in sorghum improvement for production in stressful environments.

There was about a 10 times higher accumulation of proline when plants were water stressed at either temperature, compared to nonstressed plants. But, the higher temperature appeared to metabolically reduce the accumulation.

Gadiaba had a relatively larger root system than the other sorghums, which is usually favorable for stress resistance. This result indicated that Gadiaba has also evolved a stress avoidance mechanism in addition to high stress tolerance.

Objectives, Production and Utilization Constraints

Objectives

Define plant physiological characteristics which are most affected by drought and high temperature stress and identify mechanisms which may be selected or managed for improved stress 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

The primary constraint being addressed is environmental stress, 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

Malian graduate students Sidi Bekaye Coulibaly and Siriba Dione neared completion of their M.S. degrees in agronomy. Their research has been directed toward gaining a better understanding of sorghum morphological, physiological and biochemical characteristics which permit the plants to tolerate or avoid environmental stresses and to attain maximum, stable grain yields. Of particular concern has been an evaluation of the characteristics of Malian local sorghums, particularly those which evolved in the high stress-proned areas, as compared to U.S. developed geno-

types. Some of the areas receiving attention have included: photosynthesis, stomatal resistance, leaf area and dry weight development, water, osmotic and turgor potentials, stem diameter and internode length, water use and water use efficiency, leaf temperatures, heat and desiccation tolerance, rooting characteristics, accumulation of metabolites proline and abscisic acid, and the influence of abscisic acid on stress resistance.

The research reported here is that of graduate students' studies, primarily those of Mr. Coulibaly.

Research Methods

Growth chamber and greenhouse experiments were conducted in order to have better control of the environment. Studies were directed toward evaluating specific responses and characteristics that may contribute to understanding the physiological basis for high temperature and drought resistance of Malian and other sorghums.

Growth Chamber Experiments

Sorghum seeds were germinated in paper towels. Seven to eight days after start of germination, seedlings were transplanted into nutrient solution. The study included two experiments with four genotypes from Mali (CSM 63, Malisor 5, Gadiaba, and CSM 228) and one U. S. check (CK60B). Two growth chambers were used for the experiments. They were set for identical environmental conditions, except one chamber had a higher day temperature than the other. During an initial establishment period of four days, both chambers were set at the same day/night (28/22°C) temperatures. The day temperature of one chamber was then increased gradually until it reached 36°C. The day temperature of the other chamber remained at 28°C, and the night temperature of both chambers was 22°C. Water stress was induced by adding polyethylene glycol 8000 (PEG 8000) to the nutrient solution. This stress was also increased gradually. Physiological measurements began three days after the final application of PEG. In the second experiment, after the plants were stressed the PEG was removed and seven days were allowed for plant recovery and the physiological measurements repeated.

Photosynthetic rates were measured on plants using the syringe method. Leaf proline was determined as described previously (1990 Annual Report). Leaf water potentials were made on a fully expanded leaf from the top of the plants in both stressed and nonstressed treatments. Measurements were done with Peltier psychrometers. Leaf osmotic potentials were measured with the same psychrometers and cups after freezing the leaf samples with dry ice and thawing, without removing the samples from the cups. Leaf turgor potentials were calculated from the leaf water and osmotic potentials.

Because of closeness of plants, leaf area was measured as the product of leaf length and leaf width with appropriate regression coefficients.

Cellular heat tolerance was measured by the conductivity method.

Greenhouse Experiments

Greenhouse experiments related to possible genotypic differences in water use (WU) and water use efficiency (WUE). Plants were grown in plastic cylinders (102 cm deep and 10 cm diameter) containing aerated nutrient solution. The first experiment included five sorghums with two genotypes from Mali (CSM 219 and Malisor 7), one genotype from Ethiopia (E35-1), and two genotypes from the U.S. (B35-6 and CK60B). In the second experiment, four sorghum genotypes were used with three genotypes from Mali (CSM 63, Malisor 5, and Gadiaba), and one genotype from the U.S.(CK60B). At 30 days after planting, water was withheld from plants that were to be water stressed, which permitted the nutrient solution level to lower gradually in the cylinders. This allowed stress to develop slowly. At approximately 60 days after transplanting, measurements began. Measurements included number of main roots, number of leaves, total dry weight (shoot and root), and water use. Water use efficiency (WUE) was calculated as the ratio of total dry weight (shoot + root) to total water use.

Research Findings

Growth Chamber Experiments

Table 1 gives the average photosynthetic rates and total leaf area for the five sorghums studied. The higher temperature increased leaf area relative to those grown at the low temperature. Under both temperatures, the highest total leaf area was obtained by Gadiaba. Malisor 5 had the next highest leaf area at both 28°C and 36°C. The genotypes Gadiaba and Malisor 5 had the highest percent increase in leaf area in the high temperature.

Table 1. Total leaf area and average photosynthetic rate of sorghums grown at two different day temperatures.

	Average rate of photosynthesis		Total leaf area	
Genotype	28/22°C	36/22°C	28/22°C	36/22°C
	- - mg CO_2/sec/m^2 - -		- - - - - cm^2 - - - - -	
CSM 63	A 0.13 b	A 0.15 b	B 132 b	A 171 c
Malisor 5	A 0.16 ab	A 0.18 ab	B 164 b	A 229 b
CK60B	A 0.20 a	A 0.25 a	A 110 b	A 138 c
Gadiaba	B 0.14 b	A 0.21 ab	B 219 a	A 343 a
CSM 228	B 0.15 ab	A 0.24 ab	A 142 b	A 165 c
Mean	B 0.15	A 0.21	B 154	A 209
C.V.(%)	22.9	36.03	27.92	21.55

[1] Ps = Average rate of photosynthesis.
[2] TLA = Total leaf area.
Capital letters compare the two temperatures for each genotype.
Lower case letters compare the genotypes within temperature. Values with the same letter in a column and in a row within a temperature treatment are not significantly different at the 0.05 level.

In the higher temperature, Malisor 5 and Gadiaba had significantly more total leaf area than CK60, but there were no significant differences in average photosynthetic rates per unit leaf area, which means that effectively Gadiaba and Malisor 5 had higher photosynthesis per plant. Genotypes CSM 228 and Gadiaba had significantly greater increases in photosynthetic rates in the higher temperature than the other sorghums. Gadiaba is a durra type sorghum that is grown in a high stress area near Kayes and Bema, Mali. Malisor 5 is an improved Malian sorghum, selected for agronomic attributes and stress resistance. CSM 228, a guineense local, is also grown in the more stressed areas of Mali. Both genotypes have apparently evolved with adaptive mechanisms for stress resistance.

There were generally no marked differences in heat tolerance among genotypes, although CSM 228 tended to have an inherently higher heat tolerance when not stressed at the lower temperature. There was also a tendency for CSM 63, which is grown in less stressful areas, to have less cellular heat tolerance than the other genotypes. All genotypes had higher heat tolerance when water stressed and grown at the higher temperature.

There were significant differences in leaf water potentials between genotypes in both temperatures. When water stressed at 28°C, CK60 maintained a higher leaf water potential than Malisor 5, and in the higher temperature (36°C) it maintained higher leaf water potentials than Malisor 5 or Gadiaba when water stressed. These results indicate that the Malian local Gadiaba and improved variety Malisor 5 have evolved, or were selected, to tolerate stress rather than to rely on avoidance alone. The check CK60 exhibited more avoidance characteristic in this experiment than the Malian locals.

Osmotic potentials (OP) and amount of osmotic adjustment (OA) for the sorghums grown at the two temperatures are shown in Table 2. When water stressed at 28°C, Malisor 5 and CSM 63 osmotically adjusted to a greater extent than the other genotypes. However, when water stressed at a higher temperature, Gadiaba, CSM 228, and Malisor 5 adjusted to a significantly lower OP than CSM 63 and CK60. These results indicate that OA is a significant physiological characteristic for adaptation of the Malian local sorghums to the stressful conditions of sub-Sahara Africa. Also, when water stressed at the higher temperature Gadiaba and CSM 228 maintained higher leaf turgor potentials than Malisor 5 when water stressed, further indicating good adaptation of the locals to drought stress.

Table 2. Effects of temperature and water stress on grain sorghum leaf osmotic potential.

Genotype	Osmotic potential 28/22°C Control[1] (MPa)	28/22°C St[2] (MPa)	28/22°C OA[3]	36/22°C Control[1] (MPa)	36/22°C St[2] (MPa)	36/22°C OA[3]
CSM 63	B-1.7 b	A -2.7 ab	1.0	B-1.9 a	A -2.4 b	0.5
Malisor 5	B-2.1 ab	A -3.2 a	1.1	B-1.9 a	A -2.8 a	0.9
CK60B	A-1.9 ab	A -2.2 b	0.3	A-1.8 a	A -2.3 b	0.5
Gadiaba	B-2.0 ab	A -2.4 b	0.4	B-1.9 a	A -3.0 a	1.1
CSM 228	A-2.2 a	A -2.4 b	0.2	B-2.1 a	A -3.0 a	0.9
Mean	B-2.0	A -2.6	0.6	B-1.9	A -2.7	
C.V.(%)	14.06	18.30		14.79	11.64	

[1] Control = Nonstressed [2] St = Stressed [3] OA = Osmotic adjustment.
Capital letters compare the water treatments. Lower case letters compare the genotypes within water treatments. Values with the same letter in a column or in a row within a temperature treatment are not significantly different at the 0.05 level.

Table 3 shows the proline levels among genotypes and between water stress and temperature treatments. Water stress caused a pronounced increase in proline accumulation at both temperatures. It accumulated about 10 times higher when plants were water stressed. Malisor 5 and Gadiaba accumulated the greatest amount of proline when water stressed at 36°C and CK60 and CSM 228 the least amounts.

Table 3. Leaf proline content of water stressed and nonstressed sorghums grown in two different day temperatures.

Genotype	Temperature (°C) 28/22°C Proline Stressed (mg/gdw)	28/22°C Proline Control[1] (mg/gdw)	36/22°C Proline Stressed (mg/gdw)	36/22°C Proline Control[1] (mg/gdw)
CSM 63	A 3.67 a	B 0.24 a	A 2.05 b	B 0.22 bc
Malisor 5	A 2.25 a	B 0.55 a	A 3.49 a	B 0.31 ab
CK60B	A 2.41 a	B 0.23 a	A 0.82 c	B 0.11 c
Gadiaba	A 3.71 a	B 0.56 a	A 2.62 ab	B 0.41 a
CSM 228	A 3.38 a	B 0.13 a	A 0.63 c	B 0.19 bc
Mean	A 3.08	B 0.30	A 1.92	B 0.30
C.V. (%)	74.26	88.61	89.56	52.59

[1] Control = Nonstressed
Capital letters compare the water treatments for each genotype and means within water treatment and temperature. Lower case letters compare the genotypes within water treatment. Values not followed by the same letter in a column or in a row within a temperature treatment are significantly different at the 0.05 level.

The accumulation of proline was less when the sorghums were grown at 36°C than at 28°C and water stressed, except for Malisor 5 which had a slight increase. It was believed that increased metabolic rates in the higher temperature decreased the proline levels in the other genotypes. A negative correlation was found between leaf proline accumulation and leaf water potential for all genotypes.

Table 4 gives the root and shoot dry weights for these sorghums grown at the two temperatures. Gadiaba had the highest root dry weight at both temperatures, with or without stress. There were no significant differences in root dry weight for CSM 63, Malisor 5, CSM 228, or CK60 when water stressed at either temperature. At 36°C and nonstressed, Gadiaba, Malisor 5, and CSM 228 had higher root dry weights than CSM 63. Gadiaba had the highest shoot dry weight when plants were water stressed at 36°C. This again indicates the superior stress resistance of Gadiaba. Gadiaba and CSM 228 had higher shoot dry weights when not water stressed at both temperatures than CSM 63.

Greenhouse Experiments

Two experiments conducted in a greenhouse were concerned with water use and water use efficiency when plants were grown with and without water stress.

Table 4. Root and shoot dry weights of five sorghums when plants were water stressed and grown at two different day temperatures.

Genotype	Temperature 28/22°C Control[1]	28/22°C Stressed	36/22°C Control[1]	36/22°C Stressed
	RDW[2]		RDW[2]	
	---g---		---g---	
CSM 63	A 1.7 c	A 3.4 b	A 2.1 c	A 3.0 b
Malisor 5	A 3.2 b	A 3.1 b	A 4.5 b	A 3.9 b
CK60B	A 2.1 bc	A 1.8 b	A 2.6 bc	A 2.2 b
Gadiaba	A 8.3 a	A 7.9 a	A 9.3 a	A 7.6 a
CSM 228	A 2.3 bc	A 4.2 b	A 2.6 b	A3.1 b
Mean	A 3.5	A 4.1	A 4.2	A 4.0
C.V. (%)	39.97	46.82	36.71	38.83
	SDW[3]		SDW[3]	
	---g---		---g---	
CSM 63	A 4.6 c	A 5.6 bc	A 7.1 c	A 6.4 bc
Malisor 5	A 8.9 b	A 6.9 b	A 12.7 ab	B 7.8 b
CK60B	A 6.0 bc	A 3.8 c	A 8.0 bc	A 6.0 c
Gadiaba	A 17.9 a	A 11.75 a	A 19.9 a	A 15.3 a
CSM 228	A 8.7b	A 7.1 ab	A 9.4 ab	A 7.8 b
Mean	A 9.2	A 7.0	A 11.4	A 8.6
C.V. (%)	34.89	32.55	37.03	26.16

[1] Control = Nonstressed [2]RDW = Root dry weight [3]SDW = Shoot dry weight. Capital letters compare the two water treatments. Lower case letters compare the genotypes within water treatment. Values with the same letter are not significantly different at the 0.05 level.

As expected, water stress reduced plant height for all genotypes. Over all genotypes there was a 16% reduction in plant height due to water stress. At the time of measurement there were no significant differences among genotypes for number of internodes. However, water stress reduced the number of internodes by an average of three per genotype. Malisor 7 was reduced by four internodes. When nonstressed E35-1 had the longest internodes and B35-6 the shortest. Water stress reduced the internode length of CK60, but CSM 219 internode length remained the same as nonstressed controls.

When not water stressed, Malisor 7 and CSM 219 had longer roots than CK60. There were no differences among genotypes for root length when plants were water stressed. However, there was about a 60% increase in root length over all genotypes when water stressed as compared to the controls. E35-1 had the greatest increase in root length when water stressed (90%) followed by CK60 and Malisor 7, respectively. In general, water stress reduced only slightly the number of main roots. Genotype x treatment interactions for root length were highly significant, but not significant for the number of main roots.

There were also genotypic variabilities for root and shoot dry weights. When not stressed Malisor 7, CSM 219, and E35-1 had heavier root dry weights than CK60. When water stressed, however, there were no differences between Malisor 7 and CK60, while CSM 219 and E35-1 had higher root dry weights than B35-6 and CK60. Malisor 7 produced more shoot dry weight than CK60 and B35-6 when plants were not water stressed. It was interesting that the genotypes did not differ for root to shoot ratios under either water stressed or nonstressed conditions. They also produced more shoot dry weight when stressed, but the differences were not significant. While the stress x genotype interactions for shoot dry weights were highly significant, there were no stress x genotype interactions for root to shoot ratios.

Total dry matter produced generally followed the same pattern as shoot dry weight. Total water use records revealed that Malisor 7 and CSM 219 used the most water when plants were well watered, while CK60 used the least water whether with or without water stress. In this experiment, there were no differences among genotypes for water use efficiency (WUE). However, the means over all genotypes showed that there was an increase in WUE when plants were water stressed. Similar results have been reported by other researchers for sorghum, pearl millet, corn, and wheat.

Publications and Presentations

Publications

Sullivan, C. Y. and W. R. Jordan. 1991. Physiological effects of high temperatures and drought stress: Screening techniques and scope for genetic improvement. Proc. ICARDA-INIA Symp., Improvement and Management of Winter Cereals Under Temperature, Drought and Salinity Stresses. Cordoba, Spain, October, 1987. INIA, Madrid, Spain, pp. 115-129.

Lansac, A.R. 1990. Effects of cold on proline accumulation in sorghum pollen. Ph.D. Dissertation. University of Nebraska. Lincoln, Nebraska.

Barker, D. J. 1990. Physiological responses of sorghum and six forage grasses to water deficits. Ph.D. Dissertation. University of Nebraska, Lincoln, Nebraska

Presentations

Sullivan, C.Y. 1991. More on proline accumulation. Grain Sorghum Producers and Utilization Conference, Lubbock, Texas.

Networking Activities

Research Investigator Exchanges

The principal INTSORMIL scientist from Mali visited collaborating scientists and their facilities in Nebraska. Discussions were held on project research and activities, and some needed equipment and supplies were taken to Mali.

Germplasm and Research Information Exchange

Assistance was given to collaborating scientists with purchase of research equipment and supplies. Also, membership was paid for Dr. Traore in the American Society of Agronomy, including subscriptions to Agronomy Journal and Crop Science.

Training Output

The P.I. is serving 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.

Germplasm Enhancement and Conservation

Pearl Millet Germplasm Enhancement for Semiarid Regions

Project KSU-101

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Summary

The primary objective of this project is to develop pearl millet materials possessing agronomic, yield, and quality characteristics that address production constraints common to both LDC's and the U.S. Central Great Plains.

Preliminary results indicate variation within Malian millets for root systems that can penetrate a dense, hard B horizon of the soil profile as a form of drought tolerance and extract stored subsoil moisture.

Twenty-nine yellow and white seeded germplasm introductions received from the SADCC/ICRISAT program in Zimbabwe produced excellent F_1 hybrids and a large number of good F_2 families from crosses to KSU-101 lines. Color segregation ratios indicate the yellow or white seed colors of several of the introductions are dominant which increases the utility of these materials for production of grain used in the manufacture of milri-type food products.

Selection and inbreeding continued within 3900 F_3, S_2, and advanced generation lines to develop elite materials possessing characteristics needed to enhance millet production in both host countries and in the U.S. Moderate drought stress in late summer provided an opportunity to screen early generation materials for resistance to stalk rot infection and crown lodging, but fall rains and moderate temperatures reduced selection effectiveness for lodging of the peduncle.

Two hundred sixty A/B pairs in A_1 and A_4 male-sterile cytoplasms were advanced by selection and backcrossing and a group of 124 A-lines were evaluated in testcross hybrid combinations. Hybrids of superior A-lines flowered 3 to 10 days later than the sorghum checks but the period of time from planting to physiologic maturity was similar.

Continued screening for stable male-fertility restoration of hybrids made with cytoplasmic male-sterile seed parents indicates the stable restoration characteristics of R-line 86-7909 are being transmitted to inbred selections of crosses involving 86-7909.

Inbred lines selected for improved stand establishment ability have long seedling length, rapid elongation of the mesocotyl, and the ability to emerge from planting depths of 75 or 100 mm. Comparisons with unselected lines indicate the improved lines usually emerge from planting depths of 30 to 45 mm one-half to one day earlier and weigh 5 to 10 percent more at 10 days after planting. Fifty-four of 56 long mesocotyl lines planted on the Cinzana Research Station, Mali, failed to establish satisfactory stand because of severe downy mildew infection.

Eight populations were advanced with mass-selection and S_1 progeny testing methods. Test cross hybrids of S_4 to S_6 progenies show good combining ability for drought tolerance and grain yield. Tests of topcross hybrids of two tall populations indicate drought tolerant forage hybrids could be developed for the western Great Plains area.

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, 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 the 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

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 soilbeds 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.

Eleven Malian millet varieties and synthetics were grown in the 1991 quarantine greenhouse. Fifty-seven hybrids were obtained from crosses of elite KSU-101 lines used as seed parents and the Mali materials. Five of the 11 introductions each produced from 10 to 30 S_1 selections with sufficient quantities of seed to permit field testing in Kansas followed by evaluation of superior S_1 lines in Mali. At 30 days after planting (DAP) differences in plant height (range: 30-60 cm) and vigor, numbers of tillers, and amounts of foliage among S_1 lines were readily observed. In years of normal precipitation, these differences in biomass, tillering, and vigor do not become so apparent until the plants reach heights of 1.2 to 2 m and stored subsoil moisture in the upper portions of the soil profile approaches exhaustion. Rainfall during this period was 31 percent of normal and temperatures averaged 2.5°C above normal, resulting in rapid drying of surface soils forcing the plants to subsist on stored subsoil moisture.

Twenty-nine yellow and white seeded millets from the SADCC/ICRISAT/Zimbabwe germplasm collection in 1989 and 132 F_1 hybrids with KSU seed parents obtained from these lines were grown in the field. Additional crosses of several introductions to KSU lines were made in the field. Several of these hybrids have produced excellent F_2 families in the 1991 field under conditions of moderate drought. Segregation ratios of yellow:slate or gray within some F_2 families indicate the yellow or white seed color of some introductions is dominant. This would be a desirable trait in varieties or F_1 hybrids used in the production of food products such as milri. Remnant seeds of superior F_2 families will be returned to the SADCC/ICRISAT program at Bulawayo, Zimbabwe.

Inbred line development continued with selection and inbreeding within 3900 F_3, S_2, and advanced generation lines derived from both the pedigree breeding and population improvement programs. Dry weather conditions following anthesis provided an opportunity to screen F_3 to F_6 lines for reduced levels of stalk rot diseases and crown lodging in mid-September. Advanced materials in the KSU-101 program have relatively high levels of resistance to crown lodging when compared to millets selected in higher rainfall areas. However, breaking of culms in upper internodes and the peduncle continues to be the predominant form of lodging. This type of lodging usually appears in early to mid-October when plants are drying and losing green coloration because of drought stress. Several minor stalk characteristics influencing resistance to peduncle breaking and lodging appear to be either additive or recessive in their inheritance. Transfer of these characteristics to elite materials has been time consuming and progress is difficult to identify in the progenies because drought stress during the late seed fill and maturation stages of plant development is necessary for this type of lodging to occur. In 1990, selection for increased resistance to peduncle breaking within lines and hybrids was only partially successful because drought stress was reduced by fall rains and moderate air temperatures.

A group of 260 A/B pairs in the A_1 and A_4 male-sterile cytoplasms received additional backcrosses in the greenhouse and field. Another group of 124 A-lines, having received a third backcross, were evaluated in test cross hybrid combinations with two tester males. Most of the A-lines in this group were derived from lines selected from progenies of KSU X ICRISAT B-line crosses. A-lines possessing superior combining ability for lodging resistance and grain yield had larger diameter culms, wider leaves, and flowered 5 to 10 days later than 79-2068A and 81-1163A which usually flower in 52 to 58 days. The hybrids of these later maturing A-lines, when compared to sorghum hybrids flowering in 55 days, reached the half-bloom stage at 58 to 65 days and produced grain yields 85 to 95 percent as great as the sorghum yields. The number of days from planting to physiological maturity of these millets and the sorghums are similar.

Numerous crosses have been made to transfer the male-fertility restoration characteristics of 86-7909 and sister selections to elite advanced inbred lines that produce good hybrids but have inconsistent fertility restoration of the F_1 in the central Great Plains environment. Approximately 40 F_4 and F_5 lines derived from those crosses have been tested in hybrid combinations in four environments and appear to have stable fertility restoration in the A_1 cytoplasm. Grain yield potential of several of the experimental hybrids equal or exceed yields of 86-7909 hybrids.

Development of inbred lines possessing long seedling lengths, rapid elongation of the mesocotyl portion of the seedling, and the ability to emerge through a thick overburden of soil continues to have positive influences on stand establishment. In comparisons of selected lines to unselected lines at normal planting depths of 30 to 45 mm, the selected lines usually emerge one-half to one day earlier and the seedlings are five to ten percent larger at 10 DAP. Each year, selection is carried out within 300 to 1050 F_3 lines that have previously been screened for desirable agronomic characteristics. A large variation occurs within and between long- mesocotyl F_3 lines for emergence from deep planting depths (75 or 100 mm), because many of the seedlings do not maintain a vertical growth attitude and fail to emerge from the seedbed. F_4 lines selected from the best F_3 lines (emerging to stands of 40 percent or higher of desired stands within 6 DAP) appear to have emergence indices higher than the F_3 parent lines. About 50 percent of a group of 240 F_4 lines had emergence scores of 50 percent or higher at 5 DAP and 85% of the lines had scores above 60% at 7 DAP.

Fifty-six of the long mesocotyl lines were planted on the Cinzana station in Mali. Severe downy mildew pressure destroyed 54 of these lines as the seedlings were emerging or within a few days following emergence leaving a few widely spaced plants in the nursery. Although many of these lines had African germplasm in their background only one line appeared to be highly resistant to downy mildew. These lines will be replanted at Cinzana for selection and crossing

to Malian materials in off-season nurseries when downy mildew pressure is reduced.

Population improvement using mass-selection and recurrent selection methods was continued within eight populations. Two populations in recurrent selection programs using the S_1 progeny testing method have S_4 to S_6 progenies from early cycles of improvement that have demonstrated good combining ability for yield, plant type, and drought tolerance in hybrid combinations. A composite of long mesocotyl materials being random-mated and mass-selected has emerged from a planting depth of 90-100 mm to excellent stands. Seedling vigor is good and early plant developmental rates, i.e., numbers of leaves and leaf expansion, were very good.

Glyphosate (Roundup) applied with a wick applicator carried by a high- clearance field sprayer has been used in the conversion of two normal-height populations to dwarf populations of d_2 and d_1, d_2 heights. These populations are 185642, used as a source of B_1 maintainer lines, and HMP-BR, a bristled bird-resistant population. The glyphosate was applied following several cycles of random-mating in which frequencies of the dwarfing genes were gradually increased to 50%. This method of plant height conversion within a population is effective, economical, and requires minimal labor inputs. Phenotypically, the populations resulting from this system appear to be nearly identical to the original populations except for the difference in plant height. These populations have been sent to several cooperators.

Although commercial forage hybrids of pearl millet are available, they have received only limited attention in the western Great Plains because they are not sufficiently drought tolerant. Forage performance tests were conducted for two years comparing three tall populations, six topcross hybrids derived from two tall populations, and two commercial forage hybrids. The topcross hybrids produced total plant yields that equalled, or exceeded by 15 percent, yields produced by the commercial hybrids, and were 10 to 20 percent greater than yields of the tall populations. Grain yields of the topcross hybrids were not obtained, but were estimated to be 50 to 100 percent greater than grain yields of the commercial hybrids.

The glyphosate destruction of tall millet plants should be adaptable to selection of dwarf plants within F_2 families segregating for height. With normal precipitation patterns and amounts received, the thick canopy formed by normal-height plants restricts plant development of dwarf segregates, increases the difficulty of locating desirable segregates, and increases worker discomfort. Glyphosate applied to the upper 10 to 30 cm area of the tall plant is sufficient to stop head development and flowering, however, plant death occurs sooner if a larger area of the plant is treated. The green coloration of treated plants fades sufficiently within 7 to 10 days so that untreated plants are readily identified. Treated plants start to bend and buckle at this time and have usually fallen below the canopy of surviving plants within three to four weeks. The increased light penetration through the canopy produces more robust dwarf plants and increases seed quantity and size.

Presentations

August 29, 1990. Presented results of pearl millet research at the FHBES Fall Field Day.

Networking Activities

Research Investigator Exchanges

August 30, 1990. Mr. David Andrews, UNL-118, and two INTSORMIL sponsored graduate students toured the FHBES millet program.

September 19-20, 1990. Mr. David Andrews and Dr. Anand Kumar, Senior Millet Breeder, ICRISAT, Sahelian Research Center, Sadore, Niger visited the millet breeding program. More than 60 lines and populations were selected to use in their programs.

October 23, 1990. Dr. Ray Burns and Mr. Eldon Fastrup, Director of Marketing, Kansas State Board of Agriculture, toured the pearl millet program.

Travel to Mali, September 22-October 6, 1990, to view the IER and ICRISAT pearl millet breeding and agronomic programs, discuss millet problems and constraints, and plan collaborative research with Malian scientists.

Other Cooperating/Collaborating Scientists

Dr. S. King, Head Millet Pathologist, ICRISAT Center, ICRISAT/Patancheru PO, Andhra Pradesh 502 324, Hyderabad, India.

Dr. B. Quendeba, Millet Breeder, INRAN, B. P. 429, Niamey, Niger.

Mr. Amadou Fofana, Millet Breeder, CNRA, Institute Senegalais de la Recherche Agronomique, BP54, Bambey, Senegal.

Dr. John Clark, Sorghum Breeder, Purdue/INRAN, Niamey, Niger.

Dr. L. Gourley, Sorghum Breeder, Box 5248, Department of Agronomy, Mississippi State University, Mississippi State, MS 39762.

Dr. G.E. Hanning, Research Coordinator, Tissue Culture for Crops Project, Department of Botany, Colorado State University, Fort Collins, CO 80523.

Drs. G.W. Burton and W.W. Hanna, Pearl Millet Geneticists, USDA/ARS, Coastal Plain Experiment Station, P. O. Box 748, Tifton, GA.

Germplasm Conservation and Exchange

Eleven accessions were acquired; 785 imported accessions are in storage.

A group of 56 F_4 lines selected for improved stand establishment capability were sent to Mali. Two dwarf F_1 hybrids were sent to Senegal via UNL-118 to be grown in an irrigated performance trial in the Senegal river valley.

A total of 102 inbred lines, populations, and hybrids were provided to U.S. domestic programs.

The cytoplasmic male-sterile line 79-2068 AA (843AA) continues to be the leading seed parent of hybrids grown in northwest India. The maintainer line, 2068B, is being used extensively in breeding programs by both ICRISAT and the Indian national breeding programs as a source of early maturity, large seed size, and high yield potential. ICRISAT Center/Patancheru has recently released two d_2 dwarf A-lines, ICMA 88006 and ICMA 89111 for use in India. ICMA 88006 was developed from a cross of 2068B and a line derived from a cross between 81B and a smut resistant West African line. ICMA 88006 has large seed, a high level of smut resistance, downy mildew resistance similar to 81A, and flowers 5 to 6 days earlier than 81A. ICMA 89111 is derived from a cross between 2068B and a progeny derived from a cross of the West African lines, Gero New Strain and Saria Synthetic. 89111 has excellent downy mildew resistance and head exsertion, flowers three to four days earlier than 81A, and seed size is 10 percent larger than 81A. Its high tillering ability makes it suitable for production of either grain or forage hybrids.

A 320 kg lot of grain was shipped to Dr. L. W. Rooney, TAM-126, for his work on developing millet food products with extended shelf-life. Increased emphasis has been placed on the development of R-lines capable of producing white-seeded hybrids as a result of his preference for this color.

Seed lots with brown and blue colored grain were sent to Dr. C. Klopfenstein, Department of Grain Science and Industry, Kansas State University, for studies of the goitrogenic effects of flavinoid pigments in pearl millet.

Breeding Sorghum for Tolerance to Infertile Acid Soils

Project MSU-104

Lynn M. Gourley
Mississippi State University

Principal Investigators

Drs. Lynn M. Gourley and Susanna A. Goggi, Department of Agronomy, Mississippi State University, Mississippi State, MS 39762

Collaborating Scientists

Dr. Manuel Torregroza, Crops Director, ICA, Apartado Aereo 15248, Bogota, Colombia. (Host Country Coordinator)
Dr. Dorance Munoz, Director of Genetics and Plant Breeding, FEDEARROZ, Calle 72 #13-23 Piso 11, Bogota, Colombia
Mr. Cesar Ruiz, Sorghum Breeder, ICA, La Libertad, Apartado Aereo 2011, Villavicencio, Colombia
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
Dr. Lee House, Research Director; Dr. Tunde Obilana, Sorghum Breeder; Dr. Walter de Milliano, Cereals Pathologist; and Dr. Emmanuel Monyo, Forage Post Doctoral Fellow, SADCC/ICRISAT, Southern Africa Regional Sorghum/Millet Research Program, P.O. Box 776, Bulawayo, Zimbabwe
Mr. Hamis Saadan, Tanzanian Sorghum Breeder, on study leave at Mississippi State University
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. C.K. Kamau, Sorghum Breeder, Katumani National Dryland Farming Research Center, P.O. Box 340, Machakos, Kenya
Mr. B.A.N. Wabwoto, Sorghum Breeder, and Mr. C.O.A. Oduori, Millet Breeder, Kakamega Regional Research Center, P.O. Box 169, Kakamega, Kenya
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Dr. Henry Pitre, Entomologist, MSU-105 PI, Department of Entomology, Mississippi State University, Mississippi State, MS
Dr. Jerry Maranville, Plant Nutritionist, UNL-114 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. Bill Stegmeier, Pearl Millet Breeder, KSU-101 PI, Kansas State University, Ft. Hays Experiment Station, Hays, KS
Drs. 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

The Instituto Colombiano Agropecuario (ICA) announced the release of two sorghum varieties from the collaborative breeding effort with INTSORMIL at the International Sorghum Workshop "Sorghum for the Future" held at CIAT Cali, Colombia on 14-19 January 1991. Sorgica Real 40 and Sorgica Real 60 will provide the farmers cultivating acid soils in the eastern plains (Llanos) of Colombia with a cash crop. Sorgica Real 40 was developed for use in the mixed acid soils areas with Al saturation levels of 40% or less. Sorgica Real 60 tolerates higher Al saturation levels of up to 60% while still producing grain yields of 2-3 t ha^{-1}.

These varieties have undergone extensive evaluation to develop agronomic production recommendations to present to the farmers at the same time as the new releases. Sustain-

ability of cereal crop production in these fragile, acid soils requires that varieties be bred to tolerate this environment.

Year 12 was the first full year that the MSU-104 Principal Investigator was assigned to Kenya as the result of the INTSORMIL buy-in by the USAID funded MIAC Kenya Country Project. Kenya was an INTSORMIL collaborating site in the past and now has several active sorghum and millet research projects conducted by INTSORMIL PI's in collaboration with KARI and ICRISAT/SAFGRAD scientists.

Kenya's agricultural research infrastructure has been greatly strengthened by the reorganization of KARI and the results of the MIAC Country Project over the last three years. Several sorghum and millet breeders and agronomists have received their M.Sc. training in the U.S., many from INTSORMIL PI's programs, and have recently returned to Kenya. These products of the human resources development effort will strengthen the sorghum and millet improvement programs, not only in Kenya, but throughout East Africa.

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.

Enhance 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

The PI spent three weeks of this year out of Kenya on INTSORMIL activities; one week at CIAT Cali, Colombia attending the International Sorghum Workshop and the second week involved in an external review of the INTSORMIL project in Colombia. The workshop "Sorghum for the Future" had 240 participants. The MSU-104 PI was presented with an award by the Colombian Minister of Agriculture in recognition of the INTSORMIL research contribution of developing sorghums tolerant to infertile, acid soils.

During the workshop, ICA announced the release of two acid soil tolerant sorghum varieties, Sorgica Real 40 and Sorgica Real 60. These sorghum varieties are tolerant to Al saturation levels of up to 40 and 60% as indicated by their designations. The package of agronomic practices was developed in concert with these varieties to promote the sustainability of sorghum grain production in the fragile acid soils in the Llanos of Colombia.

The third week was spent at Mississippi State University meeting with graduate students from Kenya (M'Ragwa), Uganda (Zake - IDRC funded) and Tanzania (Saadan - ICRISAT/SADCC funded). A portion of the time at Mississippi State University was spent preparing sorghum breeding nurseries for Colombia and Mississippi. The PI organized hybrid seed from Colombia winter nursery and Mississippi State University summer nursery for observation nurseries at five locations in Kenya. The 128 hybrid entries were selected to be useful across several Kenyan ecological zones. Evaluating hybrids produced from the best lines in international programs will allow KARI to proceed with line development (varieties) and also shorten the time to make more stress tolerant hybrid releases to Kenyan farmers.

Element Concentrations in 26 Acid Soil Tolerant Sorghum Genotypes

Twenty-six sorghum genotypes were grown on an acid oxisol (clayey, kaolinitic, isohyperthermic, Tropeptic Haplustox) on the Instituto Colombiano Agropecuario (ICA) La Libertad research farm near Villavicencio, Colombia and on an acid ultisol (clayey, oxidic, isohyperthermic, Typic Palehumelt) on the International Center for Tropical Agriculture (CIAT) Quilichao substation 80 km southwest of Cali, Colombia. Two trials were planted on the oxisol; location 1 at 60.3% and location 2 at 68.0% aluminum saturation. Three trials were planted on the ultisol; location 3 at 63.0%, location 4 at 45.1%, and location 5 at 31.8% aluminum saturation.

The 26 sorghum genotypes were all rated as relatively tolerant to acid soil stress in previously conducted screening

trials in Colombia. Genotype designations and country of origin are shown in Table 1

Table 1. Genotype designation and country of origin of the 26 sorghum lines.

Genotype	Origin
IS 2728	Uganda
IS 2765	Uganda
IS 3071	Sudan
IS 3522	Sudan
IS 3553	U.S.A.
IS 6902	Sudan
IS 6944	Sudan
IS 7132	Uganda
IS 7151	Kenya
IS 8577	Kenya
IS 8931	Kenya
IS 8933	Kenya
IS 8959	Kenya
IS 8996	Kenya
IS 9084	Kenya
IS 9101	Kenya
IS 9138	Uganda
IS 9277	Uganda
IS 12152	Ethiopia
1696B	U.S.A.
M-35585	India
MN 4508	Uganda
156-P-5-SERERE-1	Uganda
SDX61/6/2	Uganda
3DX57/1/1/910	Uganda
IS 7173C	Tanzania

The Al saturation level of the soils at each test location was adjusted using equal quantities of dolomitic and varying quantities of calcitic limestone. The quantities of limestone used were different for the oxisol and the ultisol soils. Some of the chemical characteristics of the three ultisol locations are shown in Table 2. Complete soil test data were unavailable for the oxisol locations. Mineral nutrients other than P and N were considered adequate for plant growth at each location. Phosphorous was added preplant as triple superphosphate at 44 kg P ha^{-1} and N was added as urea 30 days after planting at 75 kg N ha^{-1}.

Table 2. Mean topsoil (0 to 20 cm) chemical characteristics of the CIAT-Quilichao fields used for Locations 3, 4 and 5 trials.

Soil characteristics	Location 3	Location 4	Location 5
pH (H_2O)	4.4	4.6	5.0
P (ug g^{-1})	17.9	16.2	17.8
Ca (c mol kg^{-1})	1.24	2.44	3.33
Mg (c mol kg^{-1})	0.52	0.53	0.51
K (c mol kg^{-1})	0.24	0.26	0.23
Al (c mol kg^{-1})	3.40	2.65	1.90
ECEC (c mol kg^{-1})	5.40	5.88	5.97
Al saturation (%)	63.0	45.1	31.8

Methods for extraction and/or determination were: pH - 1:1 soil:water; P-Bray II; exchangeable cations - 1N KCl from 100 g of soil; effective cation exchange capacity (ECEC) - sum of exchangeable cations; and Al saturation - exchangeable Al

The genotypes were grown using a randomized complete block design with three replications. Each genotype was planted in 2-row plots, 3 m long, and 0.60 m between rows. Plant population was approximately 200,000 plants ha^{-1}. Weeds were controlled initially with atrazine and later by hand.

After physiological maturity, three leaves (first leaf below the flag leaf) were randomly selected per plot and combined. Each leaf sample was dried at 60°C for four days, ground to pass 0.5 mm screen, and representative amounts were sent to the University of Nebraska for mineral element analysis.

At the University of Nebraska, leaf samples were dried at least one day at 70°C in a forced-air oven before 100 mg (13 mm diameter) pellets were made from each sample. Pellets were analyzed for Mg, Si, P, S, Cl, K, Ca, Mn, Fe, Cu, Zn, and Al by energy-dispersive x-ray fluorescence (Knudsen et al., 1981).

The combined analyses of variance showed that genotypes (G) were different for all mineral element concentrations analyzed and that locations (L) were different for all except Cu and Zn. The significant G x L interactions for all mineral element concentrations except for Al, Mn, Cu, and Zn required that separate analyses of variance be conducted for genotypes and locations. Means of these analyses with separations at the 0.05 level of probability according to Duncan's Multiple Range Test are shown in Table 3.

Genotypes - Several of the 26 sorghum genotypes showed differences among the five test locations for higher or lower leaf mineral element accumulation relative to the other genotypes. Regarding toxic mineral elements, genotype IS 7173C accumulated a high concentration of Al in the leaf tissue while genotype MN 4508 accumulated slightly more than one half as much Al as IS 7173C. Both genotypes are tolerant to high levels of Al saturation. This would suggest that perhaps there is more than one mechanism of tolerance to Al in sorghum. For Mn concentration, genotypes IS 6902 and IS 7173C were high accumulators and genotypes IS 3553 and IS 9277 could be considered low accumulators. Iron in high concentrations in acid soils can be toxic in some plant species. Genotypes IS 9277 and IS 7173C accumulated high concentrations and genotypes IS 3553 and IS 9101 low concentrations of Fe in their leaves.

For P concentrations, genotypes IS 7173C and IS 9138 accumulated about 80% more of this essential element than genotypes IS 8577 and 3DX57/1/1/910. The ability of a genotype to accumulate P under conditions of high Al saturation or otherwise low P availability would be a valuable gene(s) to identify in sorghum. Genotypes IS 9101 and IS 9138 accumulated about 25% more K than genotypes IS 7173C and IS 9277. Note that IS 9138 accumulates more P and K while IS 7173C accumulates more P but less K than many other genotypes.

Table 3. Leaf mineral element concentrations of Mg, Si, P, S, Cl, K, Ca, Mn, Fe, Cu, Zn, and Al of 26 acid soil tolerant sorghum genotypes grown at five locations in Colombia.

	mg g^{-1}							ug g^{-1}				
G : L	Mg	Si	P	S	Cl	K	Ca	Mn	Fe	Cu	Zn	Al
IS 2728:												
1	0.9a	11.2c	1.3b	1.1c	8.0b	14.8a	15.0a	328a	210b	29a	11a	777c
2	0.9a	15.1c	1.0b	1.1c	9.6a	15.2a	14.8a	309a	261ab	33a	45a	1117c
3	1.2a	29.2b	2.9a	2.3a	0.7c	13.6ab	10.6b	295a	326a	27a	33a	1270bc
4	1.3a	53.1a	2.6a	2.1a	0.9c	12.4bc	10.3b	302a	311a	35a	37a	1640b
5	0.7a	59.9a	2.4a	1.8b	0.7c	10.7c	14.1a	223b	242ab	29a	21a	2153a
IS 2765:												
1	2.4a	12.0d	1.0b	1.0b	9.9a	14.5a	15.3a	300a	280ab	26a	13b	963b
2	0.9a	9.6d	0.8b	1.0b	9.3a	14.7a	12.5ab	287a	314a	29a	60a	1283b
3	1.4a	26.2c	2.5a	2.4a	0.8b	13.8a	10.5b	338a	274ab	29a	38ab	1080b
4	1.1a	47.6b	2.3a	2.4a	0.8b	9.9b	13.5ab	319a	254ab	28a	33b	1477b
5	1.0a	62.0a	2.8a	2.2a	0.9b	11.8ab	14.2ab	205b	238b	28a	23b	2187a
IS 3071:												
1	0.8b	12.5c	1.4c	1.2c	10.5b	16.5a	14.7a	292a	219a	24b	10c	887a
2	0.7b	14.4c	0.9c	1.2c	12.4a	17.0a	13.6ab	289a	252a	34a	31ab	1070a
3	1.6a	29.1b	2.8a	2.8a	0.8c	13.6ab	11.3b	351a	301a	26ab	37a	1383a
4	1.3ab	46.9a	2.2b	2.0b	0.8c	11.4b	12.3ab	319a	319a	32ab	28ab	1297a
5	1.1ab	51.0a	2.6ab	2.2ab	0.8c	11.9b	13.6ab	162b	227a	26ab	20bc	1450a
IS 3522:												
1	1.0a	10.7c	1.3b	1.1b	9.3a	14.9a	15.7a	304b	223a	25b	13a	1247b
2	1.4a	14.1c	1.0b	1.0b	10.3a	16.1a	15.2a	259b	278a	38a	39a	1383b
3	1.4a	37.9b	2.4a	2.1a	0.7b	11.8b	10.6c	410a	297a	28b	29a	1610b
4	1.1a	55.5a	2.5a	2.2a	0.9b	11.4b	12.9b	283b	267a	33ab	35a	1200b
5	1.1a	65.4a	2.7a	2.1a	0.8b	11.3b	14.4a	231b	240a	28b	20a	2070a
IS 3553:												
1	1.1a	10.5d	1.4b	0.9c	9.2a	17.9a	10.3a	242a	204b	28b	13b	837c
2	1.1a	10.6d	1.1b	0.9c	11.0a	17.3ab	10.4a	216a	206b	32ab	40a	1060c
3	1.5a	31.0c	2.6a	1.9a	1.1b	13.7bc	8.2a	299a	287a	35ab	34a	1307bc
4	1.9a	57.8b	3.0a	1.9a	1.1b	12.3c	9.6a	277a	265ab	41a	30a	1630ab
5	1.9a	80.8a	3.3a	1.5b	0.9b	9.7c	9.5a	196a	272a	40a	30a	2127a
IS 6902:												
1	1.2a	11.6d	1.7b	1.2b	9.4a	13.3ab	14.8a	331b	283b	30ab	17a	1183c
2	1.2a	16.5d	1.4b	1.2b	10.4a	15.6a	14.7a	382ab	268b	35a	50a	1453bc
3	1.4a	35.9c	2.9a	2.1a	0.6b	12.4ab	11.2c	441a	362a	26b	44a	2007ab
4	1.4a	55.7b	2.6a	2.0a	0.6b	10.4b	12.0bc	332b	301ab	31ab	33a	1760ab
5	1.5a	66.1a	2.4a	2.0a	0.6b	9.4b	14.0ab	222c	289b	30ab	26a	2170a
IS 6944:												
1	1.0b	11.8c	0.8b	1.0c	10.4a	14.4a	14.4bc	289a	299a	46a	11a	1073a
2	1.2b	11.9c	0.6b	1.0c	11.4a	13.9a	15.3ab	293a	238a	27a	41a	1390a
3	1.8a	28.6b	2.3a	2.4a	0.6b	14.4a	12.2cd	360a	285a	24a	32a	1310a
4	1.5ab	47.2a	2.0a	1.9b	1.0b	12.7ab	11.0d	305a	315a	31a	26a	1447a
5	1.2b	49.0a	2.5a	2.2ab	0.6b	10.7b	16.9a	163b	254a	27a	20a	1517a
IS 7132:												
1	0.7b	10.6c	0.8c	1.0b	10.5a	13.8a	16.9a	300ab	249b	24a	11a	893a
2	1.0ab	11.2c	0.6c	0.9b	12.7a	13.8a	15.4a	282ab	270b	27a	48a	1360a
3	1.4ab	26.9bc	2.2ab	2.3a	0.8b	12.6a	10.4b	343a	292ab	30a	28a	1800a
4	1.9a	36.7b	1.8b	2.2a	0.7b	12.4a	11.3b	308ab	348a	29a	25a	1733a
5	1.1ab	67.9a	2.8a	2.3a	0.8b	11.6a	13.4ab	200b	254b	28a	20a	1873a
IS 7151:												
1	1.1a	9.6d	0.9b	1.1b	6.6a	12.6b	16.4a	300ab	238b	27a	9a	1037a
2	1.3a	10.8d	1.0b	1.0b	7.8a	16.2a	13.4b	263ab	282ab	33a	43a	857a
3	1.4a	30.8c	2.3a	1.9a	0.8b	10.8b	10.7c	344a	326a	25a	32a	1350a
4	0.9a	46.0b	2.5a	2.3a	0.9b	11.8b	10.7c	304a	254b	27a	28a	1313a
5	0.8a	65.7a	2.6a	2.0a	0.7b	11.6b	13.4b	216b	254b	29a	21a	1897a
IS 8577:												
1	0.9b	10.2c	0.8b	1.0b	11.1a	13.3ab	16.2a	310ab	236b	23a	7a	1190a
2	0.9b	12.0c	0.7b	1.0b	12.5a	15.7a	13.2ab	253ab	264ab	27a	41a	1323a
3	2.1a	34.8b	2.0a	2.1a	1.0b	13.3ab	11.6b	346a	311a	28a	32a	1487a
4	1.5ab	39.2b	2.0a	2.0a	0.9b	13.7ab	12.6b	287ab	291ab	27a	28a	1290a
5	1.4ab	55.4a	2.5a	1.8a	0.8b	12.5b	12.6b	184b	258ab	23a	20a	1643a
IS 8931:												
1	0.8c	13.2d	0.9b	1.1c	11.1a	14.4ab	17.1a	313ab	240b	27a	12b	940a
2	1.2bc	14.3cd	1.1b	1.1c	10.3a.	16.3a	14.0ab	294ab	222b	30a	31ab	877a
3	1.6ab	22.9c	1.7b	1.8bc	0.7b	12.4b	9.5b	354a	332a	25a	26ab	1247a
4	1.8a	43.8b	2.7a	2.6a	1.0b	11.8b	12.2b	244ab	277ab	29a	35a	1327a
5	1.1bc	68.0a	2.9a	2.3ab	0.7b	12.4b	14.0ab	203b	228b	26a	22ab	1307a

Table 3. (Continued)

G:L	mg g^{-1} Mg	Si	P	S	Cl	K	Ca	ug g^{-1} Mn	Fe	Cu	Zn	Al
IS8933:												
1	0.9a	9.4d	1.1cd	1.0b	9.1a	14.3b	14.1a	247ab	237a	26a	12b	907b
2	0.9a	10.1d	0.7d	0.9b	10.0a	17.9a	11.9a	238ab	237a	26a	24ab	1096ab
3	1.4a	28.2c	2.3ab	1.9a	0.9b	13.5b	9.4a	354a	291a	28a	29a	1350ab
4	1.5a	42.3b	2.0bc	2.2a	0.8b	13.4b	13.0a	344a	326a	29a	26cb	1390ab
5	1.5a	53.2a	2.9a	2.4a	0.8b	12.9b	12.6a	183b	246a	28a	20ab	1443a
IS 8959:												
1	1.1b	11.2c	1.0b	1.0b	12.2a	15.4a	16.3a	272ab	227b	25a	11a	1180a
2	1.6a	12.1c	0.8b	1.0b	11.2a	14.5a	15.1ab	262ab	254ab	29a	29a	1373a
3	1.6a	31.7b	2.4a	2.3a	0.8b	13.1ab	10.7b	381a	287a	27a	31a	1297a
4	1.6a	48.8a	2.2a	2.2a	1.1b	12.4ab	12.4ab	367a	268a	24a	31a	1550a
5	1.6a	50.0a	2.4a	2.4a	0.9b	11.2b	15.3ab	201b	275a	27a	23a	1637a
IS 8996:												
1	1.0a	11.1d	0.8c	1.1b	8.7b	13.8a	16.2a	320a	239b	26a	9a	1063a
2	1.1a	11.3d	0.6c	0.9b	12.4a	15.1a	14.7ab	279a	241b	26a	29a	860a
3	1.2a	27.3c	1.9b	1.8ab	0.7c	15.8a	10.7c	311a	345a	26a	28a	1477a
4	1.0a	49.9b	2.9a	2.8a	1.1c	13.9a	9.6c	320a	292ab	32a	32a	1383a
5	1.5a	61.2a	2.8a	2.0ab	1.0c	12.7a	12.1bc	205b	231b	27a	18a	1640a
IS 9084:												
1	1.3a	13.6c	1.1b	1.1b	9.7b	15.3ab	15.9a	318a	242b	26a	12b	1537ab
2	0.7a	12.5c	1.0b	1.1b	12.2a	17.5a	15.0a	282ab	234b	26a	44a	1133b
3	1.6a	29.7b	1.8ab	2.1a	0.7c	13.7bc	11.3b	345a	273ab	26a	33ab	1113b
4	1.3a	53.2a	2.9a	2.0a	1.0c	14.1bc	10.4b	282ab	358a	32a	31ab	1737ab
5	1.0a	54.2a	2.7a	2.2a	0.9c	12.0c	14.1a	238b	246b	28a	23ab	1847a
IS 9101:												
1	1.3b	19.2d	1.6b	1.3c	11.6a	18.1ab	15.0ab	331ab	220c	35a	16a	1290ab
2	1.0b	12.8c	1.0c	1.2c	11.8a	19.6a	12.4c	256bc	236bc	33a	46a	1037b
3	2.3a	37.8c	2.4a	2.1ab	0.6b	15.2bc	13.0bc	412a	264ab	33a	38a	1290ab
4	1.5b	52.3b	2.4a	2.2a	0.7b	14.0bc	12.1c	282b	278a	33a	36a	1470ab
5	1.6b	68.5a	2.6a	1.8b	0.6b	11.9c	15.9a	177c	248bc	36a	29a	1920a
IS 9138:												
1	1.0a	15.9d	2.8ab	1.6b	7.3b	15.0ab	13.2a	338a	334bc	51a	23a	1357bc
2	0.7a	17.5d	2.3b	1.5b	10.4a	16.6a	12.2a	309a	400ab	48a	60a	1760ab
3	1.1a	32.7c	3.0ab	2.1ab	1.4c	16.8a	8.2c	303a	427a	42ab	40a	2013a
4	1.2a	52.0b	2.6ab	2.3a	1.3c	13.9b	9.6b	259a	278c	34b	33a	967c
5	0.8a	77.9a	3.3a	1.8ab	1.1c	13.4b	10.3b	237a	309c	48a	32a	2123a
IS 9277:												
1	1.3ab	13.5c	0.8b	1.1b	4.2ab	12.1a	12.6a	213ab	353b	36a	22b	1217c
2	1.2ab	13.4c	0.8b	1.1b	6.2a	12.3a	12.8a	179b	394b	37a	63a	1403bc
3	1.5ab	30.3b	2.4a	1.9ab	0.7b	13.8a	8.9b	272a	567a	28a	31b	2490a
4	1.9a	41.0b	1.8a	2.2a	0.7b	11.4a	9.8ab	261a	375b	32a	24b	2147ab
5	0.9b	68.8a	2.3a	1.6ab	0.8b	11.2a	12.3ab	217ab	287b	33a	27b	1563bc
IS 12152:												
1	1.2a	13.5c	1.5b	1.1c	6.8b	15.5ab	12.7a	281ab	246b	29a	14b	1283b
2	1.0a	14.0c	1.2b	1.1c	11.5a	17.4a	13.3a	283ab	232b	32a	45a	1157b
3	1.5a	35.8b	2.7a	2.2a	0.6c	12.4bc	10.1a	357a	329a	26a	49a	1677ab
4	1.2a	48.6b	2.8a	2.2a	0.9c	13.5bc	10.4a	293ab	288ab	30a	37ab	1523ab
5	1.4a	68.7a	3.2a	1.8b	0.9c	11.6c	11.6a	185b	271ab	33a	36ab	2067a
1696B:												
1	1.4b	9.4d	2.4ab	1.5b	6.1a	17.9a	5.7b	209b	243b	35a	16a	680b
2	1.6b	10.2d	2.2b	1.4b	6.3a	18.8a	6.4b	250ab	255b	27a	37a	1003b
3	2.2ab	33.5c	3.2a	2.3a	0.6b	12.7b	9.6a	374a	411a	30a	41a	1980a
4	2.2ab	51.3b	2.4ab	2.0a	0.8b	12.0bc	11.6a	338ab	315b	31a	30a	2023a
5	2.8a	70.0a	2.8ab	1.9ab	0.5b	8.6c	12.7a	254ab	283b	29a	39a	2257a
M-35585:												
1	1.0a	8.8d	1.4b	1.1c	7.7a	16.8a	8.7ab	258b	264b	32a	17a	913b
2	1.5a	9.7d	1.1b	0.9c	6.1a	17.5a	7.9b	236b	285ab	33a	44a	1150ab
3	1.7a	27.4c	2.4a	1.9a	0.6b	9.5b	8.9ab	350ab	339a	35a	37a	1223ab
4	1.7a	50.8b	2.8a	1.9a	0.9b	12.0b	10.9a	389a	277ab	38a	37a	1517ab
5	1.5a	62.6a	2.4a	1.5b	0.6b	11.5b	11.5a	237b	287ab	36a	29a	1897a
MN 4508:												
1	0.8a	11.3c	1.0c	1.1bc	11.0a	14.6a	13.8a	296a	238b	27a	14a	1153ab
2	0.9a	11.8c	0.7c	1.0c	11.0a	14.7a	13.6ab	284a	231b	28a	46a	813b
3	1.5a	30.9b	2.2b	1.9ab	0.8b	12.2ab	11.0b	350a	305a	31a	32a	1073ab
4	1.6a	51.8a	2.3ab	2.6a	0.8b	10.6b	11.6ab	294a	258b	28a	28a	1170ab
5	0.9a	51.2a	2.9a	2.3a	1.0b	12.6ab	12.9ab	147b	260b	26a	22a	1343a

Table 3. (Continued)

	mg g^{-1}							ug g^{-1}				
G:L	Mg	Si	P	S	Cl	K	Ca	Mn	Fe	Cu	Zn	Al
156-P-5-SERERE-1												
1	1.0a	14.2d	1.1b	1.1bc	9.5a	16.0a	14.7a	288a	313ab	32a	17b	1500ab
2	1.2a	11.2d	0.7b	1.0c	13.4a	17.7a	11.7ab	275a	298b	27a	60a	1237b
3	1.4a	32.1c	2.2a	1.8b	0.7b	14.8a	9.5b	303a	448a	28a	29ab	2467a
4	1.4a	41.5b	2.4a	2.5a	0.8b	12.0a	10.2b	272a	360ab	27a	28ab	2030ab
5	1.3a	62.9a	3.0a	1.7b	0.7b	12.6a	10.4b	195b	289b	33a	26ab	1910ab
5DX61/6/2:												
1	1.2a	15.3d	1.0b	1.1c	7.4a	15.9ab	13.0a	303ab	314b	33a	14a	1483a
2	1.3a	13.9d	0.7b	1.1c	8.3a	16.8a	11.5ab	243ab	338b	38a	46a	1400a
3	0.9a	38.2c	2.2a	1.9b	1.0b	13.1bc	9.8b	356a	507a	34a	31a	1963a
4	1.4a	48.9b	2.2a	2.2a	0.9b	12.6c	9.9b	295ab	320b	33a	32a	1723a
5	1.0a	64.3a	2.3a	1.7b	0.9b	12.1c	10.5ab	214b	283b	33a	23a	1890a
3DX57/1/1/910:												
1	1.0b	14.2c	0.8b	1.0b	8.1a	16.5a	13.6a	250bc	289b	28a	12b	1007b
2	0.9b	12.2c	0.7b	1.1b	8.2a	14.3ab	11.8a	252bc	385b	35a	52a	1487ab
3	1.7a	33.4b	2.2a	2.5a	0.8b	11.7b	12.0a	365a	557a	28a	31ab	2280a
4	1.5ab	38.7b	1.8a	1.7ab	0.8b	13.0b	10.7a	296ab	339b	29a	23ab	1510ab
5	1.0b	56.1a	2.2a	1.6ab	0.7b	13.4ab	12.0a	173c	296b	31a	21ab	2010ab
IS 7173C:												
1	1.3ab	14.2c	1.9b	1.3b	9.7a	12.5ab	13.1a	305ab	343b	34a	13b	1757ab
2	0.8b	14.3c	1.4b	1.2b	10.2a	14.7a	12.5a	246b	333b	36a	41a	1480b
3	1.9a	40.5b	3.7a	2.5a	0.9b	12.8ab	8.6b	366a	573a	41a	37a	2180a
4	1.8a	63.0a	3.5a	2.2a	0.9b	11.2b	11.2ab	333ab	365b	36a	36a	2197a
5	1.6a	69.5a	3.8a	2.3a	0.8b	12.1b	12.4a	258ab	346b	38a	25ab	2067a
Genotypes within Locations:												
1	1.1b	12.3d	1.2c	1.1b	9.0b	15.0b	14.1a	290b	261c	30a	13b	1129c
2	1.1b	12.6d	1.0c	1.1b	10.3a	16.0a	12.9b	269b	277c	32a	44a	1214c
3	1.5a	31.6c	2.5b	2.1a	0.8c	13.2c	10.3c	349a	358a	29b	34ab	1605b
4	1.5a	48.6b	2.4b	2.2a	0.9c	12.3d	11.2c	304ab	304b	31ab	31ab	1556b
5	1.3ab	62.7a	2.7a	2.0a	0.8c	11.7e	12.9b	205c	266c	31ab	24ab	1846a

Means for a particular element of a genotype across locations or of locations across genotypes followed by a letter in common are not different at the 0.05 level of probability according to Duncan's Multiple Range Test.

Locations: 1 = oxisol 60.3% Al sat.; 2 = oxisol 68.0% Al sat.; 3 = ultisol 63.0% Al sat.; 4 = ultisol 45.1% Al sat.; and 5 = ultisol 31.8% Al sat.

Silicon has been correlated with tolerance to Al toxicity. Genotypes IS 7173C and IS 9138 accumulated about 35% more Si than IS 6944 and IS 8933. Genotype 1696B had higher concentrations of Mg and lower concentrations of Ca relative to other genotypes.

Two genotypes were conspicuous for their extremes in leaf mineral element concentrations. Genotype IS 9138 accumulated high concentrations of Si, P, S, Cu, Zn, and K, and low concentrations of Mg relative to the other genotypes. Genotype IS 7173C accumulated high concentrations of Al, Si, P, S, Fe, and Mn, and low concentrations of K relative to the other genotypes. These sorghum genotypes warrant further study.

Locations - Locations 1 and 2 were on an oxisol soil and locations 3, 4, and 5 on an ultisol soil. Differences in leaf mineral element concentrations observed for location or soil type could be due to natural or man-made differences in the soil. The leaf element concentrations of the 26 sorghum genotypes grown on the oxisol soil were significantly higher for Cl and K, and lower for Al, Si, P, and S than for these genotypes grown on the ultisol soil. Excluding the location with the lowest level of Al saturation (location 5), higher concentrations of Ca and lower concentrations of Mg and Fe were found for the genotypes grown on the oxisol compared with the ultisol soil. Perhaps some of these differences were due to the high level of Al saturation for the oxisol locations.

As the Al saturation increased in the ultisol soil, leaf concentrations of K, Mn, and Fe increased while that for Si decreased. Concentrations of Al, Ca, and P were significantly higher at location 5, the lowest level of Al saturation, and not different for locations 3 and 4, the two higher levels of Al saturation.

These results should be useful in a sorghum improvement program in tropical acid soil areas. If the differences in element concentrations observed among genotypes are under genetic control, the efficiency of some genotypes to extract P under conditions of low availability or reduce the uptake of toxic elements, such as Al and Mn, would be of value wherever sorghum is grown.

Sorghum and Millet Research in Kenya

Year 12 was the first full year the sorghum/millets (S/M) breeding research technical advisor (TA) (MSU-104 PI) was at station in Kenya. Much has been accomplished during the year, although progress has been slower than originally

anticipated. A great deal remains to be done before the KARI S/M breeding projects become self-sustaining.

A KARI S/M research planning meeting was held at NARC Muguga on August 9, 1990. The purpose of the meeting was to review the research actually being conducted under the current broad research program titles. During the discussion, research priority areas were identified. Current manpower and S/M scientists in training from each station were discussed. A short written report from each station conducting S/M research was requested listing priorities, specific experiments, objectives, goals and budgets.

The first Sorghum/Millet Specialist Committee (SMSC) meeting was held on May 16-17, 1991 at Lanet Regional Beef Center. The SMSC was charged to evaluate KARI's S/M short- and long-term research plans. Now that the S/M project leaders have prioritized and focused their research programs, it is important that research projects and numbers of experiments be maintained within available manpower and funding.

The SMSC expressed concern about the lack of trained manpower in breeding and the low percentage of time some agronomists spent on S/M research. They recommended that more assistance be given to finger and pearl millet improvement. The SMSC felt that the S/M Release Committee should meet soon to consider the release of finger millet varieties P-224 and KAT 1, and the sorghum variety KAT 369. They approved of the breeding objective of line development toward developing sorghum hybrids and the simultaneous evaluation of hybrids from INTSORMIL, ICRISAT, and those made up in the KARI breeding nurseries from elite introduced lines. This does not inhibit varietal development because some of the same populations can be used with slightly different selection criteria.

National Performance Trials (NPT's) were planted at a reduced number of sites and an effort was made to increase the quality of the trials. The entry make up of the trials was also reorganized. Kakamega will, in the future, prepare NPT's for their area of responsibility and for Kisii. Entries in these NPT's will include the bird resistant varieties used by most farmers in western Kenya. Katumani will prepare the dryland and coastal NPT's. Entries in these trials will be mainly white or yellow colored types with some bird resistant brown seeded check varieties. The finger millet NPT's will be prepared and sent out by Kakamega.

The PI attended a USAID-KARI National Agriculture Research Project Phase II Workshop and assisted the MIAC Phase II design team with input for their recommendations for the future of this project. Research sites were visited in eastern and western Kenya to evaluate the progress of the S/M program in Phase I and to determine the requirements in Phase II. The team shared the PI's concern that the S/M research programs do not have any depth in terms of trained personnel and that the S/M graduate students have just started to return to Kenya. They recommended to KARI and USAID that the S/M programs were not mature enough at this time to be self-sustaining and that further long-term TA assistance was required in Phase II.

The PI works closely with the S/M breeders in the following three regions:

Eastern Kenya - The sorghum breeding site at Kiboko is the logical location to spur expansion of the S/M production area into the semiarid regions of Kenya. Collaboration with ICRISAT and INTSORMIL scientists at this location has assisted the KARI effort; however, logistical improvements and infrastructure support by KARI are required. The irrigation system is critical at this location due to the nature and the large number of experiments directly or indirectly dependent on the operation of this equipment. It is essential that it be properly maintained.

Mr. Ben Kanyenji, Katumani sorghum breeder, returned from M.Sc. training at Texas A&M University. Ben's training and experience in drought tolerance breeding will strengthen KARI in this area of sorghum expansion.

An estimate was obtained to restore the KARI irrigation system at Kiboko to its original designed condition. Approval has been obtained to purchase a new pump and to repair or replace the broken and missing field equipment. When finished, the irrigation system at Kiboko should make this site a reliable S/M breeding location for KARI.

Western Kenya - A large quantity of germplasm from the PI's INTSORMIL project in Colombia was evaluated at Alupe during the two growing seasons in 1990. From these nurseries, over 1000 new lines will be evaluated in the future in variety trials and as hybrid combinations in hybrid trials. Sorghum breeding nurseries at Alupe in the future will be 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. Line development and evaluation of sorghum hybrid trials have been initiated. Bird and weathering resistant varieties and hybrids are required in the western humid areas. Breeding of finger millet varieties will continue at Kakamega.

Highlands - 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.

Publications and Presentations

Publications

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Presentations

Gutierrez, O. A., L. M. Gourley, C. E. Watson, Jr., and S. D. McLean. 1990. Combining ability for aluminum tolerance of sorghum in nutrient culture. Presented at the 1990 ASA Meetings. 20-26 October 1990. San Antonio, Texas.

Gourley, L. M. 1991. Breeding sorghum for stress environments of the tropics. Presented at the International Sorghum Workshop "Sorghum for the Future". 16-18 January 1991. CIAT, Cali, Colombia.

Goggi, A. S., J. C. Delouche, and L. M. Gourley. 1991. Sorghum seed internal morphology as affected by seed specific gravity, weathering and immaturity. Presented at the Scanning Microscopy and Food Structure 1991 Meeting. 4-9 May 1991. Bethesda, Maryland.

Networking Activities

Workshops

Attended and participated in the KARI Sorghum and Millet Planning Meeting, 9 August 1990 at Muguga, Kenya.

Attended the Second KARI Scientific Conference, 5-7 September 1990 at Nairobi, Kenya.

Coauthored a paper presented at the American Society of Agronomy Annual Meetings, 20-26 October 1990 at San Antonio, Texas.

Presented a paper at the International Sorghum Workshop "Sorghum for the Future", 16-18 January 1991 held at CIAT, Cali, Colombia.

Planned and participated in the First Sorghum and Millet Specialists Committee Meeting, 15-17 May 1991 at Lanet, Kenya.

Participated in the USAID-KARI Phase II of the Kenya National Agricultural Research Project Workshop and assisted the MIAC design team with input and site visits to determine the sorghum and millet research requirements in the $ 15 million Phase II of this project.

Attended the Fifth International Symposium on Parasitic Weeds. 23-29 June 1991 at Nairobi, Kenya.

Research Investigator Exchanges

In July 1990, following the 7th East Africa Regional Sorghum and Millets (EARSAM) Workshop Drs. Darrell Rosenow (TAM-122 PI) and Henry Pitre (MSU-105 PI) visited KARI, INTSORMIL, and ICRISAT sorghum and millet research in Kenya with the MSU-104 PI as guide.

January 13-20, 1991 the MSU-104 PI traveled out of Kenya on INTSORMIL activities to Colombia to participate in the International Sorghum Workshop at CIAT Cali, Colombia.

January 21-25, 1991 the MSU-104 PI participated in the external review of the INTSORMIL project MSU-111 at several locations in Colombia.

January 26-February 6, 1991 the PI met with graduate students at Mississippi State University from Kenya (M'Ragwa - MIAC funded), Uganda (Zake - IDRC funded) and Tanzania (Saadan - ICRISAT/SADCC funded).

Drs. Larry Butler (Purdue), Gebisa Ejeta (Purdue), Dale Hess (Niger), and Dick Frederiksen (Texas A&M) visited the KARI sorghum and millet program during and after the June 23-29, 1991 Parasitic Weed Symposium with the MSU-104 PI as guide.

Germplasm and Research Information Exchange

The 2300 entry Sudan sorghum collection obtained from ICRISAT by Darrell Rosenow and Gebisa Ejeta was subdivided by the MSU-104 PI and one set was handcarried to the Sudan for planting and evaluation. The second set will be sent to the USDA Plant Introduction Officer for eventual seed increase and storage at Fort Collins, Colorado.

Hybrid sorghum seed from crosses made in INTSORMIL projects MSU-104, MSU-111, TAM-122, and TAM-121 were imported into Kenya for evaluation at five locations. The 140 hybrid entries were selected to be useful across several Kenyan ecological zones.

Mr. George Ombakho, Dr. Fred Miller's (TAM-121 PI) Kenyan student, sent sorghum germplasm to Kenya to make crosses of two- and three-way hybrids to be evaluated in Kenya as part of his Ph. D. requirements at Texas A&M University.

The MSU-104 PI obtained approval for MIAC to purchase a new pump and to repair or replace the broken and missing irrigation field equipment at KARI's Kiboko Station. When this $ 5000 contract is completed, Kiboko should be a reliable sorghum and millet breeding location for KARI.

Five single-head threshers are on order by MIAC for KARI sorghum and millet breeders.

Breeding Sorghum for Increased Nutritional Value

Project PRF-103
John D. Axtell
Purdue University

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Dr. Brian Larkins, University of Arizona
Dr. Emmanuel Monyo, SADCC/ICRISAT, Sorghum Breeder, Bulawayo, Zimbabwe
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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.

1. 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 where sorghum is used as a feed or food grain.

2. The International Division of the U.S. Census Bureau, in a unique agreement with many other agencies, projects that the population of the world will double within the next 40-50 years (Jamison, E. 1989. World Population Profile. Bureau of the Census. Issued September 1989). This means that agricultural scientists will have to learn how to produce as much food, feed and fiber in the next five decades as they have learned how to produce during the past 2,000 years. There is virtually no alternative scenario to this view short of a major human calamity. This fact poses an unprecedented challenge to plant and animal scientists around the world. Fortunately, at the same time new and powerful research tools are available from the explosion of knowledge in the biological and agricultural sciences. Crop and livestock yields must increase significantly to avoid a level of human misery in the world which is intolerable to civilized society. Some of this increase will occur on productive land with adequate rainfall, but many of these lands are already stretched to capacity. Much of the increase will have to come from marginal agricultural lands with relatively poor soils and chancy rainfall, which are subject to frequent periods of drought. The goal of the INTSORMIL and McKnight Research Projects is to utilize the best basic information from recent advances in plant biology to understand the mechanisms of drought resistance in crop plants, and to apply this knowledge to the improvement of crop and livestock yields in the U.S. and throughout the world. The model crop used for these studies is sorghum, which has developed mechanisms which have allowed it to evolve in semiarid regions of the world over the centuries. Sorghum is generally grown in those parts of the world where it is too dry to grow corn or other cereals. Even though the drought resistance of grain sorghum has been known for centuries, relatively little effort has been expended in the study of mechanisms of drought resistance in sorghum at the genetic, physiological and molecular levels. The mission of our interdisciplinary program is to combine the resources of the International Sorghum Improvement Program at Purdue University with the expertise of scientists in Stress Physiology and Plant Molecular Biology in a concerted effort toward an understanding of the mechanisms of drought resistance in sorghum and to utilize this information for the

improvement of sorghum and other crop species such as maize. An understanding of these mechanisms will provide better 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 in Ethiopia when he returns home at the end of 1991. 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. S.C. Gupta and Dr. Tunde Obilana, who are principal sorghum research scientists at the ICRISAT program for the SADCC region of Southern Africa in Bulawayo, Zimbabwe. Both will be spending their sabbatical leaves 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 Dr. Sam Mukuru has now proven in studies conducted in our laboratory that high tannin sorghums traditionally grown at high elevations in Eastern Africa are very satisfactory sources of digestible nutrients if the grain is processed adequately by traditional means. Protein quality improvement will be a major breeding objective during the next five years. We have identified good sources of modified quality protein sorghums which are comparable in yield potential and grain quality to quality protein maize as developed by CIMMYT. The basic high lysine gene, P-721 opaque, has been combined with sources of vitreous endosperm to give the QPS (Quality Protein Sorghum). The high yield potential has been demonstrated by Emmanuel Monyo and the modified vitreous endosperm characteristics have recently been 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 Mr. Mauricio Lopez has shown a strong relationship between the gamma-zein fraction and modified vitreous endosperm characteristics. An Elisa technique is being developed which will make selection for vitreous endosperm opaque-2 much more reliable and faster. The same technique will be adapted to sorghum P-721 modified lines in improvement programs. Trials will be conducted at several locations during 1989 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 Allen Kirleis, 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 lactobacillus. Many improved sorghum varieties lack this characteristic and this factor may be responsible for the low adoption rate of improved varieties. Joe Mushonga's research on developing rapid assays for diastatic power and studying inheritance of diastatic activity in sorghum cultivars will be continued. Second, Dr. 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 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 is currently the major cause of global crop failures. In the U.S., major yield losses associated with drought have occurred on average once every four or five years over the last 50 years. The droughts of 1983, 1988 and again in 1990 in the U.S. offer grim testimony to this continuing pattern of water shortages for crop production. The problems of water deficits are even more pronounced in the continent of Africa. There is clearly a long-term need for plant breeding efforts devoted to minimizing these yield losses associated with water deficits. The present proposal addresses these needs through an interdisciplinary research effort focused on an understanding of the fundamental genetic determinants of drought resistance in *Sorghum bicolor*. Sorghum is known for its drought and heat tolerance. It is a native plant in the Sub-Saharan zone of Africa and is the preferred cereal crop wherever it is too dry to grow maize. Purdue University has developed an international sorghum breeding program over the past 20 years with extensive cooperative arrangements with many African countries, including Niger and Sudan. During this period, a vast number of sorghum varieties and lines have been screened extensively for drought resistance in the U.S. and Africa. However, very little is known or understood about the biochemical and genetic basis of plant stress tolerance in dry, harsh environments. The drought resistant and susceptible lines thus far identified provide a valuable source of germplasm which can be utilized to help dissect the mechanisms of stress resistance. The available resistant lines are known to have both preflowering and postflowering stress resistance.

Research aimed at elucidating the genetic basis of the complex characteristic of drought resistance would allow the eventual transfer of this resistance to many other crops, especially other cereals. Significant progress has recently been made in sorghum transformation which will expedite gene transfer in this species. Information we gather will produce realistic genetic markers for other cereal crops as well as a more general appreciation for strategies of drought resistance in dicotyledonous plants. The potential benefit to human welfare for increasing drought resistance of other cereal species to the level of resistance currently available in sorghum is enormous. The future of agriculture in arid regions depends upon such basic information and the training of highly skilled scientists.

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 will continue his collaboration with the Sudan and Niger on *Striga* tolerance and drought tolerance. 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 qual-

ity. This program also will be carried out jointly with Niger and Sudan. Much of the breeding work will be done in Niger with backup using laboratory facilities at Purdue. Screening and trials will be conducted at three locations in Niger as well as in Sudan.

Our approach to investigating the genetic determinants of the exceptional drought resistance of certain sorghum cultivars (P898012 and P954035) will first entail constructing hybrids between exceptionally resistant and susceptible (e.g., P721-N) lines and evaluating F_2, F_3 and subsequent advanced progeny and their backcrosses to the original parents, using traditional plant breeding methods. Second, 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 M_1 plants were self-pollinated to provide M_2 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 current 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 may have an important new tool for following the modified vitreous endosperm trait in high lysine sorghum. Dr. Brian Larkins and Mauricio Lopez have discovered the mechanism of endosperm hardness in QPM maize. QPM was developed by CIMMYT over many years at great expense, which we really could not afford to do in sorghum. Their identification of the gamma-zein endosperm protein fraction as the cause of endosperm hardness in opaque-2 maize should allow similar results to be achieved in sorghum at only a small fraction of the cost of CIMMYT's development of QPM. Collaborative work with Dr. Allen Kirleis and Dr. Julie Watterson suggests that QPS (Quality Protein Sorghum) also has an elevated gamma-kafirin content. An Elisa technique is being developed for rapid screening of a large number of progeny from P-721 crosses with elite vitreous endosperm normal sorghums.

Second, 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.

Third, 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 will be 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.

Fourth, 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.

Fifth, 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 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 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.

Sixth, 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. These betaine-deficient lines offer the opportunity to determine the genetic and biochemical basis of betaine-deficiency in sorghum, and to determine the precise contribution of this trait to drought resistance and osmotic adjustment.

Seventh, 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 antisense 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.

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Networking Activities

Workshops

Participant and organizer of "International Conference on Sorghum Nutritional Quality". Purdue University, West Lafayette, IN. February 26-March 1, 1990. Proceedings published in March 1991 and single copies are available to sorghum researchers.

Organizer and participant of "The Second Annual Purdue University McKnight Program Retreat." Presentation entitled "The McKnight Foundation Interdisciplinary Research Project on Mechanisms of Drought Resistance." McCormicks Creek State Park, IN. April 12-13, 1991.

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 Program, Bulawayo, Zimbabwe

Mr. Joe Mushonga,SADCC/ICRISAT Sorghum & Millet Research Program, Bulawayo, Zimbabwe

Dr. Vartan Guiragossian, Sorghum Breeder, ICRISAT, Nairobi, Kenya

Dr. John Rogler, Animal Science, Purdue University, West Lafayette, IN 47907

Dr. Ed Ashworth, Horticulture, Purdue University, West Lafayette, IN 47907

Dr. Nick Carpita, Botany, Purdue University, West Lafayette, IN 47907

Dr. Mike Hasegawa, Horticulture, Purdue University, West Lafayette, IN 47907

Dr. Darrell Rosenow, Texas A&M University Agricultural Research Center, Lubbock, TX 79401

Dr. Lloyd Rooney, Soil & Crop Sciences, Texas A&M University, College Station,TX 77843

Dr. Richard Frederiksen, Texas A&M University, College Station, TX 77843

Dr. George Teetes, Entomology, Texas A&M University, College Station, TX 77843

Mr. William Stegmeier, Ft. Hays Experiment Station, Kansas St. 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.

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

Project PRF-107
Gebisa Ejeta
Purdue University

Principal Investigator

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Collaborating Scientists

Dr. Osman Ibrahim El Obeid, Sorghum Breeder, ARC, Sudan
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
Dr. John Clark, Team Leader, Sorghum Breeder, INRAN, Niger
Mr. Shadou Bawa, Director General of INRAN, INRAN, Niger
Dr. Sam Mukuru, Sorghum Breeder, ICRISAT, Kenya
Dr. Vartan Guiragossian, Sorghum Breeder, ICRISAT, Kenya
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. Allen Kirleis, Food Science Department, Purdue University, West Lafayette, IN
Dr. Darrell Rosenow, Texas A&M University Agricultural Research Center, Route 3, Lubbock, TX
Dr. Jerry Eastin, Department of Agronomy, University of Nebraska, Lincoln, NE
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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 12 we provide brief reports on inheritance of *Striga* resistance, on release of 10 fertility restorer drought tolerant lines for public use, on characterization of African pearl millet landraces, and on the role of phenolic compounds in grain mold resistance in sorghum.

In multilocation testing of selected *Striga* resistant sorghum varieties conducted in Sudan and Niger over several years, we identified a superior source of resistance in cultivar SRN-39. This cultivar was officially released this last year for wide cultivation in *Striga* endemic areas of the Sudan. Genetic studies on SRN-39 showed simple recessive inheritance for *Striga* resistance. Intercross of SRN-39 with high yielding adapted but *Striga* susceptible varieties resulted in superior progenies that combine *Striga* resistance with agronomic superiority.

A joint effort between Purdue University, Texas A&M University and the Sudan Agricultural Research Corporation has resulted in a release of ten drought tolerant fertility restorer parental lines for potential use in Sudan and the U.S. seed industry.

Pearl millet landraces widely grown in several African countries were characterized for morphological and agronomic characteristics resulting in a series of potential heterotic groups. This information will be useful as a foundation to initiate a productive pearl millet breeding program in some African countries.

Our earlier finding on the association of a low molecular weight phenolic compound, flavan-4-ols and grain mold resistance was confirmed in a developmental study we conducted last year on 10 sorghum genotypes at Purdue University Agronomy Research Center.

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 is 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 12 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 possessing 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 deliberate 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 — Genetics of Host Plant Resistance

Witchweeds are widely recognized as one of the most noxious weeds of crops and a production constraint of significant importance. Cereal crops seem to suffer the most, although some legumes are also known to be devastated by *Striga* attack. As the most predominant cereal crop of the semiarid tropics, production losses in grain sorghum are perhaps much higher than for other crops.

Cultivar resistance is the most economic control measure, since adapted, resistant cultivars can be grown without additional input from the subsistence farmer. Information on the genetics of resistance to *Striga* is scant. This is partially attributable to the rarity of germplasm which exhibits stable resistance across geographical regions. In a multilocation testing of selected *Striga* resistant sorghum cultivars, conducted in Sudan and Niger over several years, we identified a stable and superior source of resistance in cultivar SRN-39. To establish if the resistance observed in SRN-39 was heritable, we made crosses between this line and a susceptible line, P-954063. Parental, F_1, F_2, and backcross generations were grown in infested pots and development of both host and parasite was monitored. A completely randomized design was used. The experiment was laid out in five double rows of 29 pots each. Spacing between plants within double rows was 33 cm and rows were 63 cm apart.

Significant variation among genotypes was observed for both host traits and effects on parasite populations. The F_1

did not differ significantly in *Striga* resistance from the susceptible parent, suggesting recessive inheritance. However, hybrid vigor was exhibited by the F_1 which yielded and developed as well as the resistant parent. Broad sense heritability ranged from 0.23 to 0.55 for host traits and from 0.10 to 0.43 for effect of genotypes in the *Striga* population. Joint scaling tests showed that observed variation in each host or parasite trait consisted of additive and dominant components, suggesting that progress can be made for further improvement. We have involved SRN-39 in various cross combinations with high yielding and broadly adapted, but *Striga* susceptible varieties. This has resulted in superior progenies that combine *Striga* resistance with agronomic superiority. These newly derived elite progenies are currently under international testing in Africa. Meanwhile our *Striga* resistance source, SRN-39, has been recommended for commercial cultivation in *Striga* endemic areas of the Sudan. This variety is also under consideration for release in Niger, West Africa.

Drought - Release of Drought Tolerant Parental Lines

One of the mutual benefits accrued from international collaborative research is the development and availability of useful germplasm. Joint research between Purdue University, Texas A & M Experiment Station at Lubbock, and the Agricultural Research Corporation, Sudan that has been underway for the last eight years recently produced drought tolerant sorghum lines that should be useful in both the Sudan and the United States. These sorghum lines were derived from deliberate crosses between elite U.S. restorer lines and restorer lines selected for drought tolerance, tropical adaptation, and food grain use in Sudan, as part of an on-going collaborative research effort between scientists in the two countries. Pedigrees and plant characteristics of the ten R-lines are given in Table 1. The initial crosses were made by Dr. D.T. Rosenow at Lubbock, Texas and by Dr. Gebisa Ejeta at West Lafayette, Indiana during the 1984 crop season. Selection and evaluation of early generation segregating populations were done using the pedigree method of breeding with alternative selection at West Lafayette, Indiana (Summer) and Isabella, Puerto Rico (Winter). Selection at West Lafayette emphasized yield potential, early maturity, and seed quality. Selection in Puerto Rico focused on tropical adaptation and foliar disease reaction. Elite selections in advanced generation (F_6) were crossed on to commercially available male-sterile seed parents at West Lafayette. These selections and their resultant hybrids were evaluated for agronomic merit and/or drought tolerance at West Lafayette, Indiana; Lubbock, Texas; and Wad Medani, Sudan (Table 2). Ten restorer lines that exhibited excellent combining ability were further evaluated in hybrid combination with commercial A lines (Table 3).

Table 1. Pedigree of release lines.

Release Designation	Pedigree
P-89001	(TAM428 * M62641)-8-bk-3-1-bk-bk-bk
P-89002	(TAM428 * M62641)-17-bk-3-3-bk-bk-bk
P-89003	(TX2794 * K22/35)-3-bk-1-1-bk-bk-bk
P-89004	(TX2794 * K22/35)-10-bk-3-3-bk-bk-bk
P-89005	(TX2794 * K22/35)-15-bk-2-2-bk-bk-bk
P-89006	(TX430 * K1597)-10-bk-1-1-bk-bk-bk
P-89007	(TX430 * K1597)-3-bk-2-2-bk-bk-bk
P-89008	(TX430 * K443)-8-bk-1-1-bk-bk-bk
P-89009	(TX430 * K22/35)-1-bk-3-3-bk-bk-bk
P-89010	(TAM428 * K1/4)-2-bk-2-1-bk-bk-bk

All ten parental lines restore fertility in A_1 cytoplasm, but their fertility restoration in other cytoplasms is not known. The lines and their hybrids showed broad adaptation with excellent potential for use both in the U.S. and Sudan. The parental lines were selected primarily on the basis of superior drought tolerance, evident grain quality, and agronomic merit both as lines per se and in hybrid combinations. All ten lines are excellent pollen shedders. Other characteristics of these parental lines including plant color, glume color, midrib color, endosperm color, and endosperm texture were scored. These lines have panicles that are semicompact and erect. Seeds are white or yellow in appearance and translucent, ranging from medium to large in size. All possess no pigmented testa; most have yellow endosperm, a white or colorless epicarp and a thin mesocarp.

The ten parental lines and their hybrids range from medium to late in maturity compared to other commercially available inbreds and hybrids. Both the lines and their hybrids range from good to excellent in lodging resistance and overall stalk strength. All ten lines have juicy culm with midribs that appear green. All ten R lines tiller profusely, producing secondary tillers with even height and maturity with the main plants.

Continued testing of these ten parental lines in an array of environments has shown that they combine excellent drought tolerance, combining ability, yield stability, and good foliar disease reaction. These inbreds should be useful as pollinator parents both in the U.S. and in the tropics for developing drought tolerant food grain hybrids with high yield potential.

Diversity among African Pearl Millet Landraces

Pearl millet evolved in the dry and semiarid regions of Africa where landraces have been grown since the beginning of settled agriculture. Introduction of improved pearl millet cultivars into the region is recent and limited to favorable areas. For the drier and marginal areas, farmers continue to rely on landraces that have shown good stability and reliability. Continued selection by farmers over hundreds of years has resulted in the establishment of ecologically well-adapted landraces. Many of these landraces, however, have low yield potential.

A comprehensive genetic study has been under investigation by Ouendeba Botorou, millet breeder from Niger who is currently a Ph.D. candidate at Purdue University. One of the objectives of Ouendeba's study was the genetic characterization of African pearl millet landrace populations

Table 2. Agronomic characteristics of elite pollinator lines, their original parents, and new experimental hybrids.

Cultivar	Flowering (50%) (days)			Plant height (cm)		Yield (kg/ha)		
	TX[1]	IN[2]	SU[3]	IN	SU	TX	IN	SU
P89001	58	71	64	155	142	4975	6389	3546
P89002	63	72	66	160	145	3130	4937	3753
P89003	62	72	63	120	128	3822	4646	3392
P89004	65	73	69	140	137	4230	4211	3238
P89005	63	75	69	115	127	4245	3194	2751
P89006	66	-	69	110	112	5283	3775	2698
P89007	60	72	64	135	110	4030	4501	3031
P89008	64	74	68	165	167	5222	6678	3778
P89009	65	74	67	125	130	4076	4792	3263
P89010	64	73	67	150	147	4107	5808	4986
TAM428	63	73	69	107	109	4224	3775	3836
M62641	65	71	67	183	175	3896	6098	4606
K22/35	61	74	60	102	102	2402	2759	1876
TX430	59	74	66	117	122	5598	5227	4172
K443	67	-	68	109	127	3184	3528	2394
K1/4	65	73	64	127	122	3237	5227	4270
TX623B	58	69	67	142	142	4801	5953	4914
K1597	68	-	70	117	122	2127	3877	1960
TX623*P89001	56	68	63	185	185	6021	7696	4780
TX623*P89002	59	68	64	185	182	6513	7886	4471
TX623*P89003	63	70	69	145	148	6029	6534	5063
TX623*P89004	61	69	66	160	163	6867	7115	5807
TX623*P89005	61	68	66	150	140	6006	6824	4009
TX623*P89006	63	70	67	170	158	6490	7550	6322
TX623*P89007	59	68	64	160	155	6606	5953	6167
TX623*P89008	63	71	66	205	198	6583	9728	5011
TX623*P89009	66	67	63	160	152	6406	6679	4881
TX623*P89010	61	69	67	180	165	6444	5953	5112
TX623*M62641	60	69	67	198	203	5350	8422	4046
TX623*K443	64	72	66	175	173	6860	7158	5404
TX623*TAM428	64	73	67	183	178	7523	7550	4970
TX623*K1597	59	69	67	163	167	6073	6490	6594
TX623*TX430	57	70	64	147	147	5460	6345	4270
TOPAZ (ASGROW)	58	67	60	119	124	6601	6868	5124

[1] TX = Lubbock, Texas
[2] IN = West Lafayette, Indiana
[3] SU = Wad Medani, Sudan, Africa

widely grown in several African countries, and two experimental pearl millet hybrids were evaluated at two locations in Niger during the 1989 rainy season. Table 4 lists the seed source and origin of the pearl millet landraces utilized in this study. Thirteen characters including downey mildew incidence, days to flowering, spike length, peduncle length, spike girth, flag leaf width, stem diameter, spike number per plant, nonproductive tillers per plant, plant height, spike yield per plot, grain yield per plot, and 1000-seed weight were measured on six replications of each cultivar.

The cultivars were all significantly different for all characters evaluated (Table 5). The Niger millet landraces showed much less variation than the other African millets for all characters investigated. Ward's cluster and principal component analyses were used to investigate the nature and degree of divergence in the pearl millet populations. The cluster analyses revealed similarities between Niger and Senegal and between Niger and Nigerian pearl millet landraces. Four principal components were found to explain more than 90% of the total variation. Flowering time, plant height, stem diameter, spike length, and yield seemed to be the major sources of diversity among the cultivars.

Adequate genetic variability is essential for an effective crop improvement program. Effective utilization of germplasm in breeding programs is enhanced if the variation is properly characterized and described. The results of this study should be useful in choosing potentially heterotic pearl millet populations for intercrossing in the development of improved varieties, synthetics, and hybrids for use in West Africa.

Grain Mold - Phenolic Compounds in Grain Mold Resistance

Sorghum seeds contain phenolic compounds some of which have been reported to contribute to mold resistance. We have previously reported a strong association between levels of flavan-4-ols, and favorable grain mold rating in a working collection of diverse sorghum germplasm assembled at Purdue University. Recently we evaluated ten sorghum genotypes during seed development and maturation to determine relationships between changes in polyphenol content and mold development. Seed samples were analyzed for flavan-4-ols, 3-deoxyanthocyanidins, and proanthocyanidins (tannins) concentration. Samples were also plated on culture medium to determine infection by different

Table 3. Agronomic characteristics of hybrids made with new elite pollinator parents and commercial A-lines at West Lafayette, Indiana.

Cultivar	Redlan A	Wheatland A	SA3042	A1
		50% Flowering (days)		
P89001	78	78	77	76
P89002	80	79	68	76
P89004	81	80	68	78
P89006	86	84	77	83
P89008	84	82	74	82
P89009	90	87	79	87
P89010	80	81	70	80
TX2737	83	83	84	80
TX430	82	82	71	79
K1597	87	84	80	82
		Plant height (cm)		
P89001	178	160	147	160
P89002	183	163	157	173
P89004	167	130	140	160
P89006	157	132	137	147
P89008	208	178	163	178
P89009	157	122	135	137
P89010	160	152	142	150
TX2737	137	112	137	135
TX430	137	122	117	130
K1597	150	127	137	147
		Yield (Kg/ha)		
P89001	7452	6825	4904	6724
P89002	7910	7316	5181	4951
P89004	6914	6373	5525	6728
P89006	6916	7875	5734	6872
P89008	8065	7585	6090	7593
P89009	7123	7330	5201	6504
P89010	6648	6090	4860	6131
TX2737	7419	7066	6412	5093
TX430	6116	5045	5451	6474
K1597	7683	6033	4409	6403

Checks	50% Flowering (days)	Plant height (cm)	Yield (kg/ha)
RS610	72	117	3097
GS712 (Asgrow)	81	127	7299
Topaz (Asgrow)	79	122	5882

Table 4. Source and origin of ten landrace populations and two intervarietal F_1 hybrids of pearl millet.

Cultivars	Source	Origin
Souna 3	ICRISAT[a]	Senegal
Iniari	ICRISAT	Togo
Mansori	ICRISAT	Sudan
Ex-Bomu	ICRISAT	Nigeria
Ugandi	ICRISAT	Sudan
CIVT	INRAN[b]	Niger
P3-Kolo	INRAN	Niger
Zongo Kolo (ZOK)	INRAN	Niger
Haini Kire Precoce (HKP)	INRAN	Niger
Zanfarwa (ZA)	INRAN	Niger
F1 hybrid No. 1 1784-91*P3Kolo	ICRISAT	ICRISAT
F1 hybrid No. 2 1784-91*GB-8735	ICRISAT	ICRISAT

[a] International Crops Research Institute for the Semi-Arid Tropics
[b] Institut National De Recherches Agronomiques Du Niger

fungi. Results showed that grain mold resistant genotypes have a higher level of flavan-4-ols and proanthocyanidins throughout grain development compared to susceptible lines. Total fungi infection and rate of fungi growth are consistently lower in genotypes with higher flavan-4-ols and proanthocyanidins. These results confirm that assays for flavan-4-ols and proanthocyanidins that have been developed at Purdue University could be used as a screen in developing mold resistant sorghum lines.

Publications

Ahlrichs, J.A., R.R. Duncan, G. Ejeta, P.R. Hill, V.C. Baligar, R.J. Wright, and W.W. Hanna. 1991. Pearl millet and sorghum tolerance to aluminum in acid soil. A.E.S. J. No. 12,529. Plant and Soil (In Press).

Ahlrichs, J.L., G. Ejeta, W.G. Smart, and T.G. Toulemonde. 1991. Plant tolerance of soil induced stress: the Aluminium case. Proc. Turkish Soil Science Society. Urfa, Turkey. September 1991.

Butler, L.G. and G. Ejeta. 1991. Several approaches to the *Striga* problem being developed at Purdue Univ. Proc. Second Workshop of the Pan-African *Striga* Control Network (PASCON). Nairobi, Kenya. June 28, 1991.

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Ejeta, G., L.G. Butler, D.E. Hess, and R.K. Vogler. 1991. Genetic and breeding strategies for *Striga* resistance in sorghum. pp. 539-544. In: J.K. Ransom et al. (eds.). Proc. of the 5th International Symposium of Parasitic Weeds. Nairobi, Kenya. June 24-30, 1991.

Hess, D.E., G. Ejeta and L.G. Butler. 1991. Research into germination of *Striga* seed by sorghum root exudates. pp. 217-222. In: J.K. Ransom et al. (eds.). Proc. of the 5th International Symposium of Parasitic Weeds. Nairobi, Kenya. June 24-30, 1991.

Hess, D., and G. Ejeta. 1991. Inheritance of resistance to *Striga* hermonthica in sorghum. A.E.S. J. No. 12,346. Plant Breeding (In Press).

Hess, D.E., G. Ejeta, and L. Butler. 1991. Selecting sorghum genotypes expressing a quantitative biosynthetic trait that confers resistance to *Striga*. Phytochemistry (In Press).

Ouendeba, B., G. Ejeta, W.W. Hanna, and A.K. Kumar. 1991. Genetic diversity among African pearl millet landraces. Euphytica (In Press).

Networking Activities

Edited Proceedings of the International Conference on Sorghum Nutritional Quality, held at Purdue University, Feb.-Mar. 1990.

Attended the 15th International Symposium on Parasitic Weeds, June 1991, Nairobi, Kenya. Participated with three presentations.

Attended the 2nd Workshop of the Pan-African *Striga* Control Network (PASCON), June 1991, Nairobi, Kenya. Presented one paper.

Attended the American Society of Agronomy at San Antonio, Texas, October 1990.

Research Investigator Exchange

Germplasm

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 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

Table 5. Cultivar means of 13 characters analyzed across two locations.

Origin/ Cultivar	Spike length (cm)	Peduncle length (cm)	Spike girth (cm)	Flag-leaf width (cm)	Stem diameter (cm)	Spike number	Number of non-prod tillers	Plant height (cm)	Downy mildew incidence (%)	Time to flowering (days)	Spike yield (g)	Grain yield (g)	1000-grain weight (g)
Niger landraces													
CIVT	47.54^{b}	1.66^{abc}	7.81^{b}	3.90^{a}	4.63^{b}	3.32^{ab}	3.33^{c}	219.99^{b}	28.39^{a}	59.92^{b}	2985^{ab}	1994^{ab}	9.42^{a}
P3Kolo	47.32^{b}	2.43^{a}	7.70^{b}	3.73^{a}	4.56^{b}	3.65^{a}	4.20^{b}	209.09^{bc}	17.21^{b}	57.67^{bc}	3304^{a}	2200^{a}	9.17^{a}
ZOK	62.88^{a}	1.43^{bc}	7.80^{b}	3.92^{a}	5.01^{a}	3.25^{ab}	5.85^{a}	268.60^{a}	26.10^{a}	63.67^{a}	3539^{a}	2290^{a}	9.42^{a}
HKP	49.18^{b}	2.12^{ab}	7.71^{b}	3.64^{a}	4.71^{b}	3.68^{ab}	4.28^{b}	208.27^{bc}	27.61^{a}	56.08^{c}	3023^{ab}	1958^{ab}	9.54^{a}
ZA	47.00^{b}	1.10^{c}	8.67^{a}	3.58^{a}	4.95^{a}	3.00^{b}	3.24^{c}	197.68^{c}	14.39^{b}	59.67^{b}	2481^{b}	1574^{b}	8.96^{a}
Other African landraces													
Souna 3	48.85$^{a(*)}$	2.91^{c}	7.90^{c}	4.24^{a}	4.93^{a}	3.48^{c}	6.35^{a}	215.97^{a}	7.42^{c}	62.17^{a}	3704^{a}	2382^{a}	7.37^{c}
Iniari	22.31^{e}	7.75^{a}	10.46^{a}	3.47^{b}	4.23^{b}	3.85^{bc}	5.74^{a}	171.83^{c}	31.59^{b}	53.00^{c}	2484^{c}	1864^{b}	9.83^{a}
Mansori	27.47^{c}	6.16^{b}	7.47^{d}	3.44^{b}	4.00^{c}	4.39^{ab}	3.75^{b}	173.58^{c}	24.81^{b}	56.08^{b}	2070^{c}	1399^{c}	8.50^{b}
Ex-Bornu	31.35^{b}	6.78^{ab}	7.86^{c}	3.63^{b}	4.26^{b}	4.46^{ab}	3.54^{b}	199.55^{b}	11.52^{c}	56.26^{b}	2955^{c}	2053^{ab}	9.75^{a}
Ugandi	24.25^{d}	5.58^{b}	9.02^{b}	3.20^{c}	3.72^{d}	4.68^{a}	3.83	167.66^{c}	41.57^{a}	51.50^{c}	2037^{c}	1440^{c}	10.21^{a}
F_1 hybrids													
Hybrid 1	39.42^{b}	6.26^{a}	8.55^{a}	4.03^{b}	4.36^{b}	4.47^{a}	5.24^{b}	204.48^{b}	10.45^{a}	53.58^{b}	4658^{b}	3408^{b}	10.58^{a}
Hybrid 2	26.05^{a}	9.19^{b}	9.61^{b}	3.65^{a}	3.77^{a}	4.75^{a}	3.51^{a}	163.09^{a}	17.28^{a}	48.83^{a}	3448^{a}	2579^{a}	11.08^{a}

(*) Means with identical letters have no significant differences among them. Mean separations done within each group.

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.

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

Project TAM-121

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Summary

Sorghum is the primary cereal of choice in several parts of the world because of its resistance to high temperature and water stress. During the last 30 years, yields have steadily increased thereby sustaining production levels despite a leveling of total area devoted to the crop. This has been accomplished by meeting the needs of producers and remaining ahead of yield limiting constraints. The principal objective of TAM-121 is to bring together in a deliberately focused manner all those traits which cause the production of higher yielding sorghums with acceptable or superior food quality, and have adequate resistances to biotic and abiotic stresses.

During 1990-1991 TAM-121 developed and released for public distribution four new grain female cultivars. A/B TxARG-1, an elite white translucent grain, tan plant color line with high combining ability was jointly distributed by Texas A&M University and Instituto Nacional de Tecnolo-

gia Agropecuaria, Manfredi, Argentina. This line should significantly increase the possibilities for new 3-dwarf hybrids for human food use and poultry-livestock feeds. A/B Tx635 is a nonsenescing, tropically adapted, short 2-dwarf sorghum female with exceptional foliar disease resistance, food quality grain, yield potential, and immunity to head smut. This line was developed in collaboration with ICRISAT, Centro de Tecnologia Agricola de Salvador (CENTA), and Texas A&M University. A_2/B_2Tx636 and A_2/B_2 Tx637 were developed and distributed by Texas A&M University. These two females provide significant additions to the A_2 sterility system which can be used to broaden the taxonomic array of hybrids. The B_2 lines of both releases are excellent R-lines in the A_1 sterility system.

The evaluation of charcoal rot, a disease often associated with drought stress showed that the high depletion rates of reserve nonstructural carbohydrates from the stem inhibit defense mechanisms, through limiting synthesis of inhibitors of fungal degradative enzymes. Resistance to charcoal rot was determined to be under multiple-locus control with dominant and recessive epistatic effects.

As a part of the long term research effort to identify and manipulate mechanisms of drought resistance, we have studied inheritance of resistance - via osmotic potential, heat tolerance, water potential, and relative water content of the cell. Inheritance of resistance was determined to be under control of multiple loci systems with dominant and recessive epistatic effects. We propose that each system is affected by two genes. Whether the gene(s) system for high RWC, ψ and π, and heat stress was the same could not be established.

Farmers in developing countries generally believe that varieties perform superior to hybrids under harsh environmental conditions because hybrids require higher levels of inputs and culture to express their potential. When we compared hybrids and their parents under four very diverse environments, we found that even in the most harsh dry low yield environments hybrids performed better than their parents.

When we compared an array of U.S. developed inbred lines with traditional African cultivars for their ability to emerge in moisture deficient soils, we found the traditional cultivars to be superior. These cultivars (Hegari and CSM388) had the best germination performance in low soil water content; (Segaolane and CSM388) had the best seedling emergence in situations of very low soil water content, and (CSM388, Bagoba, Ajabsido, etc.) had the fastest emergence under limited soil water content. These data indicate that there are potentials for increasing germination, emergence and survival in soils with very low water contents.

Many new germplasm resource lines were added to the project via introductions from collaborators. Materials from Argentina and ICRISAT Mexico appear to be very useful. These and others have been crossed into our program materials and/or increased for distribution. A large amount of materials consisting of A/B-lines, R-lines, and breeding selections as well as replicated trials were distributed to LDC's, other international, and domestic collaborators. This project aims to support collaborating scientists with enhanced breeding materials from which they can choose specifically adapted types to establish local programs. We do this with distribution of a very large array of materials. In 1990-1991 the project distributed more than 3,347 different sorghums, 116+ replicated trials, and numerous selections, etc., entered into trials distributed by TAM-122 and TAM-124.

Objectives, Production and Utilization Constraints

Objectives

Develop through crossing, selection, and appropriate evaluations under field and laboratory conditions stable, high yielding, agronomically desirable sorghums with high levels of disease, insect, and agronomic stress resistance, high grain quality with resistance to weathering, and environmental stresses.

Develop sorghum grain hybrids and lines which possess acceptable human food quality.

Determine the yield constraining attributes of West African guinea sorghum taxonomic types.

Assess the physiologic mechanisms of drought resistance and use to improve sorghum stress tolerance.

Determine interaction of temperature and photoperiod on the growth and development of sorghum.

Develop specific germplasm resources and enhanced sorghum pools for use in affecting productivity in Latin America, South America, and Africa.

Distribute improved lines, hybrids, and early generation materials possessing superior productivity to collaborating LDC's.

Constraints

Sorghum is the primary cereal of choice in several parts of the world because of its resistance to high temperature and water stresses. During the last 30 years, yields have steadily increased thereby sustaining production levels despite a leveling of total area devoted to the crop. This was accomplished by meeting the needs of producers and remaining ahead of yield limiting constraints (diseases, insects, stresses, etc.). This has been true for most areas of the world but there still remain areas where the sustainable yield has not changed from its low range. It is the latter as well as the former production regimes that this project impacts, and is designed to collaborate with scientists and lay leaders within each type of agriculture.

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 contraints where sorghum is considered a staple food resource. The overall objective of this project is to reduce risks through the creation of enhanced germplasm pools, lines, and hybrids (properly evaluated) with stable potentially high yield, good food quality and 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 nutrition 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. It is assumed that the project's enhanced germplasm can be fitted into a political and economic system that will allow benefit to society.

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 the available germplasm.

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. Materials which are utilized in Mexico are evaluated for stepwise enhancement and transfer to Guatemala, El Salvador, etc., and are reinforced in Honduras (prime site) and in collaboration with other Latin American countries which 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 other 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. Colombia has a potential to research acid-soil tolerance and add yield levels that make sorghum attractive in several million hectares in Central and South America. 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.

In Kenya, Ghana, Zambia, Sudan, Niger, and Mali, the overall situation is somewhat different. 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 germplasm from the Honduran breeding program should be very useful in providing additions 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 when coupled with higher yield potential.

In Uganda, sorghum is the second most important cereal and is used for food, beer, and livestock fodder. The major constraints are yield with stability of production and adapted cultivars possessing resistance to diseases and insects while maintaining excellent food quality factors, as well as meeting the needs of both larger plantings and small farms. Lines and hybrids have potential, but both must fit the rainfall/photoperiod constraints. In Cameroon, the same situation exists. Hybrid production represents good potential. But there has been a decline in yield and hybrids are seen as a way to produce greater returns. Grain quality sufficient for human consumption and nutrition must be the constraint addressed within any hybrid program. In Zambia, sorghum production and breeding research have improved with the program of Dr. Bhola Nath. The constraints which need attention are yield, stability of production, tolerance to acid soils, food quality, and brewing quality. It is apparent that sorghum materials developed, enhanced, and exchanged with these programs and the others (Niger, Mali, Sudan, Ethiopia, Burkina Faso) through TAM-121 will have an impact.

Research Approach and Project Output

Research Methods

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 sustain-

able production of sorghum for grain (feed and food) and forage (silage and pasture).

Materials from the Sorghum Conversion Program and breeding materials from other TAES sorghum projects are evaluated annually 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 the most useful sources of resistance(s) and economical gene deployment. Screenings 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 identify either 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. Maintaining greenleaf area through nonsenescence, high levels of nonstructural carbohydrates in the stem, and the ability to differentiate a large number of seeds per panicle under stress, coupled with the efficient use of water to fill those seeds, give stability to production.

The TAES/INTSORMIL sorghum research program has and continues to contribute sustainability to the commodity worldwide. The blend of practical field evaluations with basic research endeavors, identification, and utilization of exotic germplasm with protection traits, strengthens enhancement of utilization traits to make products more useful and economical for the grower and consumer. This research effort in sustainability is focused on increased yield of food energy per unit area, maintenance or increased yield of available protein, and diversification of germplasm to protect yield.

Planned crosses among selected elite or recognized trait possessing lines were made and evaluated in appropriate replicated trials at numerous locations. These sites were specifically chosen to test responses to various disease resistance sources, agronomically superior lines, drought resistance mechanisms, and food quality traits. Selections were made from these trials and advanced to more elite testing.

Enhancing sorghums for productivity has received considerable attention in the U.S., 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 U.S. or in LDC's. In order that progress can be made to improve sorghum's potential for yield, multiple diverse sites were used in selections and screenings. This project in cooperation with other INTSORMIL activities evaluated germplasm for yield, disease resistances and food quality across a wide range of environments. Genotypes have been 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 Findings

This project acts as a delivery vehicle for several other projects in the CRSP. Not only are the basic germplasm resources cooperative in nature but the collaboration with LDC's is also cooperative and includes scientists and graduate students. Large field evaluation nurseries are grown in areas of significant climatic variations and are especially designed to select desired recombinations for appropriate yield, stability, drought tolerance, disease resistance, and grain quality. Major emphasis of this project has been placed upon the development of tropically adapted cultivars with high levels of nonsenescence and high yield. The basic operating scheme of this project is to create a base of yield that is sustainable across varying environmental conditions and add mechanisms and traits that increase value and performance. There is significant interaction and exchange of information and germplasm from TAM-122 and TAM-124. The cooperation and evaluations from TAM-126 insure the inclusion of new sources of food quality which are placed into the breeding enhancement program.

During the reporting period TAM-121 released four new female cultivars for international distribution. These are listed and described here. A/B TxARG-1, an elite white translucent grain, tan plant color parental line was distributed jointly by Texas A&M University and Instituto Nacional de Tecnologia Agropecuaria (INTA), Estacion Experimental Agropecuaria, Manfredi, Argentina.

This A_1 cytoplasmic-genetic male-sterile line was derived from an intentional cross between MR807, an Indian breeding stock and BTx624. Its complete pedigree is ((MR807*BTx624)-Bulk F_1)-5-5-1-2-bk-bk-1-bk. The sterilization process consisted of five backcrosses to an A_1 cytoplasm source. Ing. Agr. Cristian Domanski selected the original F_3 and F_4 plants at Manfredi, Argentina, from a germplasm observation nursery obtained from ICRISAT (International Crops Research Institute for the Semi-Arid Tropics, Hyderabad, India) designated as B/A Line Observation Nursery (BON). Seed was obtained in 1987 from INTA for the Texas Agricultural Experiment Stations (TAES) sorghum improvement program by the project leader during a visit to Manfredi. Following introduction into Texas three additional backcrosses were made using paired plant selection and crossing.

A/B TxARG-1 is genetically 3-dwarf ($\underline{dw_1}\underline{Dw_2}\underline{dw_3}\underline{dw_4}$), and has excellent exsertion, medium sized white semitranslucent round seeds, nonpigmented testa, awnless lemmas,

and straw colored glumes. The line has pretty good resistance to *Fusarium* head blight but is susceptible to *Puccina purpurea* (rust). A/B TxARG-1 flowers about the same time as A/B Tx631 and sheds an excellent quantity of pollen. Sterility of the A-line under bag is complete and does not appear to be affected by high or low temperatures or drought. The response of the line in other cytoplasmic-genetic male-sterility systems is not known. A/B TxARG-1 has tan necrotic plant color (ppQQ) and leaves have a juicy midrib. Endosperm is waxy and intermediate in hardness. The line has excellent tropical adaptation. ATxARG-1 has good combine height and in hybrid combinations rarely produces hybrids which are too tall for mechanical harvest. ATxARG-1 has shown excellent combining ability in hybrid combinations for yield, drought resistance, and general disease resistance.

This line should significantly increase the possibilities for new tan plant color, white-translucent grain, 3-dwarf sorghum hybrids for both human food use and poultry-livestock feeds. Hybrids made with ATxARG-1 appear to be adapted across a wide array of environments in the United States, Argentina, India, and Africa. Hybrids with ATxARG-1 have acceptable maturity, excellent bright grain color and quality, excellent standability, tropical adaptation, and improved disease resistance.

A/B Tx635 is a nonsenescing, tropically adapted, short two-dwarf sorghum with exceptional foliar disease resistance, food quality grain, yield potential, and immunity to head smut caused by *Sporisorium holci-sorghi* (Rivolta) K. Vánky. This line was developed in collaboration with ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), CENTA (Centro de Tecnologia Agricola de Salvador), and Texas A&M University.

The original plants which eventually gave rise to this cytoplasmic-genetic male-sterile line, A/B Tx635, were originally selected in breeders' nurseries of ICRISAT, Hyderabad, India, and designated as A-5621. This line came from the nursery of Dr. Bhola Nath Verma who was responsible for population breeding at ICRISAT. A-5621 was derived from cycle two of the RS/R population (see ICRISAT Annual Reports from 1973-74 for the origins of this population) and was known in ICRISAT records as RS/R-S10-20-682-5-1. It was selected from S1 trials in 1975 Kharif season. A single selection from this S1 family was advanced to S2 in 1975 Rabi season, and then advanced under pedigree selection to S7 in 1978 Kharif, using alternate Kharif and Rabi nurseries. A conventional pedigree for the line at this stage would be RS/R (C2) S1 102-1-1-2-1-5-1. It was bulked then advanced as such until 1979 Rabi when it was testcrossed to a cytoplasmic male sterile (A_1 cytoplasm). When the testcross was grown in 1980 Kharif and found to be sterile, a backcross was made on a plant to plant basis to convert to male sterility. The -5 plant pair of A- and B- plants were selected from breeders' nurseries at the ICRISAT center by Ing. Réne Clara, then coordinator of CENTA's national sorghum program in El Salvador in 1980. Ing. Clara completed four additional backcrosses and named the resulting A/B pair "VAR" in honor of the regional work of ICRISAT's Dr. Vartan Guiragossian who was stationed in Mexico at the time. In 1983 seed of the pair was introduced into the TAES sorghum improvement program via ICRISAT's LASIP (Latin America Sorghum Improvement Program).

A/B "Var" was found to be irregular in height when grown in Texas in 1984. Subsequently, Dr. Fred Miller made paired plant selections and continued backcrossing to produce the line A/B Tx635 which is now at BC10. This line has tan plant color, straw colored glumes, white-translucent seed color, juicy midrib, and short panicle exsertion. The white translucent caryopses are medium size and possess a nonpigmented testa. A/B Tx635 is ZZ, having no or few starch granules in the mesocarp, and the caryopsis is intermediate in hardness. A/B Tx635 is apparently a short 2-dwarf, $dw_1Dw_2Dw_3dw_4$ with modifiers and is approximately 160 cm tall or 10 to 12 cm taller than A/B Tx623. The line is five to eight days later to anthesis than A/B Tx623, and maintains its relative lateness into the tropics. A/B Tx635 produces good pollen quantity on the B-line while the stigmas of the A-line are small but protrude satisfactorily for good pollination.

A/B Tx635 exhibits excellent combining ability in hybrid combinations. Most hybrids tend to have longer than normal panicles and caryopses thresh well from the glumes. The line and its hybrids maintain very high green leaf retention throughout the season. A/B Tx635 is tropically adapted and transmits the trait to hybrids. Hybrids range widely in height and maturity with the female depending upon the male used. The line produces hybrids with good to excellent grain weathering resistance.

A/B Tx635 is immune to head smut caused by *S. holci-sorghi* and this resistance is genetically dominant. All hybrids tested at all locations throughout Texas where this disease is of major importance have been completely free of head smut. The line is moderately resistant to anthracnose caused by *Colletotrichum graminicola* (Cesati) Wilson in Texas and Georgia.

A_2/B_2 Tx636 and A_2/B_2 Tx637 were developed and distributed by Texas A&M University. These two inbred lines provide significant additions to the A_2 sterility system which can be used as female parents in hybrid seed production. The B_2 lines of both releases also are excellent inbred R-lines in the A_1 sterility system.

Pedigrees of A_2/B_2Tx636 and A_2/B_2Tx637 are ((SC120-6*Tx7000)*Tx430)-4-1-1-2-bk-2-2-1-9-C3-bk and (SC108-6*Tx7078)-4-3-1-bk-10-4-2-2-2-C3-bk respectively and both have A_2 Tx2753 cytoplasm. The two inbred lines were developed using conventional qualitative breeding procedures, with selections alternating between College Station, Beeville, and Lubbock, Texas and Isabela, Puerto Rico. Both lines were developed originally in the A_1 R-line

breeding program but were identified as maintainers also in the A_2 system.

These materials appear to be adapted across an array of environments and produce hybrids with medium maturity, excellent grain color and quality, 3-dwarf height and good standability, and improved disease resistance. A_2Tx637 produces early hybrids with good drought resistance and outstanding grain color. A_2Tx636 is more tropically adapted than A_2Tx637. Both lines have high levels of green leaf retention at maturity as well as high levels of foliar disease resistance. Both females are completely restored to fertility by good R_2-lines such as SC103-12E, RTx432, SC599-11E, etc. When these females, which have no Kafir germplasm in their pedigrees, were compared in hybrid combinations with A_1 hybrids no significant yield or performance differences were observed. This provides evidence that broader genetic diversity can be used to protect the yield of sorghum.

(Mr. Abdou Tenkouano-Burkina Faso-Ph.D. Student)

Charcoal rot of sorghum has been reported from nearly all sorghum growing areas of the world. Charcoal rot reaction in sorghum plants has been considered to be primarily a postflowering drought response. Therefore, we have examined disease response in relationship to nonsenescence.

Four sorghum inbred lines, B35, SC599-11E, BTx378, and BTx623 and their diallel F_1, F_2, and backcross progenies were evaluated for resistance to charcoal rot in relation to nonstructural carbohydrates (NSC) partitioning during reproductive growth. Six experiments were conducted under controlled environments (laboratory, greenhouse, and rainshelter) and field conditions.

Significant differences were obtained for NSC content and partitioning between plant organs over time. Basal stem NSC depletion occurred in all inbred parents from anthesis to 15 days after anthesis or beyond that stage. However, depletion rates were lower for B35 and SC599-11E both resistant to charcoal rot, than for the susceptible lines, BTx378 and BTx623. Resistant lines displayed homeostatic patterns for total NSC content due to an increase in reserve NSC (starch and polysaccharides) which partially compensated for reduction in soluble NSC (mono- and oligosaccharides). In contrast, both NSC fractions were depleted in susceptible cultivars. Highest infection levels were obtained with inoculation at anthesis, i.e., when inoculation was followed by a period of rapid stem sugar depletion. We thus postulate that high NSC depletion rates create substrate-limiting metabolic pathways that would in turn inhibit defense mechanisms, through limited synthesis of inhibitors of fungal degradative enzymes.

Significant differences also were found between cultivars for all traits of disease response *in vivo* and for nonsenescence, a trait often associated with resistance to the rotting organism. Resistance to charcoal rot was determined to be under multiple-locus control with dominant and recessive epistatic effects. The same conclusion was reached for inheritance of nonsenescence. It was further proposed that the expression of both resistance and nonsenescence genes depended on activation/inhibition signals coded for by a common, external stimulus-sensitive, regulatory gene. Whether active resistance (i.e., genes conferring to the cell the ability to stop or delay infection) could be equated with nonpredisposition (i.e., genes conferring to the cell the ability to escape infection by virtue of tolerance to drought) was not delineated by this investigation.

Heritability of resistance to charcoal rot was shown to be largely dependent on nonadditive genetic effects and designated SC599-11E as a better source of resistance than B35. Heritability estimates for nonsenescence were low to intermediate due to large environmental effects. This could be a limiting factor to consider while using nonsenescence as a breeding criterion for resistance to charcoal rot. That charcoal rot was a yield limiting factor was further evidenced by the negative correlation between grain yield and lesion size.

(Mr. Bill Khizzah - Uganda - Ph.D. Student)

Much of the sustainability of production is dependent on performance in below optimum moisture conditions. As a part of the long term research effort to identify and manipulate mechanisms of drought resistance, we have studied inheritance of resistance - via osmotic potential (π), heat tolerance, water potential (ψ), and relative water content (RWC) of the cell. Osmoregulation has a major role in drought avoidance. The objectives of this study were to determine osmotic adjustment and heat tolerance components of postflowering drought resistance and to assess the genetic basis of these traits. Both field and greenhouse studies were conducted at several locations. B35, BTx3197, RTx7000, and RTx430 were used in these studies. B35 and BTx3197 consistently maintained high tissue water content under prolonged water stress. This was associated with high soluble sugars which was responsible for maintenance of high ψ and π. RTx7000 lost most of its tissue water content under drought. The soluble sugars of RTx7000 were lower, resulting in low ψ and π and severe susceptibility to drought. It was concluded that postflowering drought resistance in cultivars with large amounts of solute was due to maintenance of high RWC and its function in maintaining high ψ and π. BTx3197 and B35 had low levels of cell damage and RTx7000 had high cell damage when subjected to high heat loads.

Inheritance of high RWC, ψ and π, and heat stress resistance was determined to be under control of multiple loci systems with dominant and recessive epistatic effects.

(a)RWC: low water content two loci W_1 and W_2 with dominant effects and w_1 and w_2 with recessive effects, homozygous recessive w_1 and w_2 at either W_1, W_2 produce high water content; w_1w_1, w_2w_2 was epistatic to $W_1_W_2_$.

(b)ψ: low water potential, Wp_1 and Wp_2 with dominant effects and wp_1 wp_2 with recessive effects either recessive wp_1 or wp_2 was epistatic to Wp_1 or Wp_2; homozygous recessives produce high water potential.

(c)π: low osmotic potential, two loci Os_1 and Os_2 with dominant effects and os_1 and os_2 with recessive effects; either recessive os_1 or os_2 was epistatic to Os_1 and Os_2, homozygous recessives produced high water potential.

(d)heat stress: susceptibility to heat stress, two loci Hs_1 and Hs_2 having dominant effects, hs_1 and hs_2 having recessive effects; Hs_1 when dominant was epistatic to Hs_2, hs_2 when homozygous recessive was epistatic to Hs_1; homozygous recessives at both loci was resistant.

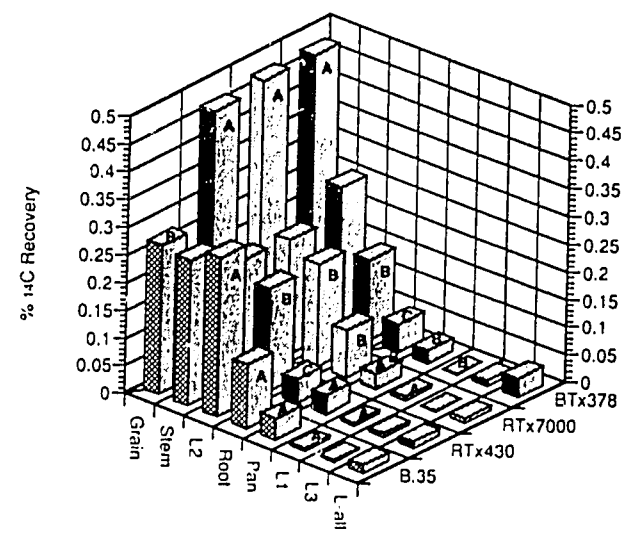
Whether the gene(s) system for high, heat stress, RWC, ψ, and π was the same could not be established by this study. Assuming a regulatory gene to be involved in stress dependent physiological response, it would be tempting to speculate that the maintenance of high RWC, ψ, and π was under a block of genes. Enzyme bioassays would be a useful study to provide information on whether synthesis or biodegradation of some specific products result in induced water stress.

Heritabilities of high RWC, ψ, and π were shown to depend on recessive and epistatic interactions and were influenced by maternal effects. For RWC and ψ, largest heritability estimates were found in crosses involving B35. It would be appropriate to use B35 rather than BTx3197 as a parent for the improvement of plant water status. For π, crosses involving both B35 and BTx3197 had high heritability estimates, suggesting that either of these parents could be used. Heritability estimates of resistance to heat stress were shown to depend largely on recessive and epistatic interactions. High broad sense heritability values obtained with B35 crosses suggested the latter would be a useful source for heat resistance genes.

(Mr. Jeff Dahlberg - United States of America - Ph.D. Student)

It has been suggested that indices of adaptation can be evaluated for cultivars in the environments in which they are to be grown. One such index could be unique assimilate partitioning patterns among different sorghum cultivars. This study compared assimilate partitioning between reduced progressive senescent sorghums (RTx430 and B35) and senescent sorghums (RTx7000 and BTx378) at three growth stages. A leaf was exposed to $^{14}CO_2$ during panicle differentiation (PD), anthesis (ANTH), and grain fill (GF). Partitioning of assimilate was determined after a chase period of four days among plant parts. Data were analyzed using a split-plot design with years as main-plots and cultivars the sub-plots. At PD when the youngest expanded blade (3 through 6) was labeled, ANOVAs indicated differences among cultivars for % ^{14}C recovered within plant parts. Approximately 65 to 76% of the ^{14}C recovered was found in new and expanding leaf growth while 25 to 35% went to root and stem development. Significant differences ($p \leq 0.05$) (see Figure 1) were found in stem and root parts among the different cultivars with B35 and RTx430 having a greater % ^{14}C recovery in the root than BTx378 and RTx7000, while B35, BTx378, and RTx7000 had greater % ^{14}C recovery in the stem. At ANTH and GF, the penultimate leaf was labeled. At ANTH, significant differences ($p \leq 0.05$) were found between cultivars for % ^{14}C recovery in stem, panicle, and labeled leaf. BTx378 was significantly different from all other cultivars for label recovery in the stem, while RTx430 was significantly different in recovery within the panicle. B35 contained greater recovered label C in the labeled leaf than did RTx430, BTx378, or RTx7000. At GF, significant differences were found among cultivars for % ^{14}C recovered in grain, labeled leaf, root, panicle, and flag leaf parts. RTx430, RTx7000, and BTx378 were significantly different from B35 in % recovery within the grain, while B35 retained more label in the labeled leaf.

Figure 1. Partitioned assimilate, reported as % ^{14}C recovered, at mid-grain fill for both 1989 and 1990 data collected at College Station, TX. Means within cultivars with the same letter are not significantly different at the 5% level according to LSD.



(Mr. Aboubacar Toure - Mali - Ph.D. Student)

In an attempt to determine why guinea sorghums of West Africa have lower yield potential, 7 converted guinea, 4 zerazera, and 2 caudatum sorghums were crossed to 3 selected improved A-lines. Evaluation of the parents and hybrids has shown that yield is highly correlated to the number of seeds/panicle and 1000 seed-weight. Yield also was correlated to flowering date and number of whorls/panicles. Seed number/panicle was found to be related to the number of primary branches and whorls on the panicle. The number of whorls/panicle has shown a positive association with plant height, panicle length, 1000 seed-weight, and the number of seeds/panicle. Length of primary panicle

branches was negatively correlated to yield, number of primary branches, and whorls/panicle but positively correlated to panicle length. Harvest index showed a negative correlation with flowering date and was positively associated with seed number, panicle width, and primary panicle branches length.

In general the zerazera showed a better hybrid combination than guineas. The best yielding hybrids were zerazera combinations while the guinea hybrids showed low yield. The panicle length was greater in guinea hybrids than zerazera derivatives. The number of seeds/panicle was significantly higher with the zerazera hybrids than that of the guineas. 1000 seed weight was higher among the zerazera hybrids than guinea hybrids. The number of primary branches and whorls/panicle did not show any difference among hybrids.

It seems that guinea sorghums during their evolution, adaptation, and stabilization have lost genes or factors that may contribute to high yield. Also, there may exist in guinea sorghums, linkages that are not favorable for the expression of yield potential. More analyses are required to resolve this problem of yield in guinea sorghums.

(Maria Eugenia Nunes - Mozambique - MSc. Student)

Farmers in developing countries generally believe that varieties perform superior to hybrids under harsh environmental conditions because hybrids require better growing conditions (higher level of inputs and culture) to express their potential. This study was designed to compare the response of hybrids and their parents in four very diverse locations of Texas representative of environments in Africa, etc. — two with high temperature and moisture stress and two with good to excellent conditions of production — to determine whether or not hybrids were more suitable for production, more stable, and had better quality than their parents, even in less favorable environments; which was the superior environment for best grain quality; how quality traits were related to those traits that influenced yield; and which traits were important for food sorghum cultivars.

It was found that even in the most harsh environment, hybrids performed better than their parents. The hybrid ATx635*R8505 was the most productive followed by ATx631*Dorado and ATx631*Sureño, however; ATx631*R8505, ATx631*Dorado, and ATx635*Dorado were the most stable across environments. Hybrids with ATx631 as a parent had a harder endosperm , higher grain density, higher endosperm recovery, a thinner pericarp, and more tolerance to weathering than hybrids with ATx635 as a parent. Dorado had the highest threshing percentage and harvest index. Similarly, hybrids with this parent had the highest threshing percentage and harvest index. Sureño was the tallest parent and had the highest test weight. Hybrids with this parent were the tallest and also had grain with the highest test weight. Some quality traits were negatively and others were positively correlated with grain yield. These plants also had the lowest weathering and the thinnest pericarp. Consequently, they had the highest grain density and the highest endosperm recovery. Therefore, grain density, endosperm recovery, pericarp thickness, and weathering are the important traits to consider in cultivars when selecting for yield and food quality. Since endosperm texture was positively correlated with pericarp thickness, and had a negative correlation with grain density and endosperm recovery, selections made for thin pericarp are expected to permit selection for high density, high endosperm recovery, and hard endosperm.

The most northerly location with supplemental irrigation but a dry environment had the highest yield. Flowering began when daylength was maximum but beginning a decreasing trend, temperatures (day and night) were lower than at any other location, and no moisture stress was detected at this location. Furthermore, this high yield site produced plants that were taller with longer panicles than at other locations, and they also had a higher harvest index, higher yield M^{-2}, and consequently higher grain yield than the other locations. The tallest plants with the longest panicles had the highest yield $\underline{M}^{-2}$ and the highest grain yield.

Even under severe conditions of drought and high temperatures hybrids performed better than varieties. Hybrids are more efficient users of water and nutrients under a much wider array of conditions than varieties. Both the small and large producer benefit from heterosis in sorghum.

(Ben Kanyenji - Kenya - MSc. Student)

In areas of the world prone to early season drought, lack of adequate crop stand contributes significantly to poor sorghum grain yields, leading to frequent famine and low standard of living. Poor stands can be attributed to poor seed germination, poor seedling emergence, and/or early seedling death. Information leading to improvement of commercial cultivars for germination, emergence, and survival under low soil moisture conditions would greatly enhance crop production in these areas. Nineteen sorghum cultivars from different regions of the world were selected for evaluation for their germination and emergence under a range of moisture levels and for their ability to survive under low and declining soil moisture. These cultivars were evaluated in a controlled environment in chambers and in the field under a rainout shelter.

Results indicated that sorghum cultivars differed significantly in their ability to germinate, emerge, and survive under low moisture situations. At the lowest moisture level (20% water holding capacity of the potted soil/media; 26% water on a dry weight basis), germination was reduced by 50 percent. Hegari and CSM388 had the highest germination performance at this moisture level. Seedling emergence was decreased by 60 percent from performance under optimum moisture (45% water holding capacity potted soil/media) and cultivars such as Segaolane and CSM388 had the highest emergence performance. Emergence of cultivars

was more sensitive to a low moisture situation than germination. Hegari exhibited high germination as well as high emergence under low moisture conditions while Ajabsido exhibited high germination but poor emergence ability under low moisture conditions. Cultivars significantly differed in their field emergence rate. The fast emerging cultivars were SC103-14E, RTx2817, CSM388, Bagoba, and Ajabsido while the slow emerging cultivars were BTx3197, RTx7078, RTx430, BTx378, and RTx09. In some cultivars, e.g., RTx09 and SC103-14E, 100% of the seedlings were dead 35 days after sowing under low and declining (10%) field soil moisture conditions. The best survival scores were recorded for Ajabsido, B35, CSM388, and Sumac 6550.

Germination, emergence, and seedling survival, were not correlated, implying that possibly they are under independent genetic or physiologic control mechanisms. Multiple regression analyses suggested that the best independent predictor variables for germination at low soil/media moisture level (20%) were seed water uptake, and 1000 seed weight. For seedling emergence at low soil/media moisture level (20%), root length, early seedling fresh weight, early seedling dry weight, and seed density were the best independent predictor variables, and for seedling survival (establishment) under declining soil moisture situations, the best independent predictor variables were field seedling fresh weight, seed size, early seedling dry weight, and secondary seminal root development under low moisture situation.

Sorghum cultivars from traditional sorghum growing areas were generally superior in overall germination, emergence, and seedling survival under low moisture conditions as compared to improved cultivars.

Improvement of commercial sorghum cultivars for germination, emergence, and seedling survival under low moisture situations should be possible. It appears that emergence and seedling survival are more important than germination in stand establishment and emphasis should be placed on improvement of these traits.

In many areas of the world where sorghum is grown, leaves are removed regularly for use by farmyard livestock, etc. In an attempt to determine the impact on leaf removal two cultivars were evaluated.

Damage to blades of sorghum by insects, disease, hail, and other causes may seriously reduce yields after plants have advanced to the anthesis and kernel filling stages. Two cultivars differing in rate of senescence were grown for two consecutive seasons and subjected to various blade removal treatments, applied to individual plants when the panicles were fully exserted but prior to anthesis.

Yield reductions exceeded 50 percent when blades 1-4, from the top of the plant, were removed and approximately 20 to 30 percent when only blades 5-7 were defoliated (Table 1). Lower blades appeared to have no contribution or parasitic influence when removed at the beginning of anthesis. The upper four blades were approximately 1.7 to 2 times as effective as blades 5-7 on the relative production potential. Size of kernels and numbers per panicle were reduced with removal of blades 1-4 but removal of blades 5-7 appeared to only reduce kernel size. Stem sucrose and starch values were significantly lower for plants when the upper four blades were removed whereas other removal treatments appeared to exert minimal influence on levels of these carbohydrates in stems (Table 2).

Understanding the genetic control of sorghum's response to photoperiod is vitally important to comprehending the adaptation of specific genotypes to different global climatic regions. Previous work has shown there are four gene loci controlling maturity in sorghum. How temperature affects

Table 1. Grain yield and relative production potential in two sorghum cultivars as influenced by various leaf blade removal treatments.

	Yield, g plant^{-1}[a]			% of check		Blade area cm plant^{-1}	
Treatment	Cultivar	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
(0)	37[c]	49.7B	59.7B			3804.0A	3180.3B
	62	59.0A	73.1A			4079.9A	3511.5A
(1) Top 4 blades	37	23.9G	22.3D	50.5C	37.7C	1621.4DEF	1468.3EF
removed	62	29.8FG	24.2D	50.4C	33.3C	1777.5CDE	1808.5D
(2) Blades 5-7 removed	37	36.9DE	42.4C	78.7B	70.9B	1269.5FG	1185.6G
	62	47.6BC	54.9B	80.8B	76.0B	1441.4EF	1340.7FG
(3) Blades 8 and	37	50.2B	59.6B	106.8A	100.8A	913.0G	526.4H
basipetally removed	62	58.7A	72.1A	99.7A	99.9A	861.1G	362.3H
(4) Blades 5 and	37	33.8EF	40.0C	71.7B	67.5B	2020.1CD	1618.3DE
basipetally removed	62	42.4CD	54.8B	69.0B	75.6B	2155.0C	1723.7D
Leaf area comparison:	37					1.08	1.06
$\frac{2+3}{4}$ (Treatments)	62					0.93	0.99

[a] Oven dry basis.

[c] (37) ATx378*RTx7000, (62) ATx623*RTx432

* Means within each column not followed by same letter or letters are significantly different by Duncan's New Multiple Range Test at 5% probability level. Means are an average of 8-10 plants.

Table 2. Carbohydrate concentrations in stems of sorghum cultivars at kernel black layer stage.

Treatment	Cultivar	Glucose	Fructose	Sucrose	Starch
		mg g^{-1} OD tissue			
(0)	37	27.8A*	35.6A	127.9A	10.8BC
	62	21.7AB	30.5AB	153.0A	105.4A
(1)Top 4 blades removed	37	8.2B	16.2AB	36.5B	3.6D
	62	8.9B	13.1B	12.3B	1.9D
(2)Blades 5-7 removed	37	20.9AB	28.2AB	126.0A	9.1C
	62	15.9AB	22.0AB	136.4A	9.1C
(3)Blades 8 and basipetally	37	21.8AB	29.2AB	117.8A	9.1C
removed	62	20.9AB	29.2AB	1044.0A	13.5AB
(4)Blades 5 and basipetally	37	20.0AB	28.4AB	131.9A	9.4C
removed	62	18.0AB	24.4AB	120.8A	11.5BC

*Means within each column not followed by same letter or letters are significantly different by Duncan's New Multiple Range Test at 5% probability level. Means are an average of 8-10 plants from each of 4 replicates.

Table 3. Effect of three temperatures and two photoperiods on leaf numbers of 10 sorghum genotypes grown in growth chambers.

Strain	Genotype	Temperature/photoperiod					
		20°C/12 h	20°C/14 h	25°C/12 h	25°C/14 h	30°C/12 h	30°C/14 h
		Leaf no.					
38M	$ma_1ma_2ma_3^R$	9.7	9.3	9.0	9.3	12.3	13.7
44M	$Ma_1ma_2ma_3^R$	9.5	9.7	9.1	9.2	11.7	13.8
SM60	$ma_1ma_2ma_3$	12.5	13.8	13.4	15.9	19.7	28.0
SM80	$ma_1ma_2Ma_3$	12.8	14.7	12.9	14.1	18.2	29.7
SM90	$ma_1Ma_2ma_3$	12.8	13.3	13.0	14.2	18.3	21.8
SM100	$ma_1Ma_2Ma_3$	12.5	13.2	12.2	14.3	16.5	19.5
60M	$Ma_1ma_2ma_3$	13.3	16.2	12.3	18.2	17.5	>35
80M	$Ma_1ma_2Ma_3$	12.7	19.8	12.3	20.1	16.5	>35
90M	$Ma_1Ma_2ma_3$	12.7	19.7	12.2	20.5	16.5	>35
100M	$Ma_1Ma_2Ma_3$	14.7	27.3	13.8	20.2	22.0	>35
	Mean Ma_1	12.7	13.8	12.9	14.6	18.2	24.8
	ma_1	13.4	20.8	12.7	19.8	18.1	>35
	Ma_2	12.8	16.1	12.7	17.1	18.0	31.9
	ma_2	13.2	18.4	12.8	17.3	18.3	27.8
	Ma_3	12.8	15.8	13.0	17.2	18.0	30.0
	ma_3	13.2	18.8	12.8	17.2	18.3	29.8
	ma_3^R	9.6	9.5	9.1	9.3	12.0	13.8

RMSE = 1.12

the response of photoperiod can dramatically impact regional adaptation.

A more complete understanding of the role of photoperiod and temperature in the genetic control of flowering in sorghum will allow breeders greater flexibility in making crosses among widely different maturity types and also will contribute to the understanding of regional adaptation requirements. The objective of this study was to characterize the photoperiodic responses of 10 sorghum lines with all known combinations of the sorghum maturity genes Ma_1, Ma_2, and Ma_3. Twenty growth chamber trials were conducted to examine photoperiods between 11 and 15 h at 0.5-h intervals and to examine the influence of mean daily temperature as well as the range of day/night temperature. Compared with other genotypes, the recessive ma_3R allele resulted in a reduction of 3.1 leaves in the basic vegetative phase (BVP-leaf number under favorable photoperiods) and also eliminated photoperiod sensitivity. There was little influence of Ma_2 or Ma_3 genes on BVP. The dominant Ma_1 allele conferred increased photoperiod sensitivity (4.5 leaves/h) compared to homozygous ma_1 condition (1.4 leaves/h) (Table 3). There were no significant differences detected in the Maximum Optimal Photoperiod (Table 4) which was about 12 h. The Ma_2 gene was implicated in a photoperiod X temperature interaction, although the exact role was not clear. The dominant allele of Ma_3 increased the phyllochron (leaf development rate) by about 0.2 d/leaf. Thus, the developmental response of sorghum to photoperiod and temperature involves the complementation of effects from these maturity genes.

Sustainability of production is a measure of a crop's success over time and locations. This project has established an international trial to monitor change of yield related traits across locations and to provide collaborators with germplasm useful to their programs. The International Tropical Adaptation Trial (ITAT) for 1990-91 contained 45 entries and yield responses for selected diverse sites are listed in Table 5. Mean yields across seven locations were in excess of 5.6 t/ha. Nine hybrids in Argentina produced more than 8t/ha, seven hybrids exceeded 8t/ha in Guate-

Table 4. Photoperiod response characteristics and phyllochron of 10 sorghum maturity genotypes determined from growth chamber results for photoperiods from 11 h to 15 h at 25°C.

Strain	Genotype	BVP[b]	MOP[c]	Photoperiod sensitivity	Phyllochron
		leaves	h	leaves/h	d/leaf
38M	$ma_1ma_2ma_3^R$	9.55b*	0.00c	0.00c	3.44b
44M	$Ma_1ma_2ma_3^R$	9.10b	0.00c	0.00c	3.10d
SM60	$ma_1ma_2ma_3$	12.72a	12.33ab	1.69b	3.38bc
SM80	$ma_1ma_2Ma_3$	12.61a	12.08ab	1.33b	3.62a
SM90	$ma_1Ma_2ma_3$	12.75a	12.78a	1.40b	3.32c
SM100	$ma_1Ma_2Ma_3$	12.42a	12.85a	1.12b	3.37bc
60M	$Ma_1ma_2ma_3$	12.62a	12.59ab	4.84a	3.44b
80M	$Ma_1ma_2Ma_3$	11.67a	11.79ab	4.29a	3.68a
90M	$Ma_1Ma_2ma_3$	11.58a	11.80ab	4.36a	3.60a
100M	$Ma_1Ma_2Ma_3$	12.00a	11.50b	4.34a	3.60a
	SE	0.636	0.396	0.499	0.058

*Means followed by the same letter are not significantly different according to Duncan's new multiple range test (P<0.05).

[b]BVP = basic vegetative phase.

[c]MOP = minimum optimal photoperiod.

mala, and six hybrids exceeded 9t/ha in Texas. The goal of this trial is to determine the type of germplasm best adapted to various climatic conditions. This replicated trial was sent to 40 collaborators with 30 going to international sites. This trial contains both feed grain type hybrids and hybrids which possess food quality.

In our continuing program to develop food quality sorghum cultivars which possess stable high yield and superior agronomic performance our project has developed the International Food Sorghum Adaptation Trial (IFSAT). This trial contains 37 hybrids and 3 varieties, each replicated three times. During 1990-91, 35 IFSAT's were distributed to collaborators of which 28 went to international sites. Table 6 is a summary of six locations from which data were returned. All of the entries have white grain and two hybrids have red or purple plant color, the rest have tan plant color. ATx630*R3338Wx is homozygous waxy endosperm and all hybrids with ATx630 and ATxARG-1 are heterowaxy endosperm. There was an array of white normal and yellow endosperm types included. Across the locations summarized in Table 6, 10 of the 40 entries produced mean yields of 6t/ha or more. Most of these hybrids not only have excellent yield potential but also possess extraordinary leaf disease resistance and tropical adaptation. Hybrids with R.8505 have a very wide range of adaptation from Argentina, to Australia, to Mali, and to China as well as within the U.S.

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Table 5. Grain yield (kg/ha) from sorghum parents and hybrids in the International Tropical Adaptation Trial (ITAT) grown in Texas and selected international locations.

No.	Pedigree	Texas[1]			Mexico	China	Guatemala	Argentina	Mean
		Wes	Col Sta	Hw					
1	B.Tx623	4173	2868	6432	1350	2133	4478	4782	3745
2	B.Tx631	3195	2210	6128	1250	2850	3759	5026	3488
3	B.Tx378	2846	2491	6761	1667	2033	4683	7316	3971
4	B.Tx2752	3020	2414	5315	1608	1133	2283	4738	2930
5	R.Tx430	4689	3539	6601	1383	2167	3905	3979	3752
6	R.8505	4013	1815	2899	1033	1533	2170	3368	2404
7	R.Tx7000	4581	3126	6225	833	2100	2926	5210	3572
8	RS610	5189	2346	5149	2267	2100	4315	7071	4062
9	ATx2752*RTx430	5419	3421	7264	2550	2917	4106	5773	4493
10	ATx378*RTx430	5197	3961	8778	3100	4333	6668	8368	5772
11	ATx623*RTx430	6544	4842	8136	2967	3717	8054	7623	5983
12	ATx378*RTx7000	4079	3381	5824	2100	2367	3382	6802	3991
13	ATxARG-1*(Tx430*Tx2817)-1-1-5-3-1-C1-CBK-C1-CBK	5555	3989	6986	2367	2633	3754	7958	4749
14	ATxARG-1*DORADO	6053	1824	9092	1500	3550	6774	6623	5059
15	ATx2752*RTx434	4817	5595	6955	2575	3633	4875	7472	5132
16	ATx378*RTx434	5246	6412	8637	1492	3933	8256	8290	6038
17	ATx378*R8505	5458	4265	7312	2933	3517	5421	7629	5219
18	ATx626*RTx433	5277	4619	6986	1783	3667	4307	6184	4689
19	ATx626*R8503	5115	3544	5096	1857	3050	6312	8036	4716
20	ATx626*R8604	6431	3353	7588	1358	3783	5502	8620	5234
21	ATx629*RTAM428	3687	4284	7348	2100	2483	5645	5561	4444
22	ATx629*RTx2817	4945	3281	7081	1800	2284	5338	6721	4493
23	ATx629*RTx434	6451	7156	8080	1708	4333	10904	7328	6566
24	ATx629*R8503	5686	5622	6936	2133	3017	6451	7122	5281
25	ATx630*RTx2817	5628	4565	8331	3217	3317	7103	7532	5670
26	ATx630*RTx435	4906	4034	8913	2933	3717	5628	5588	5103
27	ATx631*CS3541	6049	6761	7465	2800	3800	7538	6545	5851
28	ATx631*DORADO	6335	6924	7776	2825	4617	8972	7156	6372
29	ATx631*RTx435	5189	6285	8770	2333	3300	6054	7434	5624
30	ATx631*R8504	5311	5078	6098	1433	3667	5039	8777	5058
31	ATx631*R8505	5955	5182	7649	2433	3800	3719	7704	5206
32	ATx631*R8509	6836	4683	11124	2492	3883	9173	6795	6427
33	ATx635*DORADO	5524	5128	9136	2992	3583	8928	8314	6229
34	ATx635*R8504	5937	5268	7018	2147	3133	3117	7616	4891
35	ATx635*R8505	5879	5500	9535	2983	4467	4756	6311	5633
36	A155*R8509	6605	6548	9606	2142	3033	8821	7517	6325
37	A8618*RTx435	5295	3008	7576	1942	3067	4353	6812	4579
38	ATx635*SC1207-2	5914	5100	9425	2717	4550	7858	6490	6008
39	ATx631*87EON366	5102	4583	5757	2467	2850	7147	8764	5239
40	ATx631*86EON361	5027	5572	7042	3017	3167	4190	8064	5154
41	A1*R8505	5457	4592	7827	2300	3700	4345	6292	4930
42	A1*RTx430	6270	3948	7505	2292	4017	5411	8162	5372
43	A1*RTx433	5553	5995	6611	1567	3050	4926	7462	5023
44	RTx2871	5090	3739	7279	1108	1800	4428	5071	4074
45	ATx2801*RTx2871	5432	3907	5943	2042	2167	7216	4590	4471
Means		5266	4372	7333	2131	3154	5622	6813	4956

[1]Wes = Weslaco Col Sta = College Station Hw = Halfway

Toure, 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, TX. July 8-12.

Dahlberg, J.A., D.M. Vietor, and F.R. Miller. 1991. Assimilate partitioning in reduced progressive senescent sorghums at different growth stages. International Sorghum/Millet Conference. Corpus Christi, TX. July 8-12.

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Toure, 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, TX.

Dahlberg, J.A., D.M. Vietor, and F.R. Miller. 1991. Assimilate partitioning in reduced progressive senescent sorghums at different growth stages. Proceedings of 17th Biennial Grain Sorghum Research and Utilization Conference. Lubbock, TX.

Ombakho, G.A. and F.R. Miller. 1991. Comparative performance of single, three-way and double-cross sorghum hybrids using A_1 and A_2 cytoplasms. Proceedings of 17th Biennial Grain Sorghum Research and Utilization Conference. Lubbock, TX.

Tenkouano, A., F.R. Miller, R.A. Frederiksen, D.T. Rosenow, and J.T. Cothren. 1991. Genetics of nonsenescence and of resistance to charcoal rot in sorghum. Proceedings of 17th Biennial Grain Sorghum Research and Utilization Conference. Lubbock, TX.

Collins, S.D., R.A. Frederiksen, D.T. Rosenow, and F.R. Miller. 1991. Tx2891, release of a disease resistant sorghum germplasm line. Texas Agric. Exp. Sta., Texas A&M University, College Station, TX.

Miller, F.R., R. Clara, and V. Guiragossian. 1991. Release of A/B Tx635 sorghum. Texas Agric. Exp. Sta., Texas A&M University, College Station, TX.

Miller, F.R., T. Dusek, and K. Prihoda. 1991. Release of A_2/B_2 Tx636 and A_2/B_2 Tx637 sorghum females. Texas Agric. Exp. Sta., Texas A&M University, College Station, TX.

Table 6. Grain yield (kg/ha) for selected sorghum cultivars which possess food quality grain (International Food Sorghum Adaptation Trial) grown in Texas and several collaborating countries in 1990.

		Texas[1]						
No.	Pedigree	Wes	Col Sta	Hw	Mexico	Mali	China	Mean
1	SUREÑO	3713	3040	8189	6099	3004	3200	4541
2	DORADO	4909	1438	5208	3712	2646	2367	3380
3	VG153	3903	2487	4078	4779	3105	2400	3459
4	ATx635*RTx435	5581	5885	7934	9015	3374	2833	5779
5	ATx635*R8504	5772	5155	7147	10185	2410	3533	5700
6	ATx635*R8505	6228	6085	8813	8761	3441	4700	6338
7	ATx635*R8510	6305	4964	8664	7320	3800	3917	5828
8	ATx635*R8605	6391	6698	8656	10627		4037	7282
9	ATx635*R8606	5988	6825	7717	7762	3732	3283	5885
10	ATx635*R8608	6315	5972	8184	9200	3733	3000	6067
11	ATx635*80C2241	6206	6289	8428	9623	3273	4733	6425
12	A155*DORADO	6778	8072	8225	9486	4024	3268	6642
13	A155*RTx2817	5591	3707	7136	8189	3251	3067	5157
14	A155*R8504	5362	5289	6984	7298		3168	5620
15	A155*R8505	5284	4860	7256	9762	3318	3017	5583
16	A155*80C2241	5534	5391	7618	8157	2410	3317	5405
17	ATxARG-1*DORADO	6566	2922	8654	6286	4249	4000	5446
18	ATxARG-1*RTx435	4734	4615	6647	5177	2791	2567	4422
19	ATxARG-1*R8510	4629	2986	6356	3293	3015	2467	3791
20	ATxARG-1*R8505	5158	4538	7546	8196	2657	2583	5113
21	A155*CS3541	6333	6707	7662	9799	3901	3783	6364
22	ATx630*R3338Wx	5399	3344	5840	6961	3520	2433	4583
23	ATx630*RTx435	5811	4851	8893	6743		3200	5900
24	ATx630*R8510	4832	2836	7737	6750	3251	3283	4782
25	ATx631*87C1365	5700	4642	7282	10316	2657	3350	5658
26	ATx631*R8605	5893	5264	7318	6901	3161	3383	5320
27	ATx631*80C2241	6160	5559	7043	6750		3983	5899
28	ATx631*(Tx430*Tx2816)-1-1-5-3-1-C1-CBK-C1	5073	4365	6059	6602	2567	2850	4586
29	ATx631*DORADO	7287	8072	9410	9636	4013	3333	6959
30	ATx631*R8505	5872	5563	7390	6270	2769	3567	5239
31	ATx631*R8504	5492	5463	7913	7708	2410	3333	5387
32	ATx631*RTx435	5616	5454	8608	6239		3983	5980
33	ATx631*R8510	3787	2754	5535	6621	2769	3217	4114
34	ATx631*R8511	5281	5291	7029	8299	2634	3733	5378
35	A8606*R8505	6052	5436	8342	7577	3285	3700	5732
36	A8610*R8511	6115	4969	8369	8286	3228	3950	5820
37	ATx635*DORADO	6360	6561	9379	8026	4249	3183	6293
38	ATx635*87EON366	5900	5196	8415	10273	3296	2983	6011
39	ATx635*86EON361	6524	7029	8703	9985	3991	3183	6569
40	ATx631*87BH8456	4878	4270	6808	6685	3688	3100	4905
Mean		5633	5021	7581	7734	3246	3325	5483

[1]Wes = Weslaco Col Sta = College Station Hw = Halfway

Miller, F.R., Christian Domanski, and Laura Giorda M. 1991. Release of A/B TxARG-1 sorghum. Texas Agric. Exp. Sta., Texas A&M University, College Station, TX.

Presentations

Miller, F.R. 1991. Development of sorghum for high yield potential. Instituto Colombiano de Agropecuaria seminar on sorghum breeding and utilization. CIAT-Palmira, Colombia. Jan 17-19.

Miller, F.R. 1991. Genetics and management of sorghum. Presented at Methane from Biomass-Science and Technology Symposium. May 6. Colorado Springs, CO.

Network Activities

Workshops

Sorghum in the 90's Planning Committee, Oct. 23, 1990, San Antonio, TX.

Presented paper to be read at Sorghum Breeding and Utilization Seminar, Jan. 17-19, 1991, CIAT-Palmira, Colombia.

To Colon, Argentina, October 26-September 6, 1990 to collaborate with sorghum scientists.

To Honduras, December 6-12, 1990 to evaluate INTSORMIL/SRN/EAP collaborative research program and plan future research.

To Colon, Argentina and nearby areas, March 18-27, 1991 to collect data on collaborative trials and discuss future plans with sorghum scientists.

Research Investigator Exchanges

Texas Seed Trade Association - July 12, 1990. Discussion of international sorghum germplasm impact.

Dr. Tom Hash, Sorghum Breeder, ICRISAT, toured breeding nursery and visited graduate students. August 2-3, 1990.

Ms. Sonia Morales, El Salvador, toured breeding program, August 7, 1990.

Mr. Neil Mueller, Australia, toured breeding nursery. August 16, 1990.

Five senior scientists, National Academy of Agricultural Sciences, People's Republic of China, August 17, 1990.

Hans Kraizer, Breeder, Greytown, South Africa, August 23, 1990.

Two senior Russian Sorghum Breeders, N.I. Vavilov All - Union Scientific Research Institute, Leningrad, USSR, September 30, 1990.

Ing. Guillermo Valiente, El Salvador. September 20, 1990.

Dr. B.K. Mehta, Bombay, India, September 20, 1990.

Ing. Carlos Shaw, Pergamino, Argentina, September 7-11, 1990.

Ing. Francisco Navarro Perez, Mich. Mexico, discussed sorghum hybrid program for central Mexico, February 13, 1991.

Dr. Yilma Kebede, Sorghum Breeder, Ethiopia, visited to review sorghum breeding project and plan cooperative activities, February 14-16, 1991.

Ing. Carmen Lasura, Sorghum Breeder, Colombia, visited sorghum program to discuss hybrids useful to Colombia, February 22, 1991.

Mexican delegation from Matamores, TAM, Mexico, to discuss sorghum breeding program and procedures for hybrid development/food quality selection, May 23, 1991.

Colombian delegation to review sorghum breeding activities and usefulness in Colombia, May 29, 1991.

Germplasm and Research Information Exchange

In 1990, 11 sorghums were introduced from China for use in combining ability studies by Mr. Chen Yue. Eight *Striga* resistant cultivars were introduced from ICRISAT for use in studies on growth. Fifteen cultivars were introduced from Cameroon which are used for transplanting. These were increased to be used in drought resistance breeding. In 1990-91, 6 R-lines and 7 A/B-lines were introduced from Australia which possess drought resistance and insect resistance; 20 cultivars were introduced from ICRISAT/LASIP; 36 breeding lines were introduced from Venezuela; 15 lines were received from Argentina. These materials possess useful combinations of grain color and plant color, height, yield, disease and insect resistance, food quality, and drought resistance useful to the TAM/INTSORMIL program.

Many sorghum breeding and germplasm lines, including F_2, through advanced generation breeding populations, A, B, and R lines, converted lines, cytoplasm sources, and experimental hybrids were increased and distributed to international and domestic collaborators. Distribution of more than 3,347 different sorghums to numerous requestors was made. These materials included both old and new enhanced stocks possessing resistances to various diseases, insects, drought stress, temperature stress, genetic stocks for maturity, height, etc., tropical adaptation and other breeding traits. In addition, 45 International Tropical Adaptation Trials, 40 International Food Sorghum Adaptation Trials, 7 International Food Sorghum Variety Trials, 4 International Sorghum Virus Nurseries, and many modified Hybrid Evaluation Trials were sent to collaborators.

Sorghum selections were made and entered into cooperative international trials including the ADIN, IDIN, GWT, IDMN, IAVN, UHSN, and several drought nurseries.

Acted as major professor for nine 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 in Beeville, Berclair, Corpus Christi, Weslaco, Lubbock/Halfway, and College Station. Presented field tours to delegations from Russia, India, Colombia, Mexico, China, Argentina, and Australia.

Participated in a joint release of one sorghum breeding line Tx2891. Developed and released two new A_2/B_2 female parental lines. Jointly released with ICRISAT and El Salvador a food quality grain female which possesses head smut immunity, and jointly released with INTA-Argentina a high yielding food quality grain, tan plant color female parental line.

Germplasm Enhancement for Resistance to Pathogens and Drought and Increased Genetic Diversity

Project TAM-122
Darrell T. Rosenow
Texas A&M University

Principal Investigator

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Dr. Moussa Traore, Physiologist, DAR/IER, Bamako, Mali
Mr. Karim Traore, SRCVO/DAR/IER, Bamako, Mali
Mr. Mamourou Diourte, Pathologist, SRCVO/DAR/IER, Bamako, Mali
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Dr. R.A. Frederiksen, Pathologist, TAM-124, Texas A&M University, College Station, TX
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Dr. L.W. Rooney, Cereal Chemist, TAM-126, Texas A&M University, College Station, TX
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Dr. Gebisa Ejeta, Sorghum Breeder, PRF-107, Purdue University, West Lafayette, IN

Summary

The principal objectives of TAM-122 are to identify and develop disease resistant and drought resistant sorghum germplasm in diverse backgrounds for use by LDC and U.S. scientists, and to collaborate with host country scientists in all aspects of their crop improvement programs.

The disease and drought resistance breeding programs and the germplasm program progressed well. Several new disease resistant and drought resistant lines were identified and were released or are ready for release to private companies. New cultivars were introduced into the U.S., evaluated, and used in crosses. Much new diverse breeding germplasm was generated from crosses. This new segregating material plus germplasm lines, parental lines, and hybrids were distributed to LDC, other international, and domestic collaborators.

The white-seeded, tan-plant, photoperiod insensitive sorghum line developed in Mali, Malisor 84-7, showed excellent potential as a source of resistance to head bugs in Mali. It also shows wide adaptation and excellent food type grain properties. Excellent breeding progeny involving Malisor 84-7 were identified in Mali, Texas, and Central America. Breeding progeny in Mali indicated that head bug resistance is transferable, but its inheritance is rather recessive and quantitative in nature.

Drought resistant sorghum cultivars from Niger and Sudan performed very well in northern Mali, indicating the value of international cooperation and germplasm exchange.

New releases included Tx2891, Tx635, 60 new fully converted lines, and 10 Purdue/TAMU developed parental/breeding drought tolerant lines whose hybrids look excellent in Sudan, Texas, and Indiana.

New sources of resistance to head smut were identified in Texas and ICRISAT developed lines involving CS3541 and other Zerazera derivatives, with resistance showing dominant inheritance.

The inheritance of the "stay green" trait (postflowering drought tolerance) in B35 was identified as a single gene (or no more than two) with primarily dominant gene action.

A seedling emergence and survival study indicated that the ability to germinate, emerge, and survive under low soil moisture conditions differed among diverse genotypes. However, the three characters were not correlated, indicating independent genetic control mechanisms.

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 postflowering 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, including wild types, evaluate for traits needed in the U.S. and developing countries, and introgress these traits into improved lines.

Constraints

Diseases and drought are serious constraints to sorghum production worldwide. Drought stress is the major constraint to sorghum and millet production around the world. Large differences exist 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 postflowering drought tolerance, perform as expected regarding drought response in other countries of the world, including Sudan, Mali, and Niger.

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, gray leaf spot, and acremonium wilt 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.

The major constraint in Sudan 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 postresponse, 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, or 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 maturity, photoperiod sensitive sorghums are needed to assure maturity after the rainy season. In the drier, northern areas of Mali and in Niger where drought stress is severe, earlier, less photosensitive material is needed, and drought tolerant Durra and Feterita sorghums generally perform well.

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 sources of resistance to pests, diseases, and environmental stress. New collections, including wild species, can provide new sources of desirable traits. Evaluation of new introductions and new converted lines for useful traits is needed to determine the usefulness of the materials and to identify new sources of desirable traits.

Research Approach and Project Output

Research Methods

Introductions from Mali, Sudan, Niger, Honduras, 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 LDC's, particularly Honduras, Sudan, Mali, Niger, and Botswana, for selection of appropriate traits and adaptation. Technical assistance was 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 developed and selected in 1990. 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.

Crosses among newly identified sources of drought tolerance (i.e., pre- and postflowering drought tolerance) and elite, high yielding lines were made. Progeny were selected under field conditions for pre- and postflowering drought tolerance, yield, and adaptation at several locations in west Texas in the Lubbock area and at Chillicothe which vary in their degree and time of moisture and heat stress. Selected advanced materials were sent to LDC's for evaluation and use, and 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-USDA Sorghum Conversion Program. Cultivars that were not photoperiod sensitive and with known merit were incorporated directly into the regular breeding program.

Research Findings

Moisture and heat stress were severe in the large sorghum breeding nurseries in south Texas in 1990, providing an excellent opportunity to screen for drought resistance. Excellent information was obtained on both pre- and postflowering drought, depending on the nursery. The disease resistance breeding program continued with field screening nurseries in south Texas. Major diseases were downy mildew, head smut, grain mold/weathering, charcoal rot, anthracnose, and MDMV.

A large number of new crosses were made among sorghum lines to generate new breeding material for use both in the U.S. and host country sites. These crosses involved sorghum lines with elite sources of drought and disease resistance as well as other desirable traits including head bug resistance, *Striga* resistance, lodging resistance, improved grain quality, and sugarcane aphid resistance. Some of the commonly used lines in crosses included Malisor 84-7 (head bug resistant); SRN39 (*Striga* resistant); BVar (head smut resistant and stay green); B35 & B1 (stay green and lodging resistant); CE151-262-A1, TAM 428, and R3224 (sugarcane aphid resistant); B.BON34 & ICSB34 (white, tan, waxy-endosperm B-lines from Sudan and ICRISAT, respectively); 86EON361 & 87EON366 (white, tan, disease resistant, widely adapted); and Sureño and ISIAP Dorado. Also, crosses were made to develop progeny for RFLP genetic studies on drought resistance and head smut resistance.

A white-seeded, tan-plant breeding line, Tx2891, with resistance to pathotype 1 and 3 of downy mildew was released. It was developed in the cooperative program with TAM-124. It also possesses good resistance to several foliar diseases and head smut.

In the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program, sixty new fully converted lines were selected for release and will be submitted for release in late 1991. They should provide useful photoperiod insensitive diverse germplasm with certain desirable traits useful in both public and private sorghum improvement programs throughout the world.

A new white-seeded, tan-plant, female line, previously called A&B Var (or Var1 or VG1), was officially released by Texas in cooperation with ICRISAT and LASIP as A&BTx635. This line shows outstanding resistance to the most virulent pathotypes of head smut, and it appears to be dominant in nature based on reaction of F_1 hybrids. It also possesses a significant level of stay green (postflowering drought tolerance), which is partially dominant in hybrid combinations. It also produces high yielding, agronomically desirable hybrids in Central America and Mali. Its hybrids are slightly shorter and possess better standability than Tx631 or Tx623 hybrids. Thus, it should be a very useful parental line for hybrids and also as a breeding line.

Ten white-seeded, tan-plant or yellow endosperm male parental/breeding sorghum lines developed cooperatively with Dr. Gebisa Ejeta of Purdue were selected for a cooperative Purdue/Texas A&M release in late 1991. These lines were developed for use in Sudan and in the U.S., and resulted from crosses of elite U.S. parental lines with sorghum lines identified by Dr. Ejeta as drought resistant in Sudan. They were evaluated as lines and in hybrid combination in Texas, Indiana, and Sudan.

Several white-seeded, tan-plant lines of ICRISAT origin as well as several TAMU/TAES breeding lines involving

CS3541 and/or ICRISAT lines show excellent resistance to head smut in south Texas (Table 1). This indicates that CS3541, a partially converted line developed in India from IS3541, a Zerazera from Sudan, as well as possibly some other Zerazera lines, posseses unique and useful sources of resistance to head smut.

Table 1. Head smut resistant white-seeded, tan-plant sorghum cultivars from ICRISAT, India, and TAES.

Designation	Derivation, pedigree, trait[1]
CS3541	Der. of IS3541
Tortillero	Sel. of CS3541 (Honduras)
Sureño	M62650/((SC423*CS3541)*E35-1)-2
Dorado	Released in El Salvador
M50009	2-dwarf
M90318	2-dwarf
ICSV1086	Tall 2-dwarf
ICSV1087	Tall 2-dwarf
VG41	M35610/(SC108-4*CS3541)
VG153	M62676/(Wal-1*IS9327)
BVar(BTx635)	White, Tan B line
CE151-262-A1	Sugarcane aphid res, Devp. in Senegal
SRN 39	*Striga* resistant
Malisor 84-1	A13120
Malisor 84-7	Head bug res., Devp. in Mali
IS3541C(SC798-14E)	Zerazera from Sudan
Tx2891(87BB396)	(SC414-12E*CS3541)
86EON361	(R5646*SC326-6)
86EON362	(R5646*SC326-6)
86EON374	((Tx432*CS3541)*SC326-6)
87EON366	(TAM428*(Tx432*CS3541))
87BH8456-5/87EON366sis	(TAM428*(Tx432*CS3541))
87BH8445	(Tx2817*CS3541)
89CC445	(Tx430*LASON68)
89CW3954	(R8505*M90318)
89BE8236	(R2241*(R5646*SC326-6))
88B924	(Tx2817*CS3541)
88B928	(Tx2817*CS3541)
88B885	(BTx623*CS3541)
89BD1826	(R5647*(SC414*SC326-6)),P
85C13082	(CS3541*TAM428)
84BH5629	(CS3541*SC630-11E),R
88B943	(Rio*CS3541)
SC414-12E/IS2508der	CauKaf,P
82BDM499	(SC173-14E*SC414-12E),P
Tx2783	(SC110der*Capbam),R,P

[1] R5646 and R5647 = (Tx432*CS3541); LASON68 = ICRISAT 2-dwarf line; R = red pericarp, P = purple plant color.

The inheritance of the "stay-green" trait in sorghum was studied by Mr. Richard Walulu (Kenya), M.S. student at Texas Tech University. He used the F_1, F_2, and BC's derived from the cross of B35 (postflowering drought tolerant) with Tx7000 (postflowering drought susceptible), grown under postflowering drought stress in the field at Lubbock as well as under a rainout shelter. Data based on visual leaf and plant death rating soon after physiological maturity indicated that probably one, or a maximum of two, genes controlled the stay-green trait. Gene action appeared to be primarily dominant. Broad-sense heritability estimates were 0.61 and 0.80 for the experiments in the rainout shelter and field, respectively. Narrow sense heritability from the shelter was 0.61. These data indicate that it should be relatively efficient to select for the stay green trait under either shelter or field conditions as long as the stress conditions are reasonably similar.

A study of 19 diverse sorghum cultivars, from different regions of the world, for seedling emergence and seedling drought tolerance and survival, was conducted by Mr. Ben Kanyenji (Kenya), a M.S. student at TAMU. The cultivars differed significantly in their ability to germinate, emerge, and survive under low soil moisture situations. However, the three characters were not correlated, indicating that they probably are under independent genetic or physiologic control mechanisms. Sorghum cultivars from traditional sorghum growing areas (commonly arid and semiarid) were generally superior in performance under low moisture conditions in all three characters, but different exotics excelled in different traits.

Plans were finalized to grow out all Sudan-origin sorghums at Wad Medani in the Sudan in the summer of 1991. There should be approximately 3,000 accessions. They will be described, classified, evaluated for inclusion in a working collection, and seed increased, in a collaborative effort among INTSORMIL (Texas and Purdue), ARC, ICRISAT, and USDA/ARS. A complete set of seed and descriptive traits will be made available to the USDA and the GRIN system for eventual distribution to sorghum researchers in the U.S.

A grant was obtained from the USDA/ARS for the seed increase (to be planted in 1992), release, and distribution of a set of approximately 200 partially converted bulks from the cooperative USDA/ARS - TAMU/TAES Sorghum Conversion Program. This should provide private and public workers with some new sources of useful germplasm.

In Niger, F_2 progeny from Texas involving crosses of Malisor 84-7 with 87EON366, Dorado, and M50009 showed excellent drought tolerance and adaptation.

In Senegal, some experimental hybrids from Texas involving A1 and AVar performed well in the off-season in the Region du Flueve.

In Honduras, a drought test under low rainfall conditions at Rapaco revealed that the following lines showed excellent adaptation and drought tolerance: Ajabsido; El Mota; Segaolane; 82BDM499 (SC173*SC414); SC414-12E; R4244; CE151-262-A1; Tx2883; 88B1016 (Tx430*Rio); and SC1211-8 (Cacho de Chivo der.) Sources of resistance to rust, gray leaf spot, downy mildew, and anthracnose were identified among the numerous Texas A&M elite parental and breeding lines planted at various locations in Honduras.

Mali

Sorghum varieties and hybrids from various countries around the world with known drought tolerance were evaluated under severe drought at Bema, in northern Mali (close

Table 2. Performance of selected drought resistant international sorghum varieties and hybrids under drought stress at Bema, Mali, 1990.[1]

Designation, name, cultivar[1]	Days to 50% flower	Plant height (M)	Grain yield (t/ha)	Group, origin, etc.
Bagoba	59	2.0	1.62	Durra, Niger
Koro Kollo	58	1.4	1.45	Feterita, Sudan
Ajabsido	56	1.4	1.14	Feterita, Sudan
A1*P46-1 (H)	66	1.1	1.11	Exp. Hybrid
OH/84-16/63	57	1.8	1.05	Durra, Nigeria
AOK11*TX2737 (H)	51	1.0	1.03	U.S. commercial hybrid
Babadia Fara	56	1.7	0.95	Durra, Niger
82BDM499/(SC173*SC414)	67	0.9	0.92	U.S. breeding line
SC414-12E	60	0.9	0.92	Converted Cau-Kaf from Sudan
El Mota	58	1.6	0.89	Caud, Niger
DK41y (DeKalb) (H)	58	0.9	0.83	U.S. commercial hybrid
Zinnari (called)	60	1.2	0.78	Kafir, Sudan (El Obeid)
CSM-63	54	2.1	0.74	Guinea, Mali
OH/84-15/58	83	1.9	0.73	Caud, Nigeria
Fetarita	67	2.0	0.72	Caud, Sudan (El Obeid)
Segaolane	52	1.2	0.69	Caffrorum, Botswana
Malisor 84-5	64	1.5	0.69	Malian improved cultivar
AVar*Malisor 84-7 (H)	75	1.3	0.69	Exp. hybrid
A1*Tx2737 (H)	58	1.0	0.66	U.S. Exp. hybrid
A35*Tx430 (H)	66	1.0	0.64	U.S. Exp. hybrid
Najad Abyad	83	2.0	0.63	Caud, Sudan (El Obeid)
DK46 (DeKalb) (H)	60	0.9	0.60	U.S. comm. hybrid
BTx631	82	1.0	0.53	U.S. female
BTx623	74	1.0	0.47	U.S. female
SC265-14E	55	1.0	0.46	Converted malian guin.
Zinnari Hirehree	84	1.8	0.46	Durra, Sudan (El Obeid)
Tx7078	55	0.7	0.44	U.S. cultivar
B1	75	0.9	0.42	U.S. female
Tx2737	59	0.9	0.39	U.S. male
P954035	69	0.7	0.38	SC33-9 der (Dur-Eth)
Malisor 84-7	84	1.0	0.32	Malian improved cultivar
Tx7000	55	0.8	0.25	U.S. cultivar

[1] Planted July 23, 1990. Cooperative IER/INTSORMIL drought trial involving sorghum cultivars from around the world with various types of drought resistance.

to the Mauritania border) in 1990 (Table 2). In a 2-rep trial sorghums with known drought tolerance, Bagoba, a dune adapted soil toxicity tolerant cultivar (Durra) from Niger, and two Feterita cultivars from Sudan, Koro Kollo, and Ajabsido, were the three highest yielding entries, even outyielding the hybrids. Also of significance was the performance of OH/84-16/63 (a Durra from northern Nigeria), Babadia Fara (Durra from Niger), El Mota (early drought tolerant variety from Niger), Zinnari (western Sudan), and SC414-12E and 87BDM499, U.S. developed lines which have shown excellent drought tolerance in the U.S. and Sudan. It is noteworthy that sorghums with known drought tolerance from various African countries performed very well in this dry area of Mali, emphasizing the importance of international cooperation and germplasm exchange. It is also important that sorghums with preflowering drought tolerance gave the best performance in this low rainfall area of Mali.

The above lines are being used in crosses in Mali and the U.S. to enhance the drought resistance in sorghum breeding material for use both in Mali and the U.S.

The International Food Sorghum Adaptation Trial (IFSAT) at Cinzana (Table 3) indicated that hybrids with Dorado were outstanding for grain yield, possessed some resistance to sooty stripe, and had rather good grain quality. Also, hybrids involving 86EON361, R8510, and AVar combined high yield, some sooty stripe resistance, and grain quality. Head bugs and grain mold were the major factors contributing to poor grain quality in this trial. Sooty stripe was extremely severe in this trial, and appeared to significantly reduce yield in highly susceptible hybrids.

Malisor 84-7 continued to be an extremely useful breeding line and source of head bug resistance. Excellent breeding progeny involving Malisor 84-7 were identified in Mali and Texas. It appears that head bug resistance is indeed transferable, but its inheritance appears to be rather recessive and quantitative in nature. Some of the breeding lines also show good potential in Texas and Central America, with excellent food grain characteristics. Two ICRISAT developed lines, ICSV1079 and ICSV1089, also appear to possess useful levels of head bug/grain mold resistance in Mali along with good agronomic traits. Other sorghum lines identified as very useful in the breeding program in Mali are ICSV1087, ICSV401, ICSV1002, Sureño, Dorado, 86EON361, M50009, E36-1, and S34.

Numerous crosses involving the late-maturing, photoperiod sensitive sorghums from Honduras, the maicillos criollos, and some improved maicillos (IMC) developed by Dan

Table 3. Performance of the International Food Sorghum Adaptation Trial (IFSAT) at Cinzana, Mali, 1990.[1]

Hybrid/cultivar/ pedigree/designation	Days to 50% flower	Plant height (m)	Desirability rating[2]	Sooty stripe rating[3]	Overall grain quality rating[2]	Grain yield (t/ha)
AVAR* DORADO	59	1.85	2.1	3.8	2.5	3.79
AARG34* DORADO	63	1.74	1.8	3.5	2.2	3.79
A155* DORADO	64	2.04	2.4	2.5	2.5	3.59
ATx631* DORADO	62	2.09	2.5	3.8	3.0	3.58
AVAR* 86EON361	58	1.56	2.1	3.5	3.0	3.56
A155* CS3541	58	1.76	2.5	2.5	3.0	3.48
AVAR* R8510	60	1.42	2.0	4.0	3.0	3.39
AVAR* R8608	58	1.42	2.2	4.0	2.6	3.33
ATx631* 87BH8456	58	1.41	2.5	3.2	3.0	3.29
ATx630* R3338Wx	58	1.37	2.8	2.2	3.0	3.14
AVAR* R8505	55	1.46	3.0	4.8	4.0	3.07
AVAR* R8605	55	1.49	3.0	4.8	3.5	3.02
AVAR*RTx435	57	1.41	3.5	4.8	4.2	3.01
A155* R8505	57	1.47	3.0	4.0	3.5	2.96
AVAR* 87EON366	60	1.51	2.3	4.0	3.2	2.94
A8606* R8505	57	1.35	3.2	4.8	4.0	2.93
AVAR* 80C2241	57	1.42	2.8	4.8	3.2	2.92
A155* RTx2817	60	1.38	2.2	2.8	2.5	2.90
ATx630* R8510	63	1.35	2.2	3.8	2.6	2.90
A8610* R8511	55	1.40	3.2	4.8	4.0	2.88
ATx631* R8605	55	1.32	3.2	4.5	4.0	2.82
VG153	64	2.09	2.5	3.5	2.0	2.77
AARG34* R8510	60	1.21	2.2	3.2	2.5	2.69
SUREÑO	62	1.79	2.4	2.5	2.0	2.68
AARG34* RTx435	57	1.20	3.0	4.0	3.5	2.49
ATx631* R8510	61	1.33	2.5	3.8	3.2	2.47
ATx631* R8505	56	1.37	3.2	4.5	4.0	2.47
ATx631* R8504	57	1.46	3.3	4.8	4.0	2.46
ATx631* 87C1365	57	1.34	3.5	4.2	4.0	2.37
AARG34* R8505	56	1.26	3.2	4.0	3.5	2.37
DORADO	63	1.32	2.3	4.0	2.2	2.36
ATx631* R8511	56	1.34	3.2	4.8	4.0	2.35
ATx631 (Tx430*Tx2816)	59	1.44	3.0	4.5	3.5	2.29
AVAR* R8504	57	1.39	3.4	4.8	4.0	2.15
ATx631* R8504	57	1.39	3.3	4.8	4.0	2.15
A155* 80C2241	57	1.38	3.0	4.2	3.0	2.15

Mean yield = 2.79 t/ha; CV = 18%

[1] Planted July 15, 1990. Cooperative IER/INTSORMIL Trial. Ratings by D. Rosenow on one replication only. Yield on three reps. CV = 18%.
[2] Rating 1 = very good, 5 = very poor. Grain quality rating is on combined head bug and grain mold damage.
[3] Rating 1 = very resistant, 5 = very susceptible.

Meckenstock, INTSORMIL sorghum breeder in Honduras, have been made with elite, high yielding lines. These crosses are for use in developing late-maturing breeding material for adaptation to the high rainfall areas of southern Mali with a long rainy season. F_2 progeny involving these maicillos were planted in central and southern Mali in 1991.

Sudan

The drought screening nursery at Wad Medani, Sudan was excellent in 1990. Drought desirability scores on observation hybrids indicated that some of the male breeding lines such as P33-1, P37-3, P40-1, P46-1, and P69-2, which are related to the 10 cooperative Purdue/Texas releases, performed extremely well in hybrid combinations, especially with the Texas experimental female, A1 (Table 4). They were all significantly better than A1 * Karper 1597, which was superior to Hageen Dura-1.

Other breeding material developed in Texas looked promising for use in Sudan, including partially converted (BC1) lines of Tetron, F_2's and F_4's involving Ajabsido and Koro Kollo, F_2's involving the stay green female, BVar, and breeding lines involving B35, B1, and B2-1.

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Table 4. Drought desirability ratings of selected hybrids in drought screening nursery, Wad Medani, Sudan. 1990.[1]

Hybrid	Male pedigree	Drought desirability score
A1*P40-1	(Tx2794*K22/35)	1.5
A1*P37-3	(Tx2794*K22/35)	1.5
A1*P46-1	(Tx2794*K22/35)	1.2
A1*P33-1	(Tx2794*K22/35)	1.3
A1*P69-2	(Tx430*K22/35)	1.0
ATx623*P46-1	(Tx2794*K22/35)	1.5
A1*Karper1597		1.8
ATx623*Karper1597	(Hageen Dura-1)	2.5
A35*Karper1597		2.8
A1*Tx430		1.7
A35*Tx430		2.0
A1*82BDM499	(SC173-14*SC414-12)	1.5
A35*82BDM499	(SC173-14*SC414-12)	2.0
A1*Tx2794		2.5
A1*Tx2737		2.5
AOK11*P40-1	(Tx2794*K22/35)	2.0
AOK11*P46-1	(Tx2794*K22/35)	2.0
ATx631*Dorado		3.8
A1*R8505		3.5
AVar*86EON361		3.5
AOK11*86EON361		2.5

[1] Rating 1 to 5: 1 = very good, 5 = very poor. Rated by G. Ejeta

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Networking Activities

Workshops

"Sorghum in the 90's" Steering Committee, October 23, 1990, San Antonio, TX.

Planned field tours for INTSORMIL PI Conference, June 24, 25, 1991, Corpus Christi, TX.

Research Investigator Exchanges

Traveled to Kenya, June 26 - July 7, 1990 to evaluate the sorghum germplasm for drought and adaptation in the MIAC/KARI Kenya sorghum improvement program.

Traveled to Mali Oct. 1 - Oct. 11, 1990 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 Niger Oct. 11-15, 1990 to evaluate the collaborative INTSORMIL/INRAN sorghum research program and plan future collaborative activities.

Traveled to Honduras Dec. 6-12, 1990 to evaluate INTSORMIL/SRN/EAP collaborative sorghum research program, plan future collaborative research activities, and coordinate INTSORMIL research in the area.

Coordinated and funded six-week sorghum breeding training session for Niaba Teme, Malian sorghum breeding technician (Cinzana Station, Mali), July 27-Sept. 7, 1990, at Lubbock.

Coordinated and funded travel for Dr. Yilma Kebede, Ethiopian sorghum breeder to Lubbock, Feb. 16-20, 1991.

To Tampico, Mexico, Feb. 21,22, 1991 to evaluate as member of TSTA Sorghum Advisory Committee, and read sorghum purity grow-outs and discuss sorghum research with several private company researchers.

Participated in Annual ASA meetings, Oct. 21-26, 1990, San Antonio, TX where interacted with public and private sorghum researchers from around the world. Planned "Sorghum in the 90's" International Workshop with other Steering Committee members. Discussed and outlined some 1990-91 Mali winter nursery plans with Dr. Noel Beninati and Aboubacar Toure.

Participated in Biennial Grain Sorghum Research and Utilization Conference, Feb. 17-20, 1991, Lubbock, TX where interacted with numerous graduate students and public and private sorghum researchers.

To INTSORMIL EZC and joint TC/EZC meetings, July 30-Aug 1, 1990 and April 2-4, 1991, Kansas City, MO.

Coordinated and conducted sorghum breeding training for Ben Kanyenji and Richard Walulu, Kenya graduate students (TAMU and TTU, respectively) in Corpus Christ area, July 23-27, 1990.

Coordinated and conducted sorghum breeding training for Aboubacar Toure, Niaba Teme, and Abdul Sow (Malian scientists) in Corpus Christi area, August 4-6, 1990.

To College Station, TX, August 2-3, 1990 to discuss sorghum research with Dr. Tom Hash, ICRISAT/CIMMYT sorghum breeder.

Investigator Visits to Lubbock

Ed Grote (Purdue Graduate Student), Aug. 27-29, 1990

Hoesch Seed Co. (Colombians-4), Sep. 11-12, 1990.

Dr. John Mullet (TAES), Dr. Keith Schertz (USDA), Sep. 24-26, 1990.

Mr. Jack Eberspacher, Nat. Grain Sorghum Producers, Sep. 27, 1990.

Dr. Fred Miller, Dr. L.W. Rooney, Dr. Sergio Serna-Saldivar, September, 1990.

Texas Grain Sorghum Producers Board, November, 13, 1990.

Colombian sorghum producers (25), May 17, 1991.

Dr. Tal Kipnis, Israel sorghum scientist, June 16, 1991.

National Grain Sorghum Producers Advisory Commission, June 21, 1991.

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. Aboubacar Toure, Sorghum Breeder, SRCVO/DAR/IER, Bamako, Mali (Ph.D. student, TAMU)

Dr. John Clark, Sorghum Breeder, Purdue/INRAN, Niamey, Niger

Mr. Issoufou Kapran, Sorghum Breeder, INRAN, Maradi, Niger

Mr. G. Trouche, Sorghum Breeder, CNRA, ISRA, Bambey, Senegal

Mr. Louis Mazhani, Sorghum/Millet Breeder, MOA, Sebele, Botswana

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. Richard Walulu, Kenyan MS student (Sorghum), Texas Tech Univ., Lubbock, TX

Mr. Alejandro Palma, Sorghum Breeder, EAP, Zamorano, Honduras (M.S. student, TAMU)

Dr. Tom Hash, Sorghum Breeder ICRISAT/CIMMYT, El Batan, Mexico

Dr. Compton Paul, Agronomist, ICRISAT/CIMMYT, El Batan, Mexico

Ing. Rene Clara, Sorghum Breeder, ICRISAT/CIMMYT, El Batan, Mexico

Dr. Leopoldo Mendoza, Coordinator Sorghum Program, INIAFAP, Chapingo, Mexico

Ing. Ricardo Ortiz, Pathologist, CENTA, El Salvador

Mr. Rafael Reyes, Entomologist, CENTA, El Salvador

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)

Mr. 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. C.W. Wendt, Soil Physicist, Texas A&M University, Lubbock, 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

Two hundred and six sorghum lines from the ICRISAT/LASIP program at CIMMYT were introduced. These include a wide range of material such as midge, shoot fly, etc., resistant lines, grain mold resistant exotics, ICRISAT white, tan-plant A&B pairs, as well as parental and breeding lines developed or selected for use in Latin America.

Seventy-five newly introduced exotic sorghum cultivars from Zambia, Malawi, Ethiopia, Gambia, Niger, Mauritania, Ghana, Mali, Benin, and ICRISAT were evaluated in Puerto Rico, with 25 identified as candidates for the Sorghum Conversion Program. Sixteen of these lines were aluminum tolerant exotics identified in Georgia. Approximately 35 elite breeding lines from the Mali program and from the ICRISAT West African program were also introduced.

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 sorghum cultivar released in Honduras, is now being grown by a rather large number of small farmers in southern Honduras. It was estimated by Miguel Lopez that 43% of the farmers had grown Sureño, and that perhaps 5% of the crop area of the small farmers of southern Honduras is planted to new INTSORMIL developed cultivars.

Assistance Given

Joint evaluation of germplasm was done collaboratively with national scientists in Mali, Honduras, Sudan, and Kenya. This included training in disease and drought screening and rating methodology, as well as information on sources of new useful germplasm and sources of desirable traits. Similar training was provided to LDC graduate students in the Texas breeding and disease nurseries in the Lubbock and Corpus Christi areas.

Germplasm Enhancement through Genetic Manipulation for Increasing Resistance to Insects and Improving Efficient Nutrient Use in Genotypes Adapted to Sustainable Production Systems

Project TAM-123
Gary C. Peterson and Arthur B. Onken
Texas A&M University

Principal Investigators

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Dr. Arthur B. Onken, Soil Chemistry and Fertilizer, Texas Agricultural Experiment Station, Route 3, Box 219, Lubbock, TX 79401

Collaborating Scientists

Dr. Francisco Gomez, Midge Resistance, EAP/MRN, Honduras
Dr. Dan Meckenstock, Midge Resistance, INTSORMIL, Honduras
Mr. C.S. Manthe, Sugarcane Aphid, DAR, Botswana
Mr. M.D. Doumbia, Efficient Nutrient Use, IER, Bamako, Mali
Dr. G.L. Teetes, Entomology, Texas A&M University (TAM-125), College Station, TX 77843
Dr. D.T. Rosenow, Sorghum Breeding (TAM-122), Texas Agricultural Experiment Station, Lubbock, TX 79401
Dr. R.A. Frederiksen, Pathology, Texas A&M University (TAM-124), College Station, TX 77843
Dr. F.R. Miller, Sorghum Breeding, Texas A&M University (TAM-121), College Station, TX 77843
Dr. T.L. Archer, Entomology, Texas Agricultural Experiment Station, Lubbock, TX 79401
Dr. B.R. Wiseman, Entomology, USDA-ARS, Tifton, GA
Dr. R.R. Duncan, Sorghum Breeding, University of Georgia, Georgia Station, Griffin, GA 30223
Dr. A. Sotomayor-Rios, Sorghum Breeding, USDA-ARS, Puerto Rico
Dr. C.W. Wendt, Soil Physics, Texas Agricultural Experiment Station, TropSoils, Route 3, Lubbock, TX

Summary

Progress continues in the development of germplasm resistant to sorghum midge, *Contarinia sorghicola*. Resistant germplasm has been developed by TAM-123 which will produce yields similar to susceptible germplasm in the absence of the pest insect. When the pest insect is present the resistant germplasm will produce significantly more grain yield than susceptible germplasm. Progress is also being made in the identification of additional sources of resistance. Initial observations of 50 new converted lines identified six lines with potentially useful levels of resistance. Further research will continue to evaluate the lines themselves and as parents in segregating populations.

Sorghum lines will differ in response to applied nitrogen and water use efficiency. At three rates of fertilizer and three irrigation levels MB9 will produce more grain than B35. There was a significant yield response to additional nitrogen in each irrigation level. Although total water use was the same for both lines the higher yield of MB9 gave it significantly higher efficiency of water use (grain yield/water used). There was a significant genotype x N level x water level interaction for both grain yield and water use efficiency.

Objectives, Production and Utilization Constraints

Objectives

Obtain and evaluate germplasm for resistance to arthropod pests. Determine which resistance sources or mechanisms are most useful to sorghum improvement.

Determine the inheritance of insect resistance.

Develop and release high yielding, agronomically improved sorghums resistant to selected insects including the sorghum midge.

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.

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 the 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 probably the sorghum species most destructive insect pest. 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 alfisols 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 of infestation. Sources of germplasm for evaluation are elite accessions from other programs (including ICRISAT), introductions, and partially or fully converted exotic genotypes from the sorghum conversion program.

New sources of resistance are crossed to elite material in the breeding program and to other germplasm lines with superior trait(s). Studies to determine the genetics of resistance and the resistance mechanism are conducted when possible. Advanced elite materials are evaluated at diverse locations for stability of resistance, adaptation, and reaction to additional stress factors. Based upon data collected, crosses are made among elite lines to produce additional germplasm for subsequent evaluation. Improved adaptation, other stress resistance (disease resistance and/or drought tolerance), and additional favorable traits are incorporated into insect resistant germplasm whenever possible.

Elite lines and hybrids are provided to LDC cooperators for evaluation in indigenous environments. The germplasm is evaluated under the local production system (fertilizer, tillage, plant population, etc.) and agronomic and yield data collected. TAM-123 will assist in evaluation at maturity. Larger quantities of germplasm are provided to cooperators based upon initial observations.

For insects of importance 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 obtained 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 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.

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 numerous 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), EON (Elite Observation Nursery), and BON (B-line Observation Nursery). The ADIN, ITVAN, and TAT are evaluated at many locations domestically and internationally.

Selections for resistance to sorghum midge were made in populations from the F_2 through advanced generations. Progress the last two years was hindered by drought conditions in the south Texas sorghum nurseries. In addition to excellent midge pressure at anthesis the germplasm was subjected to severe preflowering drought stress. Several potentially useful pollinators were identified based upon seed set (less than 30% of kernels blasted) and yield potential. Several new females were evaluated in hybrid combination for the first time. Fifty germplasm lines from the sorghum conversion program were evaluated for resistance to sorghum midge. Initial observation indicated that the following may possess useful resistance levels: IS6919C (SC846-14), IS8179C (SC752-14), IS7156C (SC807-14), IS3693C (SC632-14), IS2655C (SC113-14), and IS12595C (SC86-14). Two lines, IS6919C and IS3693C are B-lines in A1 cytoplasm and offer the potential of using different genes in the females of midge resistant hybrids. Additionally, IS6919C is a tan plant line and offers potentially that useful trait in B-line germplasm.

Diverse germplasm resistant to biotype E greenbug was selected in all segregating generations. In addition to possessing excellent levels of aphid resistance many of the selections contain other useful traits (disease resistance, resistance to foliar discoloration, tan plant, white pericarp). A number of new pollinators were initially evaluated in hybrid combination. Lines with superior combining ability have been identified for further evaluation and testing. Included in the hybrids were several which combine greenbug resistance with resistance to rust and/or anthracnose in tan plant, white pericarp hybrids. Superior lines and hybrids were selected for further evaluation and testing.

Midge resistant germplasm was evaluated in Olancho state, Honduras and in Guatemala. The Olancho trials had poor germination and useful data were not obtained. Data received from Guatemala are presented in Table 1. The midge resistant germplasm expressed excellent resistance and adaptation in the absence of sorghum midge. The data confirm observations made in Texas that in certain environments in the absence of midge, resistant germplasm will outyield susceptible germplasm.

Research to diversify the genetic base of the breeding programs continued. Emphasis continues to be on combining multiple genes for resistance to sorghum midge and incorporating into a single genotype resistance to more than one stress. Incorporating resistance to insects and diseases in the same genotype is complicated by essentially all sources of resistance to major diseases being susceptible to greenbug and very susceptible to sorghum midge. Most midge resistant lines and hybrids possess some level of preflowering drought tolerance, principally developed through the intrinsic nature of the midge resistance breeding program. This combination of traits will be further exploited to create a more environmentally fit plant genotype.

Data in Table 2 show a wide range of grain yields with and without fertilizer nitrogen, as well as a wide range of response to the applied nitrogen. If we select the top 12 yielding lines with nitrogen applied and use regression analysis to relate that yield to their yield without applied nitrogen, we find a poor relationship with an R^2 value of 0.101. Similarly, if we relate the grain yield of the top 12 lines to the yield increase we again obtain a poor relationship with an R^2 value of 0.224. While there is some tendency for sorghums that yield well under good fertility to respond to fertilizer application and for those lines that yield poorly under good fertility to yield poorly under low fertility, yield under good fertility conditions cannot be the sole selection criteria for performance over a range of fertility conditions. Obviously, other factors are influencing this performance and they need to be determined.

Grain yield ranged from 2340 to 5290 lbs/A for MB9 and from 890 to 3720 lbs/A for B35 (Table 3). MB9 produced more grain that B35 at all treatment combinations, however, the differences were much larger at 0 and 20 lbs N/A than at 80 lbs N/A. For both lines there was a significant yield response to additional nitrogen in each irrigation level. At the two lower levels of nitrogen, increases in water supply resulted in only small or no yield increase for MB9 and reductions in yield of B35. At 80 lbs N/A, yields of both lines increased significantly with additional water.

Total water use was the same for both sorghum lines. The higher yield of MB9 gave it significantly higher efficiency of water use (grain yield/water used). Since nitrogen additions had relatively small effect on water use but significantly increased grain production in each water level, efficiency of water use increased significantly in response to additional nitrogen. There was a significant genotype x N level x water level interaction for both grain yield and water use efficiency.

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. (in press).

Onken, A.B., G.C. Peterson, M.D. Doumbia, A.A. Sow, and D.T. Rosenow. 1991. Interaction effects of sorghum genotype, water level,

Table 1. Agronomic data for midge line test from Finca Las Vegas, Guatemala

Designation	Class[1]	Yield lb/A	Midge damage rating	Days to 50% anthesis	Desirability	Plant height cm	Panicle exsertion cm	Panicle length cm	Threshing %	Moisture %
R.Tx2767	R-CK	6824.4	1.0	58	3.3	200	3	31	76.8	18.4
Tx2761	R-CK	6741.8	0.0	62	3.0	200	3	34	78.1	17.0
B.Tx378	S-CK	6694.3	1.0	62	3.0	233	4	26	75.2	20.1
B.Tx2801	R-CK	6533.0	0.0	62	2.8	193	3	33	77.3	18.0
MR101-14-5-1-LBK-BMBK	R	6380.8	0.0	60	2.3	172	3	34	78.6	16.5
Tx2782	R-CK	6317.8	0.0	59	2.8	183	3	33	78.2	18.7
Tx2876	R	6255.7	0.0	62	3.0	217	3	32	77.3	17.9
B.Tx623	S-CK	6255.6	0.0	61	3.0	207	3	31	78.5	16.6
TAM2566	R-CK	6164.8	1.7	60	2.8	190	3	35	74.4	19.3
Tx2880	R	6155.3	1.0	59	2.8	202	3	31	78.1	17.0
Tx2877	R	6081.1	0.0	62	3.0	192	3	34	77.1	18.1
Tx2883	R	5785.5	0.0	62	3.3	208	3	34	77.1	18.0
Tx2889	R	5709.5	1.0	59	2.8	183	3	33	78.0	17.1
Tx2766	R	5615.7	1.0	63	3.0	213	3	33	75.6	19.7
Tx2874	R	5594.8	0.0	58	3.0	202	3	34	78.5	16.6
Tx2884	R	5484.1	0.0	60	3.2	182	3	35	77.4	17.7
Tx2885	R	5478.6	0.0	62	2.8	193	3	32	77.9	17.9
Tx2888	R	5427.6	0.0	59	2.8	167	2	33	80.1	17.9
Tx2871	R	5415.6	0.0	58	2.8	172	3	34	78.5	16.6
Tx2881	R	5401.0	0.0	57	3.0	177	3	32	78.9	16.2
B.Tx430	S-CK	5125.9	0.0	64	3.0	183	4	30	77.7	17.5
Tx2872	R	5105.9	0.0	61	3.0	163	3	32	77.8	17.3
Tx2870	R	5072.3	0.0	61	2.7	167	3	33	77.1	18.0
Tx2869	R	5043.6	0.0	59	3.0	160	3	34	77.5	17.6
B.Tx2755	R-CK	5039.7	0.0	59	3.2	177	3	29	78.3	16.0
Tx2879	R	5009.5	0.0	61	2.5	168	3	34	75.8	19.5
Tx2873	R	4991.7	0.0	62	2.8	172	3	30	76.0	19.3
Tx2886	R	4980.2	1.0	61	3.2	183	3	31	77.4	17.8
Tx2878	R	4942.6	0.0	62	2.8	172	2	33	75.3	18.6
MR104-9-5-3-CC2-BM2-BM2	R	4920.0	0.0	58	2.8	147	3	34	77.8	17.3
MR110-9-6-1-B2-BMB-BMBK	R	4715.5	0.0	57	2.8	163	3	32	78.6	16.5
MR102-3-2-5-4-B1-L1-CC1	R	4705.4	1.0	61	3.0	163	3	32	77.4	17.8
MR102-3-3-6-2-L2-BM1-CC1	R	4655.2	0.0	57	3.3	160	3	34	77.5	17.6
Tx2875	R	4558.9	0.0	59	3.2	150	3	31	76.6	18.6
MR106-73-3-4-B4-BM2-BM2	R	4231.7	0.0	62	3.7	158	3	34	78.0	17.1
Tx2882	R	4203.5	0.0	61	3.0	165	3	34	77.5	17.6
MR102-40-2-3-2-CC4-CCBK-C	R	4201.7	0.0	58	3.0	163	3	34	66.8	16.8
B.Tx3042	S-CK	4128.2	0.0	62	2.8	173	3	31	76.3	17.8
Tx2890	R	3605.4	0.0	57	3.5	155	3	33	77.7	17.4
Tx2887	R	3399.1	0.0	62	2.8	213	3	32	54.1	17.0
Test mean		5324								
$LSD_{.05}$		2395								

[1] R = Resistant; S = Susceptible; CK = Checks.

and nutrient level. In Proc.of the International Sorghum Millet CRSP Conference. July 8-12, 1991. Corpus Christi, TX (in press).

Peterson, G.C. 1991. Yield of sorghum midge resistant hybrids in the presence and absence of the pest insect. 17th Biennial Grain Sorghum Research & Utilization Conference. Feb. 17-20, 1991. Lubbock, TX. (in press).

Peterson, G.C. 1990. Comparison of sorghum midge resistant and susceptible hybrids. Agronomy Abstracts, October 21-26, 1990, San Antonio, TX. p. 104.

Peterson, G.C., G.L. Teetes, B.R. Wiseman, A. Sotomayor-Rios, J.W. Jones, and K. Schaefer. 1991. Registration of 22 midge-resistant sorghum germplasm lines. Crop Sci. 31:498-499.

Peterson, G.C., T.L. Archer, G.L. Teetes, and J.W. Jones. 1991. Registration of 10 biotype E greenbug- resistant sorghum germplasm lines. Crop Sci. 31:499-500.

Presentations

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. (in press).

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. (in press).

Peterson, G.C. 1991. Yield of sorghum midge resistant hybrids in the presence and absence of the pest insect. 17th Biennial Grain Sorghum Research & Utilization Conference. Feb. 17-20, 1991. Lubbock, TX. (in press).

Peterson, G.C. 1990. Comparison of sorghum midge resistant and susceptible hybrids. Agronomy Abstracts, October 21-26, 1990, San Antonio, TX. p. 104.

Networking

Workshops

International Sorghum Millet CRSP Conference, July 8-12, 1991. Corpus Christi, TX. Member of planning committee for Conference and Chairman of the Poster Session. Participated in the field tour by making presentation on "Breeding for resistance to sorghum midge".

Table 2. Average grain yields[1] of various grain sorghum breeding lines at both high and low levels of applied nitrogen fertilizer at the Texas Agricultural Experiment Station, Lubbock, Texas, 1990.

Breeding line	Yields (lbs/A) 0 lbs/A N	120 lbs/A	Increase (lbs/A)
SC325-12	3875 a-d[2]	4722 e-g	847 g-i
R6956	4278 ab	5722 abc	1444 b-h
SC630-11E	3899 abc	6038 ab	2139 abc
MB9-41	4626 a	5879 ab	1253 d-i
B35	3175 d-g	4154 g	979 c-i
P8-98012	4295 ab	6242 a	1947 a-d
Sureño	2648 g	2776 h	128 j
CSM63	2994 fg	5205 c-e	2211 ab
SC963	3775 b-e	4383 fg	608 ij
Segaolane	4101 ab	5836 abc	1735 a-e
SC650	4033 ab	6017 ab	1984 a-d
El Mota Galmi	3295 c-g	4964 def	1669 a-f
SC283	3062 e-g	4408 f-g	1346 c-i
C151-262-A1	4313 ab	6171 a	1858 a-d
SC170	3944 abc	4853 def	909 f-i
R9188	3584 b-f	4768 e-g	1184 d-i
B1	3153 d-g	4340 fg	1187 d-i
VG15	3563 b-f	6040 ab	2477 a
TX2801	4297 ab	5189 c-e	892 hij
TX399	4168 ab	5472 b-d	1304 d-i
TX623	4094 ab	5771 abc	1677 a-g

[1] Grain sorghum yields are calculated at 13% moisture.

[2] Means followed by the same letter are not significantly different at the 0.1 probability level.

Table 3. The effect of nitrogen fertilizer and irrigation level on grain yield and water use of two grain sorghum breeding lines at the Texas Agricultural Experiment Station, Lubbock, Texas, 1990.

Irrigation level[1]	Sorghum line	Fertilizer rate (lbs/A)	Grain yield (lbs/A)	Total water used[2] (inches)	Grain yield water used (lbs/A/inch)
W1	MB9	0	2340 fg[3]	16.0 e	147 e
		20	2810 e	16.1 e	174 b
		80	3270 d	15.9 e	206a
	B35	0	1270 i	15.8 e	81 gh
		20	2050 gh	16.5 e	124 f
		80	2490 ef	16.2 e	153 cde
W2	MB9	0	2650 ef	20.4 cd	129 f
		20	3380 d	20.2 cd	167 bc
		80	4340 b	20.3 cd	214 a
	B35	0	890 i	20.1 cd	44 i
		20	1780 h	19.8 d	90 g
		80	3380 d	20.8 c	162 bc7d
W3	MB9	0	2790 e	23.6 b	118 f
		20	3480 cd	23.8 b	146 e
		80	5290 a	25.0 a	212 a
	B35	0	960 j	23.8 b	40 i
		20	1740 h	23.5 b	74 h
		80	3720 c	24.8 a	150 de

[1] W1—Preplant (4.6 acre inches/A) plus 2.4 acre inches/A on May 18 and 2.5 acre inches/A on June 9.

W2—Same as W1 plus 4 applications from July 2 to September 6 total 6.0 acre inches/A. This level allowed periodic plant water stress from late June to grain maturity

W3—Same as W1 plus 8 applications from June 26 to September 7 totaling 10.5 acre inches/A. This level prevented plant water stress throughout the growing season.

[2] Total water used—Total water input after planting—rainfall, irrigation and soil water depletion.

[3] Values followed by the same letter are significantly different (0.05 Duncan Test).

Research Investigator Exchanges

G.C. Peterson. Honduras - Dec. 6-12, 1990. Evaluated cooperative Recursos Naturales/INTSORMIL research at Zamarano, Rapaco, Olancho, Choluteca, and Comayagua. Evaluated LUPE (Land Use Productivity Enhancement) research activities in southern Honduras. Discussed collaborative program with Minister of Recursos Naturales, and with officials from the Pan American School and USAID/Honduras.

Germplasm and Research Information Exchange

Distributed germplasm samples for cooperative research or from specific requests. Seed was sent to several states, and to counties/programs including but not limited to Honduras, Mexico (ICRISAT-MASIP), Australia, England, and Niger. Germplasm was also distributed to commercial seed companies upon request.

Germplasm previously released by this project but not in the National Seed Storage Laboratory was harvested, inventoried and packaged for inclusion in the National Plant Germplasm System.

Furnished funds for supplies and labor to M.D. Doumbia to conduct sorghum genotype x fertility interaction research at the Cinzana Research Station in Mali.

Tropical Sorghum Conservation and Enhancement in Honduras and Central America

Project TAM-131
Dan H. Meckenstock
Texas A&M University

Principal Investigator

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Ing. Edgar Salguero, NSP Head, Instituto de Ciencia y Tecnología Agrícolas (ICTA), Guatemala City, Guatemala
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Ing. David Erazo, Rural Sociologist, EAP, Department of Agronomy
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Dr. Lloyd Rooney, Cereal Chemist, TAM-126, TAMU, Department of Soil & Crop Sciences, College Station, TX 77843
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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 1981. Its overall objective is to improve the quality of life of farm families that produce sorghum. This is accomplished through *in situ* conservation and enhancement of local landrace sorghum populations and the promotion of advanced technology intended to shift sorghum production from a tradition-led enterprise to a science-based industry. Honduras is an INTSORMIL prime site and research is conducted under an MOU with the MNR (1981) and the EAP (1988). The GOH and USAID/H provide local currency support for research activities in Honduras through the Title I PL480 program. Regional networking is conducted through the exchange of information and germplasm. TAM-131 collaborates with nine INTSORMIL projects representing four land-grant universities as well as PIs and program directors in the Honduras Inter-CRSP initiate. This interaction focuses on students conducting research in-country and the entry of other CRSPs into Honduras. To date, TAM-131 has

participated in the completion of research prerequisites for eight advanced degrees from U.S. universities and six Ingeniero Agronomo degrees from local universities. Presently, it is collaborating with in-country research surrounding four advanced degrees, including one with TropSoils, and two Ingeniero Agronomo degrees.

The technical thrust in germplasm enhancement focuses on developing photoperiod sensitive lines and hybrids for the tropics. Studies with progressive dosages of maicillo genes and heterosis suggest hybrids derived from parental lines containing 50% of the maicillo genome maximize productivity. However, additional breeding is needed to delay the date of flowering (1-2 weeks) to maximize adaptation and grain utility.

Studies associated with the technical thrust in conservation indicate that maicillo possesses shade tolerance, i.e., less self-thinning in maize intercropping. This discovery adds a new dimension to the role of sorghum in sustainable agricultural systems — particularly alley cropping systems designed to check deforestation and desertification.

Follow-up of the Sureño release with a survey of 32 small farmers in southern Honduras that tried this improved variety three years ago (1988) indicates that 76 percent of them continue to use Sureño on 37 percent of their sorghum acreage. Also, percentage of Sureño acreage increased with dependency on sorghum tortillas. We concluded that small farmers will upgrade their traditional cultivars to make gains in utility and productivity.

Objectives, Production and Utilization Constraints

Overall Objectives

To improve the quality of life of rural families who produce sorghum through the conservation and enhancement of traditional sorghum cultivars.

To support sorghum research in the region through joint planning and coordination of research activities, collection and evaluation of local landrace sorghum, development of new biotechnologies, joint release of enhanced germplasm, and on the job training of local scientists.

To transfer new sorghum technologies through on-farm demonstrations and publication of research results.

Year 12 Project Objectives

Several new initiatives were undertaken in Year 12. These included the evaluation of 19 maicillo and 14 enhanced maicillo cultivars for shade tolerance; the introduction of 54 elite broomcorn varieties from the world collection; and the development of 3-dwarf male-sterile isolines.

Other activities in Year 12 related to the overall project objectives and included the collection, evaluation, and conservation of maicillo germplasm; development of enhanced maicillo varieties and hybrids with improved yield potential, adaptation, insect and disease resistance, and acceptable grain and forage quality; and development of a control strategy for the langosta insect complex which includes the fall armyworm, *Spodoptera frugiperda*.

Constraints

Conservation and evaluation of maicillo diversity. Maicillo criollo is the local name for landrace tropical sorghum populations found in semiarid regions of Central America. 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 hectares. 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 Central American farmers. As the need to boost sorghum productivity increases in Central America, maicillo is slowly being replaced by higher yielding but uniform sorghum cultivars. This process not only threatens the extinction of many undiscovered useful genes, but it also increases the probability of having an epidemic.

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 techniques and fertilizer can 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, dry 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*—wreak havoc each spring by chaotically attacking seedling fields with little or no warning. Understanding the complex, its species diversity, density, time of occurrence, and origin, is necessary to develop an adequate control strategy.

Sorghum downy mildew. Sorghum downy mildew is a recently introduced disease that is now 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.

Economic crisis in Central America. The Honduran National Sorghum Program (NSP) has maintained its viability by adjusting to changes in the economic and political environment. Legislation passed in the United States Congress last year (1990) jeopardized local currency support for sorghum research by taking the responsibility of PL480 Title I loans out of USAID and placing it with USDA. This move reduced the effectiveness of the MNR because the lion's share of its operating budget comes from PL480 Title I funds. As in most developing countries, the international community finances most of the research in Honduras and we are currently working to get the NSP's funding lifeline replaced through the PL480 Title III grant. However, 1993 is the earliest this mechanism can be tapped. To carry the program through 1992, a straight line funding level with unused PL480 Title I monies is being negotiated with the Government of Honduras (GOH).

Present austerity measures taken by the GOH call for a mandatory reduction of 500 Ministry of Natural Resources (MNR) employees. Consequently, the NSP lost two collaborating scientists this past year, Lindolfo Fernández in Comayagua and Humberto Mejia in Olancho. The Comayagua site has special relevance to the overall success of the NSP because of the International Sorghum Downy Mildew Nursery established there in 1983. Due to the absence of the MNR counterpart in Comayagua, the International Sorghum Downy Mildew Nursery will not be used in 1991. Other changes in MNR personnel include the recent appointment of Orly García as the Head of the Department of Agricultural Research.

Some of the events mentioned above were foreseen and steps were taken to shelter the NSP by transferring it to the EAP in 1990. As a result, we were able to retain our principal counterpart, Dr. Francisco Gomez, and maintain local currency support for activities in the EAP. An MOU is presently being negotiated between the EAP and MNR with the approval of the Ministry of Finance and Public Credit. This MOU places the responsibility of sorghum research in the EAP and continues GOH support for local costs. Once signed, the MOU will enable the EAP to restart sorghum research activities on-farm and at MNR experiment stations.

In contrast to other agricultural research programs in the MNR, which have lost the bulk of their funding for 1992, the NSP has managed to maintain its viability. The MNR-EAP-INTSORMIL joint effort has given the NSP a "can-do" image and has set it up to play a larger leadership role in the region—a region in which other departments of agriculture suffer from similar economic weaknesses and political pressures.

Research Approach and Project Output

Conservation and Evaluation of Maicillo Diversity

The beauty of landrace populations is beheld in their wealth of genetic diversity. Breeding programs based in regions where these primitive cultivars exist have a special obligation to collect and conserve that diversity. Tropical landrace sorghum populations have been grown in Central America since their introduction in the colonial period and harbor a bounty of untapped genetic resources.

The first step in the conservation of maicillo is its collection and evaluation. It is through this process that useful genes are identified for inclusion in the conservation's ark. The INTSORMIL network of scientists plays an integral role in this task and many useful traits have already been identified. For example, Ronnie Duncan at the University of Georgia has discovered a maicillo source for tolerance to acid soils with 50 percent aluminum saturation in San Bernardo II (PI 536581). Darrell Rosenow at Texas A&M University has identified drought tolerance in SC1211, a partially converted line of Cacho de Chivo. Henry Pitre and Marco Castro at Mississippi State University have uncovered antibiosis to fall armyworm, *Spodoptera frugiperda*, in San Bernardo III (SC1207), Lerdo (SC1384) and Piña (SC1385). And there is more. While evaluating maicillo for resistance to important foliar diseases in the humid tropics at Sete Lagoas, Brazil, Richard Frederiksen at Texas A&M University and Carlos Casela of Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA) found excellent combined sources of resistance to diseases caused by *Cercospora scalariforme*, *Colletotrichum graminicola*, and

Puccinia purpurea in Billy (SC1370), Enano, Nance Dulce (SC1375), and Porvenir (SC1371).

To date, more than 220 landrace populations have been collected throughout Central America—with the help of National Sorghum Programs—and placed into the maicillo criollo working germplasm bank at the EAP. As an additional measure of conservation, 44 elite accessions, including most of those mentioned above, have been placed in the TAMU-USDA sorghum conversion program. This will make this material available to researchers worldwide and bring new useful sorghum genes into the mainstream.

Since its arrival in the New World, maicillo has been conserved *in situ* by small farmers who have unwittingly served as village-level custodians. However, dynamic demographics has placed this germplasm at risk because a rapidly expanding Honduran population (3.6 growth rate from 1974 to 1988) is demanding higher yielding maize and sorghum cultivars. In spite of these pressures, maicillo continues to persist on small farms because of its adaptation to neotropical farming systems such as intercropping with maize in drought risky agroecosystems.

Maicillo appears to have an advantage over "new and improved" sorghum cultivars in maize intercropping because of landrace traits like photoperiod sensitivity which staggers the reproductive growth phases of sorghum and maize and low stable yield. However, other important traits, such as shade tolerance, are believed to be involved in adaptation to maize intercropping. One new initiative in Year 12 was to determine whether maicillo tolerates shade better than other sorghum cultivars.

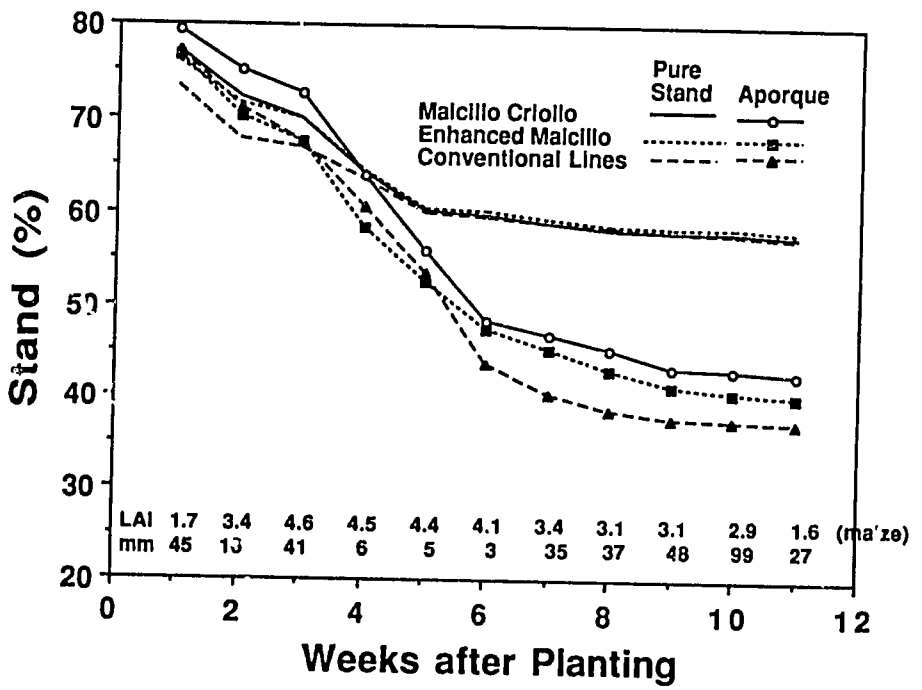
Methods. Forty sorghum cultivars—19 maicillo landrace populations, 14 enhanced maicillo cultivars and 7 conventional breeding lines—were evaluated for shade tolerance. Two cropping systems were used, pure stand and aporque. The aporque system derives its name from the practice of planting maicillo between the rows of maize at the time of its cultivation or aporque (in Spanish). A natural maize canopy was used to induce shading, because the quality of light (which includes scattering of far-red radiation from surrounding plants), as well as intensity are believed to affect plant response to shade.

This study was initiated 8 June 1990 with the planting of a local early maturing maize population called maicito. Maize was seeded in hills, 0.25 m apart, and in 0.8 m row widths. Maize rows were 6 m long. Hills were thinned 15 days after planting to two plants to achieve 100,000 plants ha^{-1}. Eight hills (16 plants) were selected at random throughout the experiment and monitored weekly for changes in leaf area index (LAI).

Sorghum was seeded 20 days after maize in one row plots (5.0 x 0.8 m), thus each sorghum plot in the aporque treatment had a border of two maize hills at both ends of the row. One hundred sorghum seeds were planted in each plot an equal distance apart (0.05 m) to give 250,000 plants ha^{-1}.

The experimental design was a randomized complete block arranged as a split plot. Cropping system was the main plot effect and sorghum cultivar was the split-plot effect. Each treatment combination was replicated twice. The plants in each sorghum plot were counted weekly (until maize matured) to make inference about shade tolerance.

Figure 1. Maicillo criollo, enhanced maicillo, and conventional lines have similar mortality rates in pure stand, but maicillo criollo tolerates shade better and suffers less self-thinning (plant loss) when intercropped with maize in the aporque system.



Cultivars with less self thinning (plant death) were assumed to be shade tolerant.

Results. Three weeks after planting sorghum, maize reached its maximum LAI of 4.6 (Fig. 1). At this point, sorghum stands in aporque began to decline significantly. A brief drought also ensued and maize LAI began to decline. After four weeks, the drought let up, and the decline in the maize canopy leveled off to about LAI = 3.0, and sorghum stands stabilized in the aporque system (Fig. 1).

On average, maicillo criollo tolerated shade better than the enhanced maicillo varieties and exotic materials (Fig. 1). The intermediate shade tolerance of the enhanced maicillo varieties suggests shade tolerance is a heritable trait. Individual cultivars with apparent shade tolerance were identified within each group. The most shade tolerant maicillo accessions were Billy-203 (51% stand in aporque), Apretado (49.5%), Coludo-110 (49.5%), Cacho de Chivo-169 (49%), and Lerdo-104 (49%). The best shade tolerant enhanced maicillo varieties were the F_1 hybrid A(Tx623* Pespire)*DMV206 (63%), (CS3541*Lerdo-104)-3 (54%), SC1207-2 (49%), and DMV206/(CS3541*Liberal)-6 (48%). Apparently, heterosis enhances shade tolerance. The best exotic materials were CS3541 (46%), Redlan (45.5%), and Tx430 (44%) but these fell short of maicillo's performance. The least shade tolerant materials were the maicillo criollo Sapo (23%), BTx623 (23%), SPV346 (24%), DMV106/(8ILL691*Porvenir)-16 (24%), DMV177/(SBIII *TAM428)-6 (25.5%) and SC326 (28%).

Discussion. Shade tolerance is a unique trait in maicillo that promises to add a new dimension to the role of sorghum in sustainable agricultural systems—particularly for small farmers on marginal land. We believe shade tolerance in maicillo developed as a direct result of intercropping with maize. Less self-thinning or dying-off of individual plants under the maize canopy in low light intensity environments suggests a lower respiration rate is involved. Indeed, if a lower respiration rate is at play, then sorghum yields—both grain and forage—can be raised across the board because a more efficient energy system will have been discovered. Max Clegg and Patricio Gutiérrez, INTSORMIL team members at the University of Nebraska, are currently investigating this phenomenon to determine maicillo's secret.

Although shade tolerance has broad implications for sorghum improvement that will take years to realize, its immediate application goes straight to the heart of low-input sustainable agriculture in Central America. Maicillo's ability to survive shaded environments, in essence, enables sorghum to be used in agroforestry systems such as alley cropping with fast growing deep-rooting leguminous trees (e.g., *Leucaena leucocephala*). The sustainable benefits that arise from alley cropping with hedgerows of leguminous trees include fixation of atmospheric nitrogen, recycling of subsoil nutrients, and improved water infiltration.

In Honduras, maicillo is grown principally on steep slopes in semiarid regions. LUPE is teaching these farmers soil and water conservation techniques, in conjunction with alley cropping practices, to control water runoff and soil erosion. Annual pruning of trees not only provides a convenient source of fuelwood and green manure, but it helps conserve woodlands that give birth to streams and aquifers that have off-site importance—particularly for urban centers down stream. In short, the use of shade tolerant sorghum adds instant economic value to agroforestry schemes designed to check deforestation and desertification.

Maicillo Enhancement

After collection and evaluation, the second step in the conservation of maicillo is its transformation to stable high yielding cultivars with improved food processing properties and resistance to predominant diseases. It is through this process that maicillo is enabled to meet the productivity demands of small farmers who will conserve this germplasm *in situ*.

Methods. The transformation of maicillo is achieved through crossing with exotic lines to acquire shorter stature, higher yield, and other valuable traits. This method not only increases the genetic diversity of maicillo but it avoids maicillo's loss or replacement by "quick fix" introductions which historically have failed to adapt to maize intercropping. Other valuable traits transferred to maicillo include tan plant color for improved tortilla quality, and resistance to diseases like *Cercospora sorghi*, *Puccinia purpurea*, and *P. sorghi*, which enhance yield stability and forage quality. Those maicillo traits that facilitate adaptation to maize intercropping are maintained and include sensitivity to photoperiod and shade tolerance.

Simple gene changes in plant architecture, like switching a dominant height gene for a recessive one, increase yield by shifting the stem to head ratio in favor of storing more energy in the grain. Gene swapping is an old trick used in the domestication of crops and, in fact, was the basis for the Green Revolution which ushered in the predominance of short stature wheat and rice varieties in many countries.

Two recent breeding objectives have focused on the prolongation of the grain fill period and transfer of the IS 3443 source of resistance to *P. sorghi*. Grano de Oro, a large seeded yellow endosperm feterita type, is being used in an attempt to delay maturity and augment yield by increasing the duration of grain fill. The zerazera line IS 3443 not only possesses strong resistant genes to pathotype 5 of *P. sorghi* but it also has tan plant color, excellent grain quality, and resistance to many foliar diseases. The combination of these traits make IS 3443 an outstanding breeding line.

Another breeding objective has been to develop an enhanced maicillo germplasm bank. The purpose of this bank is to bridge the gap between maicillo and exotic materials and increase the probability of selecting desirable pheno-

types. Entries in this bank are designated with a DMV (dwarf maicillo variety) number and are primarily 2- and 3-dwarf photoperiod sensitive varieties with 25-75% maicillo germplasm. In order to use the DMV lines more efficiently, these materials are systematically evaluated for their reaction to A1 and A2 cytoplasms, plus height and testa genotypes. To facilitate this process, 3-dwarf male-sterile isolines with the Tx631 genome are being developed. These tester lines will simplify identification of Dw_1, Dw_2, Dw_3, and Dw_4 height genotypes.

In developing materials for the DMV germplasm bank, multilocation testing is used to select wide adaptation and resistance to multiple diseases. In 1990, early generation materials were evaluated in head row plots (4 m^2) at La Lujosa (2450 plots), Las Playitas (2790 plots), and Rapaco (4505 plots). Selection for resistance to SDM, gray leaf spot, and ladder spot were made at Las Playitas. Resistance to gray leaf spot and acremonium wilt were selected at La Lujosa. And resistance to postflowering drought and shade tolerance was selected at Rapaco. Breeding work was conducted at the EAP (5239 plots).

In order to develop shade tolerance, F_3 and F_4 lines were intercropped with maize at Rapaco. This was the second year (1990) that we ran the intercropping nursery at Rapaco and the F_4 population, which has been screened two consecutive years for shade tolerance, appears to be developing nicely. Maicito, a local maize population, was used in the intercropping nursery. Like other native maize populations used for intercropping, it is shorter in stature and matures earlier than commercial hybrids. Maicito was planted 12 days (6 June 1990) before the sorghum nursery. The sorghum lines were sown in head-row plots, about six inches to the side of the maize. Due to maicito's rapid growth and earlier planting, the sorghum was forced to grow under the maize canopy. Selection was based on maturity, plant stand, yield, seed color (white), and plant color (tan).

As breeding materials advance, superior ones are selected for testing in a replicated yield trial called the International Improved Maicillo Yield Trial (IIMYT). This trial features the best enhanced maicillo cultivars and is distributed to other NSP in the region upon request. In 1990, one copy of this test was sent to El Salvador and Guatemala.

Discussion. The 1990 IIMYT consisted of 40 cultivars and included 20 enhanced maicillo varieties and 16 experimental photoperiod sensitive hybrids. Results of the 1990 IIMYT were obtained from three locations: El Zamorano, La Lujosa, and Rapaco (Table 1). As in previous years, photoperiod sensitive (TAM428*Porvenir)-29-2 performed exceptionally well (5.1 t ha^{-1}). However, the photoperiod sensitive hybrids dominated the test in pure stand. The outstanding performance of these hybrids offers the tantalizing possibility of putting Donald Plucknett's proposed yield take-off point (1.7 t ha^{-1}) within the grasp of small farmers.

Because most Honduran farmers feed sorghum stover to their cattle, we also try to develop cultivars that also have good forage quality. In general, this has been accomplished by selecting for nonsenescence and resistance to foliar diseases, which gives an abundance of clean green leaves at harvest. In an effort to delve deeper into the forage quality aspect of our materials, Francisco Gomez measured brix of the IIMYT cultivars at the La Lujosa Experiment Station (Table 2). Because we have not directly selected for high sugar content in the stem, we were surprised to discover that many of the enhanced maicillo cultivars had high brix values. In fact, four varieties had values of 20 or better and this level surpasses most sweet sorghum varieties. This find increases the value of maicillo as a genetic resource and is just one more example of the progress to be made by working with landrace populations rather than discarding them.

Maicillo Hybrids

Maicillo hybrids contrast strikingly with conventional hybrids, particularly in appearance and management. They are taller, later maturing, and produce far more phytomass. These major differences are due to their dominant maturity and height genes. Because of their photoperiod sensitivity, they are restricted to the tropics; but perhaps more importantly, they are an example of custom technology that can be developed from within the third world.

Specific breeding objective. The primary constraint to developing maicillo hybrids has been the preponderance of B-lines in the DMV germplasm bank and the lack of good males. For example, the top three dwarf maicillo varieties (DMV 137, DMV 179, and DMV 177) in the 1990 IIMYT are B-lines. Systematic screening of the DMV germplasm bank for restoration genes will allow us to make crosses that match males with males and females with females.

The present breeding objective for photoperiod sensitive hybrids has concentrated on the development of 3-dwarf parental lines with acceptable maturity and that make use of complementary plant height genes to restore acceptable height in hybrids. Specific work with male-sterile lines has emphasized sterility stability, tan plant color, and white pericarp color. Use of short stature female lines will make commercial seed production economically feasible. Work with male lines has stressed tan plant color, white pericarp color, plus the capability of restoring both A1 and A2 cytoplasms.

Discussion. Performance of the varieties and hybrids in the 1990 IIMYT are summarized by maicillo gene dosage in Table 2. As a group, hybrids are clearly superior to varieties. Within hybrids, those made with photoperiod sensitive female lines come closest to meeting farmer requirements for high yield and lateness. Hybrids made with Texas female lines, ATx631 and A155, had yields comparable to enhanced maicillo females, but were too early (farmer preferences for maturity are discussed in the follow-

Table 1. Summary of the 1990 International Improved Maicillo Yield Trial (IIMYT).

Pedigree	DMV no.	Sd/Plt[1] color	Yield[2] t/ha	Yield[3] t/ha	Flower[4] date	Ht[5] m	P1[6] %	P5[6] %	GLS[7] 1-5	Rust[8] 1-5	Brix	Masa[9] 1-5
(TAM428*Porvenir)-29-2-3-bk-bk	137	whT/P	5.1	1.1	16-Oct	2.0	1	0	2.2	1.0	13.0	3.3
A(SEPON77*Sta Isabel)*DMV 180 3dw	F1	BrS/T	5.0	1.1	15-Oct	2.1	0	0	2.0	3.8	18.5	2.0
A(Redlan*Coludo)-3 BC4*DMV 180	F1	BrS/P	4.9	1.2	17-Oct	2.8	0	1	4.8	3.0	15.0	1.5
A(Tx623*Pespire)-1*DMV 194	F1	wh /P	4.9	1.2	27-Oct	2.7	0	0	3.5	4.0	17.0	3.5
A(SEPON77*Sta Isabel)-6*DMV 195	F1	whT/T	4.7	1.1	1-Nov	2.6	1	0	1.5	4.0	19.0	3.0
ATx631*[SPV346(81LL691*Billy)]-36	F1	whT/T	4.6	1.3	28-Sep	2.0	2	5	2.2	3.8	14.0	—
Variedad Blanca	003	Brs/P	4.6	1.7	7-Oct	3.4	0	0	3.0	2.5	17.3	5.0
A155*Liberal-63	F1	BrS/P	4.4	1.1	6-Oct	3.2	2	3	2.8	3.5	12.0	5.0
ATx631*DMV180 3 dw	F1	whT/T	4.4	1.1	28-Sep	1.8	0	2	2.5	3.5	16.0	3.0
A155*(Billy*CS3541)-1-1-7-2-1	F1	whT/T	4.3	1.2	30-Sep	2.2	0	11	1.5	3.5	15.5	2.0
A(Tx623*Pespire)-1*(CS3541*Liberal)-6	F1	whT/P	4.3	1.2	14-Oct	2.4	0	0	3.0	3.5	15.0	3.5
ATx631*DMV180	F1	wh /T	4.3	1.1	30-Sep	2.3	0	3	2.0	4.0	17.3	3.0
A(Sepon77*Sta Isabel)*(CS3541*Lib.)-6	F1	whT/T	4.3	1.2	13-Oct	1.8	0	0	1.5	4.2	18.5	3.0
A(SEPON77*Sta Isabel)*DMV 206 3dw	F1	whT/T	4.2	1.2	17-Oct	2.2	0	1	2.2	4.0	17.0	3.5
(SPV346*Gigante Pavana)-1-1-2	179	whT/T	4.1	0.8	17-Oct	2.3	4	1	0.5	2.5	20.0	2.5
A155*DMV180	F1	whT/T	4.1	0.9	24-Aug	1.7	0	3	3.5	1.5	17.0	1.5
A(Tx623*Pespire)-1*DMV 180	F1	whT/P	4.1	0.8	17-Oct	2.4	0	0	3.8	4.2	17.5	5.0
(San Bernardo III*TAM428)-6-1-1-3-1	177	whT/P	4.1	1.3	22-Oct	2.4	0	1	3.0	2.0	15.0	2.5
A155*DMV206 3dw	F1	whT/T	3.9	1.1	29-Sep	1.8	0	1	3.0	3.0	18.0	1.5
A Gigante-16 BC2*Liberal-63	F1	whT/P	3.8	1.4	22-Oct	3.4	11	5	2.5	4.0	17.0	1.5
(TAM428*MC100)-2-2	210	whT/R	3.8	1.4	14-Oct	2.3	0	0	4.2	2.0	17.0	—
(TAM428*San Bernardo III)-23	143	whT/P	3.7	1.2	18-Oct	2.2	0	0	4.0	1.5	14.0	1.5
Maiz Maicillo	005	whT/P	3.7	1.3	27-Oct	2.9	6	0	3.8	3.0	18.8	—
(Billy*CS3541)-1-1-6-1-bk	169	whT/T	3.7	1.1	7-Sep	1.7	0	2	3.5	4.0	18.0	3.0
Lerdo Ligero	002	Brs/P	3.6	0.8	18-Oct	2.1	8	4	4.0	4.8	17.5	5.0
(TAM428*Porvenir)-30	184	whT/P	3.5	0.8	21-Sep	1.9	0	0	3.2	1.0	12.0	—
(SC414-12*Plano Namasigue)-53	194	wh /P	3.5	1.4	25-Oct	2.2	1	2	3.8	2.8	18.5	2.5
(TAM428*Porvenir)-29-1-1	198	whT/R	3.5	0.9	13-Oct	2.2	1	0	2.8	2.0	17.8	2.5
Peloton	MC	wh /P	3.4	2.3	31-Oct	2.9	25	5	3.0	3.8	13.0	1.0
San Bernardo III	MC	whT/P	3.3	1.4	22-Oct	2.8	43	5	2.5	3.5	17.3	2.5
(Peloton*TAM428)-3-bk	112	wh /P	3.2	0.6	29-Oct	2.3	0	1	3.5	1.5	20.3	2.0
ES 727	MC	whT/P	3.0	0.9	30-Oct	3.2	7	5	3.5	3.8	18.0	—
(81LL691*Porvenir)-16-1	107	wh /T	3.0	1.2	24-Oct	2.1	0	2	2.2	2.8	18.5	1.5
(MC117*82EON112)-42-2	208	whT/T	2.8	0.8	14-Sep	1.6	0	1	3.2	4.5	21.0	2.5
(79HW207*Liberal)-11-bk-bk-1-2	188	whT/T	2.8	1.0	20-Oct	1.9	45	39	4.0	3.2	12.0	2.0
{[(TAM428*77CS3)GPR148]Billy}-24-1	180	whT/T	2.7	0.5	20-Oct	2.2	0	3	2.2	4.2	18.0	1.5
Porvenir	MC	wh /P	2.3	1.4	31-Oct	3.0	77	15	3.0	3.5	11.0	4.0
(SPV346*Peloton 99)-14-2-3-2	195	wh /T	2.2	1.0	9-Sep	1.9	3	1	2.5	3.8	20.0	2.5
(BTx2801*San Miguel No 1)-3-2	207	whT/T	2.1	1.2	13-Aug	1.3	1	0	2.5	4.2	14.5	3.0
(MC117*82EON112)-36-1	209	whT/T	1.8	0.9	25-Sep	1.9	3	8	1.5	4.5	11.0	3.0

[1] Seed/Plant color: wh=white 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 two locations: El Zamorano, Francisco Morazán and La Lujosa, Choluteca.
[3] Yield in intercropping with maize at RAPACO, El Paraíso. Sorghum was planted in "aporque" 20 days after maize Maicito.
[4] Date of flower at El Zamorano with a 15 June 1990 planting date.
[5] Plant height in pure stand, mean of two locations: El Zamorano and La Lujosa.
[6] Percent systemic infection of sorghum downy mildew caused by pathotype 1 of *P. sorghi* at El Zamorano, Terrace #10 and the more virulent pathotype P5 at the International SDM Nursery, Las Playitas, Comayagua.
[7] Scale of 5, where resistant = 1 and susceptible = 5. GLS = Grey Leaf Spot caused by *Cercospora sorghi* at Las Playitas.
[8] Scale of 5, where resistant = 1 and susceptible = 5. Rust caused *Puccinia purpurea* at El Zamorano.
[9] Subjective evaluation of nixtamal using grain samples from LaLujosa. Scale of 5, where 1 = light, clean yellow masa and 5 = dark, dirty yellow color.

Table 2. Effect of maicillo gene dosage and heterosis on grain yield and maturity and the effect of plant pigments on nixtamal (tortilla) color.

Class	Plant color	n	Dosage %	Yield[1] t ha^{-1}	Flower[2] date	Nixtamal[3] color
EM*EM	Pigmented	4	50	4.5 a	18-Oct	3.4
EM*EM	Tan	4	50	4.5 a	19-Oct	2.9
ATx631*EM	Tan	3	25	4.4 a	29-Sep	3.0
A155*EM	Tan	3	25	4.1 ab	17-Sep	1.7
ME	Pigmented	8	50	3.8 b	16-Oct	2.4
Maicillo	Pigmented	4	100	3.2 c	28-Oct	2.5
ME	Tan	9	50	2.8 c	26-Oct	2.4

[1] Yield values with the same letter are not significantly different according to Fisher's protected L.S.D. (α=0.05). Average of two locations, La Lujosa and El Zamorano.
[2] Data collected at El Zamorano with a 15 June 1990 planting date.
[3] Grain samples from La Lujosa, analysis performed at the TAMU Cereal Quality Laboratory, College Station, TX. Source: 1990 EIME, Table 1, this report.

ing on-farm research section). Only A155 hybrids had acceptable nixtamal color, thus indicating more work is required for developing tortilla quality in enhanced maicillo cultivars.

In addition, 32 BC6 male sterile lines were evaluated for sterility stability at the EAP (800 m above sea level) and La Lujosa (40 m above sea level). The ability to maintain sterility under different environmental conditions is an important factor in developing male sterile lines that can be used by other research programs in the tropics. This could save many resource stressed NSP as much as ten years of work. These lines were selected at the EAP in alternating short day length seasons (January-May) and long day length growing seasons (June-December). Although 11 of the lines were 100 percent male-sterile at El Zamorano, none were fully male-sterile at La Lujosa. Only 6 of the 11 lines identified at El Zamorano showed 98-99 percent sterility at La Lujosa. All of these were (Redlan*Coludo) derivatives. It is important to have these lines because they represent a base from which other photoperiod sensitive female lines can be developed.

On-Farm Research

After enhancement, the third step in the conservation of maicillo is its delivery to small farmers. This is accomplished through our on-farm research activities which are designed to evaluate each cultivar and its acceptability. The target group of this activity is hillside subsistence farmers in southern Honduras.

Methods. Much of our on-farm research is conducted through graduate students working on special problems (e.g., developing insect control strategies) and volunteer extension agents who service small farmers who produce sorghum on marginal land. The LUPE project has been our primary collaborator and the NSP provides pure seed, fertilizer, and instruction guides for demonstration plots.

Because different farmers accept different levels of risk, on-farm demonstrations are conducted with four graduating levels of technology. This design gives critical information for determining the potential impact of different levels of technology and associated risks as well as determining the technological level required to reach the yield take-off point. On-farm trials consist of four treatments: T1 = the control or local maicillo population and traditional practices; T2 = enhanced maicillo variety and traditional practices; T3 = enhanced maicillo variety and seed treatment with a furathiocarb insecticide; and T4 = enhanced maicillo variety, seed treatment, and urea applied at floral differentiation. Each treatment is planted in a 144 m^2 plot.

On-farm trials are designed to compare the enhanced maicillo cultivar to the local variety under the same input conditions (Ho: T1 = T2), as well as demonstrate the yield potential of the enhanced maicillo cultivar when seed is treated with a systemic insecticide and 60 kg N/ha is applied at floral differential. The number of participating farmers is maximized by testing only one enhanced maicillo cultivar at a location and by using each location as a replication.

Four enhanced maicillo varieties—DMV134, DMV179, DMV180 and DMV198—were tested in the spring planting season of 1990 and two introduced cultivars—Sureño and Catracho—were tested in the fall. This was the first year for on-farm testing of DMV179, DMV180 and DMV198. Sureño and Catracho began testing in 1988 and DMV134 first went on-farm in 1989.

The enhanced maicillo varieties consisted of 50 percent maicillo germplasm and had intermediate height (ca. 2.1 m). DMV134 has pedigree (TAM428*Porvenir)-20-2-6 F_9 and was selected because it was the top of the on-farm demonstrations in 1989. It also has good downy mildew resistance and red plant color. Variety DMV179 has pedigree (SPV346*Gigante de Pavana)-1-1-2 F_8 and was selected because of its excellent tortilla processing properties and good yield potential. Its superior tortilla quality was determined by INTSORMIL project TAM-126 at the Cereal Quality Laboratory at Texas A&M University and, in part, is attributed to tan plant color. Variety DMV198 has pedigree (TAM428*Porvenir)-29-1 F_{10} and possesses red plant color. It was selected because of its superior yield in the 1989 IIMYT and good exsertion which pushes panicles above the canopy where farmers can appreciate their yield. Variety DMV180 has pedigree {[(TAM428*77CS3) GPR148]Billy}-24-1 F_9 and was selected for its large head size and tan plant color.

In addition to demonstration plots, a special study was conducted by David Erazo to determine the index of acceptability of Sureño, an improved sorghum variety released by MNR and INTSORMIL in 1985. The purpose of this study was to interview the 32 small farmers living in the municipalities of Concepción de María, El Corpus, El Triunfo, Namasigüe, Orocuina, and Soledad who were introduced to Sureño via LUPE in 1988 and to determine how many farmers continue to use Sureño and on what percentage of their sorghum acreage. An index of acceptability was used to quantify the adoption of Sureño. The index of acceptability is defined as the percentage of farmers who continue to use Sureño multiplied by the percentage of their sorghum acreage on which Sureño is grown.

Discussion. Results were obtained from six on-farm demonstration sites, one for each cultivar sent out. The low number of sites reporting was due to a combination of factors. Among these was LUPE's termination of some of our collaborators. However, two LUPE collaborators, Gilberto Araujo (two sites) and Silvio Morales (four sites), should be recognized for their diligence and effort in delivering the results we obtained.

In general, the enhanced maicillo cultivars were 0.5-1.5 m shorter in stature, 2-3 weeks earlier in maturity, and 30-50 percent higher yielding than their maicillo ancestors. Be-

Table 3. On-farm performance of Sureño, Catracho and four enhanced maicillo varieties compared to traditional varieties and practices in southern Honduras, 1988-1990.

Technology level	Sureño t/ha	Catracho t/ha	DMV134 t/ha	DMV143 t/ha	DMV179 t/ha	DMV180 t/ha	DMV198 t/ha
T1: Traditional variety and practices	1.1	1.2	1.1	0.8	1.6	0.3	1.5
T2: T1 with enhanced variety	1.3	1.6	1.3	1.2	lost[1]	0.6	1.8
T3: T2 with seed treatment	1.5	2.0	1.5	1.2	1.5	0.5	2.6
T4: T3 with 60 kg N/ha, urea	1.8	2.4	1.6	1.8	2.7	1.0	3.0
	n = 34	n = 15	n = 10	n = 3	n = 1	n = 1	n = 1

[1]Poor germination.

cause of limited yield data, results for each cultivar were pooled over the past three years (Table 3). Although insufficient data limits inference about the potential impact of DMV179, DMV180, and DMV198, the overall trend in Table 3 demonstrates the superiority of enhanced germplasm at both ends of the input scale (i.e., T1 < T2 < T4) and strikes a blow against the persistent belief that improved germplasm does not perform as well as traditional cultivars when grown under traditional management. It also indicates soil fertility enhancement is essential to reach the yield take-off point.

Other information was collected from farmers that was helpful in guiding the breeding program. In general, farmers were impressed with the yield of the enhanced maicillo varieties. However, two farmers commented about their earliness. One farmer indicated that earliness caused problems with birds because flowering was not synchronized with later maturing maicillo in neighboring fields. The other farmer indicated earliness caused problems with grain mold when he planted DMV134 in mid-May at San Juan Abajo. This latter factor has sparked some discussion and the conventional wisdom emerging among farmers is that enhanced maicillo cultivars should be planted later than their maicillo cousins. Although this is a viable option for farmers who plant a series of small fields in the spring, existing data on photoperiod sensitive maicillo cultivars suggest the effect of spring planting date has minimal effect on flowering date. Therefore, additional breeding and selection to increase the density of maicillo maturity genes in enhanced maicillo cultivars would be a better solution for the long-term. Although grain weathering due to earliness is a problem with some enhanced varieties, others are later maturing and escape this problem. In fact, DMV179 which was planted near San Juan Abajo at Tablones Arriba in mid-May did not weather.

Forty pound grain samples from DMV179 and DMV198, plus their respective maicillo checks, were bought from cooperating farmers and shipped to the cereal quality laboratory at Texas A&M University for tortilla processing studies on a pilot plant scale. Grain from DMV179, which was collected from Las Espaveles and had a mid-June planting date, made tortillas with superior quality (color) to the maicillo check—thus confirming 1989 laboratory tests as to its excellent tortilla processing properties.

The 1990 on-farm evaluations also indicate that DMV179 and DMV198 work well in alley cropping with *Luecaena leucocephala* trees. Both performed well in this shaded environment and did not lodge as did their maicillo checks. Although maicillo is regarded as having shade tolerance in maize intercropping systems, alley cropping is a novel practice that extends and intensifies shading beyond maicillo floral differentiation. It is after differentiation that maicillo enters internode elongation and shading and/or far-red radiation scattered by surrounding vegetation accelerates stem elongation, thus weakening the stem and increasing lodging. Reduction in maicillo plant height may be essential for some alley cropping systems.

Our interest in on-farm research goes beyond demonstration plots. We also try to follow-up the demonstration plots 2-3 years later to determine the level of adoption of the cultivars being tested. David Erazo evaluated the adoption of Sureño by LUPE assisted farmers in January 1991. Through interviews, he determined that 76 percent of the farmers that tried Sureño three years ago in 1988 were still using it on 37 percent of their sorghum acreage today. This translates into an index of acceptability of 28 percent. From an economic impact or development perspective, this number may seem low, but from a genetic diversity point of view, this number is too high because it suggests Sureño has the potential to replace about one-third of the maicillo population. The conclusion from this survey is that small farmers are willing to upgrade their old cultivars and that there is room for additional enhanced sorghum cultivars.

David also determined some of the attributes of Sureño that contributed to its success. Of the 32 farmers interviewed, the majority considered Sureño superior to maicillo in yield (89%), tortilla quality (80%), forage (89%), drought tolerance (79%), disease resistance (94%), resistance to grain storage insect (60%) and lodging resistance (100%). In short, there was very little that farmers did not like about Sureño. Interestingly, David found a significant positive correlation ($r = 0.65$) between sorghum tortilla consumption and the percentage of sorghum acreage planted to Sureño. In other words, the more sorghum tortillas a family eats, the more Sureño displaces maicillo. Because tortilla consumption increases as one descends the economic strata, Sureño's most important social contribution will be improving the quality of life of resource poor farmers.

Although some of the enhanced maicillo cultivars that go on-farm are beginning to show promise in repeating Sureño's success, the demonstration of enhanced maicillo also plays a subtle, but important, role in the conservation

of maicillo genetic diversity. It is through on-farm demonstrations that enhanced maicillo germplasm is released and that new genes are launched into landrace populations. Some of the enhanced maicillo varieties have already begun to work their way into informal seed markets which not only sustains their use from one year to the next, but also aids their dissemination. One example is DMV179 which was produced by Miguel Gomez, a LUPE model farmer, at Las Espaveles, Namasigüe. In January 1991, he sold four pounds of seed at local prices to Lorenzo Sell who took it to the World Neighbor's project working near San Ramon. There it was planted on about 625 m^2 to increase seed. Remaining seed was given to three other farmers for their use. Informal markets like these have sustained maicillo since its beginning. As enhanced maicillo begins to work its way into these markets, it promises to change the traditional sorghum landscape into a mosaic of traditional and enhanced traditional cultivars.

Plant color can be used as a marker gene to distinguish many enhanced maicillo cultivars from pure maicillo which have purple plant color. Plant color will be an important factor in measuring the introgression of enhanced germplasm into the maicillo population.

Control of Sorghum Downy Mildew

Method. Sorghum downy mildew is routinely monitored in Honduras by the NSP for occurrence and changes in virulence. Differential lines provided by Richard Frederiksen (TAM-124) are used to determine pathotype.

Discussion. To date, pathotype 1 is predominant throughout Honduras, with the exception of pathotype 5 which prevails at the Las Playitas Experiment Station near Comayagua. No changes in virulence were detected in 1990.

Sorghum downy mildew was observed for the first time in our sorghum hybrid tests at CEDA, Comayagua in 1990. Sureño at this site, which is resistant to P1, had 23% infection. This pathotype may be related to P5 which is nearby at Las Playitas (both Las Playitas and CEDA were once the same farm). Localization of P5 and wide dissemination of P1 suggests *P. sorghi* in Honduras has at least two different origins.

Sorghum downy mildew was observed for the first time at La Angostura, El Paraíso in a maize hybrid with 23% infection. Of the differentials planted at this location, Tx7078 was susceptible thus indicating P1 to be the predominant pathotype.

Downy mildew was also observed in 1991 one-half kilometer from the Las Acacias Experiment Station on the road to Danlí. This sighting was in a yellow seeded maize hybrid. The differentials were planted at this site but infection did not occur. This pathotype has not yet been identified.

Commercial Hybrid Performance Test

The notion that a butterfly beating its wings in China can change storm systems in the United States a month later exemplifies the "butterfly effect" in the science of chaos. The butterfly effect captures the concept that tiny differences in input can cause overwhelming differences in output. The commercial hybrid performance test, coordinated by Francisco Gomez, has been our butterfly effect. It has had enormous impact on increasing sorghum production with just a little well directed effort.

The success of the performance test comes from its ability to fulfill an array of individual needs. For seed companies, it is a way to put their hybrids in the public's eye. For seed vendors, it is an economical means to select the best hybrids for distribution. For farmers, it reduces the risks associated with accepting new hybrids and acquaints them with their distributors. And for public officials, it provides pertinent information such as performance data and resistance to downy mildew which is necessary for granting import permits.

The 1990 commercial hybrid performance test consisted of 20 hybrids and two varieties produced by eight companies: Agrigenetics, Cristiani Burkard, Dekalb-Pfizer Genetics, EAP, MNR, Northrup King, Pioneer International, and R.C. Young. The test was conducted in four sorghum producing areas: Choluteca, Comayagua, El Paraíso, and Olancho. Field days were held at Comayagua and Olancho to introduce producers to the high yield potential of hybrids, their respective distributors, and credit bank representatives. Results were published in the technical report *"Comportamiento de Sorgos Graníferos, 1990"* and 1,000 copies were distributed to seed distributors, extension agents, and public officials. Experimental yields attained 7.7 t/ha.

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Networking Activities

Inter-CRSP

A six member Inter-CRSP team visited Honduras 13-19 January 1991 to investigate and propose opportunities for Inter-CRSP research collaboration in Honduras that would lead to agricultural sustainability, natural resource conservation, and environmental quality. Honduras was one of four regions in the world (West Africa, Central America, Egypt and Indonesia) that the Inter-CRSP Council chose to evaluate. Team members were the three CRSP PIs currently stationed in Honduras; Dan Meckenstock, Sorghum/Millet CRSP (INTSORMIL); David Coddington, Pond Dynamics/Aquaculture CRSP; and Juan Rosas, Bean/Cowpea CRSP; plus Harold van Es, Soil Management CRSP (TropSoils), Cornell University; Manuel Murillo, Fisheries Stock Assessment CRSP, CIMAR, Costa Rica; and Manjeet Chinnan, Peanut CRSP, University of Georgia. Dan Meckenstock was the Inter-CRSP team leader.

The Inter-CRSP team visited officials and potential collaborators in USAID/H, LUPE, and EAP and made a field trip to Choluteca. Based on information collected, the team put together a concept paper which sets forth ideas of how all eight CRSPs could collaborate with five institutions in Honduras to develop a landscape approach to sustainable agriculture in southern Honduras. The concept paper focuses on three agroecosystems in southern Honduras: 1) low input hillside subsistence farming in dry tropical forest, 2) high input cash crops (primarily canteloup) on the coastal plain (tropical savanna), and 3) shrimp production in the Gulf of Fonseca and estuaries. The Honduras Concept Paper has received favorable reviews from USAID, Inter-CRSP Council, and MNR officials and is being used as a floor plan for building an Inter-CRSP initiative in Honduras. It will be published in the proceedings of the International Sorghum and Millet CRSP Conference held 8-12 July 1991 in Corpus Christi, Texas.

Picking-up on Inter-CRSPing, Marc Thompson, TAMU/TropSoils, traveled to Honduras 8-12 April 1991 and discussed with LUPE and AID/H officials the possibility of conducting his M.S. thesis research in Honduras. A study on the effect of land modification on soil productivity and crop performance on selected hillside farms in southern Honduras was conducted. Marc collected his research data in Honduras from mid-May through August (1991) and is analyzing results at TAMU. Local costs were paid by LUPE through a special services contract. Project TAM-131, which encouraged Marc's involvement, contributed the use of a pick-up. Although Marc's report is not completed, raw data suggest stone wall terraces increase maize yields 40-100 percent.

After Marc's arrival, a TropSoils team consisting of Roger Hanson, TropSoils Program Director, North Carolina State University; Tony Juo, TAMU; and Harold van Es, Cornell University, visited Honduras 16-26 June. This visit was to follow up the Inter-CRSP initiative. The Minister of MNR was visited as well as officials in LUPE, EAP and USAID/H. A field trip was made to southern Honduras to review the sites Marc had selected at Namasigüe, Soledad, and Texiguat. It was evident from this field trip that even though LUPE and its predecessor project had done a lot of work in building stone wall terraces, fields were not yet stabilized. Fertility gradients caused by leaching of nutrients towards the front of the terrace and washing out of stone walls were two examples seen by the team that indicate constraints must be overcome before a sustainable agriculture in southern Honduras can be achieved. These ideas were reported in a Soils Management concept paper for Honduras. The TropSoils team also decided to negotiate two MOUs, one with the EAP which has already been signed and the other with the MNR which is awaiting an opportune signature date.

Another spin-off from the January Inter-CRSP team visit was a Peanut CRSP decision to begin testing varieties in Honduras. Olin Smith, peanut breeder from TAMU, sent an

assortment of nine genotypes and Manjeet Chinnan of the University of Georgia sent two varieties—one from Jamaica and one from Belize for evaluation in southern Honduras. These 11 varieties, along with the local checks Gigante and Menudo, were planted by LUPE collaborators at sites near Texiguat and San Lucas. The purpose of this initial test was to determine adaptation requirements and farmer preferences. A third site at the EAP was included for the purpose of increasing seed for wider testing in 1992 and for establishing a peanut germplasm bank at the EAP.

Other Collaborating Scientists

Dr. Max Clegg, Agronomist, UNL-113, University of Nebraska, Department of Agronomy, Lincoln, NE 68583.

Dr. Richard Frederiksen, Pathologist, TAM-124, TAMU, Department of Plant Pathology and Microbiology, College Station, TX 77843.

Dr. Frank Gilstrap, Entomologist, TAM-125, TAMU, Department of Entomology, College Station, TX 77843.

Dr. Tony Juo, Soil Scientist, TropSoils, Department of Soil and Crop Sciences, College Station, TX 77843.

Dr. Gary Peterson, Sorghum Breeder, TAM-123, Texas A&M Agricultural Experiment Station, Lubbock, TX 79401.

Dr. Juan Rosas, Bean Breeder, Bean/Cowpea CRSP, EAP, Department of Agronomy, P.O.B. 93, Tegucigalpa, Honduras.

Dr. John Sanders, Economist, PRF-105, Department of Agricultural Economics, Purdue University, West Lafayette, IN 47907.

Dr. Olin Smith, Peanut Breeder, Peanut CRSP, Department of Soil and Crop Sciences, College Station, TX 77843.

Research Investigator Exchanges

Hector Portillo, a Honduran PhD degree candidate at Mississippi State University (MSU-105), worked from May through August, 1991 at the EAP on his dissertation. Hector collected data on oviposition preference and induction of *S. latifascia*, *Metaponpneumata rogenhoferi*, and *S. frugiperda* on sorghum, maize, and noncrop vegetation.

Julio Lopez, a Nicaraguan M.S. degree candidate at Mississippi State University (MSU-105), worked from mid-June through August, 1991 at the EAP on his thesis research. Julio analyzed data from his fall armyworm antibiosis studies conducted the previous year.

Dan Meckenstock traveled to Guayaquil, Ecuador, 12-19 Dec. 1990, to meet with FUNDAGRO representatives, Jorge Chang, Executive Director, Julio Chang, Program Director, and David Cardenas, sorghum specialist, on the promotion of sorghum in Ecuador. He reviewed ongoing sorghum extension work and suggested ideas in a written trip report for improving on-farm demonstrations.

Delroy Collins (TAM-124), Fred Miller (TAM-121), Gary Peterson (TAM-123), and Darrell Rosenow (TAM-122) visited Honduras 5-12 Dec. 1990. Field trips were made to four on-farm sites in Choluteca and to Comayagua, La Lujosa, Rapaco, and Zamorano to evaluate sorghum nurseries for disease resistance and adaptation. Team members also met with the Minister, Director of Agriculture, and Head of Agricultural Research of the MNR, as well as the Director of the EAP and USAID/H officials in the Office of Agriculture and Rural Development.

Alejandro Palma left the NSP at the EAP in December, 1990, to pursue a master of science degree in plant breeding at TAMU. Alejandro, a Honduran, is studying on a Fullbright-Laspau Scholarship. Fred Miller (TAM-121) is his committee chairman and is directing his research on head smut resistance.

Patricio Gutierrez also left the NSP at the EAP in December, 1990, to pursue a master of science degree in agronomy at the University of Nebraska with Max Clegg (UNL-113). Patricio, an Ecuadorean, is conducting his thesis on the physiologic response of landrace sorghum (maicillo) to light intensity and intercropping.

Edgar Salguero, a TAM-131 collaborator in Guatemala, rolled over from the public sector to the private sector in 1990 by resigning his position with ICTA as the head of the NSP.

Francisco Gómez attended the 17th Grain Sorghum Research and Utilization Conference in Lubbock, Texas, 21-23 Feb., 1991.

Francisco Gómez attended an EEC-IICA workshop in Tela, Honduras, 13-15 Nov., 1990, to participate in formulation of the EEC-IICA basic grains research support program in Honduras. Francisco is the EAP liaison.

Francisco Gómez and David Erazo attended the annual PCCMCA and CLAIS meeting in Panamá City, Panama, 18-22 Mar., 1991. Francisco is chairman of the CLAIS technical committee.

Germplasm and Research Information Exchange

Germplasm Exchange

Four kilos of DMV 198 (TAM428*Porvenir)-29-1, were sent to Michael Bannister for use in the Pan American Development Foundation's agroforestry project in Haiti. This enhanced maicillo variety performed well in alley cropping with leucaena in southern Honduras in 1990. Michael intends to measure its leaf water potential and yield at

different distances from trenched and nontrenched leucaena hedgerows and to compare its performance to the local landrace population—Pompom.

Nineteen elite enhanced maicillo lines and ten maicillo hybrids were sent to Christian Nwasike, sorghum breeder, at the Institute for Agricultural Research, Faculty of Agriculture, Samaru, Ahmandu Bello University, Zaria, northern Nigeria via David Andrews (UNL-115).

Four maicillos criollos and eight enhanced maicillo lines were sent to Patricio Gutierrez (UNL-113) at the University of Nebraska for studies in shade tolerance.

Twenty-eight elite enhanced maicillo 3-dwarf tan B-lines, some segregating for earliness and all believed to be dw_2, were sent to Fred Miller (TAM-121) for evaluation for disease resistance in south Texas.

Forty-four elite lines with resistance to pathotype 5 of *P. sorghi* were sent to Tom Hash at ICRISAT/CIMMYT, Mexico. Also, four lines with antibiosis to fall armyworm were sent to Tom for studies in resistance to African armyworm.

Seven sources of resistance to *P. sorghi*—IS 3443, IS 2132, IS 2204, IS 3547, IS 4696, IS 8185, and IS 8283—were sent to Darrell Rosenow (TAM-122) for inclusion in the TAMU/USDA sorghum conversion program. These lines were obtained from ICRISAT in 1987 via Richard Frederiksen (TAM-124) and were the best agronomic types with resistance to pathotype 5 in Las Playitas.

Five elite lines—including ISIAP Dorado, Sureño, and Tortillero—were sent to Manuel Torregroza, Colombian Institute of Agriculture (ICA), Bogota, Colombia.

Twenty lines were sent to Fred Miller (TAM-121) to be planted at the Agricultural Research Station at Beeville, Texas for exhibit during the International INTSORMIL Conference tour 11 July, 1991.

Ten (AF28*San Bernardo III) F_5 lines were sent to Billy Wiseman via Henry Pitre (MSU-105) for evaluation in laboratory feeding studies for resistance to fall armyworm. The objective of this study was to confirm combined sources of resistance selected by Julio Lopez after two years of field screening using a bazooka artificial inoculation technique in Honduras.

Sixty-five maicillo accessions were received from Fred Miller (TAM-121) for inclusion into the maicillo criollo working germplasm bank at the EAP. Many of these accessions originated in Honduras. Seven had been lost since their collection by a young Peace Corps volunteer named Dan Meckenstock in 1975 so we were happy to get these back into the national collection.

Tom Hash sent 17 maicillo populations from Panamá (2) and Nicaragua (15) for inclusion into the Honduran working maicillo criollo germplasm bank. He also sent 54 elite broomcorn varieties from the world collection. The goal for the broomcorn introductions is to release the best varieties with resistance to *Peronosclerospora sorghi*. Local broomcorn varieties have been implicated in the dissemination of SDM in Honduras, Guatemala, and El Salvador and resistant varieties are needed to nurture a fledgling broomcorn industry in Honduras.

Five enhanced maicillo varieties and hybrids were sent to Francisco Gomez for distribution in the 1991 on-farm demonstration plots:

Designation	Pedigree	Generation	Sites
DMV 179	(SPV346*Gigante Pavana)-1-1-2	F_9	16
DMV 194	(SC414-12*Plano de Namasigüe)-53	F_9	5
DMV 198	(TAM428*Porvenir)-29-1	F_{10}	8
H 1103	ATx631*(CS3541*Liberal)-6	F_1	5
H 1202	A(BTx623*Pespire)*DMV 194	F_1	5

Seed from DVM 198 was from the same 1989 source used in 1990.

Seed Production

Basic seed of the following cultivars was produced: Tx2784 (7 lbs), ATx623 (4.5 lbs), A Redlan (7 lbs), Sureño (4 lbs), BTx623 (6 lbs), B Redlan (4 lbs), DMV 179 (9 lbs), Tortillero (7 lbs), Tx430 (4.5 lbs) and ATx631*[(SC326* SC130)SB III]-12 F1 (300 lbs).

Assistance Given

An annual subscription to CAB International Sorghum and Millets Abstracts was donated to the EAP Library for student reference. Several reports and INTSORMIL student theses were sent to the libraries at the EAP and MNR in Honduras, and CATIE in Costa Rica.

A remote telephone operating on two FM channels with base station and two antennae on 75 ft towers was procured for the La Lujosa Experiment Station. This communications link will help coordinate on-farm and Inter-CRSP activities in Choluteca.

Graduate Student Research and Training

Miguel Talavera conducted his Ingeniero Agronomo thesis research at the EAP on the response of Sureño and ISIAP Dorado to nitrogen fertilizer. Dan Meckenstock was his major professor.

Edward Moncada conducted his Ingeniero Agronomo thesis research at the EAP under the direction of Dan Meckenstock. Edward screened 40 sorghum varieties for shade tolerance in maize intercropping. Some of his results are reported in the conservation and evaluation section of this report and Fig. 1.

Breeding Sorghum for Stability of Performance Using Tropical Germplasm

Project UNL-115
David J. Andrews
University of Nebraska

Principal Investigator

Mr. David J. Andrews, Sorghum/Millet Breeder, Department of Agronomy, University of Nebraska, Lincoln, NE 68583

Collaborating Scientists

Dr. Louis M. Mazhani, Sorghum and Millet Breeder, Department of Agricultural Research, P.O. Box 0033, Sebele, Botswana
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Dr. John Clark, Sorghum Breeder, INTSORMIL/INRAN, Niamey, Niger
Mr. Gilles Troucne, 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

The testing of lines derived from the U.S. x high yielding tropical food quality germplasm crossing program commenced in 1990.

Two types of seed parents have been developed—those taller, later types intended to serve the collaborative programs in developed countries, and those with phenotypes more suited to Midwest situations in the U.S. The best hybrids made in each group were competitive with their respective check hybrids. This indicates that the germplasm base has been widened for hybrid seed production, particularly where evident food grain quality is desired in the U.S. Further testing will be conducted to identify the best seed parents for release. A hybrid N122A x Tx430 (N122A was released earlier) gave yields in Nebraska 1990 state tests that equalled or were slightly better than the average of all commercial entries in three regions.

To determine easily measurable traits to use in a heritability study, a preliminary investigation of traits associated with seedlings was studied. Seedling height at 14 days was well correlated ($r^2 = 0.84$) with total shoot + root dry weight and can, therefore, be used to rapidly and nondestructively estimate vigor. Seed size was also associated with vigor, but the amount of unexplained variation may indicate that improvement in seedling vigor is possible independently of seed weight.

INTSORMIL hybrids, or hybrids made with INTSORMIL seed parents, continued to yield well in Senegal tests, especially in irrigated tests in the Senegal River Valley, where high yield conditions (6 t/ha in test) make hybrids attractive.

In Botswana, the breeding of seed parents has commenced after four years of selecting parental material in drought stress situations from segregating populations supplied in 1987.

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, the Botswana and the IRAT West African sorghum breeding programs were introduced and crossed with U.S. B-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 F_4/F_5, 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 non-restorers will be considered for producing new seed parents. Well adapted partial inbreds/lines are released as germplasm stocks/parental lines for use in the U.S. The introductions are also tested for per se performance and in hybrid combinations for possible dissemination in international nurseries. 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 postgraduate 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 preceding soybean crop), since most LDC's use little chemical fertilizer on dryland cereals but can use rotations with legumes.

Research Findings

Development of lines with evident food grain quality which can be used in crosses in collaborative programs and in the production of hybrid parents in the U.S. continued.

Fifty-seven new crosses were made, 21 of which were for the Senegal program. One thousand nine-hundred F_3-F_6 lines were evaluated with emphasis on grain size and evident food quality. Testcrosses were made in the F_4 or F_5 generation to characterize lines for fertility restoration and combining ability. Backcrossing continued on 450 lines to develop seed parents.

Sixty new seed parents were evaluated for combining ability in several tests. Twelve taller, later seed parents and two check seed parents designated for collaborative programs were evaluated with three common testers in a test that averaged 8980 kg/ha. Testcrosses with six seed parents gave yields equal to those of the best check and the Midwest hybrid check at 9100 kg/ha. The mean yield of the testcrosses with the best seed parent No. 8416, derived from the cross Tx623 X MB12, was 9700 kg/ha. Pollinator line M90378R gave the highest yielding testcross average.

Similarly, seed parents with phenotypes suitable for the Midwest were evaluated in testcrosses to either or both of two testers, Tx2721 and Tx433 which when crossed on to white seeded female lines produce white and red seeded testcrosses, respectively. The mean yield of this test was 6500 kg/ha. Four new seed parents developed from different crosses gave testcrosses which equalled the yield of the commercial check hybrid, P 8358, and exceeded the yield of DK 46 (Table 1). Where they were paired on the same seed parents, testcrosses with Tx2721 averaged 7490 kg/ha compared to those with Tx433 at 6010, however, the top testcross was with Tx433.

The results from these tests indicate that the crossing program between tropical food quality germplasm and leading U.S. seed parents has yielded new seed parents with food quality grain which are variously competitive with existing tropical and U.S. seed parents; and this serves to diversify the germplasm base for hybrid production. A limited amount of crossing has been done on the pollen parent side with a similar objective.

A small selection program has been conducted for very short-season sorghums at Sidney, NE, where lodging is important. The tan plant restorer line, 840089, appears to have good combining ability for yield and lodging resistance (Table 2).

Seed parent N122A was released earlier from this project and hybrid N122A x Tx430 was entered in the Nebraska state tests in 1990. In three principal dryland sorghum production areas, N122A x Tx430 equalled or was slightly better than the mean yield of all the commercial hybrids in test and equivalent or slightly better in lodging resistance (Table 3). As part of a project funded by the Nebraska Grain Sorghum Development, Utilization and Marketing board, to investigate the possibilities of producing shattercane-free sorghum seed, 700 kg of N122A seed was produced in Washington State.

Table 1. New sorghum seed parents test, Mead, NE, 1990.

Hybrid	Seed parent parentage	Yield (kg/ha)	Days to 50% bloom	Plant height (cm)	% lodge
699 x Tx433	(CK60 x IS89-2B)	8930	76	123	0
687 x Tx2721	(CK60 x D.465)	8190	71	118	1
614 x 7x2721	(Tx623 x MB12)	7640	81	160	13
599 x Tx2721	(Tx623 x MB12)	7610	75	128	0
712 x Tx433	(CK60 x IS892B)	7430	82	134	14
647 x Tx2721	(SRB x D346)	7450	76	115	0
P.8358	check	7320	75	123	0
528 x Tx2721	(SRB x D346)	7260	65	113	0
594 x Tx433	(Tx623 x MB9)	6950	81	130	2
528 x Tx433	(SRB x D346)	6850	73	120	6
673 x Tx433	(Tx623 x IS89-2B)	6820	80	124	1
559 x Tx2721	(SRB x Tx625)	6820	76	115	0
559 x Tx633	(Tx623 x MB12)	6660	77	123	4
647 x Tx633	(SRB x D346)	6400	80	133	18
773 x Tx433	(F1#8 x NQB1)	6330	76	130	4
762 x Tx433	(Tx623 x MB12)	6180	80	135	5
645 x Tx433	(SRB x D346)	6110	75	116	2
671 x Tx433	(Tx623 x IS89-2B)	5900	79	133	32
DK46	check	5820	77	130	0
542 x Tx433	(1181-1-3)	5780	75	133	24
614 x Tx433	(Tx623 x MB12)	5760	79	170	18
599 x Tx433	(SRB x Tx625)	5640	75	130	21
548 x Tx433	(1207-1-2)	5300	77	130	24
596 x Tx2721	(Tx623 x MB9)	5070	81	170	24
627 x Tx433	(SRB x US/R-50)	4760	75	120	18
687 x Tx433	(CK60 x D465)	4730	76	120	14
Mean		6506	76.4	129.7	10
LSD P = 0.05		1935	3.2	9.6	—

Table 2. Grain yields and other data for 10 out of 21 early maturing sorghum hybrids in the 1990 test at Sidney, NE

Variety	Yield (kg/ha)	Plant height (cm)	% lodging
455A x 467	4400	95	6
SRA x 840089	4330	105	7
SRS x 3115	4200	120	65
455A x 840089	4060	90	9
SRA x 2359	4050	108	17
N123A x 840080	3970	100	13
455A x 3082-1	3950	92	0
N123A x 3115	3920	119	55
455A x M317667	3870	97	13
F2233 (check)	3750	92	1
Mean (21 entries)	3730	93	32
LSD P = 0.05	660	7.0	15

Measurement of seedling vigor was examined in preparation for inheritance studies involving Naga White, a Ghanian variety with high vigor. Correlations among 22 lines that ranged from 12 to 60 mg dry weight per seedling at 14 days after planting showed that seedling height was a good nondestructive indicator of seedling weight ($r^2 = 0.84$) and, therefore, could be used instead of destroying and weighing seedlings. The relationship of seedling weight with initial seed weight was significant ($r^2 = 0.45$, Fig. 1) but the amount of unexplained variation indicated there may be opportunities to improve seedling vigor independently of seed weight.

Publications

Marinesco, O., P. J. Bramel-Cox, F. Zavala-Garcia, J. D. Eastin, D. J. Andrews, and M. D. Witt. 1991. The influence of environment and tester on combining ability of a sorghum population. 17th Bien. Grain Sorghum Res. & Utiliz. Conf., Lubbock, TX. (in press)

Zavala-Garcia, F., P. J. Bramel-Cox, J. D. Eastin, and D. J. Andrews. 1990. Stability analysis of S_1 population derived sorghum families. Agron. Abstr. p. 117.

Zavala-Garcia, F., O. Marinesco, P. J. Bramel-Cox, J. D. Eastin, D. J. Andrews, and M. D. Witt. 1991. Alternative selection schemes to improve the relative efficiency of selection over a range of environments. 17th Bien. Grain. Sorghum Res. & Utiliz. Conf., Lubbock, TX. (in press)

Networking Activities

Botswana (also see country report)

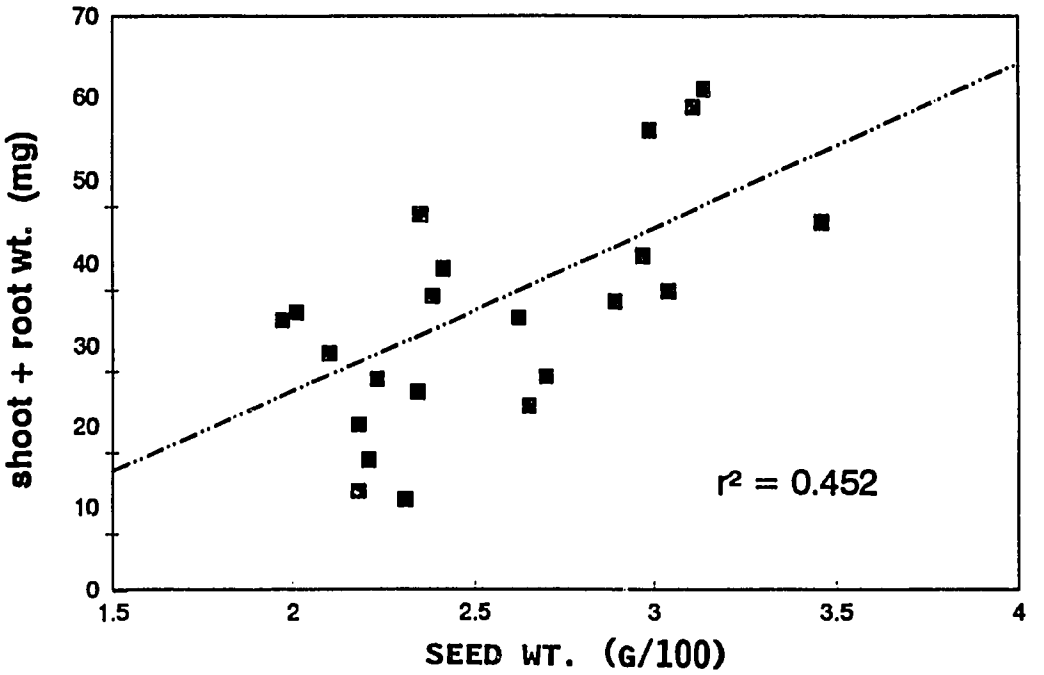
The objectives of the sorghum breeding program developed by the Department of Agricultural Research in Botswana include the development of adapted seed parents. Three phases of breeding material have been supplied (be-

Table 3. Performance of hybrid N122A x TX430 in Nebraska Dryland State Grain Sorghum Hybrid Tests in 1990[1].

	Southeast		Southwest		West Central	
	Gage + Saunders		(Frontier + Dundy)		(Lincoln + Perkins)	
	kg/ha	Lodge %	kg/ha	Lodge %	kg/ha	Lodge %
N122A x TX430	6210	2	4520	0	2700	0
Mean, all entries	5900	9	4140	0.4	2380	8
Range, all entries	6960-3890	1-38	5580-2450	0-6	3070-1070	0-74
No. of entries	67		44		24	
LSD 5%	890	11.9	850	NS	490	NS

[1] Source: 1990 Nebraska Grain Sorghum Hybrid Tests, IANR/ARD No. EC90-106, University of Nebraska-Lincoln.

Figure 1. Relationship of seed weight with shoot + root dry weight in 22 sorghum genotypes.



low) and PI visits have been timed so that material can be jointly evaluated and selected in the field.

1. Segregating material from the Nebraska introgression program:

After four generations of selection in severe drought stress conditions at Sebele, 24 lines derived from segregating populations supplied in 1987 were shown to be potential seed parents and the first backcrosses were made.

2. New Nebraska B-line nursery:

Fifty lines were selected from 65 tested. The same set was grown by Dr. Tunde Obilana at Matopos and testcrossed. The testcrosses will provide a basis for developing further A-lines in Botswana.

3. Parental line nursery:

A 24 entry nursery of hybrid parents from Nebraska provided six seed parents and one restorer (pollen parent) line with apparent potential to make hybrids in Botswana.

In each of the above sections, all of which deal with the selection and evaluation of seed parents, testcrosses will be conducted at an early stage to determine combining abilities. Where A-lines have not been developed, testcrosses will be accomplished by using A1 R lines sterilized in A2 or A3 cytoplasms—seed of which has been supplied. The development of seed parents of diverse genetic origins complements other components of the Botswana national program, which has produced adapted varieties and restorer lines.

Senegal (also see country report)

The UNL-115 activities in Senegal have served as a channel to introduce germplasm from other INTSORMIL projects (UNL-116, PRF-103, and TAM-121 and 122) to support the ISRA sorghum breeding program, which is working in three different production environments, rainfed and in two different seasons, summer and cool-winter, with irrigation in the Senegal River Valley. The research in irrigated sorghum production is in response to the Government of Senegal's objective to diversify crop production in the expanding irrigation area.

INTSORMIL's main contribution to the Senegal program has been in the rainfed program, of diversifying germplasm under development, now at the F_4-F_6 stage, from which new varieties will be developed. No introduced varieties have exceeded the yield of the improved variety, CE145-66, bred by ISRA but several hybrids using INTSORMIL seed parents (A35, A1, Avar, and AVG1) have produced substantially higher yields than the existing hybrids.

In the irrigated environments, again no introduced varieties could outyield the existing varieties which are capable of yielding 4 t/ha, however, INTSORMIL hybrids or hybrids made with INTSORMIL seed parents and ISRA pollinators were able to give substantially higher yields (20%) than the existing hybrids.

Travel

Senegal, October 15-24, reviewed collaborative sorghum research with ISRA scientists at Bambey and Senegal River Valley.

Mexico, January 25-February 14, San Juan de Abajo, Nayarit, winter nursery breeding operations.

Botswana, April 15-18, collaborative sorghum research with DAR scientists, Gaborone.

Lubbock, TX, February 15-19, SICNA conference.

Kansas City, MO, April 2-4, INTSORMIL EZC meeting.

Germplasm Exchange

Forty sorghum lines were sent to Botswana, 62 to Senegal, 76 to ICRISAT/India, 49 to ICRISAT/Mexico, 16 to Mali, 4 to France, and 2 each to India, Spain, and Yugoslavia.

One hundred and thirty-eight were received from ICRISAT/Mexico.

Breeding Pearl Millet for Stability Performance Using Tropical Germplasm

Project UNL-118
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Summary

The principal objectives of this project are to supply collaborating scientists at LDC locations with both useful genetic material and information on how best to select the required types of varieties or hybrids for grain production. In order to develop genetic material useful to most collaborating scientists in African situations, crosses must be made between their best varieties and elite U.S. lines and the early generation progeny used in the collaborative research.

The main emphasis in UNL-118 has been the continued development of elite inbred lines which will be used in custom crosses with host country varieties and also to produce parental lines and varieties for the U.S.

Eight hundred and ten F_2-F_7 lines from tropical x early parent crosses were evaluated and selfed in 1990, and backcrossing continued on 150 male sterile testcrosses and backcrosses. Selection was continued for lodging resistance, drought tolerance, and herbicide resistance. Backcrossing, selfing and hybrid production was continued on 170 elite lines sent to the winter nursery. Hybrids with 50 breeding lines from the ICRISAT Sahelien Center were evaluated.

Recurrent selection continued through modified mass selection on the Nebraska Dwarf Pearl Millet Population and on testing varieties EDS and MLS produced from it. The first of two years of testing of new populations to identify a new population for recurrent selection was conducted.

Postgraduate research was concluded on the comparison of parental tests to predict performance of synthetic varieties. Predictions of combining ability of parent lines used to make synthetic varieties based on either testcrosses or topcrosses to an unrelated tester largely agreed, but only testcrosses correctly predicted variety yields. Three further tests using mechanical mixtures of pro-hybrid seed and parental line seed to simulate selfing during seed production showed that even if 20% selfing occurred, it would have relatively little effect (-4 to -6%) on hybrid yields. Thus, the possibility of selfing during seed production should not prevent the use of these hybrids.

A pearl millet regional test containing grain hybrids from Georgia, Kansas (KSU-101) and Nebraska (UNL-118) plus sorghum checks was grown at six locations in the U.S. Top millet yields ranged from 3130 to 4950 kg/ha compared to sorghum at 2720 to 6090 kg/ha. Overall, the best pearl millet grain yields were 85% of sorghum and only where the season was short, as in late planting for a double crop after wheat in Indiana, and in North Dakota, did millet exceed sorghum. The results from three years of this test suggest there are at least two adaptation zones for grain pearl millet in the U.S.: 1) the Southwest, and 2) the MidWest/High Plains.

Trips were made to participate in breeding work in Botswana, Senegal, and Zimbabwe. In Botswana, with the assistance of SADCC/ICRISAT in Zimbabwe in providing off-season facilities, the second cycle of recurrent selection was completed in population Botswana Serere 6A. In Senegal, INTSORMIL dwarf varieties and hybrids averaged 5000 kg/ha in about 80 days in the Senegal River Valley under irrigation in the hot dry season—a period when little opportunity exists for other cereal cultivation.

Objectives, Production and Utilization Constraints

Objectives

The objectives of the breeding program, with slight modifications, remain as in previous years:

1. 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 (for maintenance of noninbred diversity see 2 below). 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 makes possible the identification of parents to make hybrids adapted to the U.S.

2. 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 selection will commence on one of the new populations when comparative population bulk tests are completed. Besides information, improved lines and varieties will result from this process.

3. Training LDC personnel in plant breeding and genetics is an important objective. Both of the above breeding approaches provide opportunities and material for postgraduate 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 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 they 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

1. Inbreds and partial inbreds are being produced from 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 were made in 1987. Producing satisfactory inbreds in pearl millet is a relatively protracted process, where, unless parents previously selected for good seed set have been used, considerable attrition during selection may be expected.

2. 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, 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, through the unequal competition between hybrid and inbred plants, the effects of any self pollination in the female parent. Pro-hybrids will also avoid the additional sensitivity to ergot commonly associated with hybrids made with any cms (male sterile) seed parent.

3. 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 conducted (using the NBDMP) and ways of using products of recurrent selection relevant to LDC conditions are tested. Equally transferable will be the methods and operational techniques being developed.

Research Findings

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 third year of the regional grain yield test was coordinated.

Pedigree Breeding

One hundred and fifteen new exotic x adapted and adapted x adapted F_1's were grown and 810 F_2 to F_6 lines evaluated. Selection emphasis continued on per se performance and lodging resistance for material intended for the U.S. This year the presence of chinch bugs and drought at flowering made possible some selection for those stresses. Screening was continued for the second year for Ramrod tolerance in a separate nursery.

Backcrossing continued in 150 lines for the development of seed parents in A_1 cytoplasm (Tift23A cytoplasm). A number of testcrosses of diverse West African stocks to the A_m cms system (developed with *Pennisetum monodii* cytoplasm) revealed several sources of fertility restoration which are scarce in this system. Elite lines, which could not be sterilized in the A_1 system, were also testcrossed to the A_m source.

Recurrent Selection

Recurrent selection continued on the Nebraska Dwarf Pearl Millet Population (NBDMP) and tests were commenced to identify a second population for recurrent selection.

The third cycle of selection on spaced plant modified mass selection on NBDMP was completed. The selection differential on a family basis was 17% more than overall mean of 1530 kg/ha, indicating the continuing presence of adequate genetic variation. In this population, grain yield was strongly correlated with head size, but weakly correlated with plant height, heads per plant and bloom date.

In order to identify which new population would be best for recurrent selection, eleven new populations were compared to the NBDMP reference population both for their performance per se and in crosses to a common tester, KS68A. The test was grown at three locations. The topcross hybrids on average gave 15% more yield than their variety parents. Two of the highest yielding populations, the stiff stalk population (SSP) and the early dwarf synthetic (EDS) also gave the best hybrids, which showed 20% heterosis over the variety parent. The test will be repeated a further year.

Hybrids

Two types of hybrid tests were conducted. The conventional type, where hybrids are made with cms (male sterile) seed parents, and pro-hybrids made as described above.

Two new seed parents and KS68A were evaluated in the line x tester trial using six pollen parents. Average yields of hybrids with seed parents 414A and 443A were significantly higher than those with 68A (Table 1). Among the pollen parents, hybrids with 0206 were significantly better than the hybrid averages with other pollen parents (Table 2). The best individual hybrid was 443A x 0206, as expected, yielding

Table 1. Mean grain yields, days to bloom, plant heights, and percent lodging of hybrids with three seed parents averaged over six pollen parents (Exp. 90-61).

Seed parent	Grain yield (kg/ha)	Days to 50% bloom	Plant height (cm)	Lodging %
443A	3600	67	82	12
414A	3580	71	89	12
2068A	3170	68	86	10
LSD P = 0.05	334	1.5	4.1	NS

Table 2. Mean grain yields, days to bloom, plant heights, and percent lodging of hybrids with six pollen parents averaged over three seed parents (Exp. 90-61).

Pollen parent	Grain yield (kg/ha)	Days to 50% bloom	Plant height (cm)	Lodging %
0206	4320	67	95	7
MLS	3600	65	92	12
0235	3570	65	84	6
0249	3370	72	77	0
0223	2920	66	88	23
0183	2830	75	80	37
LSD P=0.05	703	3.9	14.5	NS
MLS (check variety	3160	57	95	37

Table 3. Mean grain yields (kg/ha^{-1}) in 1990 Pearl Millet Regional Grain Yield Trial.

Entry	GEORGIA Tifton	INDIANA Purdue	KANSAS Hays	NEBRASKA Mead	NEBRASKA Sidney	NORTH DAKOTA Carrington
MLS variety	2640	2990	2340	3120	3540	3090
68A x MLS[1]	2300	3790	3120	4130	4440	3670
EDS variety	2600	3120	2190	2360	3320	2580
68A x EDS[1]	2980	3780	3070	3610	4360	3670
90PV0046 x 0049[2]	2640	3060	1920	2670	3190	1510
90PV0003 x 0005[2]	4790	2570	2460	4010	3480	790
90PV0016 x 0017[2]	3690	2980	2320	2900	2560	2730
90PV0016 x 0015[2]	3220	3330	2840	4050	3770	2190
H23DA1E x 77[3]	2950	1930	1260	3720	2510	810
RR23DAE x 77[3]	4950	2320	1180	4020	2590	1380
1163 x 86-7907[3]	2670	3960	3130	3330	3670	3810
2068 x 87-8025[3]	4610	2930	1990	3830	3030	2220
DK 39 sorghum[3]	5650	—	4860	6090	4170	1210
F 2233 sorghum[3]	5840	—	3660	5660	5220	2720
Mean	3680	3060	2590	3820	3560	2310
CV	24	20	13	14	13	28
LSD 0.05	1509	1064	551	934	787	1088

[1] cms topcross
[2] pro-hybrid single cross
[3] cms single cross

4440 kg/ha, 40% more than the variety check MLS. Similarly a number of new pollen (male) parents were evaluated in several tests on existing seed parents, and four showing both complete restoration and good combining ability were identified.

Several tests were grown to evaluate pro-hybrids. In each of these, several pro-hybrids were found which equalled or were numerically higher (but not significantly different) in yield than the conventional hybrid checks (see also 1990 regional test results, Table 3). These pro-hybrids, however, were in general 15-20 cm shorter and superior in lodging resistance and, with few exceptions, showed no weakness in seed setting. The parent lines used to create the SSP population produced the best pro-hybrids.

Research on the effect on hybrid performance of potential selfing in the "seed parent" during pro-hybrid seed production continued. A total of five tests on four dwarf hybrids over two years have now been completed, the hybrids used being both of the topcross and single-cross type. In three out of the four hybrids, the yield reduction due to the mechanical inclusion of 20% selfed parent seed was insignificant compared to the performance of the pure hybrid. In numerical terms, the reduction was 4 to 6%. These results very closely substantiate those reported in 1990 (Annual Report, page 116 and 117, Figures 1a and 1b). Only in one hybrid in 1990 did the 80:20 hybrid/parent seed mixture show a significant yield reduction, however, this seemed an anomaly as the mixture with 60:40 hybrid:parent seed mixture gave a higher yield, which was not significantly different (actually 13.4% less) than the pure hybrid.

The overall implications of these results are that research on identifying combinations, and on the practicalities of seed production can proceed since a) a level of 20% selfing in the seed parent would not be expected, and b) the results were obtained on dwarf hybrids which are expected to be more sensitive to competition.

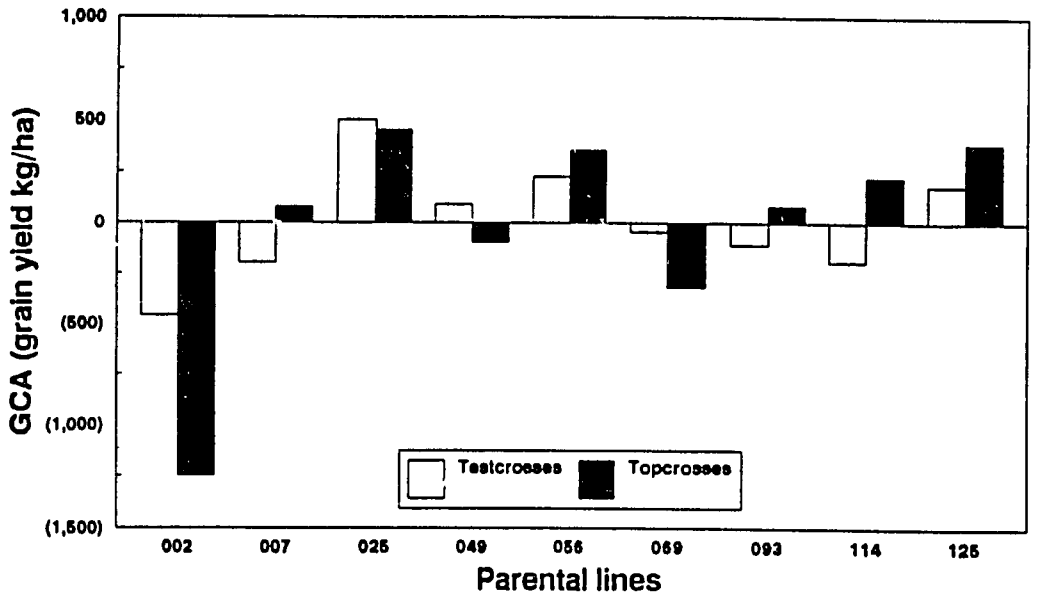
Research on hybrids of this type is particularly directed to developing countries in Africa, where varieties are the main products of breeding. By simply identifying a shorter statured, slightly earlier line or variety, with good combining ability, which then becomes the "seed parent", the benefits of heterosis can be simply added to the breeding program by making a pro-hybrid between the "seed parent" and the variety product. High heterosis levels between adapted cultivars in Africa have been recorded several times in the past and recently by Dr. B. Oendeba in Niger who reported heterosis levels over the high parent of 25 to 81%. Such pro-hybrids avoid the lengthy development period of conventional hybrids, and retain all the advantages of adapted varieties.

Varieties

Dr. Rowland Chirwa in his Ph.D. dissertation studied a third important use of lines emerging from a breeding program—how to make the best synthetic varieties. He used *ex poste* situations by taking three existing varieties and examining which method of parental evaluation gave the best estimation of the actual variety yields. The three varieties were composed of five, seven, and nine parents, respectively.

Each set of parental lines was evaluated for general combining ability in two ways: a) through a sample of paired testcrosses in a central circulant partial diallel, and b) through topcrosses using a common unrelated variety tester.

Figure 1. Comparison of gca estimates from testcrosses and topcrosses in dwarf variety.



The correlation between the general combining ability values estimated through testcrosses and those estimated through topcrosses was significantly positive (r = 0.74, Fig. 1).

Yield for each of all possible single-cross hybrids in each set was predicted by summing the actual mean yield of the F_1's and the general combining abilities of the two parents involved in the cross. Predicted mean yields of the F_1's were equal to the actual mean yield of the F_1's. The mean yields of the F_1's and the mean per se yield of the parental lines were used to predict yields of synthetic varieties. Two formulae: 1) Wright's, and 2) Busbice's were used to predict yields of synthetic varieties.

Predicted yields of the synthetic varieties using Wright's and Busbice's formulae were similar. Predicted synthetic variety yields using combining abilities derived from topcrosses were 12% higher than predicted yields using testcrosses. Comparison of predicted and actual yield of Syn 3 showed that predictions using testcrosses were similar to the actual yield and those using topcrosses were 17% higher than the actual yield.

Although topcrosses and testcrosses are both useful in selecting parental lines for a synthetic variety, based on general combining ability, the use of heterosis derived from topcross F_1's to predict yield of a synthetic variety, either through Wright's or Busbice's formula is inappropriate. Only testcrosses provide information on average heterosis that is comparable to the expected heterosis in a synthetic variety.

The proportion of selfing in a pearl millet population influences the predictions. Estimates at 20% selfing seem to be close to the actual performance. Average synthetic variety yields were 20% over the mean yield of the parental lines, showing a considerable amount of heterosis. The highest yielding synthetic variety was made from a set of parental lines that had a high mean yield and a high mean yield of the F_1's. The parental worth for yield is shown to be positively correlated to that for plant height. Plant height and days to bloom in synthetic varieties can be predicted in the same way yield is predicted.

Regional Test

Pearl millet regional grain yield tests evaluating initial experimental hybrids and other entries from ARS/USDA, Tifton, GA; KSU, Hays, KS; and UNL, Lincoln, NE; have been grown cooperatively at 5 locations in the U.S. since 1988. The 1990 results shown in Table 3 are typical. Across locations the best pearl millet hybrids averaged 85% of the grain yield of the sorghum hybrid checks. Only where the season was short as in North Dakota, and in double cropping after wheat in Indiana (sorghum failed to mature) did millet yields exceed sorghum. Considerations of maturity, height, lodging, leaf disease occurrence and relative genotype yields suggest that there are at least two contrasting adaptation areas within the region in which the tests have been conducted. These are the Midwest/High Plains and the Southeast. Cultivars from the Southeast are too late maturing in the Midwest (will mature in Kansas but require more moisture), tend to be tall and have little resistance to lodging following frost. Conversely, Midwest cultivars are too early in the South, and have little resistance to leaf diseases.

Publications and Presentations

Publications

Andrews, D. J., and J. F. Rajewski. 1990. 1988 and 1989 pearl millet regional grain yield tests. Dep. of Agronomy, UN-L.

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Presentations

Andrews, D. J. 1991. Principles for breeding small millets. Second International Workshop on Small Millets. SADCC/ICRISAT Bulawayo, Zimbabwe, April 8-12, 1991.

Networking Activities

Botswana

The second cycle of recurrent selection in the Botswana Serere 6A composite was completed at Sebele using 195 half-sib progenies generated by Dr. Emmanuel Monyo in the SADCC/ICRISAT off-season nursery in Zimbabwe. The 46 progenies identified for recombination showed a selection differential of 7.6% for grain yield.

An experimental variety of six elite progenies was identified that had a selection differential of 16%. The recombinations to create cycle 2 of the composite and progeny for further testing, and the experimental variety will again be completed in the off-season by SADCC/ICRISAT. These will be evaluated in 1991/92 against the original composite, and exotic varieties which have performed well in tests in Botswana. The decision to proceed with further cycles of selection within the Botswana Serere 6A composite will depend on results from these tests.

Senegal (see also Senegal Country Report)

The collaborative program between INTSORMIL and the Institut Senegalais de Recherche Agricoles (ISRA) is funded by the Senegal Agricultural Research II Project from AID/Dakar administered by Michigan State University.

The program has consisted of supplying and working with cooperating scientists on segregating populations for the rainfed program at the National Research Center at Bambey and hybrids and varieties for testing under irrigated conditions in the Senegal River Valley in both the summer (planting in July) and dry hot off-season (planting in January). The Government of Senegal had requested information on the performance of crops other than rice to diversify cropping within the recently enlarged irrigation command area. Compared to sorghum, pearl millet experimental grain yields on the heavy clay soils have been low, 1500-2500 kg/ha in either the summer or the hot dry season with no difference in yield between tall and dwarf cultivars. This year pearl millet off-season agronomy and variety tests were moved to a sandy soil site at Thiago and substantially higher yields were recorded. Average grain yields in the agronomy tests were 4000 kg/ha, 3500 ha in the tall variety trial, and 5000 kg/ha in the dwarf hybrid/variety test (see Table 3 in the Senegal Country Report). The highest yields came from dwarf INTSORMIL varieties and hybrids which matured in as little as 75 days. No disease or pests were recorded and it is likely in this season that disease pressures will remain low. Palatability tests conducted on two representatives of the dwarf cultivars determined that grain of these types was acceptable compared to the local variety. This collaborative program has provided data that will enable studies on the economic feasibility of producing pearl millet on the Senegal River Valley in the hot dry season when there is little opportunity for other cereal cropping.

Travel

Senegal, October 15-24, reviewed collaborative pearl millet research with ISRA scientists at Bambey and Senegal River Valley in company of Dr. Claflin.

Mexico, January 25-February 14, San Juan de Abajo Nayarit, winter nursery operations.

Zimbabwe, April 6-14, Second International Workshop on Small Millets and sorghum and millet research.

Botswana, April 15-18, collaborative pearl millet research, DAR, Gaborone.

Germplasm Exchange

Twenty-two germplasms were received from ICRISAT/Mexico, six from KSU-Hays, and three from Tifton, Georgia.

Eighty-five lines and populations were sent to Senegal, 20 to ICRISAT/India, 8 to KSU-Hays, and 10 to Tifton, Georgia.

Crop Utilization and Marketing

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Chemical and Physical Aspects of Food and Nutritional Quality of Sorghum

Project PRF-103B
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Summary

This project was involved in collaborative research with INRAN in Niger and ARC in Sudan during the past year. Consumer test panels were carried out in Niger to identify the desirable food quality criteria for the thick sorghum porridge, tuwo. Sixteen varieties which varied in grain hardness and endosperm color were evaluated. Results showed that texture was the most important attribute affecting acceptability of tuwo. Several laboratory methods for evaluating texture are being tested for their correlation to the consumer evaluation results. Studies to formulate a starter culture for the Sudanese flat bread, kisra, have continued. Seven bacteria, two yeasts, and four molds have been identified in the traditional fermentations. We have also identified the end-products of these microorganisms which contribute to the unique taste of kisra. They include lactic acid, acetic acid, propionic acid, isobutyric acid, ethanol, propyl acetate, and 2-furanmethanol. Consumer test panels are being carried out in Sudan to evaluate kisra produced from sorghum fermented by several developed starter cultures.

Studies on the endosperm proteins of sorghum are bringing us closer to an understanding of what effect they have on grain hardness and protein digestibility. Kafirins are the storage proteins of sorghum and are found in protein bodies in the seed endosperm. They have been divided into alpha-, beta-, and gamma-kafirins according to differences in molecular weight, solubility, and structure. Transmission electron microscopy showed that protein bodies are composed of dark and light staining regions and that protein bodies in the peripheral endosperm differ from protein bodies in the central endosperm. We have used immunocytochemical techniques to determine how alpha-, beta-, and gamma-kafirins are organized in the protein body. We found that these different kafirin types appear to be laid down in an organized fashion, and that a higher proportion of the cysteine-rich, beta- and gamma-kafirins are laid down in the central endosperm protein bodies than in protein bodies of the vitreous endosperm. Biochemical studies to determine the differences in the protein composition of the vitreous and opaque endosperm of mature grain were also carried out. We found that vitreous endosperm contained more protein than the opaque endosperm. The kafirin fraction of the opaque endosperm had a higher percentage of beta- and gamma-kafirin and a lower percentage of alpha-kafirin compared to the vitreous endosperm. In addition, the albumins/globulin content was higher in opaque endosperm than in the vitreous endosperm and it contained some higher molecular weight polypeptides not seen in the same fraction of vitreous endosperm. Glutelin proteins in the two regions were very similar both quantitatively and qualitatively. Possible implications of these new findings on sorghum grain hardness are discussed.

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 affect 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. The overall objective of this project is to develop a better understanding of the structural and chemical components of the grain that affect the food and nutritional quality of sorghum. We then hope to apply this knowledge to develop useful methodologies for screening sorghum germplasm for end-use quality and to develop processing techniques to make the grain more nutritious.

Research Approach and Project Output

Tuwo Quality

In Niger, sorghum is commonly consumed in a thick porridge called tuwo. Currently improved sorghum cultivars developed by Nigerien breeders are being evaluated for food quality by preparing the local porridge from sorghum flour and carrying out consumer test panels for sensory evaluation. These food quality trials provide useful data to breeders, however, they are time consuming, expensive, and limit the number of cultivars that can be evaluated. In addition, the food quality trials require large quantities of grain which is only available from advanced breeding material. Previous studies using consumer test panels have determined that consumer acceptability of tuwo depends not only on color and taste but also on texture. Tuwo which is firm and does not stick to the fingers or roof of the mouth is preferred. A number of laboratory procedures have been developed for measuring thick porridge texture. All of these procedures were developed to provide breeders with an estimate of the food quality of early generation material. However, none of these laboratory procedures have been compared with consumer test panel results. The purpose of this study is to identify desirable food quality criteria for tuwo and then to develop laboratory methods for evaluating food quality.

Consumer test panels were carried out at two locations in Niger, West Africa. A total of 16 varieties including both local varieties and new sorghum cultivars were grown in Niger during the 1990 crop season. These varieties varied in grain hardness and endosperm color. Grain was decorticated and prepared into tuwo by local women each day. Twenty-seven panelists from Maradi town and 30 panelists from Kollo town were composed of men and women who regularly consumed tuwo in their respective households. Each of the 57 panel members evaluated the appearance, aroma, color, taste, firmness, cohesiveness, stickiness, and overall texture of the tuwo by completing a questionnaire. The attributes were evaluated along with the acceptability of the products using an anchored 0 to 100 point scale. The sensory data were analyzed using the Analysis of Variance (ANOVA), Pearson correlation analysis and linear regression. Slopes were obtained by plotting acceptance against attribute liking. Slope values indicate the impact of an attribute on overall acceptance. Low values indicate that a wide range of variation in the attribute is acceptable to the consumer, high values indicate that small changes in the attribute greatly affect consumer acceptability.

Table 1 shows the consumer test panel overall means and reliability of mean rating for each of the attributes tested. The reliability values, which measure the ability of the consumers to assess differences between varieties, were high for all attributes except chewiness.

The linear correlations of overall acceptance with attributes and the slopes of the regression lines made it possible to rank the sensory attributes in terms of the impact on acceptance. Although appearance and color are highly correlated with acceptability as indicated by their high correlation coefficients, there is a wide range of appearances and colors which are acceptable (Table 2). This study shows that texture and more specifically cohesiveness, stickiness, and melting are the most important attributes affecting accept-

Table 1. Partial database for overall means of tuwo sensory attribute liking and reliability of means rating[a].

	Best 3 samples			Worst 3 samples			
Attribute	MDW (1)	Sepon 82 (2)	UV1002 (3)	BG (12)	El Mota (13)	HD-1 (14)	Reliability of mean rating
Overall	87	77	68	34	27	14	0.98
Color	86	83	69	34	17	8	0.99
Appearance of exterior	82	82	65	22	21	9	0.99
Appearance of interior	82	73	61	25	20	14	0.98
Aroma	68	68	60	39	35	24	0.94
Taste	70	70	65	44	36	28	0.94
Texture (overall)	73	76	63	38	31	28	0.96
Cohesiveness	67	59	55	36	34	32	0.91
Stickiness (tongue)	67	62	55	46	43	38	0.81
Firmness	73	56	57	44	51	41	0.89
Melting	63	64	60	44	45	47	0.82
Chewiness	53	51	47	50	50	56	0.33
Stickiness (fingers)	58	45	48	27	30	33	0.83

[a]Means of rating data from 57 consumers (ages 23 to 48).

Table 2. Correlation coefficients and slopes of acceptance versus attribute liking.

Attribute	r value	slope
Color	.96	0.77
Appearance of interior	.98	0.94
Appearance of exterior	.97	0.83
Aroma	.97	1.53
Taste	.94	1.59
Texture (overall)	.97	1.38
Cohesiveness	.97	2.00
Stickiness (tongue)	.90	2.55
Firmness	.90	2.55
Melting	.81	2.38
Chewiness	-.13	-0.65
Stickiness (fingers)	.74	1.87

ability. Small changes in these textural qualities greatly affect the acceptability of tuwo.

Work is presently in progress to compare consumer evaluation of tuwo firmness and stickiness to several laboratory methods for texture evaluation. Results from this work will show which of the laboratory procedures can best predict consumer acceptance.

Sudanese Sorghum Fermentation

Several studies involving human, animal, and *in vitro* pepsin digestibility showed that cooked sorghum has low protein digestibility compared to other cereals. Both *in vitro* and *in vivo* digestibility studies have shown that fermentation prior to cooking improves sorghum digestibility. Fermentation is commonly used in Sudan for making sorghum food products such as kisra, nasha, aceda, and beverages. Kisra, a flat bread, constitutes a major part of the dietary staple in Sudan. It's preparation, however, is labor intensive and time consuming which has led to an increase in consumption of commercially baked bread made from imported wheat. Traditionally, the naturally occurring microorganisms in sorghum flour are utilized in fermentations, however, the formulation of a kisra starter culture would enable commercial bakeries to prepare and market kisra.

To formulate a starter culture, the microorganisms which are present in traditional fermentations were isolated and the end products they produced were identified. Sorghum flour of the Dahar variety was obtained from Sudan. The flour was mixed with water in 1:2 (wt/vol) ratio and fermented at 30°C for 24h. The bacterial populations increased with fermentation time and reached a plateau at approximately 18h. At the end of 24h, sorghum batter pH dropped from 5.95 to 3.95 and had a lactic acid content of 0.80%. The microbial population during the 24h period of fermentation consisted of bacteria (*Pediococcus netosaceus, Lactobacillus confusus, L. brevis, L.* sp., *Erwinia ananas, Klebsiella pneumoniae*, and *Enterobacter cloacae*); yeasts (*Candida intermedia* and *Debaryomyces hansenii*) and molds (*Aspergillus* sp., *Penicillium* sp., *Fusarium* sp., and *Rhizopus* sp.). *Pediococcus pentosaceus* was the dominant microorganism at the end of the 24h fermentation. When three consecutive fermentations using an inoculum from the previous fermentation were carried out, the bacterial population increased and then plateaued at 9h. The lactic acid content and pH were 0.90% and 3.86, respectively, by 9h and 1.45% and 3.58, respectively, by 24h. The microbial populations in these fermentations were dominated by *P. pentosaceus.*

The end products produced during the sorghum flour fermentation were lactic acid, acetic acid, propionic acid, isobutyric acid, ethanol, propyl acetate, and 2-furanmethanol. Lactic and acetic acids were the major organic acids produced. The total water-soluble sugars of sorghum flour consisted of a high percent of sucrose and maltose and lesser amounts of fructose and glucose. As the fermentation progressed, the amounts and type of water soluble sugar changed. There was an increase in glucose and maltose, and a decrease in the concentration of sucrose during fermentation. In sorghum flour that was fermented by using an inoculum from the previous fermentation, sucrose, glucose and fructose were not detectable.

Developed starter cultures that consist of combinations of lactic acid bacteria with different proportions of hetero- to homolactics or combinations of lactic acid bacteria and yeasts did not produce the same amount or types of end products that were produced during the traditional fermentation of sorghum flour. Sensory evaluation of kisra produced from sorghum fermented by these developed starter cultures remained the key to selecting combinations for formulating a starter culture suitable for making kisra.

Localization of alpha-, beta-, and gamma-kafirin

Kafirins are the storage proteins of sorghum and are found in protein bodies in seed endosperm. They are divided into alpha-kafirins (Mr 25,000 and 23,000), beta-kafirins (Mr 20,000, 18,000, and 16,000), and gamma-kafirins (Mr 28,000) according to difference in molecular weight, solubility, and structure. They also differ in amino acid composition with both beta- and gamma-kafirins being relatively high in cysteine. Although immunocytochemistry has been used to show that kafirins are localized in protein bodies, alpha-, beta-, and gamma-kafirins have not been individually localized. Since they differ in structure and amino acid composition, such knowledge will provide further information about how protein bodies are organized. It is not known whether these kafirins are laid down randomly in the protein body or in an organized fashion that would account for the concentric rings and dark inclusions. In addition, it has not been determined whether protein bodies throughout the sorghum endosperm vary in composition.

Immunocytochemical methods were used to determine the organization of kafirins within the protein body and the distribution of kafirins throughout the endosperm. To provide a more complete picture of protein body structure and how it differs throughout the endosperm, we studied both peripheral and central endosperm regions. Sorghum samples (P721N) were collected 20 days after half bloom. Alpha-, beta-, and gamma-kafirins were purified as de-

scribed in the 1990 INTSORMIL Annual Report. Purified kafirins were injected into rabbits for antibody production. After six weeks, the rabbits were sacrificed and antiserum was collected. Western blot analysis showed that alpha-kafirin antibodies reacted with Mr 25,000 and 23,000 polypeptides; beta-kafirin antibodies reacted with Mr 20,000, 18,000, and 16,000 polypeptides; and gamma-kafirin antibodies reacted with Mr 28,000 with essentially no crossreactivity. Lack of crossreactivity with other polypeptides shows that they are good probes for localization.

Transmission electron microscopy showed that protein bodies in the peripheral endosperm were spheroid with concentric rings and few darkly stained inclusions. In contrast, protein bodies of the central endosperm were irregularly shaped with a higher proportion of darkly stained material. Our results show that the light staining regions of the protein bodies are composed predominantly of alpha-kafirin with minor amounts of beta- and gamma-kafirin. The darkly stained inclusions contain some alpha-kafirin but are predominantly beta- and gamma-kafirins. Since beta- and gamma-kafirins are both relatively high in cysteine and can readily form disulfide bonds, they may exist in the protein bodies as crosslinked proteins. Immunocytochemical staining showed that the protein bodies of the peripheral endosperm are predominantly alpha-kafirin with minor portions of beta- and gamma-kafirin. The central endosperm protein bodies are also predominantly alpha-kafirin, but have a higher proportion of beta-kafirin and gamma-kafirin. Reasons for structural differences observed between peripheral and central endosperm protein bodies are not yet known. Further studies examining sorghum protein bodies at different stages of development will be necessary before the compositional differences between peripheral and central endosperm protein bodies can be fully understood.

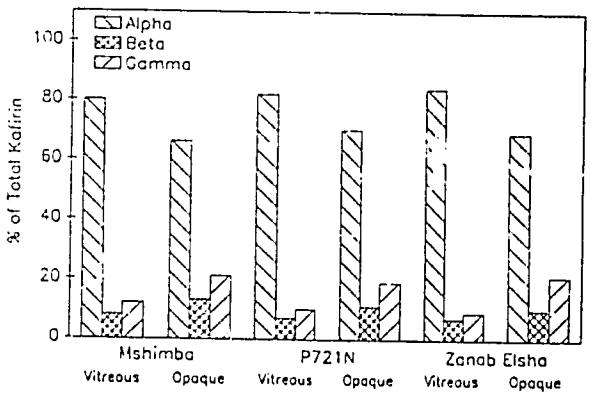
Protein Composition of Vitreous and Opaque Endosperm

Sorghum hardness affects milling and storage quality of sorghum grain as well as keeping quality and texture of sorghum food products. Sorghum varieties differ in the ratio of vitreous to opaque endosperm and there is a significant correlation between percent vitreous endosperm (% vitreousness) and grain hardness as measured by mechanical means. Beyond the relationship between grain hardness and endosperm structure, little is known about the chemical basis of grain hardness. Most of the current research focuses on the protein components of the endosperm. Two theories exist. One suggests that kafirins may be responsible for grain hardness since harder, more vitreous sorghum varieties generally have a higher kafirin content than soft, opaque varieties and also because adding kafirin extract increases the breaking strength of starch pellets. The other theory attributes sorghum hardness to the formation of a continuous glutelin protein matrix in the vitreous portion of the endosperm.

Determining differences in the protein composition of the vitreous and opaque endosperm may lead to a better understanding of the biochemical basis of sorghum hardness. Three sorghum varieties with hard (Mshimba), intermediate (P721N), and soft (Zanab elsha) endosperm textures were selected. Grain was mechanically decorticated and hand degermed. From the resultant endosperm pieces, opaque endosperm was manually separated from vitreous endosperm using a Dremel adjustable speed drill. Landry-Moureaux type fractionation followed by SDS-PAGE analysis was used to determine the qualitative and quantitative differences in albumins/globulins, prolamins (kafirins), and glutelin protein fraction between the vitreous and opaque regions of the sorghum endosperm. To look more closely at the kafirin fraction, enzyme-linked-immunosorbent-assays (ELISAs) were developed to quantitate the relative proportions of alpha-, beta-, and gamma-kafirin in both the vitreous and opaque regions.

Vitreous endosperm contained 1.5-2.0% more protein than opaque endosperm of the same variety. This was due to the higher prolamin content of vitreous endosperm. Both the SDS-PAGE gel of a total kafirin extract and data from the ELISAs indicate that the kafirin fraction of opaque endosperm has a higher percentage of beta- and gamma-kafirin and a lower percentage of alpha-kafirin compared to the kafirin fraction of vitreous endosperm (Figure 1). These results suggest as previously reported that protein bodies of the vitreous endosperm differ in composition from those of the opaque endosperm. The albumin/globulin content was higher in opaque endosperm than in the vitreous endosperm and it contained some higher molecular weight polypeptides (Mr 44,000 and 38,000) not seen in the same fraction of the vitreous endosperm. Vitreous endosperm contained some lower molecular weight polypeptides (Mr 18,000 and 15,000) which did not appear in the opaque endosperm extracts. Glutelin proteins in the two regions were very similar both quantitatively and qualitatively except for a Mr

Figure 1. Alpha-kafirin, beta-kafirin and gamma-kafirin distribution in vitreous and opaque endosperms of Mshimba, P721N, and Zanab elsha sorghum.



60,000 polypeptide present in the opaque endosperm which was either not present or present in very low amounts in the vitreous endosperm.

In sorghum, it is suggested that differences in hardness between vitreous and opaque endosperms are due to the formation of a continuous protein matrix in vitreous endosperm which entraps protein bodies and starch granules. This protein matrix is derived from deteriorated cytoplasm and is composed of glutelin, and albumins and globulins type protein. Therefore, it may be expected that the total amount of albumin, globulin and glutelin proteins would be higher in vitreous endosperm than in the opaque endosperm. However, as reported, the amount of glutelin protein per gram of endosperm was the same in both vitreous and opaque endosperm while the amount of albumin and globulin was actually higher in opaque endosperm. These findings may not be contradictory to the continuous matrix theory. Opaque endosperm has much less kafirin protein than the vitreous endosperm, indicating a reduction in the amount of protein bodies in this area. It is possible that in the opaque endosperm the cytoplasmic proteins deteriorate and form disulfide bonds similar to those of the vitreous endosperm. The opaque endosperm, however, lacks the protein bodies and tightly packed starch granules which would prevent this protein from being compressed and formed into thin sheets giving it the ability to entrap or adhere to starch granules and protein bodies.

If or how the noted qualitative differences in albumin and globulin content or protein body composition may affect this adhesion between endosperm components is unclear. However, if the extracted albumins and globulins are from the protein matrix then it is possible that the presence or absence of a particular protein from the matrix may affect its adhesion capabilities. In terms of protein body composition, it has been suggested in maize that increased amounts of gamma-zein increases grain hardness due to the high cysteine content of gamma-zein which would theoretically enable gamma-zein to disulfide bond with other endosperm proteins. However, we found that the percentage of gamma-kafirin is actually lower in the kafirin fraction from opaque endosperm. Yet opaque endosperm has far less total kafirin than vitreous endosperm, suggesting that in sorghum the total kafirin content or protein body amount may be more important than the protein body composition in determining grain hardness.

Publications and Presentations

Publications

Abstracts

Leonard, D.L. and A.W. Kirleis. 1990. Microscopic evaluation of *in vitro* pepsin digestibility of sorghum proteins. Cereal Foods World 35:821.

Shull, J.M., J.J. Watterson and A.W. Kirleis. 1990. Localization of gamma-kafirin in *Sorghum bicolor* endosperm. Cereal Foods World 35:823.

Watterson, J.J. and A.W. Kirleis. 1990. Isolation and characterization of kafirin proteins. Cereal Foods World 35:823.

Journal Papers

de Barros, E.G., K. Takasaki, A.W. Kirleis and B.A. Larkins. 1991. Nucleotide sequence of a cDNA clone encoding gamma-kafirin protein from *Sorghum bicolor*. Plant Physiol. (in press).

Mohammed, S.I., L.R. Steenson and A.W. Kirleis. 1991. Isolation and characterization of microorganisms associated with the traditional sorghum fermentation for production of Sudanese kisra. Appl. Environ. Microbiol. 57:2529-2533.

Rom, D.L., J.M. Shull, A. Chandrashekar and A.W. Kirleis. 1991. Effects of cooking and treatment with sodium bisulfite on the *in vitro* protein digestibility and microstructure of sorghum flour. Cereal Chem. (in press).

Shull, J.M., J.J. Watterson and A.W. Kirleis. 1991. Proposed nomenclature for the alcohol-soluble proteins (kafirins) of *Sorghum bicolor* (L. Moench) based on molecular weight, solubility, and structure. J. Agric. Food Chem. 39:83-87.

Book Chapters

Kirleis, A.W. The prolamines of Sorghum: their role in protein digestibility. pp 168-176. In: Proceedings of the International Conference on Sorghum Nutritional Quality, West Lafayette, IN.

Ph.D. Theses

Mohammed, S.I. 1991. Isolation and characterization of microorganisms associated with sorghum fermentation and development of starter culture for production of Sudanese kisra. Ph.D. Thesis, Purdue University, West Lafayette, IN.

Shull, J.M. 1991. Identification and localization of kafirins in *Sorghum bicolor* (L. Moench) endosperm. Ph.D. Thesis, Purdue University, West Lafayette, IN.

Watterson, J.J. 1991. Isolation and characterization of sorghum kafirin proteins and the development of ELISAs for the quantitation of alpha-kafirins, beta-kafirins, and gamma-kafirin. Ph.D. Thesis, Purdue University, West Lafayette, IN.

Presentations

The three abstracts listed above were from papers presented at the American Association of Cereal Chemists 75th Annual Meeting, Dallas, November 1990.

Watterson, J.J. and A.W. Kirleis. Isolation and characterization of sorghum kafirin proteins and the development of ELISAs for the quantitation of alpha-kafirins, beta-kafirins, and gamma-kafirin. 201st American Chemical Society National Meeting, Atlanta, GA, April 14-19, 1991.

Networking Activities

Research Investigator Exchange

Dr. Abdel-Mageed Abass Mohamed from the Department of Food Science and Technology, University of Gezira, Wad Medani, Sudan worked in my laboratory as a visiting professor.

Mr. Moussa Oumarou, chemist from INRAN, Niamey, Niger visited my laboratory in July 1991 to be updated in grain and food quality analysis techniques.

Adam Aboubacar, graduate student, travelled to Niger to carry out tuwo quality research, Jan. - March 1991.

Utilization and Quality of Sorghum and Millet

Project TAM-126

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Prof. D. Andrews, Millet & Sorghum Breeding, University of Nebraska, Lincoln, NE
Mr. W. Stegmeier, Millet Breeding, Kansas State University, Hays, KS
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Summary

The goal of this project is to improve the utilization of sorghum and millet by development of new or modified processing methods to produce new food products and through cooperation with breeding programs to develop sorghum and millets with improved quality for industrial and traditional foods.

The process for parboiled millet (milri) was modified to save energy and reduce processing costs. The improved process consists of soaking the grain overnight followed by bringing the steeped grain to boiling and air drying. The new procedure was developed because consumer studies conducted in Bamako, Mali indicated that small pieces of endosperm were the most desirable for preparation of foods from parboiled sorghum and millet.

Changes in the structure of millet parboiled with different procedures were documented and explained why certain processes gave different products.

Parboiling of pearl millet eliminated the undesirable "mousy aroma" obtained when pearl millet is moistened and milled. The compounds responsible are related to the compound responsible for the aroma of aromatic rice varieties. Parboiled millet products have improved shelf stability although they do develop rancid aromas over extended storage. However, the rancid aroma can be eliminated by proper aeration prior to use.

Two improved maicillo sorghums developed in Honduras were found to produce good tortillas with lighter color than the local maicillos criollos. However, the cooking time and other processing parameters must be adjusted because they are harder than maicillos criollos.

The head bugs of West Africa cause significantly reduced grain yields and food quality. The kernels are soft and cannot be dehulled. Porridges are of poor quality. Malisor 84-7, developed in Mali, has hard grain with resistance to head bugs and molds probably because it accumulates dry matter

faster than other sorghum varieties after anthesis. In addition, Malisor 84-7 kernels appear to localize head bug damage to a relatively few cells in the area of the bite while other more susceptible genotypes have extensive damage to the kernel. More study is needed to confirm these observations.

More efficient methods for analyzing alpha- and beta-amylases in sorghum malt were tested using several sorghum cultivars. Optimum germination time of sorghum varies depending upon the variety.

Sorghum malt can be used to reduce the viscosity of weaning foods made with cowpeas and cereal blends.

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.

Effect of Head Bugs on Kernel Structure

The effect of head bugs on the internal and external structure of six varieties of sorghum was documented with a scanning electron microscope. The damage of several representative kernels was mapped prior to coating and viewing in the SEM. The head bugs inflicted damage on the endosperm and pericarp in all six varieties of sorghum, however, the pattern of damage varied from one variety to another. In all varieties, the pericarp separated from the kernel through the mesocarp, especially along the bite areas, allowing mold or fungal growth. Growth was most severe in ICSV 1063, Sureño and ICSV 16-5. Malisor 84-7 allowed only moderate growth, and Kende and SCM-388 allowed growth only in the embryo.

Extensive changes in the endosperm texture were noted in Sureño, ICSV 1063, and ICSV-16-5. The endosperm cells in these varieties were very floury in texture, with a vastly increased number of air spaces compared to the uninfected controls. Localized modification of the endosperm occurred in Malisor 84-7 and to a much lesser extent in Kende. These two varieties appeared to be the most resistant to head bug attack. In Figure 1, the bite marks and areas of discoloration are marked by arrows. Malisor 84-7 endosperm texture became very floury only in the area around some of the bite marks, and retained its corneous texture throughout the rest of the endosperm (Fig 2d). Other resistant varieties also showed only localized reaction to the bites. The endosperm of ICSV 1063, on the other hand, became floury throughout, with little or no corneous areas retained (Fig 2c). Sureño endosperm texture was also more floury than normal, although the changes were not as dramatic as in ICSV 1063. There were no ascertainable differences in protein body structure between any of the varieties, although in the floury kernels, there was less protein matrix present.

Malisor 84-7 was different from the other varieties. In some of the discolored, damaged areas, only the endosperm cells in that localized area developed into a floury texture, and the starch granules were partially degraded (Fig 1c). There was more actual starch damage in the affected areas of Malisor than in the entire endosperm of any other variety, excluding Kende, which showed no damage at all. In contrast, the entire endosperm of head bug inoculated ICSV 1063 kernels developed into floury endosperm cells (Fig 1d). It appears that Malisor has a defense mechanism whereby damage is limited to localized areas of the kernel in or near the peripheral endosperm layer, thus protecting the rest of the kernel from damage. Thus, the kernels, although damaged, retain sufficient integrity to enable decortication.

The pericarp of the head bug resistant varieties appeared to contain a thicker waxy cutin layer on the epicarp than the nonresistant varieties. The most resistant variety, Kende, had a thick smooth cutin layer over the epicarp, which apparently prevented the bites from affecting the endosperm. Malisor 84-7 also had a very smooth layer of cutin

Figure 1a. Inoculated Malisor 84-7 kernel. Arrows point to a patch of black material that has developed on the outside of the kernel in response to insect attack or other environmental factors. When viewed at a higher magnification, the cell layers of the epicarp and mesocarp can be seen through the blackened area (not shown).

Figure 1b. Normal Malisor 84-7 kernel that has not been exposed to head bug attack. The endosperm is corneous and the pericarp is thin-to-intermediate in thickness. No degradation of the endosperm is visible.

Figure 1c. Cross section of an inoculated Malisor 84-7 kernel showing a bite area. Arrow points to black material described in Fig. 1a that has grown in response to the headbug bite. The endosperm is floury at the area of the bite, but becomes more corneous as distance from the bite area increases.

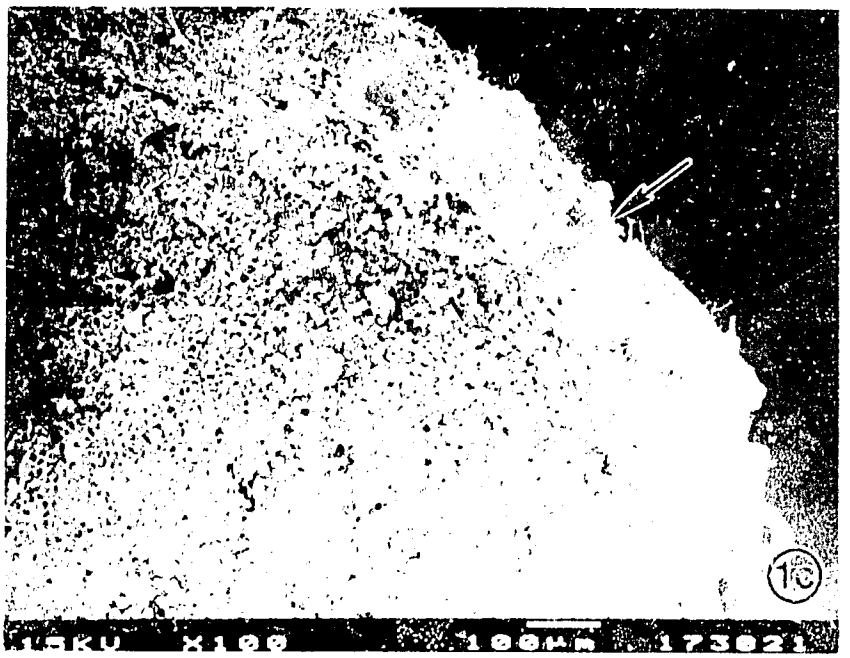


Figure 1d. A similar type of bite area in an ICSV-1063 inoculated kernel reveals that the entire endosperm has degraded and become extremely floury and disorganized, as though development continued after the bite in a chaotic fashion. There is also evidence of fungal growth in the lower right hand area near the pericarp.

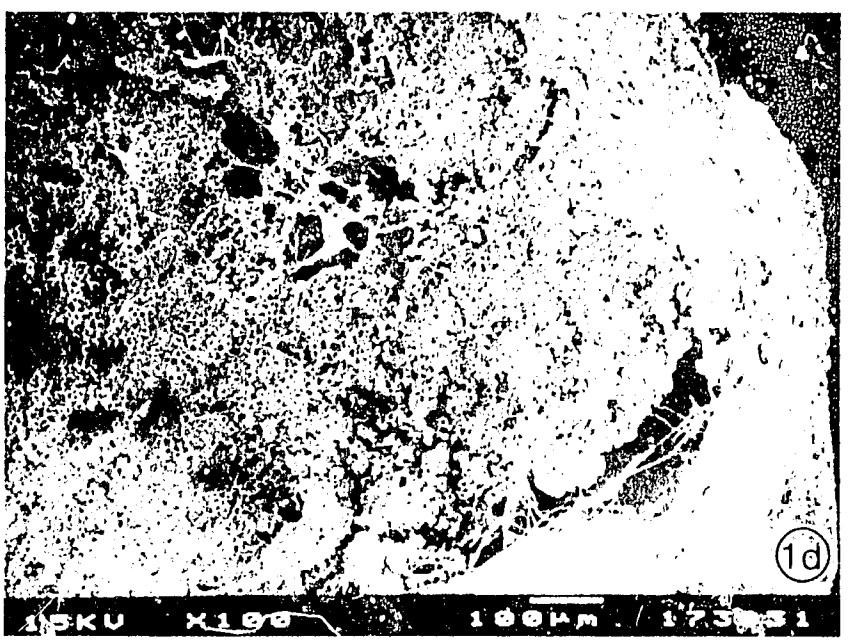


Figure 2a. External view of the outside surface of the pericarp in an ICSV-1063 inoculated kernel. The long thin veins are epicarp cells, and the small protruding pieces of material are probably waxes adhering to the pericarp. The waxy cutinous layer is discontinuous.

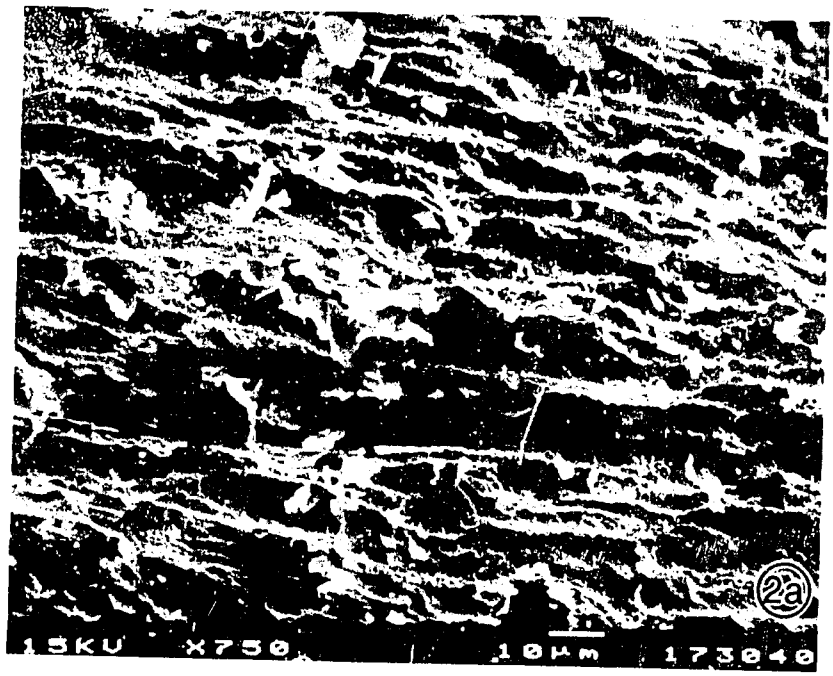


Figure 2b. Contrasting view of the external pericarp surface of a Malisor 84-7 inoculated kernel. The cutin layer is continuous and completely covers the epicarp cells beneath it. In some cases, the long veins of the epicarp cells are not even visible due to the thickness of the cutin layer.

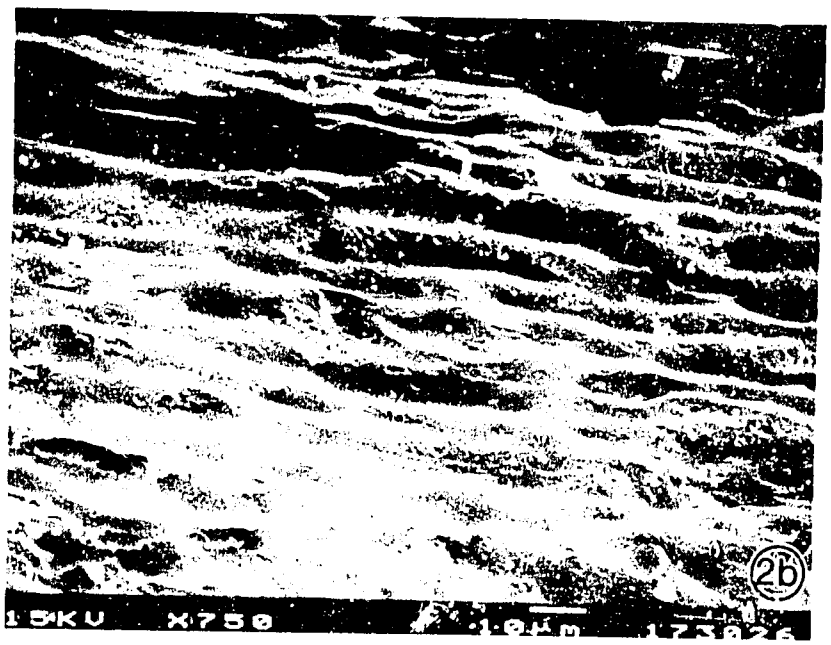
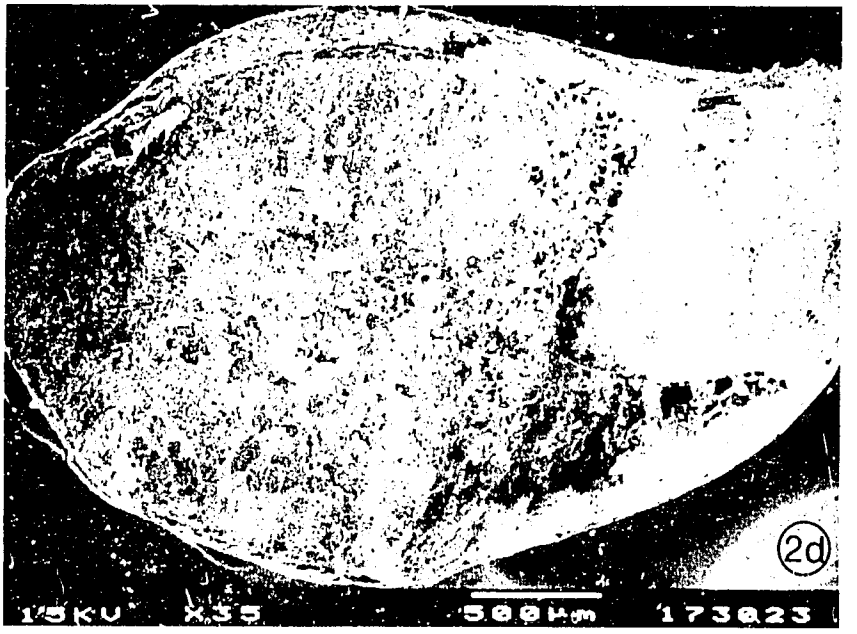


Figure 2c. Inoculated kernel of ICSV-1063 showing the extremely floury texture and unorganized state of the endosperm. Air pockets can be seen near the germ and beneath the pericarp, and no corneous endosperm is visible. The control kernel (not shown) had clearly defined corneous and floury endosperm areas.

Figure 2d. Inoculated kernel of Malisor 84-7 showing only localized endosperm damage in the tip of the kernel, where a bite area was found. The remainder of the endosperm was organized in corneous and floury areas, as in the control. This illustrates the superior response of Malisor to head bug attach. The large cavity at the lower right contained part of the germ, which popped out during preparation.



with few visible invaginations (Fig 2a). In sharp contrast, ICSV 1063 (Fig. 2b) and SCM-388 have rough, discontinuous cutin layers over much of the epicarp surface. Small, feathery pieces of a wax-like material are visible over some areas of the surface, but the underlying rows of epicarp cells are clearly visible. These differences were present in both inoculated and control samples. The absence of or alteration in the protective cutin layer could allow easier penetration by the insects into the kernel.

A general effect of head bug infestation seen in all varieties was an increase in the thickness of the mesocarp layer in the damaged areas. The mesocarp cells were thicker, with more starch granules present inside the cells in areas where head bugs had attacked the kernels. Some varieties also contained a thick layer of material around the bite areas that consisted of hard blackened cell layers (Fig 1a). This may serve as a defense mechanism developed by the maturing kernel.

Developmental Study of Six Sorghum Varieties

Samples of six varieties of sorghum (Malisor 84-7, CSM-63, SC605, BTx623, SC265, and P721) were harvested at 3-5 day intervals from anthesis to maturity and evaluated with scanning electron and fluorescence microscopy. Wet and dry kernel weights were recorded and dry weight gain was determined.

Protein bodies began developing in CSM-63 and SC605 3 days after anthesis (DAA), and 3-6 DAA in the other samples. The protein bodies were covered by a thin, filamentous webbing, which later developed into protein matrix. Both compound and simple starch granules were present in the ovary walls of all varieties at anthesis; simple starch granules were developing in the endosperm 3-6 DAA in all varieties. Starch fill was more rapid in Malisor 84-7 and BTx623 than in the other varieties. This was confirmed by the dry weight gain data. Numerous pits were found in the endosperm and pericarp cell walls of all varieties starting at 0 DAA. As development continued, the pits grew fewer in number. The pericarp began to differentiate into distinct layers 2-3 DAA in CSM-63 and 3-6 DAA for the other varieties. By 6-9 DAA, the pericarp was fully developed in all varieties and began to compress as the kernel grew larger. The testa was apparent in CSM-63 by 3-6 DAA. The aleurone layer developed at 6 DAA in SC605 and BTx623, at 6-9 DAA in CSM-63 and SC265, and at 9-12 DAA in the other two varieties.

Malisor 84-7 may be more successful in surviving head bug and mold attack because of its hard endosperm texture and rapid fill rate from day 0-6, which allows it to stabilize in its environment more quickly than other sorghum varieties. However, no definitive structural characteristics of the immature seeds were found that clearly accounted for the head bug and mold resistance.

Parboiling Millet

Methods of parboiling millet were studied to optimize the parboiling effect while minimizing the energy used during processing. The amount of broken kernels obtained during decortication was not considered important. Thus, the soak and boil method was found most effective when combined with air drying. Drying in direct sunlight caused significant kernel checking and cracking depending upon the intensity of the sun. This suggests that sun drying in Mali should continue to be done in the shade to avoid lower milling yields. Oven drying caused reduced yields of decorticated grain.

The yellow or white pearl millet consistently gave the most attractive appearing cooked products because of its lighter color and generally more likable aroma during cooking.This cultivar has been increased this season for more extensive testing. It is far superior for food products than the blue or purple millets. It makes a very attractive product. The pearl millet breeders, Bill Stegmeier, Kansas State University, and Dave Andrews, University of Nebraska, are placing increased emphasis on the yellow millet because of its improved quality.

Effects of Parboiling on Off-aroma in Pearl Millet

The 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 5 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.

Work completed has shown that parboiling eliminates production of the characteristic mousy, acidic aroma produced in pearl millet by traditional milling methods. The previously described aroma is attributed to enzymatic activity in the outer layers of the pearl millet kernel. The heat treatment from the parboiling process appears to inactivate any enzymes involved in the development of the off-aroma.

The ability to produce the off-aroma is also extractable with methanol. The enzymes responsible for the aroma may be acting on methanol soluble components in the pearl millet kernel. Previous work involving supplementation with flavonoid compounds (methanol soluble) indicates they may serve as precursors for the aroma component. There is, however, no significant reduction in flavonoid content (mg glucosylvitexin equivalent/100g sample) in the pearl millet samples during production of the off-aroma. The flavonoid compounds may serve in a catalytic capacity and not as precursors. In such a case, the flavanoids would not be chemically altered during aroma production.

Work is in progress attempting to identify the aroma component. Gas chromatographic analysis indicates a single

compound is responsible for the off-aroma. Mass spectral and infrared data indicate a structure similar to 2-acetyl-1-pyrroline, the compound responsible for the distinct aroma of aromatic rices.

Changes in Composition and Structure of Pearl Millet During Parboiling

The microstructure of yellow and blue pearl millet before and after parboiling was examined with light and scanning electron microscopy. Three parboiling methods were used: 1) Boil-soak-boil (BSB); kernels were brought to a boil, soaked for 12 hrs, brought to a boil again, then dried; 2) Soak-boil-soak (SBS); kernels were soaked 12 hrs, brought to a boil, soaked again for 4 hrs, then dried; 3) Soak-boil (SB); kernels were soaked for 12 hrs, then boiled for 5 min and dried. Samples were either air dried indoors (23°C) or sun dried outdoors at ambient temperatures (28-30°C).

Pearl millet responded to parboiling in much the same manner that sorghum did. The physical appearance of the kernels was dramatically different after parboiling. BSB kernels were translucent in appearance, indicating that they were also very hard. The SBS kernels were also translucent in appearance, but were too brittle to effectively cut in half, indicating the cause for their low milling yields. The SB kernels were opaque upon first glance, but at high power, the endosperm was milky and clear. The yellow millet had a softer endosperm texture prior to cooking than the blue millet, and was more affected by the parboiling process. Decortication yields of blue pearl millet were less consistent within treatments than those of yellow pearl millet. The air drying method produced the highest yields in all cooking treatments for both blue and yellow millets. BSB produced the highest yields in all categories, closely followed by SB. SBS yields were consistently low.

There were obvious differences in the microstructure of the two millets after cooking. In both millets, the starch granules were swollen and partially gelatinized throughout the endosperm. However, the BSB treatment had the most severe starch gelatinization, followed by SBS and then SB, as determined by loss of birefringence. However, the birefringence data can be misleading and must be interpreted carefully. Evidence suggests that when the cooked grain is steeped the starch can recrystallize and subsequently display birefringence in the cooked samples.

The primary cause for the hardening of parboiled kernels can be attributed to the swelling of the starch granules, accompanied by leaching of some starch material (probably amylose) into the surrounding air spaces. As the starch granules swell, the amylose fills the voids in the endosperm and forms an interlocking network between the protein and starch granules which, upon drying, forms a continuous network. This produces the translucent appearance of parboiled products. After cooking treatments, the only visible change seen in the protein bodies is a slight deformation of the previously round shape. The SBS and SB cooking treatments are inadequate to completely fill all the air spaces in the majority of kernels. Thus, the SB and SBS kernels have a semitranslucent milky central area because the endosperm cells still contain some very small air spaces which affects light refraction. However, the changes in the endosperm are sufficient to improve the decortication properties.

The SB treatment, which requires the least input of energy and fuel, is sufficient to produce a satisfactory increase in kernel hardness of soft pearl millet varieties. The dried kernels of the SB process were nearly as hard as the BSB treatment, and thus were able to resist breakdown during decortication. Millet cooked in this manner had increased shelf life and excellent organoleptic properties. The reduced cooking time and lower energy costs of this treatment make it a viable alternative cooking practice at the village level. The SBS treatment was completely unacceptable because the parboiled kernels had lower milling yields than the control. The BSB treatment gave the highest yields and most acceptable kernel texture, but the higher energy costs make it undesirable as a cooking alternative at the village level.

Sorghum Malting Quality

The effect of malting on composition of sorghum was determined. Dorado sorghum was germinated for 6 days at 28°C, 95% RH. Germinated grain was dried 48 hr at 50°C. After roots and shoots were removed, the grain was ground. About 94-98% of the grain developed roots and shoots by the third day. Moisture of sorghum grain, dry matter losses, water solubility, *in vitro* protein digestibility, lysine content and C-PER of sorghum increased significantly during germination.

Maximum α-amylase activity was developed after 2 to 4 days of germination. Solubilized starch was rapidly degraded after the second germination day; at the same time dextrins with DP≤3 structure were formed. Malted sorghum starch granules retained birefringence during the germination period, however, the granules contained endocorrosion channels or cavities, indicating that amylase activity was present. Sorghum malt contained fewer b-glucans than unmalted sorghum. Some degradation in the scutellum and endosperm cell walls was detected by fluorescence microscopy after the third germination day. It is possible that enzymes may pass through the cell walls to gain access to the starch during malting.

Sorghum malt has the potential to liquefy precooked starch for production of beverages with reduced cold viscosity and high content of soluble solids. This low viscosity is needed for weaning food and cereal-based drinks. The improved protein quality of malt enhances the nutritional quality of weaning food.

New Amylase Assays for Malting Quality

The feasibility of using faster methods to detect enzyme activity in the malted grains is being assessed. The control (slowest method) was the diastatic activity method used by South African scientists. Two rapid tests are being evaluated: 1) Rapid ß-amylase test (Mathewson and Seabourn, 1983, J. Agric. Food Chem., 31:1322-1326) and 2) Rapid Visco Analyzer which detects the change in viscosity related to α-amylase activity in the malt.

The rapid ß-amylase assay is based on the hydrolysis of p-nitrophenyl alpha-maltopentaoside (PNP5) and p-nitrophenyl alpha-maltohexaoside (PNP6) by ß-amylase in the malt. A commercially available substrate (Pantrak kit), which contains both oligosaccharides (PNP5 and PNP6) as well as microbial alpha-glucosidase is used.

The first step in the ß-amylase assay is to obtain the malt extract. Next, equal volumes of malt extract and substrate are mixed and reacted for 3 min. One hour later, the absorbance reading at 405 mm is taken. The yellow color development is proportional to the ß-amylase activity in the malt. A regression equation was used to translate absorbance readings to ß-amylase units.

The rapid visco-analyzer (RVA) procedure for determination of α-amylase activity consists of measuring the viscosity decrease when sorghum malt is added to a corn starch water mixture. The decrease in viscosity is proportional to the α-amylase activity of the malted sorghum. This method is relatively quick, uses inexpensive reagents and appears to have excellent reproducibility. The effect of germination time on the level of α-amylase in malt from Malisor 84-7 is presented in Figure 3. The reduction in viscosity as the germination time increases shows that α-amylase continues to increase with germination time. The liquefying power of the malts from three different sorghum cultivars varied significantly. Work continues to standardize this rapid procedure.

Dorado produced the best malt regarding ß-amylase activity; followed by Sureño and Malisor 84-7 malts. This was shown by the diastatic power method and the α-amylase assay (Tables 1 and 2). Malisor 84-7 produced the lowest level of amylase activity, even though germination appeared more vigorous than the other varieties. Malt of the three sorghum cultivars had significant differences in ß-amylase activity. Significant increases in the ß-amylase activity in Dorado, Sureño and Malisor malts were observed after 2, 2, and 4 days germination, respectively (see Table 2).

The extent of dry matter lost during malting is affected by the sorghum cultivar and by the germination time (Fig 4). Germination time beyond 4 days caused greater than 20% dry matter loss which is unacceptable. However, by choosing the Dorado cultivar and germinating for 2 days, the optimum level of ß-amylase activity is obtained (Tables 1 and 2) while minimizing dry matter losses (Figure 4). We need to confirm these observations with additional experiments.

Figure 3. The effect of germination time of Malisor 84-7 sorghum on the viscosity of standard corn starch water slurries (9.7% starch, dry basis) using a rapid visco-analyzer. The same level of sorghum malt (4.3% dry basis) was added to each starch slurry. In this figure, y-axis represents apparent viscosity as stirring number units (SNU); 1 SNU = 10 centipoises.

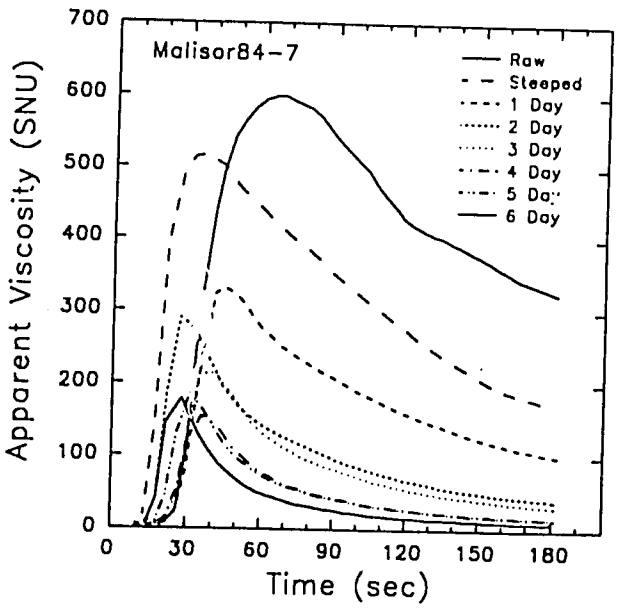


Table 1. Effect of malting time on the diastatic activity (SDU) of three sorghum cultivars.

Germination time (days)	Dorado	Malisor 84-7	Sureño
Raw	0.17[c]	0.95[a]	1.93[b]
2	5.07[d]	0.98[a]	3.79[b]
4	10.28[c]	—	5.95[a,b]
5	19.89[a]	1.26[a]	5.60[a,b]
6	16.10[b]	—	8.82[a]
LSD values	0.38	1.15	4.49

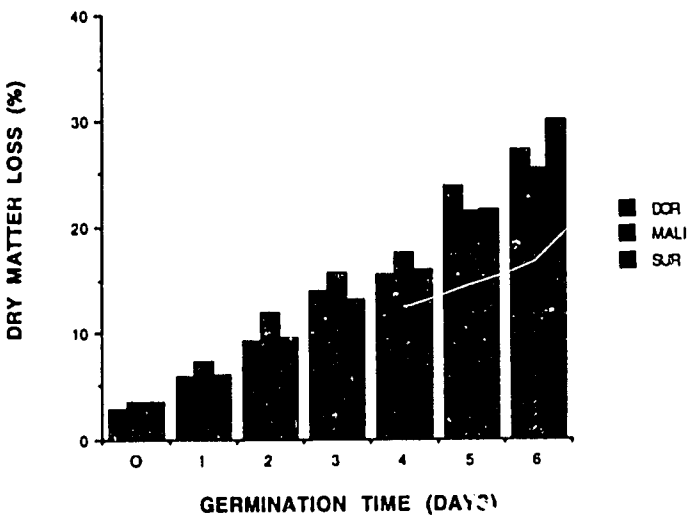
Means with different letter in the same row are significantly different ($p<0.05$). One SDU is defined as the amount of enzyme activity, which when acting under the conditions of the method, gives a thiosulfate titre of 0.5 ml of 0.05N solution.

Table 2. Effect of malting time on the ß-amylase activity* in different sorghum cultivars.

Germination time (days)	Dorado	Malisor 84-7	Sureño
0	1.78[c]	1.43[c]	—
1	8.10[b]	9.93[d]	10.39[d]
2	33.63[a]	19.43[c]	28.99[a,b,c]
3	35.73[a]	25.99[b]	30.67[a,b]
4	36.34[a]	27.14[a,b]	30.79[a]
5	34.35[a]	29.08[a]	26.74[b,c]
6	32.81[a]	26.51[a,b]	26.64[c]

Means with different letter in the same row are significantly different ($p<0.05$).
*ß-amylase units/g of malt

Figure 4. Effect of germination time on the dry matter losses during malting of three sorghum cultivars. Dor - Dorado; Mali - Malisor 84-7; Sur - Sureño. 0 time was after steeping for 20 hours in water at 28°C.



The cost of sorghum malting is high because of high dry matter losses during malting. Therefore, we must find sorghum cultivars that develop high levels of enzymes, both α and ß-amylases, very rapidly during germination. Two graduate students are continuing research on genetic factors affecting sorghum malting and dry matter losses. Brewing with sorghum malt is of increasing importance in Africa.

Thus far, the preliminary results indicate that these methods can be used to screen larger numbers of sorghum genotypes which makes them more suitable for use in the breeding program.

Sorghum utilization in Nigeria has expanded rapidly because the government has banned the importation of cereals. Dr. L.W. Rooney and Dr. D.S. Murty, ICRISAT, Kano, visited several breweries in Nigeria to determine the current status of sorghum malt production and use. In Nigeria, beer is made using sorghum and maize grits with commercial enzymes to convert the starch to fermentable sugar. Many small breweries are using sorghum malt plus some commercial enzymes to produce beer. However the high dry matter losses during malting (20%) are costly. That is why the larger companies are using commercial enzymes without any malt. A local yellow endosperm variety with an intermediate texture gives the highest level of diastatic activity with the least amount of dry matter losses. Dr. Murty and a local brewer in Kano have tentatively identified some advanced ICRISAT sorghum lines with greatly enhanced levels of enzymatic activity and with reduced dry matter losses. The sorghum varieties have white pericarp, tan plant color and intermediate texture. The potential to increase malting quality of sorghum through breeding and selection appears to be good. More information on factors affecting malt quality and variation in malting properties among genotypes is required.

Tortilla Quality

Thirty-eight improved maicillos criollos sorghum samples grown at Choluteca, Honduras in advanced yield trials in 1988 and 1989 were alkaline processed to evaluate their potential value for tortilla processing. Pericarp removal, nixtamal color and moisture, dry matter losses, density, hardness, kernel weight, and protein content were compared to standard maicillos criollos. This information was used by Drs. Gomez and Meckenstock to make selections for further testing and evaluation in farmers' fields in Honduras. Some of the material had excellent tortilla processing properties, but some gave dark, off color nixtamal with high dry matter losses and poor pericarp removal. Kernels from tan plants gave the best color even when mold and weather damaged. Dry matter losses ranged from 3.3 to 13.4% during alkaline cooking. Two of the experimental lines performed well in farmers'; fields and had excellent tortilla quality in our cooking trials in 1988, 1989 and 1990.

Digestibility and Processing of Sorghum

New sorghum varieties and hybrids with known endosperm properties and food quality attributes were increased for use in steam-flaking trials to be conducted cooperatively with the Texas Tech Animal Science Department. This research is being funded partially by the Texas Sorghum Producers Board. In preliminary trials, grain of Malisor 84-7 had significantly improved steam flaking properties over grain of commercial red sorghum hybrids. Waxy endosperm hybrids had more efficient processing properties. These studies continue.

Grain Molding

Sorghums (8) with different levels of grain molding resistance were sampled during kernel development during this year. Extracts of spikelet, glume and caryopsis will be tested for bioactivity using *in vivo* (corn armyworm) and *in vitro* (fungal growth) assays.

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.

Texas A&M University has released several parents that produce white tan plant sorghum hybrids which have excellent food and feed processing quality. However, these sor-

ghums must have more resistance to molds and weathering to be widely grown in the hot humid areas of Texas. These parents have looked good in various parts of the world, but they are attacked by head bugs in many parts of West Africa and are often too early. They mature during late rains and are attacked by molds. The most important limitation to sorghum quality improvement is attack by molds in most all sorghum producing areas.

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Networking

L. W. Rooney traveled to Mali to develop work plans, amendment #8 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 the breeders' samples. Interaction with the Regional ICRISAT (WASIP) resulted in the IER Food Technology Laboratory evaluating the processing quality of samples from WASIP. Dr. G. Fleidel, IRAT, Montpellier, France continues to monitor an E.E.C. funded project on postharvest technology that is being conducted by the laboratory. Dr. John Scheuring, Ciba-Geigy, Ms. Haidara (IER) and L. W. Rooney distributed a simple poster in French and Bambara to summarize use of cowpea-millet composite weaning foods.

L.W. Rooney participated in the East African Regional Workshop held in Nairobi by presenting a paper on parboiling of sorghum. L.W. Rooney evaluated the utilization of

sorghum in foods and beverages in Nigeria in cooperation with Dr. D.S. Murty and other ICRISAT/Kano scientists.

Mexico, Central and Latin America

Sorghum samples from Honduras advanced yield trials and farmers' fields were analyzed for tortilla making potential. Two improved maicillos criollos have good tortilla-making properties, but require different cooking parameters than the maicillos criollos. Two students from Mexico are working on sorghum/millet quality. Dr. H. Almeida-Dominquez completed his Ph.D. and returned to Institute of Technology of Merida where he is teaching and initiating research activities on food processing including collaboration with the INIFAP sorghum program. Ms. P. Torres, University of Sonora, spent one month conducting research in our laboratory. Cooperation with the University of Sonora continues. For example, Dr. M. Gomez, research scientist, Texas A&M presented a one week short course on sorghum and maize processing and nutritional quality to students and staff at the University of Sonora

ICRISAT - India

M.S. Kherdekar, ICRISAT, Crop Quality Lab, Hyderabad, spent two weeks training on Dr. Waniska's HPLC procedures for analyses of polyphenols in sorghum and millet.

North America

Several papers were presented at the annual American Association of Cereal Chemists conference in Dallas, Texas and at the Institute of Food Technologists food exposition in Dallas. Dr. R.D. Waniska participated in the U.S. Grain Sorghum Producers Bi-Annual Conference and discussed sorghum improvement for feed and foods. These conferences provided for exchange of information among domestic and international participants.

L. W. Rooney has served on the Ecogeographic Zone Council for INTSORMIL and as Country Coordinator for Mali. This included a trip to Mali and a meeting in June 1991 with Dr. Traore, IER Mali Coordinator in Nebraska.

Acknowledgment: The assistance of Dr. M. Gomez, Research Scientist, Dr. S. Serna-Saldivar, and Ms. C. McDonough, Research Associate, has been very helpful. Several graduate and undergraduate students have worked long hours to complete this research.

Host Country Program Enhancement

INTSORMIL Collaborative Sites

Botswana

M.D. Clegg
University of Nebraska

Coordinators

Dr. Lucas Gakale, Director of Agricultural Research, Botswana (Host Country Coordinator), Gaborone, Botswana
Dr. M.D. Clegg, Department of Agronomy, University of Nebraska, Lincoln, NE 68583 (U.S. Coordinator)

Collaborative Program

INTSORMIL's involvement in Botswana was initiated July 1983 and staffed in April 1984. Dr. D.C. Carter held the position of Agronomist with KSU-107 from its inception until September 1990. In December 1987, a soil management specialist position was filled to support the activities of the USAID-funded bilateral Agricultural Technology Improvement Project. 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 is provided by the U.S. Government under the provisions in Grant No. DAN-1254-G-00-0021-00 to the University of Nebraska, the Management Entity for INTSORMIL. 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. Mr. Neiso Mokete who recently earned his BSc. and returned from KSU, was assigned duties as a cereals agronomist in the DAR and works closely with the INTSORMIL collaborative program on dryland sorghum and millet.

The Botswana program is essentially two related components: an INTSORMIL researcher stationed in the country and scientist to scientist collaboration in the areas of agronomy, plant breeding, plant pathology and entomology. Various aspects of collaboration can be seen in other projects.

Financial Inputs

USAID/Botswana, GOB and INTSORMIL 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, and FAO sponsored Soil Survey and Mapping Services. Entomology, pathology, and plant breeding collaborate with ICRISAT in Bulawayo.

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 program. The planning of research by the in-country scientists 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-efficiency rainfall pattern, sandveld and hardveld soils with low moisture retention, low N and P content, broadly graded sand fractions, and unstable surface contribute to the low yield of sorghum and millet. Broadly graded sand fraction and unstable surface 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 infil-

tration and availability for promoting crop establishment and improved grain and stover yields.

Research Methodology

Because of the diverse nature of research being conducted it is not possible to outline specific research procedures. These will be included in the various individual reports.

Research Progress

Agronomy

Dr. Naraine Persaud, INTSORMIL/Botswana, Gaborone. — The objectives for this period were: 1) to evaluate several tillage practices with and without fertilizer, 2) to evaluate animal versus tractor draught for tillage operations and 3) to make fertilizer recommendations from developed response curves for dryland conditions.

Results from these studies demonstrated the importance of early primary tillage in achieving better crop stands and yields. Tillage and fertilizer did not interact at any 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 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 versus tractor showed no clear trend. Benefits were comparable for the two systems, with lower yields under animal draught 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 than 5 mg kg^{-1}. A significant response to N was obtained only when rainfall was well distributed throughout the growing season.

Soil Fertility

Dr. Dan Walters, University of Nebraska. — Research related to the fertility of the soils of Botswana is being conducted in collaboration with Dr. Naraine Persaud towards the completion of the Ph.D dissertation of Ms. Dollina Malepa. Soil from 14 sites across the major grain producing regions of Botswana (Gaborone to Maun) was collected in June 1989. Soils were 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.

In June, Dr. Walters traveled to Matopos to work with Ms. Malepa in the greenhouse phase of the experiment. In this phase we are attempting to establish baseline critical levels for this family of soils for the suite of elements listed. In addition we have been able to rank these elements on the basis of availability from least to most limiting. The greenhouse data (using sorghum) 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.

Entomology

George L. Teetes, Texas A&M University. — Chris Manthe, Entomologist, DAR, is writing his dissertation at TAMU on research he conducted in Botswana and Zimbabwe on sorghum resistance to sugarcane aphid.

Sorghum/Pearl Millet Breeding

Professor David Andrews, University of Nebraska. — Collaboration continued between 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 kindly provided off-season generation advance and seed increase of the Botswana/INTSORMIL selections.

INTSORMIL involvement in the Botswana sorghum and pearl millet breeding programs has been in the supply of both segregating populations and advanced lines in sorghum and information on and participation in recurrent selection in pearl millet. PI visits have been timed so material can be jointly evaluated and selected in the field.

As a result of the collaborative work on sorghum:

1) After four years of selection at Sebele characterized by severe drought stress, 24 lines originating from segregating material sent from UNL-115 have been retained from which seed parents can be produced. Backcrossing has commenced.

2) Additional more advanced lines from Nebraska were tested in the 1990-91 season and 50 were retained. These also, after being tested for combining ability, have potential to be converted into seed parents.

3) Six seed parents and one restorer were chosen from parental lines developed in UNL-115.

The above development of seed parents of diverse genetic origin complements the other components of the Botswana national program which has produced a seed parent from Segaolane, and many adapted breeding lines which will provide a varied set of restorers. Thus, there is variability on both the female and male sides to produce adapted hybrids for Botswana.

In the pearl millet program, with the assistance of Dr. Emmanuel Monyo from the SADCC/ICRISAT program at Matopos in growing off-season recombination generations, progeny testing and selection in the second cycle of recurrent selection in population Botswana Serere 6A was completed. Forty-six superior progenies were identified for recombination and production of progenies for the third cycle of selection, and six elite progenies for the production of an experimental variety.

Food Science and Technology

Dr. L. Rooney, Texas A & M University. — Ms. Rosemary Lekalake initiated studies in Food Science and Technology in January, 1991. She is working on food products from sorghum and millets.

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.

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 personnel for identified areas of needed research as earlier trained scientists continue to move into administrative positions.

Dr. Louis Mazhani was profiled in Agrinews (Oct, 1990) and now has been appointed Chief Arable Research Officer (CARO). Mr. Chris Manthe, entomology, Texas A&M (Ph.D), Ms. Dollina Malepa, soil fertility, University of Nebraska (Ph.D), Ms. Rosemary Lekalake, food science, Texas A&M (M.Sc.), and Mr.Etani Lele, agronomy, Kansas State University (M.Sc), are presently doing graduate studies for the indicated degree and area at the various universities.

Networking

The INTSORMIL researchers are working directly with the DAR, so there is direct communication 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; and Experimental Agriculture, printed in Great Britain.

Three SADCC/ICRISAT/INTSORMIL students are working with Dr. Richard Vanderlip, KSU-106, on thesis projects. Lawrence Gono, Zimbabwe, is doing course work and some controlled environment work on stand establishment problems of grain sorghum and will be returning to Zimbabwe in December 1991 to do part of his Ph.D. research there. The other two students, Ruth Madulu, Tanzania and Etani Lele, Botswana are working together on a series of experiments relating grain sorghum yield component response to management practices. They are evaluating two African varieties, Segaolane from Botswana and CSM 63 from Mali, and two U.S. hybrid sorghums of comparable maturity to a range of plant populations and to the effect of management levels and plant population on yield response of the varieties versus the hybrids, particularly as related to yield components. Etani is looking at the effect of management levels on weed competition and has limited his evaluation to one genotype because of the amount of data being taken. With two planting dates at two locations they have an excellent range of yield levels and effects of management. Mr. Charles Maliro working with Dr. Max Clegg 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 weed, grain and stover.

Research Accomplishments

Research is continuing on the research base of Dr. Douglas Carter (INTSORMIL agronomist in collaboration with ATIP) and 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). Much of the research has been summarized and published.

Dr. Naraine Persaud is directing research on tillage and fertilizer practices and evaluation of animal and tractor draught tillage operations. Results have shown that tillage performed as early as possible with the inception of rains can conserve sufficient moisture and give better rain use efficiencies. 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}.

Dr. Louis Mazhani (CARO), collaborating with UNL-115, has utilized 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. 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. Additional more advanced lines from Nebraska were tested in the 1990-91 season and 50 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.

In the pearl millet program at Matopos, 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 six elite progenies for the production of an experimental variety.

Mr. Chris Manthe has identified resistance to the sugarcane aphid in sorghum lines. 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 suggests that different biotypes exist among the populations. This research is the basis of his Ph.D. dissertation which he is now writing.

A soils report by the Soil Conservation Service, USDA/SMSS on data on 22 soils in Botswana was assembled. Building on this data base, Ms. Dollina Malepa (Dr. Dan Walters, advisor) is conducting research related to the soil fertility of the soils of Botswana towards the completion of the Ph.D dissertation. Soils from 14 sites across the major grain producing regions of Botswana (Gaborone to Maun) were collected in June 1989. Soils were 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 suite of elements listed are being established in greenhouse studies. Using sorghum, these 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 the relative contribution of subsoil nutrients to sorghum nutrition.

Training of Botswana students through SADCC/ICRISAT/INTSORMIL, INTSORMIL, USAID/Botswana, and ATIP educational/research programs is continuing. Chris Manthe, Dollina Malepa, Rosemary Lekalake, and Etani Lele are completing their studies. These scientists provide a good core but the movement of individuals to administration and private industry tends to reduce the number of actual research scientists. Additional training programs need to be initiated as qualified people become available.

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 October 1982. In June, 1988, a MOU with the Panamerican Agricultural School (EAP) was developed to formalize the officing of Meckenstock at the school, collaborative activities with INTSORMIL graduate students, and EAP/USAID collaboration with INTSORMIL/EAP/SRN/USAID sorghum research activities. In 1991, a new MOU was being developed between SRN and EAP, which would officially transfer the responsibility for the National Sorghum Program to the EAP and establish the 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 maicillos 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 now 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, and coordinating networking activities with researchers in neighboring countries. Dr. Gomez is responsible for the breeding program at Choluteca, the center of sorghum production in southern Honduras, as well as all on-farm trials over the entire country, and all research plots at Comayagua, La Lujosa, Catacamas, and Danli, as well as the SRN/EAP/USAID collaborative financial and administrative support of the National Sorghum Program.

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 1990, they contributed 479,000 lempires ($111,266) to the Honduras sorghum program, of which 430,000 is given directly to EAP to use in collaborative INTSORMIL/SRN/EAP sorghum research. In 1991, all L.479,000 for national sorghum research was given through the EAP. These funds pay Gomez's salary and support research at Zamarano, 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.

Collaborative Work Plans

Annual research plans and work plans are developed jointly by Meckenstock and Gomez in consultation with Rodriguez and Daccarett (SRN), Rosenow (EAP), and USAID. Graduate student research plans are developed annually and submitted to SRN for approval. Budgets for USAID/H support are jointly developed each year by Gomez and Meckenstock, and submitted by SRN through the Ministry of Finance to USAID/H.

Constraints Researched

Major emphasis is on improving sorghum production on the small subsistence farm, 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 lowlands and areas of larger commercial farms where shorter, photoperiod insensitive sorghums are adapted. Similar constraints exist in these areas. Availability of seed of improved cultivars is also a constraint.

Research Methods

Standard research methods are used for all of the Honduras related research. Research is concentrated at Choluteca, Comayagua, and Zamarano, 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 all research in Honduras can be found in the TAM-131 Project Report within this 1991 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 advantage in yield, especially when combined with improved agronomic practices, as well as in traits such as grain quality and disease resistance (see Cereal Quality and Pathology). Some of the improved maicillos have been saved 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 where photoperiod sensitivity is needed. F_2's involving improved maicillos were planted in southern Mali in 1991, and should provide the late maturity needed for that area.

Nonphotoperiod Sensitive Hybrids and Breeding

Some hybrids from Texas showed excellent potential for use in Honduras, based on evaluation of the Texas A&M developed ISTAT (International Sorghum Tropical Adaptation Trial) and the IFSAT (International Food Sorghum Adaptation Trial) at several locations in Honduras in 1990. The best males were Dorado, 86EON361, 87EON366, SC1207-2, R8503, R8510, and R8606, while the best females were ATx626, AVar (ATx635), and ATx631.

A TAMU drought trial under low rainfall conditions at Rapaco revealed that several Texas and international cultivars showed excellent adaptation and drought tolerance. The best lines were Ajabsido (Sudan); El Mota (Niger); Segaolane (Botswana); CE151-262-A1 (Senegal); and 82BDM499 (SC173*SC414), SC414-12E, R4244, Tx2883, 88B1016 (Tx430*Rio), and SC1211-8 (Cacho de Chivo der.), all from Texas A&M.

Mr. Alejandro Palma (Honduran, M.S., Miller, TAMU) initiated sorghum breeding research on head smut in Texas in 1991.

Germplasm Conservation

Six new landrace maicillo criollo cultivars were selected from a collection of Central America sorghums from ICRISAT/LASIP after evaluation in Puerto Rico and Honduras.

Forage Hybrid

The sorghum-sudan forage hybrid, ATx623*Tx2784, performed well in pilot production and feeding trials, and is planned for release in late 1991. It is resistant to pathotype one of downy mildew.

Cereal Quality

Grain from two enhanced maicillos and their criollo (landrace) counterparts grown at two farmsites in Honduras were lime-cooked and processed into tortillas in the Cereal Quality Lab at TAMU. They were compared with grain from Sureño (used as a positive control) produced at Halfway, Texas (Table 1). Kernels from the criollos were less dense, softer, and required less cooking than grain from the improved cultivars. The criollos produced darker, less acceptable tortillas. Masa and tortillas from criollos darkened during lime-cooking, especially during baking. Both improved maicillos compared favorably to Sureño. All sorghums and their respective tortillas had similar composition. Also grain samples from the 1990 IIMYT were evaluated for tortilla quality potential at TAMU, with several being superior to the criollo checks, especially those with tan plant color.

Table 1. Grain, nixtamal, and tortilla quality from cooking trial of grain of two improved maicillos and local criollo (landrace), and Sureño.[1]

Property	DMV-197	DMV-179	Criollo	Sureño
Grain hardness[2] (% removal)	15.4	17.2	26.0	12.7
Endosperm texture[3]	1.5	1.5	3.0	2.0
Pericarp removal[4]	3.0	2.5	3.0	1.7
Cooking time (min.)	20.0	10.0	6.0	20.0
Nixtamal color[5]	2.5	2.0	2.5	2.0
Tortilla color[5]	3.0	2.0	4.0	2.0
Tortilla texture[6]	1.2	2.9	2.5	1.0

[1] Grain from the improved maicillos (DMV's) and local criollo was from on-farm trials in Honduras, and grain of Sureño was from Halfway, Texas.

[2] Estimated as amount of material abraded in a TADD mill. The higher the value the softer the grain.

[3] Subjectively rated on a scale of 1 to 5, where 1 = hard endosperm and 5 = soft endosperm.

[4] Subjectively rated on scale of 1 to 5, where 1 = all pericarp removed and 5 = all attached to grain.

[5] Subjectively rated on 1 to 5 scale, where 1 = good (light-clean yellow) and 5 = poor (dark-stained).

[6] Tortilla rollability subjectively evaluated on scale of 1 to 5, where 1 = breakage and 5 = no breakage.

Entomology

Research continued by INTSORMIL graduate students in Honduras on langosta, a group of four lepidopterous larval insect pests which causes extensive damage to sorghum and maize seedlings in southern Honduras. Hector Portillo (Honduran, M.S., Pitre, MSU) studied ecology and population dynamics of the langosta complex. Julio Lopez (Honduran, M.S. Pitre, MSU) studied insect resistance of Honduran landrace sorghums with emphasis on fall armyworm. Lorena Lastres (Peru, M.S., Gilstrap, TAMU) studied the impact of two key predators of the fall armyworm, the earwig and the tropical fire ant. Research results are reported in the Project Reports of MSU-105, and TAM-125 respectively. A new student has been identified by Gilstrap to initiate research on a third predator, paper wasps.

Pathology

Disease ratings were made in the on-farm trials and in the breeding trials with some of the improved maicillos showing high levels of disease resistance (Table 2). Rust was severe, with the following TAMU lines showing good resistance: SC155, 85C13082, Malisor 84-7, 86EON361, 86EON362, 87EON366, 89BD1945, 80B2892, 84C4910, 88C5007, SC326-6, BVar, 89CC604, Tx2864, 88561, B8610, 87EON109, B2Tx8602, and TAM428. The rust reaction in Honduras is somewhat different from that in Puerto Rico and Texas, but many of the same lines consistently show resistance.

Table 2. Disease ratings of enhanced maicillos criollos (EMC) and local landrace maicillos criollos (MC) grown in on-farm trials in southern Honduras, 1990.

Entry	Leaf blight	Gray leaf spot	Rust	Grain mold
Sureño	1.5	—	3.5	1.0
DMV179 (EMC)	1.5	1.2	2.0	1.5
DMV197 (EMC)	1.5	2.2	1.5	1.2
(TAM428*Porv.)-20 (EMC)	1.0	3.0	—	2.2
Coludo (MC)	1.2	3.2	—	2.0
Caturra (MC)	2.0	3.4	3.4	1.7

A new testing location near Comayagua at CEDA (Japanese Irrigation Project) shows high infestation of downy mildew, and pathotype five is present.

In Olancho State, near Catacamas, anthracnose was extremely severe in fields of commercial hybrids. Several Texas lines showed excellent resistance, such as the SC326-6 derivative line 86EON361.

Economics

As a continuation of the farm-level analysis of new technologies in southern Honduras by Miguel Lopez (Honduran, Ph.D. 1990, Sanders, Purdue), the social returns to the introduction of the new sorghum cultivars, Sureño and Catracho, were estimated. At the present level of diffusion

of the new cultivars on approximately 13% of the sorghum area, there would be an internal rate of return of 32% or, on an annuity basis, $700,000/year for the next 30 years. Use of the new cultivars should include the cost of the expensive soil-conservation techniques (SCT) (rock terraces) to prevent soil erosion. With moderate policy changes and the new technologies including the SCT, farm income can be increased 58%.

Agronomy

A study on the physiologic and agronomic responses of maicillos was initiated by Patricio Gutierrez (Equadorian, M.S., Clegg, Nebraska). In a study in Honduras, the maicillos were shown to have superior in-shade tolerance and produce higher leaf area index, crop growth rates, grain yield, and phytomass than conventional U.S. sorghums when intercropped with maize.

Mutual Research Benefits

The landrace food type sorghums (maicillos criollos) from Central America are a source of excellent food quality traits for use by U.S. public and private breeders, as well as being excellent sources of resistance to anthracnose and foliage diseases. Honduran researchers have access to elite U.S. photoperiod insensitive food type sorghums, 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. 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 the U.S. and throughout the world. The improved maicillos being developed in Honduras should be an important source of late maturing germplasm for use in sorghum improvement programs in Africa where highly photoperiod sensitive types are needed.

Institution Building

Research Supplies and Support

The USAID/H Mission contributed 479,000 lempires (equal to $111,266) in 1990 to support sorghum research, with L.430,000 through EAP and L.49,000 to SRN. In 1991, with the reorganization of the national sorghum program, the total amount of L.479,000 is programmed to the EAP for sorghum research.

A telephone was purchased by INTSORMIL for the La Lujosa Station near Choluteca. Other small equipment and supplies were provided by INTSORMIL funds.

Travel for F. Gomez to the Sorghum Conference in Colombia was provided by TAM-122, and to the SICNA in Texas by TAM-126.

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 MIPA (integrated pest management) project at EAP.

Marco Castro (M.S. and Ph.D., MSU) is an entomologist with FIAH (USAID supported research institute) in Honduras.

Host and U.S. Scientist Visits

To Honduras

Darrell Rosenow, Fred Miller, Gary Peterson (breeding), and Delroy Collins (pathology), Dec. 6-12, 1990.

Frank Gilstrap (entomology) to plan research.

Julio Lopez and Hector Partillo (M.S. candidates in entomology, Summer 1990 and a portion of 1991.

To United States

Francisco Gomez to SICNA Conference, Feb. 17-20, 1991, Lubbock, TX and TAMU, College Station, Feb. 20-25, 1991.

Dan Meckenstock to Texas, January, 1991.

Dr. F. Martinez - Bustos, Sorghum Quality Lab, INIFAP, Mexico, one week training, Cereal Lab, TAMU, College Station, TX.

Other Travel in Area

Francisco Gomez to Sorghum Conference, Cali, Colombia, Jan. 14-19, 1991, and to PCCMCA/CLAIS meeting, March, 1991.

Networking

In-Country

Frequent visits and meetings of INTSORMIL and SRN researchers with regional and national administrators are used to plan research and share research results. Extension personnel help identify problems and research needs and assist in on-farm research and distribute seed of new cultivars. Most of the 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 and Cowpea, Pond Dynamics, and possibly the new IPM and Sustainability CRSP's. Meckenstock is serving as the key coordinator among these CRSP's, USAID, and the SRN.

Regional

Networking on a regional basis is done in several ways. One is through direct contacts at the annual regional meetings of CLAIS, PCCMCA, and the Latin American workshops (cosponsored by INTSORMIL and ICRISAT). Meckenstock and Gomez are an integral part of CLAIS with Honduras being responsible for certain regional trials. 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 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, 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 60Kg/ha nitrogen (68% and 113% respectively).

The improved maicillo advanced breeding lines performed very well in yield trials, including the IIMYT (International 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 one 30 to 50% higher yield when using an insecticide seed treatment and fertilizer. Grain of the IM's was supplied to the Cereal Quality Laboratory at Texas A&M University, where extensive grain quality evaluation was performed. A few of the improved maicillos had grain and tortilla quality equal or superior to the local cultivars. The tan plant lines were particularly good for tortilla quality.

A sorghum-sudan-grass F_1 hybrid (ATx623xTx2784) to be called 'Ganadero', for use as a forage for livestock is planned for release in late 1991.

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.

Research on grain quality research 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.

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, 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 but 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 sorghum line, AF28, and TAM428 and several native maicillos criollos 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.

Six Honduran and 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.

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, 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. The native maicillos, as some of the improved maicillos, have shown a significant level of shade tolerance compared to traditional U.S. sorghums, when grown in association with maize.

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.

The released variety, Sureño, and some of the improved maicillo lines produce tortillas superior in quality to the local landrace maicillo criollo cultivars.

Mali

L. W. Rooney and M. Traore
Texas A&M University

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Collaborative Program

The program in Mali is a coordinated effort among INTSORMIL, TROPSOILS, 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 1990-91 work

plan and budget was developed and approved by IER in July of 1990.

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 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.

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 millets 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.

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 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 grain yields with desirable food quality.

New Opportunities

The Malian program has initiated 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. The expansion in activities reflects an increase in the budget for Year 13. InterCRSP activities have been continued and plans have been made to expand activities in breeding and selection procedures for nutrient efficiencies during the 1992 cropping season when two Malian Ph.D. students, a sorghum breeder and a soil chemist, return to Mali.

Research Progress

Germplasm Enhancement

Sorghum: Drought Resistance and Breeding

Sorghum hybrids and varieties from various countries around the world with known drought tolerance were evaluated at Bema in northern Mali close to Mauritania in 1990 (Table 1). Bagoba, a dune adapted, soil toxicity tolerant cultivar from Niger, and two feterita cultivars from the Sudan, Koro Kollo and Ajabsido, were the three highest yielding entries which even outperformed the hybrids in a two replicate trial involving sorghums with known drought resistance. Also of significance was the performance of OH/84-16/63 (a durra from northern Nigeria), El Mota (an early drought tolerant line from Niger), Babadia Fara (from

Table 1. Performance of selected drought resistant international sorghum varieties and hybrids under drought stress at Bema, Mali, 1990.[1]

Designation, Name, Cultivar[2]	Days to 50% flower	Plant height (cm)	Grain yield (t/ha)	Group, origin, etc.
Bagoba	59	2.0	1.62	Durra, Niger
Kora Kollo	58	1.4	1.45	Feterita, Sudan
Ajabsido	56	1.4	1.14	Feterita, Sudan
A1 * P46-1 (H)	66	1.1	1.11	Exp. hybrid
OH/84-16/63	57	1.8	1.05	Durra, Nigeria
AOK11 * Tx2737 (H)	51	1.0	1.03	U.S. commercial hybrid
Babadia Fara	56	1.7	0.95	Durra, Niger
82BDM499/(SC173*SC414)	67	0.9	0.92	U.S. breeding line
SC414-12E	60	0.9	0.92	Converted Cau-Kaf from Sudan, U.S.
El Mota	58	1.6	0.89	Caud, Niger
DK41y (DeKalb) (H)	58	0.9	0.83	U.S. commercial hybrid
Zinnari	60	1.2	0.78	Durra, Sudan
CSM-63	54	2.1	0.74	Guinea, Mali
Segaolane	52	1.2	0.69	Caffrorum, Botswana
Malisor 84-5	64	1.5	0.69	Malian improved cultivar
BTx631	82	1.0	0.53	U.S. female
BTx623	74	1.0	0.47	U.S. female
Tx7078	55	0.7	0.44	U.S. cultivar
Malisor 84-7	84	1.0	0.32	Malian improved cultivar
Tx7000	55	0.8	0.25	U.S. cultivar

[1] Planted July 23, 1990. Cooperative IER/INTSORMIL drought trial involving sorghum cultivars from around the world with various types of drought resistance.
[2] (H) = F_1 hybrid.

Niger), Zinnari (a durra from western Sudan) and SC 414-12E and 82 BDM 499 which are U.S. developed lines that have shown good drought tolerance in the Sudan and the U.S. These data and other observations over several years demonstrate that sorghums with drought tolerance identified in other countries perform well in Mali, emphasizing the importance of international cooperation and exchange of germplasm.

In general, sorghums identified at Lubbock, Texas as preflowering drought tolerant performed better than other varieties. The material identified in these trials is being used in crosses in Mali and the U.S. to enhance the drought resistance in sorghums for use in both countries.

International Food Sorghum Adaptation Trials (IFSAT)

Dorado hybrids performed very well at Cinzana, Mali in 1990. Hybrids with 86EON361, R8510, and A-Var combined high yields, some tolerance to sooty stripe and the best grain quality. Head bugs and grain mold were major factors causing poor grain quality overall as measured in the Food Technology laboratory.

Head Bug\Grain Mold Breeding Progress

F_4 progenies with excellent tolerance to head bugs were identified and seed was increased in the off season for entry in advanced trials across Mali in 1991. Malisor 84-7 and other lines were the source of resistance. It appears that the head bug tolerance of Malisor 84-7 can be transferred although it is recessive and quantitative. ICSV 1079 and ICSV 1089 possess useful head bug resistance. Several other lines may have some potential. Many of the Malisor 84-7 crosses were made in Texas by A. Toure, a Malian Ph.D. candidate. Initial crosses to produce B-lines with head bug tolerance were made in Texas.

Late Photosensitive Cultivar Development

Numerous crosses with the very late photosensitive maicillo criollo and improved maicillo criollo sorghums from Honduras (developed by Dr. Meckenstock, INTSORMIL sorghum breeder, Texas A&M University) with elite high yielding types and Guinea types were made to develop breeding material for the southern part of Mali which requires long season cultivars. F_2 segregating populations will be planted in Mali in 1991.

Malisor 84-7, Sureño, VG153, their hybrids F_1, F_2 and selected F_3 populations were evaluated for grain hardness. Grain hardness was measured as percent of final weight over initial weight after decortication of 20g of each sample for 4 min with the tangential abrasive decortication device (TADD).

Sureño grain was the hardest followed by Malisor 84-7 (75%) and VG153 (70%). The F_1, Malisor 84-7*Sureño and Malisor 84-7*VG153 hybrids had similar grain hardness values (respectively 86% and 87%). 127 individual panicles evaluated from a Malisor 84-7*Sureño F_2 population ranged from 73% to 91% with a mean of 84%. Of 136 panicles analyzed from Malisor 84-7*VG153 F_2 population, the hardness value ranged from 53% to 89% with a mean of 80%. Thirty-two selected families of Malisor 84-7*Sureño F_3 populations showed a range of 79% to 90% with a mean of 85%. Thirty-one selected families from Malisor 84-7*VG153 F_3 populations ranged in hardness from 79% to 88% with a mean of 85%. It is possible to develop harder grain by using the TADD to select for grain hardness. The harder grain is expected to have more resistance to head bugs/molds, when other kernel attributes are similar.

Heterosis Studies of Guinea Sorghums

Seven converted Guinea, four Zera Zera, and two Caudatum sorghums were crossed to three selected improved A lines to determine the combining ability and heterosis in Guinea sorghums of West Africa. The primary evaluation of the parents and hybrids has shown that yield is highly correlated to the number of seeds/panicle and 1000 seed-weight. Yield also was correlated to flowering date and number of whorls per panicle. Seed number per panicle was related to the number of primary branches and whorls on the panicle. The number of whorls per panicle was positively associated with plant height, panicle length, 100 seed-weight, and the number of seeds per panicle. Length of primary panicle branches was negatively correlated to yield, number of primary branches, and whorls per panicle, but positively correlated to panicle length. Harvest index was negatively correlated with flowering data and was positively associated with seed number, panicle width and primary panicle branches length.

In general the Zera Zera produced much better hybrid combinations than the Guineas. The best yielding hybrids were Zera Zera combinations while the Guinea hybrids had very low grain yields. The panicle length was greater in Guinea hybrids than Zera Zera derivatives. The number of seeds per panicle was significantly higher with Zera Zera hybrids than that of the Guineas.

Seed weight was higher among the Zera Zera hybrids than the Guinea hybrids. The number of primary branches and whorls per panicle did not show any difference among hybrids. Guinea sorghums during their evolution, adaptation, and stabilization have lost genes or factors that contribute to high yields. Also there may exist in Guinea sorghums, linkages that are not favorable for the expression of yield potential. These studies have shown the great difficulty of improving grain yields using the Guinea sorghums.

Germplasm provided to Mali from INTSORMIL for evaluation and use by Malian scientists included the IFSAT (International Food Sorghum Adaptation Trial), ISFVT (International Food Sorghum Variety Trial), the ADIN (All Disease and Insect Nursery) and the ISAVN (International

Sorghum Anthracnose Virulence Nursery), and selected drought and elite breeding lines.

Pearl Millet Breeding

The Mali millet breeding program is making good progress in addressing needed improvements regarding disease and insect resistance, adaptation, and agronomic characteristics that affect productivity. Enhanced partitioning of photosynthates and harvest index improvement is being accomplished by reducing plant stature of varieties from heights of 4.5 or 5 m to 3.5 to 4 m by the use of height modeling genes, increasing tillering ability and selecting for improved yield potential. Varieties selected for the tallest expression of the D_2 dwarfing complex (1.7 to 1.9 m) have given good performance in millet/legume intercropping studies. Acceptable millet yields are produced and legume yields are increased because of improved light penetration through the millet canopy.

Dwarf (D_2) inbred lines selected at Cinzana from progenies of crosses between Mali and UNL-118 lines appear promising as germplasm sources to develop dwarf varieties for intercropping. The best of these lines, 54063-1WN and 88-57121-3, have desirable tiller numbers, synchronous tillering, and acceptable grain quality.

Many of the village varieties grown throughout Mali are very site specific having narrow ranges of adaptation. All could benefit from breeding efforts, but it is essential to have varieties adaptable to larger areas and diverse environments. Seventy-two varieties representing the germplasm base of pearl millet grown throughout Mali and neighboring countries are being tested at sites representative of all Malian millet growing areas. Approximately 20% of these varieties are being identified as possessing adaptive characteristics that permit good performance in diverse environments. These varieties will be used as a core collection or a germplasm base in the development of new widely adapted varieties and synthetics possessing needed grain quality characteristics, agronomic responses, and disease and insect resistance.

The severity of downy mildew virulence in West Africa and the low levels of resistance remaining in lines following several cycles of selection for other characteristics under U.S. conditions introduces delays in the use and conversion of superior materials from U.S. programs for use in Mali. In an attempt to retain downy mildew resistance and overcome this problem it is necessary for materials originating in U.S. programs, derived from Mali lines, to be returned to Mali as F_1, F_2, or S_1 selections possessing the desired characteristics. Further selection would continue in Mali under conditions that allow retention of resistance to these diseases.

Seeds of 56 KSU-101 F_4 lines selected for improved stand establishment characteristics were planted at Cinzana in 1991. Only two of these lines retained sufficient downy mildew resistance to allow seedling survival and acceptable stand establishment during the rainy season. Replanting of these materials in the off-season when downy mildew pressure is reduced will permit crossing of superior lines to Mali varieties.

Sorghum Pathology

During the last three years, sorghum pathology research consisted of:

a) evaluating under natural conditions breeding materials for resistance to anthracnose, sooty stripe, gray leaf spot, grain mold and long smut; and

b) developing screening methods for use by breeders.

In 1990, disease severity was evaluated in nine different trials at Sotuba, Samanko, Cinzana, and Bema locations. In addition, the ADIN and ISAVN trials were evaluated at Cinzana.

Current evidence suggests that gray leaf spot is not as serious in southern Mali (Longorola) as other diseases. Anthracnose *(Colletotrichum graminicola)* is a very serious sorghum disease in Mali. Evaluation of the international anthracnose virulence nurseries in Mali suggests that there may be different races of *C. graminicola* in Mali than in the Americas. Anthracnose resistant varieties were: BTx398, SC414-12E and SC224. Susceptible varieties were: B35-6, Tx2536, IS2057 and QL3. Over all three years only Tx2536 was always susceptible in Mali.

Long smut *(Tolyposporium ehrenbergii)* is severe in the drier regions of Mali. The actual yield losses caused by long smut are unknown. Late plantings may be a means of escaping long smut, but stand establishment may become a problem if planting is too late.

Grain mold continues to be a major sorghum disease problem in Mali. The combination of head bugs and molds render most improved varieties of sorghum unacceptable for milling. The tô produced from the grain is very dark colored with unacceptable texture.

Head Bugs of Sorghum

Panicle Feeding Bugs of Sorghum

The collaborative sorghum entomology research in Mali has a three-fold objective: (1) to develop screening methods for evaluating sorghum lines for resistance to panicle-feeding bugs that are usable by plant breeders to evaluate progeny lines and make selections; (2) to determine the relationship between resistance and glume, kernel and panicle characteristics; (3) and to determine the relationship between bug abundance and damage, pathogen infection, grain deterioration and food quality. This report covers

experiments conducted during the second year of the collaborative program.

Preliminary Screening Trial

A second-year screening trial evaluating 89 sorghum lines was conducted to replicate the screening trial conducted in 1989 when 100 sorghum lines were evaluated. Phenotypic data collected included panicle configuration, glume length, and grain color. Bug abundance was based on a sample size of five panicles per entry from two replications. At milk stage, a visual rating assessment of bug damage and pathogen infection was made. Other parameters measured included: kernel vitrosity, 1000 kernel weight, % germination, and number of floating kernels in a $NaNo_3$ flotation test. Comparisons were made between sorghum panicles that had been protected from bug infestation using bags, and panicles that were unprotected from natural bug infestation. Bug abundance in 1990 was less than in 1989. Of the 89 sorghum lines, 39% rated low levels of damage (rated 1 or 2). Data from this trial and the one conducted in 1989 were used to determine the existence of a correlation between bug damage and pathogen infection. These correlations proved to be positive. Table 2 presents data that illustrate this positive relationship.

Table 2. Damage distribution of panicle-feeding bugs and pathogen infection in 1989 and 1990.

	No. of entries				Relative frequencies			
	1989		1990		1989		1990	
classes	Bugs	Path.	Bugs	Path.	Bugs	Path.	Bugs	Path.
1-2	15	8	39	66	0.16	0.09	0.44	0.74
2-3	20	34	41	22	0.22	0.37	0.46	0.25
3-4	22	36	5	1	0.24	0.39	0.06	0.01
4-5	35	14	4	0	0.38	0.15	0.04	0.00
CV	92		92		89		89	
	6.69		9.02		16.92		25.48	

Correlation analysis was also performed on the number of bugs and visual damage, and between visual damage and the other measured parameters. Bug abundance was strongly and positively correlated to kernel damage (R = 0.74). Bug damage was negatively correlated to kernel vitrosity and germination, especially among the more susceptible entries. The number of floating kernels was positively related to head bug damage. From the two years of screening, nine sorghum lines (Table 3) appeared to be resistant to panicle-feeding bugs. These lines had damage ratings equal to or less than Malisor 84-7, the resistant check.

Interaction between Bug Damage and Pathogen Infection

The purpose of this experiment was to determine the relationship between bug damage to kernels and pathogen infection. There were four treatments: protection with a fungicide (Benomyl); protection with a plastic bag; protection with a plastic bag and fungicide; and natural infestation without any protection. Fungicide was applied three times.

Table 3. Bug abundance and visual damage ratings of the nine most resistant sorghum lines compared to Malisor 84-7, 1990.

Sorghum	No. bugs/ 5 panicles	Visual bug damage rating
Malisor 84-7	79 ± 97	2.3 ± 0.35
87-SB-F4-5-5	188 ± 262	2.0 ± 0.00
IS16357	454 ± 627	2.5 ± 0.71
IS2074C	75 ± 5	1.0 ± 0.00
IS21468	23 ± 26	2.0 ± 0.00
IS21525	52 ± 70	2.0 ± 0.00
IS27477	138 ± 189	2.0 ± 0.00
R6078	110 ± 47	2.3 ± 0.35
E [illegible]AR-1	90 ± 26	2.0 ± 0.00
1082 SEL. grain dur	57 ± 47	2.0 ± 0.00

Bug abundance was determined from a sample of five panicles per plot 14 days after anthesis. At maturity, bug damage and pathogen infection was visually rated, and weights of 200 kernels and the number of floating kernels in a $NaNo_3$ was determined. Bug infestation was uniform, but low, with 24 to 48 bugs per five panicles. Differences in level of bug damage to fungicide protected panicles and unprotected panicles were not apparent (rated 2.5 and 2.9, respectively). However, pathogen infection was greater on unprotected than on protected panicles (rated 1 and 2.4, respectively). Correlation coefficient of bug damage to pathogen infection was only 0.313, likely due to lower than normal humidities. However, kernels from unprotected panicles had 53.7% floaters, while kernels from protected panicles had 2.9 - 4.6% floaters.

Evaluation of a Simple Screening Method

Twelve sorghum lines were used to evaluate a simple panicle-feeding bug screening method in a split-plot designed experiment with three replications. The 12 sorghum lines received the following treatments: (1) natural infestation; (2) protection from bug infestation using a constructed cage; (3) protection from bug infestation using pollinating bags; and (4) protection from bug infestation using an insecticide (diazinon). Observations made and data collected were similar to previously described experiments. *Eurystylus marginatus* was by far the most predominant bug species. The sorghum variety El Mota Gami was the most severely damaged entry and most highly infested (704 bugs/5 panicles in 1989 and 343 in 1990). Bug population dynamics showed two peaks in abundance, the highest in September, and a lesser one in October. In 1990, all varieties except SC283 had visual damage ratings of less than 3. However, there was noted variability in the relationship of bug damage and kernel vitrosity, kernel weight, number of floater kernels, and pathogen infection. Some sorghums are severely damaged even when bug infestation levels are fairly low, while other sorghums are not severely damaged when bug infestation levels are fairly high. In any case, vitrosity, kernel weight, % floating kernels and pathogen infection was lower when panicles were protected than when they were not, regardless of method of protection. However, there are differences in the ease of use of the

various panicle protection methods. The use of pollinating bags is inconvenient, and the use of constructed cages is not very practical. The use of an insecticide to protect panicles did not completely protect panicles from bug damage. Pollinating bags provided the best overall protection.

Grain Quality Studies

Parboiling Trials at Cinzana

The parboiling procedure was changed to steeping overnight followed by bringing to boil and sun drying. This was done to conserve energy and time, and to reduce costs. Cooking trials were conducted at Cinzana with local women. Nearly 100 kg each of an improved Malian variety and a local Kenienke variety were processed. The dried grains were dehulled using an Engleberg type dehuller. Then they were broken into medium and small size particles using a plate mill.

Two sorghum varieties were used in the study: Malisor 84-7 and a local variety Banidoka. After parboiling, dehulling and crushing the grains, small particles were used to prepare foyo (couscous), and medium brokens were used to prepare "riz au gras", a rice type product prepared with a tomato sauce. Then the products were presented to a group of 20 panelists to evaluate taste, cohesiveness and general acceptability. Dehulling yield, cooking duration and volume increase were also determined.

The panel test (Table 4) indicated that the volume increase, product cohesiveness and general acceptability of couscous and riz au gras from the parboiled medium size particles was better than the control. However, the cooking time and product taste were better for the control.

Table 4. The cooking and organoleptic characteristics of "riz au gras" prepared from medium particles of sorghum.[1]

Product	Volume increase %	Cooking time (min)	Product taste	Product cohesiveness	General acceptability
Malisor:					
parboiled	300	45	1.90	1.00	1.45
control	150	25	1.90	2.00	1.55
Banidoka:					
parboiled	300	40	1.70	1.00	1.35
control	150	28	1.20	2.00	1.60

[1] The mean of observations by 20 village women. Each panelist was asked to indicate which sample was best by assigning a 1.0. The comparisons were made only within a variety to compare parboiled versus nonparboiled samples.

The small particles from parboiled sorghum had the best characteristics for couscous production, except that the cooking time was longer. The yield of cooked material was significantly more (Table 5) for organoleptic characteristics of couscous prepared with small particles of parboiled and nonparboiled sorghum. The increase in volume of parboiled sorghum is an important factor because a given weight of parboiled sorghum could feed significantly more people than nonparboiled sorghum. The preparation of couscous is time and energy intensive. Production of couscous via parboiling could be economically feasible and could diversify available sorghum products. For example, a precooked couscous from fonio is currently prepared by a local business, but it is very expensive.

Table 5. The cooking and organoleptic characteristics of couscous prepared from small particles of sorghum.

Product	Volume increase %	Cooking time (min)	Product taste	Product cohesiveness	General acceptability
Malisor:					
parboiled	300	60	1	1	1
control	150	45	2	2	2
Banidoka:					
parboiled	300	60	1	1	1
control	150	55	2	2	2

Effect of Parboiling on the Characteristics of Pearl Millet Grains

Eleven varieties of pearl millet grown at Cinzana, Mali were parboiled using the steep-cook-dry procedure. After washing the grains, they were steeped in water overnight, cooked and sundried. Dried grains were dehulled using the TADD for 5 minutes. Dehulled grains were produced using a Magic Mill to obtain small brokens that were used to prepare "foyo" (couscous). Grain dehulling yield, water uptake after cooking, cooking time and product cohesiveness were evaluated.

Parboiling significantly enhanced dehulling yields, water uptake and product cohesiveness (Table 6). However, cooking time was less for the nonparboiled grains. There was no significant interaction between varieties and treatment for water uptake and cooking time, but there was a highly significant interaction for dehulling yield and product cohesiveness. Millet varieties with the softest texture responded the most to parboiling. The parboiled milled products did not develop mousy odors, but they do undergo oxidative rancidity over time. The aroma can be dissipated by aeration of the grain, which is a common practice in Mali. The parboiled particles were darker than the control particles, but the cooked parboiled particles become much lighter in appearance. The opportunity to produce parboiled fractions for use as couscous is excellent. The production of couscous is tedious and time consuming, and energy consumption is high. Optimization of fractions from parboiled sorghum or millet for couscous production is particularly promising. Village trials were conducted with women's groups in Sikasso and Koulikoro where the parboiled products were well liked. Unfortunately, no further feedback is available at this time.

The trials in Cinzana showed clearly that the Malisor 84-7 parboiled products were better in terms of color and appearance than the local variety. The tan plant color of Malisor 84-7 and the lack of kernels with pigmented testa improved the color significantly over the local which had

Table 6. The effect of parboiling pearl millet on milling and couscous properties of fine particles.

No.	Dehul. yield %		Water uptake (ml)		Cooking time (min)		Product Cohesiveness	
variety	Parb.	Cont.	Parb.	Cont.	Parb.	Cont.	Parb.	Cont.
1	74.8	67.7	405	286	70	59	1.0	2.0
2	81.9	76.7	402	277	70	60	1.0	2.0
3	73.0	67.4	402	295	70	60	1.0	2.0
4	78.2	71.2	377	280	65	55	1.5	2.0
5	79.2	56.9	385	275	65	57.5	1.0	2.0
6	73.9	68.3	390	283	65	52.5	1.0	2.0
7	80.4	77.2	395	277	65	57.5	1.5	2.5
8	76.7	74.5	392	280	70	60	1.0	2.0
9	79.6	76.7	425	282	70	60	1.0	2.0
10	78.3	73.4	380	272	65	55	1.2	2.5
11	77.2	71.0	380	280	65	52.5	1.2	2.0
Mean	77.6	71.8	394	281	67	57.2	1.1	2.1
CV%	2.0		2.9		3.5		6.6	
Signific.	HS		HS		HS		HS	

off-colored kernels because of contamination with a pigmented testa and purple glumes. To make a good high quality product, sorghum with tan plant color will be necessary. Otherwise, quality will suffer. This is illustrated in Table 4 where the parboiled product from the local sorghum, Bandoka, was ranked slightly less acceptable compared to the nonparboiled product.

Laboratory Evaluation of Samples from the Crop Improvement Program

Grain quality research continues in Mali in the Food Technology Laboratory to improve methods of selecting sorghums and millets for tô quality. Nearly 400 sorghum and numerous millet lines and varieties from Malian breeding programs were evaluated for kernel characteristics, physical properties, decortication characteristics and fresh and stored tô properties. A laboratory dehuller is used to provide decorticated grain for tô tests when small quantities of grain are available and a mini tô test is performed on the flour. Potential cultivars and lines are compared with local cultivars for texture and keeping properties. For advanced materials, larger samples are milled and cooked into tô.

Milling and Tô Properties of Grain from the IFSAT Trial Grown at the Cinzana station

Thirty-nine samples of sorghum were analyzed for endosperm texture, grain dehulling yield, thousand kernel weight and tô quality. Almost all the samples had floury kernels with low dehulling yield and poor tô quality. Only 11 entries had dehulling yields higher than 70% which is considered to be a minimum acceptable yield. The kernel texture varied from 2.86 to 4.60. Thousand kernel weight varied from 11.5 to 21.3 g. Dehulling yield varied from 37.7 to 79.8%. Tô consistency varied from 8.75 to 18.25 mm. The samples that were heavily damaged by head bugs and mold had very low dehulling yields and sticky, soft tô.

Millet Grain Evaluation

Grain of 44 varieties of millet grown at Cinzana were analyzed for thousand kernel weight, shape, dehulling yield and tô quality. In general, the grains were round and elongated. Grain dehulling yield was high and tô consistency was good for most of the samples. The dehulling yield varied from 66.8 to 86.0%. The thousand kernel weight varied from 9.3 to 18.3 which is very high for pearl millet.

Agronomy Studies

Agro-Physiology

Malian graduate students Sidi Bekaye Coulibaly and Siriba Dione neared completion of their M.S. requirements in stress physiology at the University of Nebraska. The research of Mr. Coulibaly was concerned with some physiological characteristics of sorghums related to drought resistance. In summary, he found in growth chamber and greenhouse studies that high day temperature, 36/22°C, (day/night) stimulated growth relative to plants grown at a cooler temperature (28/22°C), when water was freely available. The greatest total leaf area was obtained in both environments by Gadiaba, a sorghum originating from a stressful region of sub-Sahara Mali. The mean leaf area increased 36% in the higher temperature, and photosynthesis increased 31%. Plants conditioned to the higher day temperature had increased cellular heat tolerance. Water stress combined with high temperature further increased heat tolerance. Osmotic adjustment was a major mechanism for adaptation to drought stress. The genotypes originating from Mali had greater osmotic adjustment than other sorghums measured. Leaf proline increased with water stress, but, when combined with high temperature proline levels declined.

After water stress was relieved, the stress tolerant Malian landraces resumed growth more rapidly than the other sorghums, indicating less metabolic injury during the stress.

Water stress promoted increased root length, reduced plant height, and decreased internode length. There was only a slight decrease in number of main roots.

Mr. Dion's research was concerned with abscisic acid involvement with sorghums grown in stressful conditions; his thesis is nearing completion.

Nutrient Deficiency and Toxicity Studies - Cinzana Station

Studies were done in field plots and pots to define the nature of poor early sorghum growth in sandy soils of the Cinzana Agronomic Research Station, Mali (West Africa). This problem appears as a marked spatial variability in crop establishment, growth, and yield within a single field. At the Cinzana station, it has developed into a special sorghum problem in sandy soils. Sorghum seedling emergence is, in

general, uniform throughout the field. Then, one to two weeks after emergence, the symptoms develop in areas irregularly distributed in the field. The plant symptoms of poor early growth appear as purpling of the leaves, leaf yellowing, and death of the leaf tip. In extreme cases, seedlings become completely brown. The roots show necrotic spots, and do not grow below the first 10 or 15 cm of topsoil. Plants in the most severely affected areas eventually die, leaving large areas of soil surface completely devoid of vegetation.

Previous studies have indicated that P deficiency and Al toxicity were major factors limiting sorghum growth and yield in Grossarenic and Plinthic Paleustalfs of the Cinzana station. Several sorghum genotypes were grown in soils treated with lime, manure, and rock phosphate. These studies initiated in 1990 were repeated in summer of 1991 to obtain a second set of data.

Data collected in 1990 showed large variabilities in stand establishment and crop growth within most experimental units. In addition, marked variabilities existed between replications for most data collected. However, the percentage of planting hills displaying symptoms of poor early sorghum growth was less than 23% in any of the experiments.

Data for 1991 were not consistent with what was observed in 1990. Symptoms of poor early plant growth were displayed by more than 86% of the plants within each of the soil treatments (lime, manure, and rock phosphate). In the genotype experiment, variability in stand establishment was very pronounced within experimental units. In addition, seedlings with purple leaves (77%) were observed only on Babadia Fara, a genotype which did not show any leaf purpling in the 1990 evaluation studies.

To attempt to resolve the inconsistency in the data, selected treatments will be analyzed for change in soil properties and concentration of selected nutrients in plants. Then incubation studies involving various soil moisture and temperature levels using selected soil treatments will be initiated.

Effect of Fertilizer Levels on Sorghum

Two experiments were conducted in Mali by Mr. Abdoulaye Traore which were related to N management and subsequent influence on N use efficiency of selected sorghum genotypes. Complete data did not arrive in time to be included in this report, but the following summarizes this research.

The first experiment compared an improved and a local genotype over three levels of N fertilizer (0, 50, and 100 kg/ha N), applied either all at tillering or all at panicle initiation at two locations. The results showed that the local variety had a higher grain and dry matter yield when no N fertilizer was applied. This observed interaction confirmed earlier demonstrations that local types can outperform improved types under low management (see INTSORMIL 1991 Annual Report, pp. 27-34).

A second experiment was also conducted at multiple locations to compare a "local" variety to improved varieties S-34 and ICSU 1063 at four different N rates (0, 40, 80 and 120 kg/ha N). Similar to the former experiment, a variety by N rate interaction was detected. In this instance, the "local" variety produced more grain and total above ground dry matter at the low N rates, and also more total biomass at the high N rates because of the large amount of stalk material which this variety produces. The results of the N chemical analyses are pending, but the experiments tend to support the contention that use of improved sorghum genotypes in Mali can only be effective if an improved management package is included.

Adama Coulibaly is completing his M.S. degree under the direction of Dr. Richard Vanderlip, KSU-106. (Modeling millet and sorghum establishment and growth and sustainable crop production.) He is characterizing tillering responses of a wide range of genotypes including CSM 63, a Malian variety. He has found that tillering can be related to growth rate and the relationship depends on temperature. Adama will be returning to the Cinzana station after he completes his M.S. Degree.

Institution Building

Support to purchase supplies and equipment enhanced the ability of IER to expedite the research program.

Several students are training at INTSORMIL institutions. Mr. M. Doumbia, soil fertility, returned to Mali to collect the second year of data for his Ph.D. thesis research on the soil toxicity problem at the Cinzana station. This work is funded jointly by TROPSOILS and INTSORMIL. Sorghum cultivars are being screened for response to soil toxicity.

Mr. A. Toure, a Ph.D. candidate in sorghum breeding at Texas A&M, has been producing crosses between Malian and exotic lines. He has grown some of the progeny in Mali and will have good germplasm to return with him to Mali. These crosses are designed to produce sorghums with resistance to head bugs and mold.

Mr. O. Coulibaly initiated study for a Ph.D. in agricultural economics with Dr. J. Sanders at Purdue.

Mr. A. Coulibaly is working on a M.S. in agronomy at Kansas State University. Mr. S. Coulibaly completed his M.S. and returned to Mali. Mr. S. Dione and Mr. A. Toure are finishing M.S. degrees and will return to Mali soon.

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

all of Africa and other areas of the world. Head bug and drought research are common to West African areas. CRAD has a research project in the Food Technology Laboratory on grain quality. The effective close working relationship between the Food Technology Laboratory and the Malian breeding and agronomic programs continues to provide useful, timely information.

Dr. M. Traore and Dr O. Niangado serve as Chairmen of the Steering Committee of the West and Central African sorghum and millet research networks respectively. Ms. Haidara of the Food Technology lab reviewed projects on composite flour in Nigeria for the network. Dr Y. Doumbia and Dr. G. Teetes received the OPAU/SAFGRAD award for research at the West African sorghum meeting in Niger.

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. During INTSORMIL training, these scientists see the benefits reaped by U.S. scientists through association/interaction in the sorghum improvement committee of North America. The development of regional workshops and field days in African regions is positive.

The ICRISAT West African regional program for sorghum in humid areas of West Africa located outside Bamako provides an opportunity for interaction with the regional program in West Africa. Collaboration on insects, disease, and quality continues. For example, the IER Food Technology laboratory has evaluated WASIP samples for dehulling and tô quality.

Training

Mr. N. Teme, IER, sorghum breeding technician, Cinzana, trained with Dr Rosenow's breeding project at Lubbock from July to September 1990. His training included field trips to nurseries in south Texas, College Station and private seed companies. He met other sorghum scientists and participated in all aspects of sorghum crossing, etc., at Lubbock.

Ms. Darisso, IER entomologist spent three months with Dr. G. Teetes' program at Texas A&M where she conducted a series of trials on the effect of sorghum kernel development on insect attack. She was sponsored by OAU.

Several students are being trained in INTSORMIL institutions in agronomy, plant breeding, and physiology.

Travel

INTSORMIL travelers to Mali included Dr. L. W. Rooney, food scientist, Dr. D.T. Rosenow, sorghum breeder, Dr. G. Teetes, entomologist, and Dr. R.A. Frederiksen, pathologist from Texas A&M University, and Dr. C. Sullivan, physiologist, Dr. J. Maranville, agronomist, and Dr. S. Mason, agronomist from the University of Nebraska. Dr. M. Goita, Director General, Dr. M. Traore, physiologist and Mr. K. Traore, sorghum breeder, IER, traveled to Corpus Christi, Texas to participate in the INTSORMIL PI conference. Dr. Traore traveled to the University of Nebraska and Texas A&M University. Mr. Bill Stegmeier, millet breeder, conferred with the Malian millet improvement team and developed plans for collaborative work.

Research Accomplishments

INTSORMIL has been in Mali informally since November of 1979. A formal Memorandum of Understanding was signed in 1984. The program has always closely interacted with ICRISAT-Mali, TROPSOILS and IER. USAID-Mali has supported small allocations of funds to sponsor various activities. Some of the accomplishments are:

INTSORMIL has provided short term and graduate training for several key Malian scientists. The INTSORMIL coordinator, Dr. M. Traore, completed a Ph.D. degree in physiology at the University of Nebraska. Scientists trained in food technology, pathology, breeding, physiology and agronomy have returned to Mali and collaborate in the program.

Six graduate students are training in INTSORMIL universities to provide personnel to continue the programs. The programs include agronomy, breeding, physiology, economics and soils.

Technical assistance to develop the Cinzana station, to map the soils, and obtain detailed physical and chemical analysis of the soil profiles has been provided by INTSORMIL. Equipment and short term consultants were supplied to establish and install sprinkler systems, to initiate screening procedures for drought tolerance and research at Cinzana.

Germplasm from U.S. breeders and the sorghum conversion program has been incorporated into the Malian breeding programs. Testing in Texas and Mali has demonstrated that the drought response in Mali is similar to the drought response in west Texas.

Sorghum and millet postharvest technology systems in Mali were documented in 1979 and strategies for evaluating the quality of cereals, especially sorghum, for thick porridge (tô) were devised. Mini tests for evaluating milling and tô properties were developed and currently are used in the laboratory. Equipment for the new Food Technology Laboratory was provided and personnel were provided short term training programs in the U.S.

Sorghum dehulling properties were defined by combined village trials in Mali and laboratory work in the U.S. Sorghum with hard endosperm and thick pericarps was definitely required for efficient traditional hand pounding.

Pearl millet quality is affected most by variation in dehulling characteristics. The size and shape of pearl millet affects dehulling properties significantly. Some pearl millets, especially the souna types, have reduced yields of decorticated grain. Tô quality of millet cultivars does not vary as much as it does among sorghums.

The adverse effect of head bugs on food quality of introduced sorghums was first generally recognized in Mali. Head bugs reduced sorghum milling yields and produced tô with unacceptable texture and keeping properties. The grain is difficult to dehull because the endosperm is partially degraded.

Parboiling can convert sorghum and millet into acceptable products. It improves dehulling yields, especially for soft grains. The cooked milled products can be eaten like rice. Cost of processing may limit its use.

Progress has been made to determine factors affecting the "soils problems" in Mali through joint INTSORMIL/TROPSOILS collaboration. Some "dune varieties" originating in Niger are tolerant.

Seven improved sorghum lines from the Malian program have been released. These Malisor lines (1 to 7) have different maturities and characteristics for the different regions of Mali. Malisor 84-7 has shown some advantages in multiple cropping systems. Malisor 84-7 has tolerance to head bugs which can be genetically transferred to its progeny. Some Malisor F_4 derivatives appear to have tolerance to head bugs. Head bugs and molds combine to cause devastating losses in grain yield and quality of most introduced types. Resistance to head bugs and molds appears to be inherited independently, although in Mali, under natural conditions, they appear to be inherited together.

Two improved local Malian sorghum cultivars, CSM 388 and CSM219 are being grown by farmers over a significant area. These are photosensitive types with hard grain, good food quality and stable, slightly higher yields.

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.

Millet and sorghum genotypes vary in ability to emerge through soil crusts. A soil crust breaker designed at ICRISAT has effectively enhanced the stand establishment of sorghum and millet.

Niger

John D. Axtell
Purdue University

Coordinators

Mr. Ouattara Mamadou, INTSORMIL Niger Host Country Coordinator (INRAN)
Mr. Jika Neino, INTSORMIL Niger Host Country Coordinator (INRAN)
Dr. John D. Axtell (U.S. Coordinator), Department of Agronomy, Purdue University, West Lafayette, IN
Katy G. Ibrahim, Administrative Assistant, Purdue University, West Lafayette, IN
Susie Clark (Host Country Coordinator), Administrative Assistant, Niger

Collaborative Program

Organization

There are several interdisciplinary activities involved in the INTSORMIL/INRAN/Niger Collaborative Research Program. Those include sorghum and millet breeding, agronomy, pathology, physiology, food quality and economics.

The INRAN Director General, Sahadou Bawa, 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, will be negotiated next year as the in-country administrative assistant will be leaving her post in 1992.

Collaboration with Other Organizations

Purdue/Niger Applied Agricultural Research (NAAR) Project USAID/Niger

Institut National des Recherches Agronomiques du Niger (INRAN)

TROPSOILS
ICRISAT Sahelian Center
Ministry of Rural Economy (DECOR)
Agricultural Research Corporation (ARC), Sudan
University of Nebraska
Kansas State University
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 Messrs. Jika Neino and Ouattara Mamadou as host country coordinators for this project.

Research Programs

Millet Breeding

Diversity, Combining Ability, and Heterotic Patterns among African Pearl Millet Landraces

B. Ouendeba, G. Ejeta, W.W. Hanna, W. Nyquist, and A. Kumar

A major study in millet breeding was completed this year by Dr. Ouendeba Botorou in collaboration between INRAN, Tifton, Georgia, ICRISAT and INTSORMIL.

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is a drought tolerant crop that is widely grown in the dry Sahel zone of sub-Saharan Africa and in the semiarid regions of northwestern India. African pearl millet landraces average grain yields of 500 kg ha -1 or less. This low productivity is due to inherent low yield potential, poor soil fertility, low rainfall, and high temperatures during the growing season. In India and the United States, most of the breeding procedures used in pearl millet are aimed at maximum exploitation of hybrid vigor for both grain and forage yields. Characterization of widely cultivated local African landraces and knowledge of their heterotic patterns and combining ability would be useful in the development of a sound breeding program.

Ten pearl millet landraces cultivated south of the Sahara (Senegal, Niger, Nigeria, Uganda, and Sudan), were evaluated during the 1989 crop season in two locations in Niger (West Africa). Five of the 10 pearl millet populations were used in a diallel cross to determine heterosis values and combining ability estimates. The five pearl millet landraces and their crosses were evaluated in a randomized complete block design in Niger (2 years, 2 locations) and Tifton, Georgia (1 year, 1 location). They were also evaluated for forage production and *in vitro* digestibility in Tifton, Georgia. Thirteen morphological and agronomic characters were measured on the 10 pearl millet landraces evaluated in Niger in 1989.

Entries were significantly different for all characters evaluated. Ward's cluster and principal component analyses

were used to investigate the nature and degree of divergence in the pearl millet populations. The cluster analysis revealed similarities between Niger and Senegal, and between Niger and Nigeria pearl millet landraces. Four principal components were found to explain more than 90% of the total variation. Flowering time, plant height, stem diameter, spike length, and yield seemed to be major sources of diversity among the cultivars.

In the diallel cross study, analysis was performed on all 13 characters across locations and years. Griffing's Method 4, Model 1 was used to estimate general and specific combining ability effects. Significant differences among entries for most traits were observed. Higher-parent heterosis for grain yield ranged from 25 (Iniari x Ugandi) to 81% (Mansori x Ex-Bornu) and from 38 (Mansori x Ex-Bornu) to 88% (Mansori x P3Kolo) in Niger and Tifton, respectively. P3Kolo and Ex-Bornu were the best combiners and their cross had the highest grain yield in Niger and Tifton. In the two environments, mean squares for GCA were significant for most traits indicating the importance of additive gene effects for these traits. In the 1989 crop season (Niger), the 10 pearl millet populations were similar for all grain characters except for 1000-seed weight. In the set of experiments involving five parents and their ten crosses, parents had similar grain characteristics in Niger whereas in Tifton (Georgia), significant differences were observed among parents for seed weight, density, and hardness. Crosses also showed no significant differences for all grain characteristics in Niger. They differed significantly for 1000-seed weight in Tifton. In Niger, most of the crosses had significant midparent heterosis for seed weight. For seed size and density, the five parents used in the diallel cross responded differently to environmental changes (Niger and Tifton) whereas crosses had similar response in both environments for all the traits except for seed size. The forage study revealed that differences in means of dry matter production between crosses and parents were greater in 1989 than 1990. The average heterosis values for dry matter production were 37.3 and 1.2% in 1989 and in 1990, respectively. Parents and crosses had similar digestibility levels.

The results on diversity analysis, heterosis and combining ability estimates should be useful in choosing pearl millet landraces for intercrossing in the development of cultivars with improved grain or forage yield.

Sorghum Breeding

Breeding Sorghum Cultivars Possessing Good Resistance to Drought, *Striga*, and Acceptable Grain Quality

Issoufou Kapran, Gebisa Ejeta, John Clark, and John Axtell

Sorghum is an important cereal crop in Niger. It is used mainly for human food dishes, but its stalks are also used as a source of energy, building material, and animal feed. Sorghum production is difficult however because none of the constraints it encounters have been successfully fought: frequent periods of drought, poor soils, low yielding varieties, diseases and insect pests, give an adequate picture of the situation. But the extent to which new agricultural technologies reach farmers also contributes to worsening the problem. Research to tackle the various constraints is conducted by INRAN, the national agricultural research institute, within which the varietal improvement program is at work to develop high yielding cultivars, adapted to local growing conditions, and having a good resistance to various stresses. Our breeding material comes mainly from local germplasm obtained through landrace collection trips, and from collaborating institutions like INTSORMIL or ICRISAT. We select the best and release them to Extension after a series of multilocal agronomic studies and socioeconomic evaluations; we also put together through hybridizations the two kinds of germplasm, aiming to increase our chances of success towards achieving the objectives cited above. Most of our work uses the method of pedigree selection, but we also practice population improvement through recurrent selection, and conduct a relatively small but successful hybrid breeding program. Our work on population improvement is region-oriented: the Kollo population (SPK) is intended for valley soils, the Tarna population (SPT) for sandy soils, and the *Striga* population (SPS) for regions like Konni where this parasitic weed is a serious threat to sorghum production. All germplasm in the pedigree selection and hybrid evaluation programs are tested in their early stages at Kollo and Tarna before the most elite get to advanced yield trials at the other locations in addition to the two above. But the INRAN sorghum improvement program also involves other specialists aside from breeders: they are plant pathologists working on long smut, *Striga*, foliar diseases; entomologists dealing with midge, head bugs, shoot flies; agronomists (*Striga*, studies of fertilization, optimum plant densities, dates of planting), food scientists and agricultural economists, all of whom work closely with the breeders. These areas deserve equal attention from INTSORMIL specialists. The present collaborative breeding program fits well with the goals of the INRAN sorghum breeding program; it was set from a common agreement between INRAN and INTSORMIL breeders, respectively Mr. Issoufou Kapran and Dr. Gebisa Ejeta, at the INTSORMIL meeting in Scottsdale, Arizona (January 1989). The agreement followed a field tour and discussions by the two collaborators in Niger (October 1988: trip from Kollo to Diffa, via Tarna and Magaria stations of INRAN). It gets support from other breeders, including Dr. John Clark (Purdue/PRAAN plant breeding coordinator), Dr. John Axtell (INTSORMIL/NIGER coordinator), and Dr. Darrell Rosenow (TAMU). Mrs. Susie Clark, INTSORMIL administrative assistant in Niger, provides very efficient support to our field activities.

In this report, we present the results of 1989 and 1990 crop seasons, dealing with the genetic material tested at Tarna, Konni, and Kollo.

Evaluation of the adaptability of pedigree material at Tarna (1989-1990) and Kollo (1990).

Rainfall was reasonably good at Tarna in 1989, both in amount and distribution. Under those conditions we evaluated 351 drought progenies (F_4-F_5). We were pleased with the great diversity exhibited by this material, which allowed us to correctly exercise selection. We looked for good panicle expression, grain quality, earliness, resistance to diseases and favored plants with medium height (1.5 to 2 meters). Some were uniform but in other cases we retained only one or a few heads. Good yielding entries with tan plants were also favored while susceptibility to long smut and foliar diseases led to rejection. Most entries were later than the local check Mota Galmi, but we rejected only extremely late ones. A total of 49 entries were thus selected, most of them having the pedigree (TX623xB35) xMR-732. This was in part due to our knowledge of the good performance of the hybrid TX623AxMR-732 in Niger, and of the good adaptation of the tan line MR-732 itself. On the other hand, many entries were rejected because of poor grain quality, the best example being the pedigree (TX623AxB35)xK1597 in which no single line was selected. Rejected entries were generally susceptible to foliar diseases, and we noticed this happens a lot more when K886, K1597, or B35 are in a pedigree. B35, planted in a nearby plot together with other drought lines, was indeed very susceptible to foliar diseases.

We also evaluated a group of 100 new R-lines, the 100th being however the well-known K1597. From field observations and on our list of choices, the best pedigree was TAM428xM62641. In this pedigree, plants are of medium height and maturity, have a good panicle expression and grain quality in most cases.

Last but not least, 323 F_3s sent by TAMU were split between Tarna (163) and Kollo (160). While Kollo lost all their material because of an important field flooding, those tested at Tarna had a normal growing season. Among them, lines of pedigree R8505xMOTA GALMI were very early maturing, while the opposite was true for MALISOR 84-7xM90318, which in addition had poor panicle exsertion. Most of the 163 F_3s had a poor yield expression, especially disappointing for those involving Mota Galmi. Only 33 heads were finally selected for next generation testing.

Selections from the above three groups of germplasms were evaluated during the 1990 crop season, again on sandy soil at Tarna, but for some also on valley soil at Kollo. The 1990 rainfall is presented in Table 1. It was a dry crop season, especially at Tarna where rains stopped for about 14 days at the end of August, and completely after September 7, when most entries were around their flowering period. Results of our observation nursery (COVLI) indicate that entries with pedigree TAM428xM62641 were the best ones, both at Kollo and Tarna. At the latter location, their drought and adaptations score ranged 1-3.5, while that of (TX623AxB35)xMR-732 F_6 progenies ranged 2-5. The standard was local variety Mota Maradi (score of 1), which we consider to be the most adapted variety to sandy field conditions such as found at Tarna. Varieties WSV387, and M90360, also obtained from Purdue University, had only medium drought tolerance. There were a few entries which performed well at Kollo but not at Tarna, their pedigrees being TAM428xK1597 (2), TX430xK22-35 (4), TX430xK1597 (1), and TX430xK443 (1). Other INTSORMIL entries were tested directly in a preliminary yield trial (EPVAI) at Tarna and Kollo, including nine of pedigree TAM428xM62641 and 33 coming from the group of drought F_4-F_5 progenies. In the latter, many had a bad agronomic appearance due to their lack of uniformity, poor panicle expression and grain quality, and an unexpected susceptibility to drought stress. Three entries of pedigree (TX623AxB35)xMR-732 were interesting at Kollo but not at Tarna. Pedigrees (TX623AxB35)xM90360, (TX623AxB35)xCS3541, GD82S-7xM91051, M91051xGD82S-7, had well-performing entries at both locations. But still the best pedigree was again TAM428xM62641, with good yielding entries on valley and sandy soil, good grain quality, and medium maturity. The set of 33 entries originating from TAMU's 1989 F_3s, were planted at Tarna only, but were less attractive and poor yielding. Only six were kept for 1991 preliminary trials: five of pedigree Malisor 84-7xSC1207-2, and one of pedigree Malisor 84-7xM90318.

In 1990, new entries were again received including nine F_2 populations from TAMU, while the PU sorghum breeding program contributed 43 SRN-39 progenies selected for yield potential and grain quality, a set of 31 entries to be evaluated under *Striga* infestation, SRN-39 hybrids (second year), WSV387, M90360, and the PP34 composite "food grain population". The 2-year results of the SRN-39 hybrids trial are reported separately below. WSV387 and M90360 were placed in the COVLI nursery as described above.

The set of TAMU's F_2s were planted very late (nearly one month after our first planting at the end of June) on sandy soil at Tarna, but many of them showed a remarkable adaptation potential and were reasonably early. One supplemental irrigation was needed for many entries to complete their cycle, but still we selected 81 panicles on the basis of their expression of yield potential, grain color, and absence of long smut. As with TAMU's genetic material in 1989, the best were not necessarily the ones with local varieties (Mota Galmi, Ngabiri Kime) in their pedigree. Among the parental lines, 87E0366, M50009, and Dorado, all tan plant varieties, were remarkably adapted, especially the first one.

Sorghum population PP34 "food grain population" was introduced from Purdue initially with the aim to start a new population for sandy soils at Tarna, by crossing elite Nigerien and introduced germplasm to it. PP34 appeared to be very well adapted, having a vigorous growth, early plants with medium height, good panicle exsertion, and large panicles with good grain quality. We selected only 79 fertile panicles for S_1 testing in the next crop season.

Forty-three advanced lines of pedigree SRN-39xP954063 were grown at Tarna for adaptation and yield evaluation. The two parents in the pedigree as well as three other checks were placed in the same trial. Unfortunately, these lines showed only a medium drought tolerance in general, despite their stay-green character, and many were susceptible to grain mold. We selected the five best yielders for a preliminary yield trial in 1991.

Striga Infestation

Test under Natural *Striga* Infestation of SRN-39 and Its Various Progenies at Konni (1989-1990)

Issofou Kapran, Gebisa Ejeta, John Clark, and Larry Butler

We now have two years data on the SRN-39 hybrids tested under natural *Striga* infestation at Konni. During both years, the trial was planted late because of the late arriving rains, and there was a serious midge problem. Drought, however, was more important in 1990 than in 1989. Tables 1 and 2 summarize the striking features of this trial. Analyses of variance and mean separation test (lsd) were conducted separately for the two years, and results show significant differences between entries for agronomic data (grain yield, maturity, plant height), but not for the number of *Striga* plants. This latter aspect does not reflect real differences observed in the field however; we think that *Striga* counts are not efficiently analyzed by the usual ANOVA test. Hybrids were slightly earlier maturing and showed a better yield average than their parents during the two years (in 1989, 3 t/ha vs 1.8 t/ha; in 1990, 0.6 t/ha vs 0.4 t/ha); hybrids were also taller (in 1989, average height of 1.97 m vs 1.23 m; in 1990, 1.7 m vs 1.1 m). Here also the picture is not so clear when it comes to number of *Striga* plants, even though individual entries showed some pattern. Hybrids with female parents Wheatland, Redlan, and IS10360 (Table 1) were the top yielders both in 1989 and 1990, and except for the first one at the second count of 1990, they each had few *Striga* plants. On the other hand, the hybrid A35xSRN-39 was a poor yielder in both years and had *Striga* plants like the susceptible check CK60. However, parents B35 and SA3042A, while being poor yielders, did not have a large number of *Striga* plants. The hybrid CK60AxSRN-39, cross of a susceptible by a resistant variety, was agronomically better than its two parents during the two years. Looking at the data on *Striga*, it was much closer to SRN-39 in 1989, but had more *Striga* plants than either parent in 1990. We think however that 1989 results were more reliable. Finally, more can be said about the agronomic data than about *Striga* infestation in this trial. It is well-known that natural *Striga* infestation may not be reliable; what worsened the problem here was the heavy drought of 1990, which probably affected emergence and survival of *Striga* plants.

In 1990, ten F_8s (SRN-39xP954063), five F_7s (FRAMIDAxP954063), and eleven F_6s (FRAMIDAxSRN-39) were tested under *Striga* infestation, together with the three parental lines and other varieties. *Striga* plants were counted twice during the growing season, and agronomic data were collected. Grain yield was low (average of 407 kg/ha), mostly because of drought and midge damage. The average number of days to flowering was 66 while height was around 1.4m. *Striga* plants were also few during the two counts (averages of 50 and 73 plants, respectively). The following entries, by ascending order, produced a grain yield average of 500 kg/ha or more: F8-1, SRN-39, F7-1, F7-4, F7-2, P954063, F8-7. SRN-39 had the smallest number of *Striga* plants at the first count (2) while Framida had 7; in between we have entries F8-3, F8-2, and F6-9, each with 3 plants. At the second count, SRN-39 had 17 plants and Framida had 11. The following entries had similar or fewer plants: F8-8 (16), F8-3 (11), F6-3 (5), F8-2 (4), F6-11 (4),and F6-9 (1). Three pedigree selections (F8-3, F8-2, and (F6-9) had few *Striga* plants at both counts, but none of them was on the list of best yielders, which may be due to the midge and drought problems mentioned above. We notice also that one of the top yielders, F7-4, was one of the most infested with *Striga* at both counting periods. Only varieties IS4225 and Mota Ja (local) had at the same time a high number of *Striga* plants and were among the least productive. All this tells us that due to great environmental influence, results of this trial lead to no definite conclusion. We hope to be able to test the same material in 1991.

An important aspect of our work on *Striga* concerns the agronomic study of variety by fertilizer treatments (factorial). It follows the conclusions of Hess and Ejeta (1987) who found that cultural practices could help to reduce the damaging effect of *Striga* (especially the application of 11kg/ha of urea affected *Striga* infestation and improved yield). In 1988 and 1989 we worked with INRAN agronomists and phytopathologists to study the importance of the varietal and fertilizer factors, the trial being conducted both on-station and farmers' fields, with two varieties and two fertility levels. Important conclusions were drawn, among them: the nitrogen treatment positively affected the agronomic performance of sorghum (earliness, better yield),but not *Striga* plants; the variety treatment was important for yield and *Striga* plants, the resistant SRN-39 being better yielding and less infested than the susceptible local Mota Ja; there was also an important variety by fertilizer interaction.

Finally, there are two aspects of this *Striga* research which should be reviewed because of their importance to the integrated approach we think is necessary. The first one is the *Striga* population work that was planned but the composite seed was unavailable. The population left by Dr. Hess appeared very unattractive and susceptible to diseases including long smut, and *Striga* infestation was not intense in the isolated plot we got in 1989-90 at Konni. We believe in the positive results attainable through recurrent selection and hope this aspect will be revived. The other aspect deals with a project discussed at the Scottsdale meeting, to include both millet and sorghum workers (breeders, phytopathologists, agronomists) on a joint study of the parasite. This

Table 1. High yielding entries and their *Striga* infestation level under natural field conditions at Konni (Niger) 1989-90.

1989 Description Pr. 1	Gr. yield (kg/ha) **	Pl. ht. (cm) **	50% flwr. (days) **	*Striga* early ns	Plants final ns
IS10360AxSRN-39	4722	213	56	0,3	5
WHEATLANDxSRN-39	4502	180	53	1,0	102
REDLANxSRN-39	4207	212	55	1,3	107
IS10610AxSRN-39	3600	200	54	2,0	93
TX623AxSRN-39	3183	212	58	0,7	146
Grand mean	2342	157	59	2,7	146
1990 Description Pr. 1	**Gr. yield (kg/ha) ***	**Pl. ht. (cm) ****	**50% flwr. (days) ***	***Striga* early ns**	**Plants final ns**
REDLANxSRN-39	1805	160	57	23	5
WHEATLANDxSRN-39	1284	160	68	55	520
IS10360AxSRN-39	1169	180	58	66	31
P954063	995	150	67	114	88
REDLAN	822	98	65	222	133
Grand mean	555	139	66	121	151

1 ns=non significant *,**=significant at the 99% and at the 95% level of probability, resp.

Table 2. Poor yielding entries and their *Striga* infestation level under natural field conditions at Konni (Niger) 1989-90.

1989 Description Pr. 1	Gr. yield (kg/ha) **	Pl. ht. (cm) **	50% flwr. (days) **	*Striga* early ns	Plants final ns
B-35	475	110	67	0,3	77
B-4	532	107	70	13,0	857
A-35xSRN-39	816	207	66	6,0	280
CK-60	1435	113	58	7,0	231
SA3042AxSRN-39	1603	120	50	1,3	97
Grand mean	2342	157	59	2,7	146
1990 Description Pr. 1	**Gr. yield (kg/ha) ***	**Pl. ht. (cm) ****	**50% flwr. (days) ***	***Striga* early ns**	**Plants final ns**
TX631AxSRN-39	81	178	70	127	98
B-35	98	122	76	5	81
TX623AxSRN-39	122	162	66	36	94
SA3042A	127	123	70	148	180
A-35xSRN-39	130	188	69	69	230
Grand mean	555	139	66	121	151

1 ns=non significant *,**=significant at the 99% and at the 95% level of probability, resp.

would deal with inspections in farmers' fields to evaluate *Striga* damage and collect different *Striga* strains, pot studies of their specificity to sorghum and millet, and field trials to verify the results of pot studies.

Cereal Quality

Moussa Oumarou, Issoufou Kapran, John Clark, Allen Kirleis, and John Axtell

The INRAN Cereal Quality Laboratory (CQL) has conducted a series of food trials in collaboration with the PU/INTSORMIL food quality specialist and with the INRAN sorghum breeders. The food trials were conducted in four different areas of Niger (Maradi, Konni, Gaya, and Tillaberi) with varieties SEPON-82, SRN-39, NAD-1 F1, and a local check. Tuwo made from these varieties was tested by a total of 160 people and scores were given. This work was complemented by laboratory analyses. Results show that the new varieties were quite well accepted by Nigerien consumers, which is to our satisfaction. In addition to this work, a Nigerien student working on his M.Sc. thesis in food sciences at PU conducted similar food tests with 16 varieties we produced at some of the previous locations in the spring of 1991 and will also conduct laboratory analyses of samples he collected.

The INRAN sorghum breeders also collaborate with their colleagues in phytopathology as mentioned above concerning *Striga*, and also concerning the study of resistance to long smut, this aspect receiving some support from INTSORMIL. To date, the phytopathologist is working on an

inoculation method, and screening for sources of resistance, and we are providing all the germplasm we have available including F_2s from crosses we made in 1990.

Soil Acidity and Crop Production

Evaluation of the Potential of Aluminum (Al) Tolerant Sorghum Hybrids, Lines, and Varieties Under the Acid Soil Conditions in Niger

Moussa Adamou, John Clark, Lynn Gourley and John Axtell

A new project is being initiated this year on soil acidity and crop production. Soil acidity is considered a major growth limiting factor for a number of crops including sorghum in many areas of the world. The majority of sorghums used by farmers are local landrace varieties with low yields. Most soils are sandy in texture and low in fertility. A long-term solution must be found for these soils, by developing sorghum tolerant to acid soil toxicities. There is a growing interest in Niger to consider an effective use of the sandy soil for some economically important cereals such as sorghum, yet only a few of the local sorghum varieties are grown on these soils. In crop production, the heterosis phenomenon of the hybrid being superior to its parents often means better stress tolerance than is found in open pollinated varieties. Results will be reported in the coming years.

Progress on Disease Management

Issoufou Kollo and Richard Frederiksen

Long Smut

In Niger, long smut caused by *Tolyposporium ehrenbergii* is one of the major constraints to the production of sorghum. Long smut has been present in Niger probably for as long as sorghum has been grown, however recognition of the disease as a problem dates back to the observations of Delassus Jouan in 1971. The studies reported here result from work done during 1988-1990 on the reaction of sorghum cultivars to disease, the vegetative cycle of sorghum and long smut severity and on the effect of sequential planting on the severity of the disease.

1. Screening of sorghum bicolor for reaction to long smut.

The objective of this work was to find sources of resistance to long smut and a methodology by which resistance to long smut could be used in a breeding program at Kollo. Kollo was selected because of the high frequency of natural infection.

From 75 cultivars screened, under natural conditions 11 were found to be resistant or moderately resistant based on a 0-4 scale with 0=0 sori per head, 1 = moderately resistant with >0 sori per head but <5. The most resistant cultivars were Terra, SC326-6, SC630-11E, BTx2775, Tx378, B8106, RTx7078, QL3, R9188, 87L3450, and 84C9408. The relation between date of flowering and incidence of disease was high, suggesting that all lines flowering early are subject to escape. All early maturing lines will need to be reevaluated probably by artificial inoculation to confirm their reaction.

2. Effect of date of planting on incidence of long smut.

To determine if the date of planting affects the reaction of sorghum to long smut and to determine if the disease is polycyclic.

In this experiment four cultivars were planted at three different planting dates. The cultivars were A4D4, Tehoulori, Sepon 82, and El Mota. The dates were not conclusive, however differences among cultivars depend on their date of planting. Early maturing cultivars had less disease at the first date whereas at later dates they had as much as the late maturing cultivars. Early maturing cultivars had increases in disease in each successive planting date.

Technology Development

The 1990 INTSORMIL Annual Report described the farm-level responses to new technologies and modified agricultural policies in two regions of the Sahelo-Sudanian zone in Niger. Early cultivars of cowpeas and millet are already being introduced into these systems. To make them sustainable systems, chemical fertilizer introduction is required. Otherwise the soil-mining process accompanying the decline and disappearance of the fallow system will continue. The report then examined in some detail the technology modifications and policy changes to introduce chemical fertilizer. There were some feasible modifications in the higher-rainfall zone, resulting in fertilizer introduction, but not in the lower-rainfall zone.

Then income/ha comparisons were made for the two regions with traditional and new technologies. With or without the new technologies, incomes were twice as high in the higher-rainfall zone (Table 3). Decomposing income differences approximately 60% were due to yield differences and 31 to 38% to price differences.

Technology development is a powerful instrument for increasing farmers' incomes in resource-poor regions, such as the Sahelo-Sudanian zone. However, with slightly more resources there is more response to new technologies. Strategies to focus crop technologies on areas with some potential for developing sustainable agriculture are necessary. In some regions the development of reforestation and improved grazing may be more appropriate. There already are movements in these resource-poor regions toward diversification as seasonal outmigration of most of the male workforce now occurs. Focusing crop technology on areas with more potential and facilitating the retreat from crop production in more marginal regions seems to be a more

Table 3. Comparison of expected net returns of dryland agriculture under different technologies at two sites in the Sahelo-Sudanian Zone, Niamey Region, Niger.

	Libore[a]	Kouka[b]	Ratio of net returns (per ha.)
	-----)US$/ha) -----		
Current practices:			
Millet/Cowpea intercrop	115	57	2.02
Improved cultivars (low density)	129	68	1.97
Improved cultivars (high density)	147	69	2.14
Improved millet/cowpea with fertilizer	175	76	2.30

[a] = Higher-rainfall zone of 570 mm annually. Closer and better access to the principal urban market of Niamey. Supplementary irrigation available of 0.4 ha/farm generally in improved rice cultivars with chemical fertilization.

[b] =Lower-rainfall zone of 430 mm. Only dryland agriculture. Further and poorer access to Niamey market.

Source: Shapiro, B.I., O. Coulibely, and J.H. Sanders, "Farm-Level Potential of Sorghum/Millet Research in Semi-Arid West Africa," Dept. of Agricultural Economics, Purdue University, West Lafayette, IN, 1991, p. 9.

efficient strategy than trying to utilize crop technology development to resolve all low-income agricultural problems.

Economic Evaluation of New Technologies

Maliki Kadi, Mahaman Issa, O. Zarifa, Akin Adesina, Barry I. Shapiro and John H. Sanders

Barry Shapiro, after finishing his Ph.D. thesis (Purdue, 1990) is now a principal economist at ILCA (International Livestock Centre for Africa) in Ethiopia. With farm-level modeling, he evaluated the income impacts and constraints to the introduction of early millet cultivars and of chemical fertilizer in two regions of Niger in the Sahelo-Sudanian zone. With his modeling he demonstrated farmers' adaptive strategies in response to weather conditions and considered various alternative strategies to introduce new inputs into these agricultural systems. One of his main conclusions was that presently farmers have other more favorable alternative investments rather than most types of new crop technologies. Hence, further development of technologies and policies is necessary to obtain sustainable agricultural systems. In some of these regions, this appears feasible. In other regions, a diversification out of crop production seems to be more appropriate.

Summary and Conclusions - Impact

A major study of pearl millet breeding strategies for Niger has been completed by Dr. Ouendeba Botorou. This study has important implications for Niger and other West African countries in the Sahel. Ouendeba concludes the following.

The results of the diversity and diallel cross studies indicate clearly that knowledge of the degree of similarity or dissimilarity among landraces is not sufficient when choosing the best parent for crosses. The population cross Ex-Bornu x P3Kolo gave the highest grain yield and a good level of heterosis even though the cluster analysis showed that the two cultivars had similarities for most of the traits measured. All crosses involving Ex-Bornu or P3Kolo had improved dry matter yields over their midparents but the differences were not significant. The cross Ex-Bornu x P3Kolo showed better dry matter yield when compared to their midparent. Crosses among African populations showed good forage yields at the first cut, indicating an early vigor growth compared to the checks used in the study.

Performance per se, heterosis in relation to both midparent and higher-parent performance, and GCA and SCA are key elements in choosing parents that manifest a large heterotic response in hybrid combinations.

To increase pearl millet grain production, one must bear in mind that the arid and the semiarid regions of Africa are characterized in general by poor soils, a poor supply of inputs, a low rainfall unevenly distributed, and low yielding genetic materials. To minimize the effects of such unfavorable growing environments, the development of cultivars with large genetic base, stable resistance to diseases and stable yields must be the goal of pearl millet breeding.

Senegal

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Collaborative Program

Support in the second year of the collaborative program between INTSORMIL and ISRA was funded by the Senegal Agricultural Research Project II from AID/Dakar, managed by Michigan State University. Work continued in the areas of dryland sorghum and millet breeding, and millet pathology at Bambey, and irrigated sorghum and millet breeding and millet agronomy in the Senegal River Valley at Fanaye in the summer (July-October) and at Thiago in the winter seasons (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 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 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 on finding economic solutions to maintaining soil productivity is 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 is interested in researching 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 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 116) were retained for retesting in 1990-91 on the Senegal River Valley. Some sorghum seed parents and selections from segregating populations were retained for rainfed conditions. 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. Plant population levels and alternatives to flooded bed irrigation were investigated in agronomic tests with pearl millet in the hot winter season in the Senegal River Valley.

Pearl Millet

Rainfed

Breeding. Thirty-six F_4 selections were retained from four of a number of Mali x Nebraska crosses supplied in 1988. It is interesting to note that all of the four crosses retained were 3-way crosses of the (adapted x adapted) x exotic type [(Mali x Mali) x Nebraska]. Synthetics are being created from selections from different crosses. In collaboration with the pathologist, 129 F_3 selections with resistance to downy mildew, grain smut and ergot were retained at Bambey and Nioro from Senegal x Nebraska crosses.

In 14 multilocation tests in farmers' fields over two years in the center-north of Senegal, varieties IBMV 8402 and IBV 8004 have averaged 12 and 11%, respectively, more than the local check average of 775 kg/ha.

Pathology. Downy mildew continues to be the major source of loss in local varieties and resistance is a principal factor in selection of breeding material. A diallel cross procedure involving susceptible and different sources of resistance to downy mildew grown in two locations over two years showed that resistance is primarily additively controlled.

Irrigated

Two variety tests were conducted on heavy soil at Fanaye in the summer season (planting in July) and two variety trials and two agronomy trials at Thiago (sandy soil) planting in February.

The two variety tests at Fanaye were again conducted on flat beds which are unsuitable for irrigated millet culture as standing water results, and the plant population level used in the dwarf variety test was insufficient. The average yield in the tall variety trial was 2280 kg/ha with IBV 8001 numerically top (2730 kg/ha). It was not significantly different from GB8735 (at 2500 kg/ha) which was intermediate in height and matured in 75 days as against 85. The average yield in the dwarf test was 2000 kg/ha. GAM 8201 gave numerically the highest yield (2600 kg/ha) but this was not statistically better than 68A x MLS at 2170 kg/ha. The latter was mature in 75 days as against 85 days for GAM 8201.

Winter season. Due to reconstruction of the fields and irrigation system at Fanaye, experiments were transferred to Thiago, where soils are sandy and easily drained. Planting was on February 14, 1991. The treatments in the agronomy test designed to counteract flooding in the basin irrigation system on the heavy soils at Fanaye were, therefore, inappropriate on the sandy soils at Thiago. The three soil preparation treatments, flat, ridges, and beds, gave essentially the same yields for both the genotype tests—hybrid 68A x MLS and dwarf variety IBV 8201 (Table 1). However, this trial, together with results from the fertilizer test, provided very interesting information, showing that dwarf genotypes, maturing in 75 to 80 days can give grain yields in the order of 4 t/ha in the hot dry season with a harvest index approaching 50%.

Table 1. Comparison of grain yields from three methods of soil preparation using two pearl millet genotypes grown with irrigation at Thiago, Senegal River Valley planted in February 1991.

Method of soil preparation	Variety yields 68A x MLS	GAM 8201	Average
	------kg/ha------		
Flat	3700	4970	4337
Ridges	4320	3150	3690
Beds	4150	3930	4040
Average	4020	4016	
SE	±363		±511

The effects of three levels of fertilizer were compared on the same two genotypes in the second agronomy test. There were no significant differences. The mean yield was 3900 kg/ha.

One tall and one dwarf variety test were conducted at Thiago, also planted on February 14. Significant differences were found in both trials. The main implications, however, came from the averages—that of the tall varieties taking 55 days to flower was 3300 kg/ha with the best variety giving 4500 kg/ha while the average yield in the dwarf test which averaged 46 days to flower was 5000 kg/ha with the best entry, a hybrid, giving 6300 kg/ha (Table 2).

Table 2. Performance of dwarf pearl millet hybrids and varieties grown with irrigation in the hot dry season at Thiago, Senegal River Valley, planted February 14, 1991.

Genotype	Days to 50% bloom	No. heads per plot	Plant height (cm)	Grain yield (kg/ha)
23DAE x 086	47	278	125	6360
PV379 x 57028	49	212	117	6030
68A x 086	42	263	116	5920
23DAE x 57028	47	327	120	5920
68A x N-MLS	44	293	118	5620
68A x MLS	43	305	118	5510
PV263 x 57028	45	246	113	5170
PV263 x 086	45	206	108	5100
68A x 57028	44	186	117	4950
PV414 x 086	44	170	111	4840
GAM8201	55	116	126	4840
NCD2	52	148	139	4810
CL. Pop.	48	156	114	4760
68A x CL. Pop.	45	219	120	4730
PV443 x 57028	45	200	105	4690
PV379 x 086	50	194	119	4650
68A x N-EDS	42	226	110	4580
N-MLS	45	177	118	4350
N-EDS	44	201	99	3830
PV414 x 57028	50	229	105	3130
LSD P = 0.05	2	62	12	1309

A palatability test was conducted on three representative genotypes—Souna III (the standard), GB8735 (a large seeded Togo type), and 68A x MLS (a dwarf hybrid). Scores for flour color and fineness, couscous color and taste averaged for the three varieties (on a scale of 1 = poor to 3 = best) 3, 2.5, and 2.5, respectively. Both new varieties were deemed acceptable.

Conclusion: Pearl Millet

The best opportunity for irrigated pearl millet production in the Senegal River Valley, vis-a-vis other crops, is in the hot summer season, planting in February. Use on lighter more sandy soils is indicated, where water control is less of a problem. Optimum fertilizer levels may be much less than expected. Future tests should concentrate on comparing irrigation frequencies and moderate levels of fertilizer application.

Sorghum

Rainfed, Breeding

INTSORMIL contributes to a part of the material under selection, variety and hybrid tests in the medium early maturing breeding program which contains numerous nurseries at the Bambey Center.

The season at Bambey was again characterized by low rainfall, 400 mm and prolonged periods of drought stress. In the medium to early maturing program 15 F_2 selections were retained from four out of 7 F_2's of Senegal x NE 115 crosses, and 28 F_4's out of four previous crosses. Thirteen lines from segregating populations sent from Nebraska were retained after three years of selection. In variety tests, the best variety was the Bambey variety CE 151-386 at 2130 kg/ha. Among hybrids, three hybrids from TAM-121 and TAM-122, A35 x CS3541, A1 x Karper 1597 and A1 x Tx435 gave yields which were 180, 171, and 158%, respectively, better than the check hybrid 612 x 75-1 at 2130 kg/ha. These plus hybrids Avar x Dorado, AOK 11 x Tx430, ATX623 x R9188 and Avar x 86E0631 were retained for further testing. However, the grain quality of these hybrids is classified as average compared to the existing varieties.

Senegal River Valley

Summer season (planting July). Two varieties, SDS3813 and 1231, gave yields equivalent to the check CE151-262 (3020 kg/ha) and were retained for further testing. Hybrids with INTSORMIL parents appeared in three hybrid tests. Hybrid N96A x 2673 gave significantly more yield (20%) than check hybrid 612 x 73-308 in the first test and N96A x CE151-262 gave a yield equivalent to the check (3500 kg/ha). In the second hybrid test Avar x 80C2241, A1 x RTX8505 gave yields equivalent to the check and in the 3rd test no hybrid was better than the check.

Cool off-season. Experiments were conducted at Thiago, due to the redevelopment of the experimental farm at Fanaye. Despite the delay in planting until the end of November (mid-October normal) good yields were obtained (3000-4000 kg/ha for varieties and 4500-6080 for hybrids). Three variety tests and three hybrid tests were conducted. Varieties Malisor 84-7, 1229 and 1279 gave yields as good as the check 75-14 (4390 kg/ha) and will be retested.

In a preliminary hybrid test, six hybrids exceeded the check yield (3950 kg/ha) by 30% or more. Hybrids A8 x R2241, A1 x Karper 1597, ATx631 x R3338wx, AVG1 x SC1207-1, A1 x Tx430, and AVG1 x TAM 428 were retained.

In the advanced hybrid test, hybrid A155 x RTX2817 (both parents from TAM-121 and 122) gave a yield significantly higher than the check. Other TAM hybrids also gave good yields (Table 3). In the final hybrid test, the combination of A1 x 75-14 gave a significantly greater yield (9130 kg/ha) than the check 612A x 75-14 (7680 kg/ha). It is of interest to note that the same pollinator 75-14, which is also the recommended variety for the cool off-season, was used in both hybrids. ATx631 x 75-14 also gave a good yield (8200 kg/ha) in this test.

Table 3. Performance of advanced sorghum hybrids, cool winter season 1990-91 at Thiago, Senegal River Valley, planted November 29.

Genotype	Days to 50% bloom	Plant height (cm)	Grain yield (kg/ha)
A155 x RTx2817	73	150	8180
A1 x R8508	73	130	7290
A155 x R8505	74	133	7210
A8610 x R8607	75	143	6480
ATx631 x 80C2241	77	138	6440
A8610 x R8504	77	138	6130
ATx630 x R3338wx	74	145	5860
612A x 75-14 (check)	65	158	5750
A155 x 80C2241	79	135	5520
A155 x R8504	75	138	4980
ATx631 x R8607	74	148	4860
Average	74	142	6240
S.E.	1.7	6.7	± 540

Conclusion: Sorghum

In the early maturing rainfed sorghum program no introduced variety has exceeded the existing varieties bred at Bambey, the best of which are CE151-382 and CE196-7-2-1. However, a number of selections are still under development from crosses with INTSORMIL stocks. The potential for hybrids in rainfed conditions is limited, however, hybrids with INTSORMIL seed parents showed some yield improvement over existing hybrids. Research in the two different seasons in the year in the irrigated conditions on the Senegal River Valley confirms both the high potential yield of existing variety CE151-262 in the summer season and the hybrids made with it, and other combinations. With the demonstration of good yields (4 t/ha from varieties, 25% more from hybrids) it has become urgent, as previously recommended to ISRA, to study the economics of sorghum production vis-a-vis other irrigated cereal crop options—rice and maize. The same essentially holds true for the cool off-season where similar high yields have been obtained, however, different genotypes are required. The advantage of sorghum hybrids in this season appears greater, with potentials of 6 t/ha.

Travel

Dr. Larry Claflin, pathologist, KSU, and David J. Andrews, pearl millet and sorghum breeder, UNL, visited Senegal in October 1990 and travelled to Bambey, Louga, and Fanaye (Senegal River Valley). The joint breeding/pathology work was reviewed and sorghum and pearl millet tests and breeding material evaluated and plans for further testing developed.

Future

In sorghum, selection and evaluation for rainfed conditions will continue at Bambey. Variety and hybrid work will continue in both seasons in the Senegal River Valley, some hybrids being made in Senegal with INTSORMIL parents.

Pearl millet tests will continue in the river valley and selection work at Bambey in rainfed conditions will be in collaboration with pathology to incorporate disease resistance. Agronomy tests are planned for the Senegal River Valley to compare irrigation frequency and levels of fertilizer application on sandy soils. Travel is planned for an ISRA agronomist and a cereal breeder to visit INTSORMIL research programs in the U.S. in 1991.

Research Accomplishments

Senegal River Valley

Sorghum

Yield potential of varieties in irrigated summer or cool-winter season were demonstrated to be 4 t/ha. Hybrid yields are significantly higher. The best hybrid yields are from INTSORMIL hybrids or INTSORMIL seed parents with existing pollinators.

Pearl Millet

Grain yields of 4 t/ha were obtained from three separate tests in the hot winter season (February-May) using dwarf cultivars taking 80 days to mature. This is clearly the most advantageous period in which dwarf pearl millet varieties and hybrids can best realize their potential. Yields at other times or locations, or with tall varieties are 50-60% of this. Palatability tests showed that the grain of dwarf varieties is acceptable.

Rainfed

In both sorghum and pearl millet, new variability is providing good selections in the pedigree programs.

South America (Colombia/CIAT)

Guillermo Muñoz
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Coordinators

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Institutions Involved

Mississippi State University (MSU)
Instituto Colombiano Agropecuario (ICA)
Fundación El Alcaraván
Federación Nacional de Cerealistas (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 of 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 and INTSORMIL, but 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's support to the program has been very important in achieving the goals established. 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 with three universities in Colombia. 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.

New approaches have included establishing research relations with different South American countries, trying to develop a Latin American Sorghum Research Network which is to facilitate exchange of germplasm and informal cooperation among scientists from each country.

Year 12 marks the establishment of a new organization called CIS (International Committee for Sorghum) which is the 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.

To provide orientation and enhance development of research and technology transfer programs on sorghum production.

To serve as a mechanism where sorghum research, transfer, and development programs can seek advice and orientation.

To promote and sponsor the organization and conduct of research and transfer activities related to sorghum production, as well as to diffuse information through publications and other documents on the subject.

To establish a liaison with international institutions having similar objectives.

Interdisciplinary Research

This collaborative research site was originally established to conduct germplasm enhancement research on problems related to acid soil production constraints of sorghum and pearl millet. Even though this is the program's primary research objective, a great deal of emphasis is being placed on other activities, especially due to the diversity of institutions involved. For example, the main interest for FENALCE is to develop lines for semiarid areas (drought tolerance - TAM-122) and lines with resistance to grain mold diseases. For ICA the main objectives are to develop lines with drought tolerance, 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-124 and MSU-105). Developing germplasm adapted to conditions in the acid savannas and slightly acid soils (called "vegas") is the main concern for the El Alcaraván Foundation; this institution is also developing growing interest for grain quality and utilization (TAM-126 and PRF-103B).

Mr. David Andrews (UNL-115) and Dr. Lloyd Rooney (TAM-126) will 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 on as a grain crop.

A number of the mentioned research activities are conducted by undergraduate students, depending on the specific goals of each institution, under the scheme of thesis research.

Financial Inputs and Management

Colombia does not have a USAID Mission, only a representative.

Operational funds for 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 point of view, the main accomplishment is having established 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.

Due to CIAT's interest in sorghum production, especially since this crop can become an important component of sustainable agricultural systems in the savanna ecosystem, new resources are being found to backstop sorghum research in Latin America.

The El Alcaraván Foundation supplied approximately US$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 by contracting an Agronomist (B.S.) for the La Libertad Project, another for the drought project on the Atlantic Coast (Motilonia), and one at ICA's main research center (Nataima). FENALCE also provides financial resources for overall expenses, commissions, and publications. 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

Due to scarcity of resources, much of the interinstitutional cooperation has had to be developed within Colombia; however, cooperation among Latin American countries started since January, 1991. The private sector enterprises have been a primary concern in establishing relations over the past two years.

CIAT has been supporting the program in several ways, not only through administrative assistance but also by establishing relations with other scientists and by opening alternatives for new areas of research. Land, laboratories, equipment, and transportation are only part of the facilities that CIAT has made available to INTSORMIL's project in Colombia. In addition, CIAT is increasing basic seed of INTSORMIL lines for release in Colombia.

An important sorghum researcher from ICRISAT participated in the international meeting held at CIAT ("Sorghum for the Future") with the support of scientists from all over Latin America. One of the decisions at this meeting was to assist at the PCCMCA and CLAIS meetings, both to be held in Panama. CLAIS had been an organization working only for Central America. After this last meeting, it was decided to use CLAIS's umbrella to cover both Central and South America, and the Caribbean countries. Two separate organizing committees were elected, one for Central America and the other for South America. The development of an interinstitutional approach was one of the objectives of the meeting. Dr. Guillermo Muñoz was elected coordinator of the interinstitutional and technical committees. The end goal is to strengthen the research team in Colombia, implying a greater integration of research efforts in Latin America among institutions such as CIAT, INTSORMIL, and ICRISAT.

The private sector has played an important role in the organization of courses, training activities, and conferences. New ways of cooperation are being developed in which the private sector can provide support to research conducted by the public sector.

FENALCE provides technical support to farmers through an Agronomist (B.S.) stationed in each of the sorghum-growing regions in Colombia. 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.

Research includes projects designed to solve technical constraints in the areas of breeding, plant pathology, entomology, plant physiology, soils, production, crop management, agricultural engineering, basic seed, new uses for cereals, institutional building, analysis of information obtained, and divulging of results. The latter is achieved by organizing field days, meetings and seminars, by publishing articles for journals, brochures, and manuals, and by producing audiovisual aids. For the collaborative projects, FENALCE has assigned three agronomists to the research centers where ICA conducts research in sorghum.

The Planning Process

The complexity of the relations among all the institutions involved has made the planning process very important. The goal is that all research conducted in Colombia in sorghum be a coordinated effort and that results be published each year and distributed among those involved in the process. Specific short- and long-range 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 in conducting research are discussed at these meetings.

Research on Sorghum/Millet Constraints

The main constraint to sorghum production in Latin America is the high production cost at an average yield for Colombia of 2.6 t/ha. Most sorghum has been grown on high cost lands, making production of this crop a nonprofitable enterprise. An alternative to reducing production costs is incorporating marginal lands into the production system. These low-cost lands have production constraints including the poor distribution of water, soil acidity and high aluminum saturation, presence of pests and diseases (especially head mold), excessive rainfall periods with high relative humidities, and other related agronomic problems. Thus, sorghum production in these areas requires the development of varieties or hybrids adapted to the specific ecological problems prevalent in each region.

In spite of the constraints encountered in these marginal areas, the amount of land available is such that the acid, well-watered savannas of Latin America constitute the main potential region for sorghum production; thus, this is the logical region for work in the future. Acid, infertile soil savannas account for more than 10% of the land area in Latin America and the Caribbean. Some 76 million ha of well-watered savannas are currently available for more intensive cultivation in the future. 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 with drought stress problems.

Whatever the case, farmers throughout the region require low-input technology and a great effort to avoid resource degradation problems; thus work to develop sustainable agricultural systems becomes a mandate.

Research Methods

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 MSU-104 and is evaluated in each of the levels of aluminum saturation established. This germplasm is screened in several locations by all the participating institutions. A full set of germplasm was sent to ICA and the El Alcaraván Foundation and was screened both for acid and nonacid soils. As part of the breeding methods, low-input technology was used in all the locations (using 60-60-60 N-P-K fertilization).

Since the first generation lines of the world collection are very tall, selection has focused on reducing height, in addition to maintaining high yields and tolerance to head fungus diseases. The selection process is designed to account for the different levels of aluminum saturation and expected results are based on the degree of aluminum 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	v 75% Al

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

Increase of TAM-128 breeding lines and hybrids for tolerance to drought has been conducted in collaboration with Eduardo Barragán at ICA-Nataima and with Alfredo Harma at ICA-Motilonia.

Research Progress

Breeding/Germplasm Improvement

The main accomplishment of the INTSORMIL project in Colombia was the release of two lines from the world collection. These lines have been under evaluation since 1983; ICA released these genotypes for two levels of aluminum saturation: lines 156-P5-Serere-1 (Sorghica Real 40) and MN-4508 (Sorghica Real 60) were released for soils with 40% and 60% aluminum saturation, respectively.

Year 12 required that great effort be dedicated to the introduction phase, trying to complete an evaluation of new segregating materials, with hybrids being one of the main objectives for acid and nonacid soils.

Not all lines have been found to perform the same at the different levels of aluminum saturation. Some of the crosses have excellent characteristics for vega soils (low levels of aluminum saturation) but are not good lines in high levels of aluminum, even if one of the parents is tolerant.

Therefore, all lines are screened in the three levels of aluminum saturation and each nursery is kept independent. Eighty of these lines will be tested next year in preliminary yield trials.

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. ICA-CRECED Arauca was strongly involved in research in the Department of Arauca.

In levels above 60% aluminum saturations, hybrids could be a possible alternative to increase grain yield. A full set of hybrids is being tested in Arauca under the three levels of aluminum saturation. For soils with high levels of aluminum saturation, the crossing of tolerant females with IA 28 seemed to be the best combination. The heterosis phenomenon of the hybrid being superior to its parents often implies more tolerance to stress than open-pollinated varieties.

Both the A and B semesters have been used for the evaluation of aluminum-tolerant lines. Some lines were found to perform better in the first semester and height of all lines decreased in the second semester. Also, in comparison with the commercial hybrids, these lines show less incidence of head fungus diseases.

In 1991, and within the framework of the aluminum-saturation level concept, different research approaches for each level were developed in a joint effort with ICA.

Level 1. Low input technology must be used for Latin American standards. Application of 60-60-60 N-P-K has been suggested. A study is in progress to compare loss in grain yield when using low input technology vs. high inputs under the same conditions. Agronomic type is very important under these conditions. Average yields of 3.5 t/ha are expected for Level 1. A new set of advanced materials of the F_3, F_4, F_5, and F_6 populations is being evaluated for this ecosystem. Fourteen new entries of F_2 populations sent by Dr. Bruce Maunder (Dekalb's senior vice president) were screened at La Libertad. One hundred selections were chosen among all the populations.

Level 2. Several new nurseries were sent from CIAT to Arauca and ICA-La Libertad for evaluation under this level of aluminum saturation, where tolerance to aluminum toxicity is very important. The main objective here is development of new varieties. Two lines from the world collection, IS 6944 and IS 8577, are being evaluated for possible release in the Department of Arauca. These lines are the result of research conducted in that region. Among the lines evaluated to date from the world collection, IS 6944 is one of the most effective in terms of phosphorus absorption and IS 8577 is the most tolerant to aluminum saturation, in addition to having desirable agronomic characteristics.

Level 3. Development of hybrids for this ecosystem is the main research objective. A total of 125 female (A), aluminum-tolerant lines are being tested for their general (GCA) and specific (SCA) ability using similar male parents (TX 430 and IA 28). TX 430 is a susceptible male and IA 28 has some kind of tolerance to intermediate levels of aluminum toxicity.

Another approach for Level 3 has been the use of recurrent selection. A bulk of the best aluminum-tolerant lines was obtained and has been crossed with aluminum-tolerant females. The objective is to increase the level of tolerance by incorporating two tolerant parents.

Mutual Research Benefits

National and multinational seed companies will use the technology from this collaborative site to produce acid soil tolerant varieties and hybrids in Latin America. In addition to being tolerant to aluminum, these lines show a low degree of incidence of grain mold diseases, which makes them an excellent alternative for these production regions. The release of A and B lines tolerant to aluminum will expand the market for the agricultural industry in the United States.

Institution Building

The agreement with INTSORMIL was signed on 23 March 1988. Some of INTSORMIL's contributions have been:[1]

The visit to Colombia for short periods of time of scientists having ample experience in sorghum production.

The stay in Colombia for long periods of time of scientists with ample experience and of support personnel.

ICA scientists have received the opportunity to conduct postdoctoral research and make use of their sabbatical leave.

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[1] Summarized from: Current Status of Sorghum Production in Colombia. Manuel Torregroza. 1991.

Jobs for research assistants (graduate students) chosen among the Colombian personnel.

Donation of germplasm and supply of equipment to be used by both parties.

Recent literature to support collaborative research projects being conducted in Colombia.

Supplies, equipment, and travel expenses for INTSORMIL's employees.

Trips to the United States or to other countries for ICA personnel.

Organization of periodic work meetings that benefit INTSORMIL's collaborators in Colombia and enhance the exchange of information among researchers.

Support work meetings planned and organized by both parties.

As a result of the work achieved through this agreement, the sorghum germplasm bank has substantially increased its number of entries, particularly of genetic resources having tolerance or resistance to acid soils with aluminum toxicity, to drought, to head molds, to the ovary fly, and to anthracnose. These materials come from the nurseries that have arrived in the country with the cooperation of INTSORMIL and provide the sorghum multidisciplinary team the opportunity to evaluate these genotypes and select the most appropriate for the Colombian environment. The first two sorghum improved varieties tolerant to acid soils with aluminum toxicity had their origin in these nurseries: Sorghica Real 40 and Sorghica Real 60. FENALCE also participated in the research and transfer activities related to the release of these materials.

Another contribution made by INTSORMIL has been to provide the opportunity for two Colombian professionals to continue their postgraduate studies: one at the M.Sc. and the other at the Ph.D. level. Also, others have been able to participate in international meetings held in the United States. INTSORMIL has sponsored national and international meetings in Colombia and has assigned financial resources for equipment, overall expenses, salaries, and commissions for sorghum professionals.

Research support funds provided to ICA have been limited due to a constrained operational budget. Host country capabilities have been strengthened through supplies and a limited quantity of labor to work in the field. Furthermore, the program has collaborated with ICA in terms of facilitating equipment, literature, trained staff, seed storage facilities, and distribution of 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 and seed technology, and training activities with collaborating organizations in Colombia and with INTSORMIL projects in the United States.

Mr. Alfonso González, B. Sc. (student previously trained by INTSORMIL) is the principal sorghum breeder at ICA's main acid-soil research station at La Libertad (Villavicencio, Colombia). He has developed a new approach for evaluation in the highly aluminum-toxic soils in the area.

Agronomist Walter Rendón, B.Sc. (student previously trained by INTSORMIL) is working as Director of ICA/CRECED in Arauca and has strengthened ICA's sorghum research program at La Libertad and the El Alcaraván Foundation activities. He has been in charge of specific experiments and the semicommercial fields in three regions in Arauca. He is currently coordinating all the students' research activities in that region.

Agronomist Julio Vigoya, another B.Sc. student trained by INTSORMIL, is the coordinator for the El Alcaraván/INTSORMIL cooperative program.

Annual meetings have been conducted in Colombia with INTSORMIL's support; the objective has been sharing results of experiments done in the country. As recommended in the last meeting, the report entitled "Informe de las Actividades de Investigación Realizadas en Colombia en el Cultivo de Sorgo, 1989" was published; this is the second of a series of publications that will be prepared each year.

A large amount of research has been done through B.S. degree students, as a means 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.

Dr. Bruce Maunder and Dr. Tim Schilling visited Colombia and formally reviewed the program at CIAT. They had the opportunity of being in contact with ICA entomologists and pathologists, and other researchers in Colombia.

Networking

Colombia is the only collaborative site in which the universities, the private sector (El Alcaraván), the national research institutions (FENALCE and ICA), and an international center (CIAT) are collaborating with INTSORMIL to further the accomplishment of research and training goals. However, networking activities with other national programs in Latin America are very weak. The sorghum network in Latin America is trying to be strengthened through activities coordinated by CIS and CLAIS.

In January, 1991, an International Sorghum Meeting for Latin America was organized by ICA, El Alcaraván, FENALCE, and INTSORMIL; this event was the base for strengthening relations and exchange of germplasm among Latin American countries.

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

Two new lines are under evaluation for release as a result of significant advances in ICA's breeding program, thanks to 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 to further 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.

A total of 14 populations of aluminum-tolerant lines sent by Dr. Bruce Maunder were evaluated under three levels of aluminum saturation. Selections were made in the different ecosystems from 500 F_5 lines sent by MSU-104; short-stature lines with good yield capacity are being evaluated in regional trials. These lines, considered second generation, have a better agronomic type than the lines of the world collection.

Twenty F_3 populations from Mississippi were screened in different environments (both vega and savanna); promising breeding material is available for future work. The lines selected have short stature and good yield potential. These selections are called the third generation.

As previously discussed, the principal accomplishment of the program was the release by ICA of two first-generation, aluminum-tolerant sorghum lines coming from the world collection (Table 1).

Future Activities

Selection and evaluation will continue in all locations evaluated in Colombia. Panama, Venezuela, and Brazil will be the main countries involved in initiating network activities by exchanging aluminum-tolerant germplasm.

Several studies are in progress trying to determine factors affecting the physiology of the plants and the relation with the soil complex. In breeding, the main objective will be to evaluate different hybrids, lines, and varieties for their resistance to aluminum toxicity in the different levels of soil saturation. Work with varieties and hybrids will continue during both seasons. Since downy mildew has been detected in Colombia, the pathology program will be strengthened so that selection for resistance to downy mildew and head mold diseases becomes an integral part of the breeding process.

Table 1. Origin, year of registration, and color of grain of the best sorghum genotypes cultivated by ICA to date.

Genotypes	Center of origin	Year of registration	Grain color
1. Improved varieties			
ICA-Marupaanste	Nataima	1968	Pink
ICA-Pal	Palmira	1968	Brown
ICA-Nataima	Nataima	1972	Brown
Icaima	Nataima	1988	Red
Sorghica Real 40 (156-P5-Serere 1)	La Libertad	1991	Brown
Sorghica Real 60 (<M 4508)	La Libertad	1991	Brown
2. Hybrids			
Sorghica NH-301	Nataima	1981	Brown

Source: Current Status of Sorghum Production in Colombia. Manuel Torregroza, 1991.

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
Omer El Hilu, 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. Omer El Hilu, 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 - Omer El Hilu, 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
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.

Research Progress

Since an array of disciplines are underway in sorghum and millet research in Sudan we have tended to highlight research progress of selected disciplines at different years. We will highlight the results from the following disciplines for the current report:

Sorghum Breeding

The sorghum breeding program at the Gezira Research Station continues to develop well. The scope of the program, the range of germplasm material, and the flow of germplasm through the program has been excellent. There continues to be a good balance between varieties and hybrids in the breeding program. The testing of varieties and hybrids, however, has been restricted to Wad Medani under irrigation. Planting in the rainlands has failed because of severe drought this last season. An adjustment needs to be made to perhaps undertake an extensive testing of promising varieties and hybrids under different environments including traditional rainfed areas. Experimental seed production of promising hybrids is also proposed. This is particularly important with regard to the elite hybrids, and there are several of those accumulated in the program. It is also suggested to summarize much of the yield data generated so far and make definitive plans on how to move the germplasm towards its eventual goal of release. The collaborative sorghum breeding program with INTSORMIL continues to provide the core germplasm necessary for both the Sudan and the UNDP regional program on sorghum improvement.

ARC is currently considering the release of two open pollinated varieties, namely M90393 and SuCr38:17, for use in the irrigated area, particularly the Gezira. Yield records show that these varieties are highly productive. These cultivars also have good grain quality. We are particularly concerned, however, about the merit of releasing these genotypes in the irrigated Gezira where hybrid acreage is already expanding. One of the significant benefits of Hageen Dura-1 in the Gezira has been its role in promoting the concept of seed. Farmers in Gezira have grown to appreciate the value of good seed which in turn is encouraging the development of a seed industry, albeit an infant one, in the Sudan. In general superior hybrids, in contrast to superior varieties, catalyze the development of a functional seed industry. Past experience with open pollinated varieties in the Gezira has shown that once a good variety (e.g., Dwarf White Milo) is released, farmers will keep seed from the grain crop off their field. In the short run this practice is acceptable. However, after several generations the quality of the seed deteriorates and unless the supply is refurnished from a good seed source, the cultivar will not be anything like the original seed source. This certainly is the situation with Dwarf White Milo in the Gezira. With open pollinated varieties, farmers have little incentive to buy seed from seed producers and the producer will certainly not continue to produce a supply if there is no demand.

We have come a long way in promoting the value of good seed and the increased productivity associated with good inputs. We need to seriously consider the possibility of back tracking on this front and the disincentive to seed producers if varieties are posed as viable options. Superior varieties may appear to be useful alternatives in the short run, but the negative impact on the development of a seed industry needs to be properly weighed.

Striga Resistance

An array of collaborative *Striga* research activities are underway at ARC, Sudan. Several years of collaborative testing in several locations in Sudan has clearly confirmed the superior *Striga* resistance of SRN39. This line also has a good level of drought tolerance and possesses good stand establishment characteristics. SRN39 is a tan plant with good grain quality. This season, extensive testing including on-farm trials resulted in over 3000 acres of SRN39 planted at different locations. Its *Striga* resistance coupled with its tolerance to drought made it extremely popular among farm-

ers in a year where productivity of local sorghum was drastically reduced. Under strong pressure and demand from the farm community in southern Ghedarif, the ARC is planning on an official release of SRN39 as the first *Striga* resistant sorghum variety ever released. The stability of SRN39 in productivity and *Striga* resistance across contrasting environments has been good. We all feel that for *Striga*-prone dry environments, this cultivar will be a significant contribution.

SRN39 has been intercrossed to other genotypes and progenies were selected for agronomic superiority as well as grain quality. Selection for *Striga* resistance has been hampered by lack of a reliable screening method. Recently, however, work at Purdue University has led to development of a rapid gel assay that identified potential *Striga* resistance using a single seed of a genotype. Agronomically elite progenies derived from SRN39 crosses were subjected to this assay and many were found to be low stimulators of *Striga* seed germination as was SRN39. During the 1990 crop season, field tests were conducted in South Carolina, Niger, and Sudan to establish correspondence between the gel assay and field *Striga* reactions. Our field results showed that many of our new elite progenies derived from crosses with SRN39 are also excellent sources of *Striga* resistance. This has made a large set of sorghum germplasm available with different genetic background for potential release and use by farmers who have severe *Striga* problems. In the short term, this is an economically feasible technology that can make a difference. Both the varieties generated and the screening technique developed will be used in many crop research programs. We hope this will help give our *Striga* research at Purdue some impetus to continue - - hopefully with some increased funding.

Hybrid Seed Production

With the current severe nationwide drought and the impending food shortages, Hageen Dura-1 is very popular in Sudan. Much of the campaign for increased sorghum production, particularly in the Gezira, hovers around HD-1. The biggest bottleneck has been seed supply. The Seed Production Unit of the Sudan Gezira Board has HD-1 seed production on 665 feddans (acres). At a yield of 0.7 tons/feddan (clean seed) SGB is projecting planting of 120 000 feddans of HD-1 in 1991. Total sorghum average in the Gezira this last season was over 500,000 feddans. Foundation seed supply may be acute for next year's seed production. We have agreed to help monitor to see if importation of foundation seed is required based on current harvest from their seed farms. INTSORMIL can once again help on this.

Yields of HD-1 in the Gezira this season have been high. Among the few farms that have been harvested already, a farmer in South Group, Hosh Block, Um Assaba Village obtained a yield of 28 sacs (quintals) per feddan (more than 5 tons per hectare) as opposed to the 6-10 sacs per feddan of Dwarf White Milo, the predominant Gezira variety. Average yields of HD-1 will certainly be less than 5 tons/ha, but the high yield recorded by such keen farmers indicates potential and will contribute to the growing popularity of the hybrid among Gezira farmers. In a dry year like 1990, many of these irrigated farmers stand to earn good incomes.

Economics

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 HD1. HD1 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%. These measures to eliminate 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

Research Support

The INTSORMIL/Sudan program has continued to provide the direct allocation of funds to the Agricultural Research Corporation. Research support funds for the host country in Year 12 were as follows:

Sorghum breeding	$ 9,000
Millet breeding	3,000
Physiology/agronomy	4,500
Pathology	5,500
Striga/weed control	5,500
Entomolgy	2,500
Food quality	5,500
Economics	3,500
Library improvement	3,500

INTSORMIL purchased two vehicles for use by ARC/INTSORMIL staff in Sudan. These vehicles will greatly facilitate collaborative activities in-country.

Acquisitions for the ARC libraries continue to be based upon requests from Wad Medani and El Obeid scientists.

Buy-In

At the suggestion of the USAID Mission in Khartoum, a grant proposal was prepared in November 1989 requesting PL 480 counterpart funds to supplement the INTSORMIL/ARC budgetary commitments. This grant was recently awarded after persistent follow-up by ARC staff, INTSORMIL, and the USAID Mission Staff in Khartoum. The grant was approved as requested for a total of L.S. 1,549,000 (Sudanese pounds) all in local currency. An advance of L.S. 685,000 has already been received with the following breakdown:

Labor	L.S.	400,000
Supplies		60,000
Petrol & vehicle maint.		60,000
Library improvement		12,000
Domestic travel		30,000
Land rent		90,000
Shipping		25,000
Communication		8,000
Total	L.S.	685,000

This advance total (L.S. 685,000) will need to be spent before the balance is obtained.

The grant proposal was prepared by INTSORMIL/ARC staff in consultation with USAID Mission. This grant will be governed by GOS regulations, involving certain rigid restrictions such as the requirement of prior Ministry of Planning approval for purchases greater than L.S. 5000.

An understanding has been developed with ARC staff that as long as the PL480 local currency fund is available INTSORMIL dollar funds will be used for purchase of equipment and travel support.

INTSORMIL Scientist Travel to Sudan

Drs. Larry Butler and Gebisa Ejeta traveled to Sudan from November 11 to November 22, 1990 to review and coordinate the overall INTSORMIL/ARC collaborative sorghum and millet research in Sudan, as well as to evaluate and plan specific joint projects on sorghum breeding and *Striga* research.

Networking

Sudanese Sorghum Germplasm Grow-out

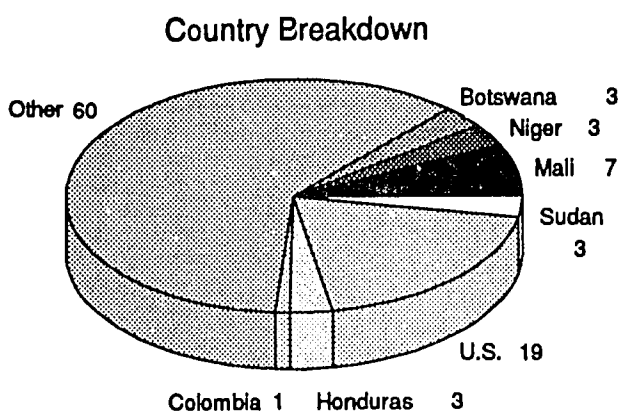
Plans have been underway for several years to assemble, grow, characterize, and increase seed of the Sudanese sorghum germplasm. It never materialized because of lack of funding early on and problems of logistics recently. Partial funding has been obtained from the USDA National Sorghum Crop Advisory Committee. Current plans are to grow this collection in Sudan in 1991. Sudanese sorghum germplasm at ICRISAT has been requested and imported to Kenya for forwarding to Sudan. We will arrange for transfer of this germplasm set to Sudan preferably to be hand-carried by Dr. Vartan Guiragossian or INTSORMIL PI's. We are also in the process of assembling a set of all collections that has been maintained in-country at ARC stations. Tentative plans are for Rosenow, Ejeta, or both to travel to Sudan in mid-June 1991 to assemble ICRISAT and ARC sets of collections with help from Dr. Osman Ibrahim and Mahmoud A. Mahmoud. The collection will be evaluated and characterized by scientists from ARC, INTSORMIL and ICRISAT. It is hoped that proper documentation of this valuable germplasm will be done for the benefit of both Sudan and U.S. sorghum scientists.

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. Most INTSORMIL students are supported via assistantships funded through INTSORMIL projects. During the year covered by this report, 99 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. 1991 INTSORMIL Training Analysis:



INTSORMIL also places a high priority on training women which is reflected in Figure 2. In 1991, 20% of all INTSORMIL graduate participants were women. Twenty-two of the total 99 students received full INTSORMIL scholarships in 1991. An additional 17 students received partial INTSORMIL funding and the remaining 60 students were funded from other sources as shown in Figure 3.

Figure 2. INTSORMIL Training Analysis:

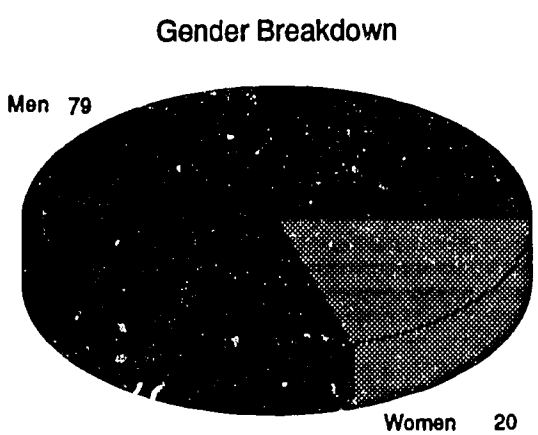
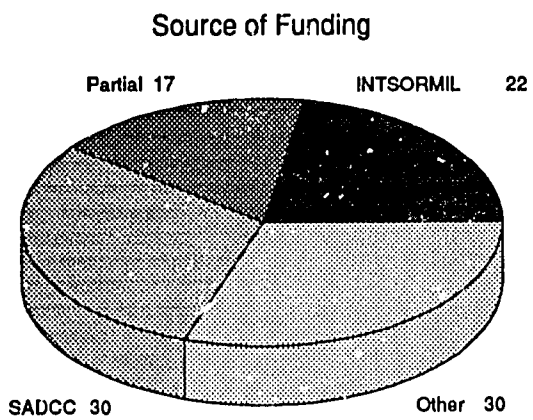
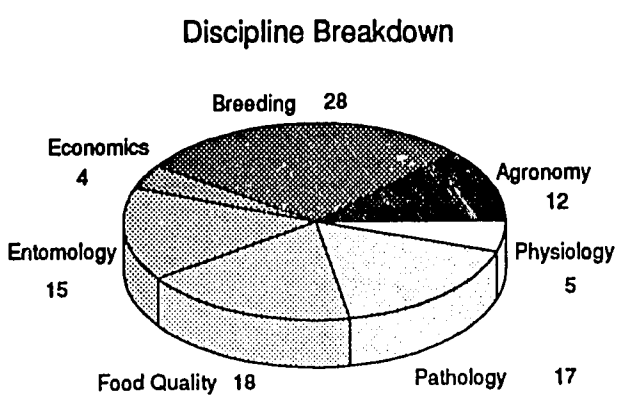


Figure 3. 1991 INTSORMIL Training Analysis.



All 99 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. 1991 INTSORMIL Training Analysis:



Total student numbers remained constant with that of 1989 and 1990. However, the number of INTSORMIL funded students has decreased by 18% from 1988. This

represents a decrease of 40% 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.

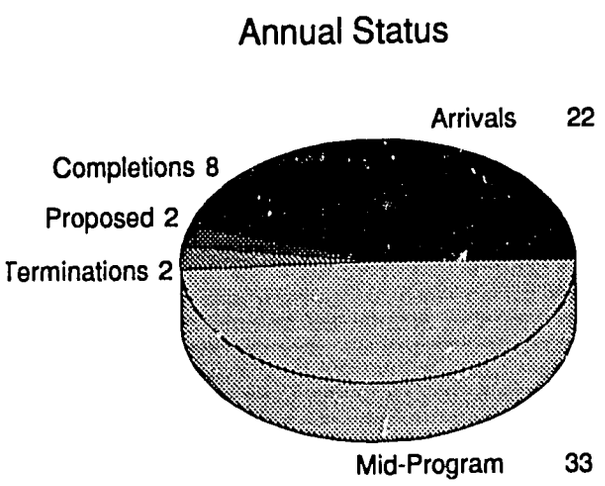
In addition to graduate degree programs, short term training programs have been designed and implemented on a case by case basis to suit the needs of host country scientists. Several Host Country scientists were provided the opportunity to upgrade their skills in this fashion during 1991.

INTSORMIL also 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 1991, INTSORMIL placed an additional 22 scientists from 9 southern African nations into graduate programs in the U.S., Canada, and Brazil. This brought the total number of active SADCC students to the record high of 67 and met our targeted cummulative total of 100 students since the program began in 1985. (Figure 5)

Figure 5. 1991 SADCC Training Analysis



Of the 22 scientists who arrived in 1991, eight were placed at Guelph Univeristy in Ontario. These students are funded by the Canadian International Development Agency, CIDA, but administered by INTSORMIL in the same manner as our AID funded students. Two others are Angolan and were placed at the University of Vicosa in Brazil with support from Germany (GTZ). Of the total 67 on board in 1991, eight completed their programs and returned home to assume new leadership positions in their respective institutes. Two of the 67 terminated their programs early for personal reasons. The program continues to be a major success and will have a great impact on Agriculture and Agricultural Research in Southern Africa.

The following table is a compilation of all INTSORMIL training activities for the period covered by this report, July 1, 1990 through June 30, 1991.

Year 12 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	MSC	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
Kasalu, Helen	Zambia	UNL	Agronomy	Mason	MSC	F	S
Masi, Cassim	Zambia	UNL	Agronomy	Maranville	PHD	M	S
Sirifi, Seyni	Niger	UNL	Agronomy	Maranville	MSC	M	I
Toure, Abdoul	Mali	UNL	Agronomy	Maranville	MSC	M	I
Adamou, Moussa	Niger	MSU	Breeding	Gourley	PHD	M	O
Gutierrez, Osman	Venezuela	MSU	Breeding	Gourley	MSC	M	O
Montgomery, Libby	US	MSU	Breeding	Gourley	MSC	F	O
Saadan, Hamis	Tanzania	MSU	Breeding	Gourley	PHD	M	S
Zake, Vincent	Uganda	MSU	Breeding	Gourley	PHD	M	O
Peters, Paul	US	PRF	Breeding	Axtell	PHD	M	O
Botorou, Ouendeba	Niger	PRF	Breeding	Ejeta	PHD	M	O
Grote, Ed	US	PRF	Breeding	Ejeta	PHD	M	O
Vogler, Renee	US	PRF	Breeding	Ejeta	MSC	F	I
Dahlberg, Jeffrey	US	TAM	Breeding	Miller	PHD	M	P
Gouveia, Sergio Jeremias	Mozambique	TAM	Breeding	Miller	MSC	M	S
Kanyenji, Ben M.	Kenya	TAM	Breeding	Miller	MSC	M	O
Khizzah, Bill W.	Uganda	TAM	Breeding	Miller	PHD	M	O
Nunes, Maria Eugenia	Mozambique	TAM	Breeding	Miller	MSC	F	S
Ombakho, George	Kenya	TAM	Breeding	Miller	PHD	M	O
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	PHD	M	O
Gorman, Chris	US	TAM	Breeding	Rosenow	MSC	M	I
Isbell, Verne	US	TAM	Breeding	Rosenow	PHD	M	P
Mkhabela, Milton	Swaziland	TTU	Breeding	Rosenow	PHD	M	S
Walulu, Richard	Kenya	TAM	Breeding	Rosenow	MSC	M	P
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
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	Teetes	PHD	M	P
Behle, Robert	U.S.	TAM	Entomology	Teetes	PHD	M	P
Ciomperlik, Matthew	U.S.	TAM	Entomology	Teetes	PHD	M	P
Edwards, Jeffrey	U.S.	TAM	Entomology	Teetes	MSC	M	P
Jimenez, Nora	Colombia	TAM	Entomology	Teetes	MSC	F	I
Magallenes, Ricardo	Mexico	TAM	Entomology	Teetes	PHD	M	P
Manthe, Chris	Botswana	TAM	Entomology	Teetes	PHD	M	S

Name	Country	University	Discipline	Advisor	Degree	Gender	Funding*
Paliani, Anderson	Malawi	TAM	Entomology	Teetes	MSC	M	S
Pendleton, Bonnie	US	TAM	Entomology	Teetes	PHD	F	O
Rojas, Edgar	Costa Rica	TAM	Entomology	Teetes	MSC	M	P
Roque, Javier	Mexico	TAM	Entomology	Teetes	PHD	M	P
Thindwa, Harriet	Malawi	TAM	Entomology	Teetes	PHD	F	S
Siame, Anthony Bupe	Zambia	PHD	Food Quality/Util	Butler	PHD	M	S
Tarimo, Thadeo	Tanzania	PHD	Food Quality/Util	Butler	PHD	M	S
Weerasuriya, Yohan H.	Sri Lanka	PHD	Food Quality/Util	Butler	MSC	M	O
Aboubacar, Adam	US	PRF	Food Quality/Util	Kirleis	MSC	M	O
Mohammed, Sulma	Sudan	PRF	Food Quality/Util	Kirleis	PHD	F	O
Shull, Jeanette	US	PRF	Food Quality/Util	Kirleis	PHD	F	I
Watterson, Julia	US	PRF	Food Quality/Util	Kirleis	PHD	F	O
Almeida-Dominguez, H.D.	Mexico	TAM	Food Quality/Util	Rooney	PHD	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
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
Yau, Jia-Chyi	Taiwan	TAM	Food Quality/Util	Rooney	PHD	M	O
Farrokhi-Nejad, Reza	Iran	KSU	Pathology	Claflin	PHD	M	O
Kedera, John	Kenya	KSU	Pathology	Claflin	PHD	M	O
Markow, Arseny	Bulgaria	KSU	Pathology	Claflin	PHD	M	I
Xu, Jin-Rong	China	KSU	Pathology	Claflin	PHD	M	O
Zvoutete, Petros	Zimbabwe	KSU	Pathology	Claflin	MSC	M	S
Casela, Carlos	Brazil	TAM	Patholgy	Frederiksen	PHD	M	O
Esele, Peter	Uganda	TAM	Pathology	Frederiksen	PHD	M	O
Kunene, Innocentia	Swaziland	TAM	Pathology	Frederiksen	PHD	F	S
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
Alexander, John	US	TAM	Pathology	Toler	PHD	M	O
Mahuku, George	Zimbabwe	TAM	Pathology	Toler	PHD	M	S
McClelan, Eddie	US	TAM	Pathology	Toler	PHD	M	I
Theu, Matthew	Malawi	TAM	Pathology	Toler	PHD	M	S
Gandoul, Gandoul I.	Sudan	UNL	Physiology	Eastin	PHD	M	I
Nyakatawa, Ermson	Zimbabwe	UNL	Physiology	Eastin	MSC	M	S
Zavala-Garcia., Francisco	Mexico	UNL	Physiology	Eastin	PHD	M	P
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

Year 12 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, Tieiso	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
Moletsane, Nyakallo	Lesotho	PRF	Economics	Farris	MSC	F
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
Theu, Matthew	Malawi	TAM	Pathology	Toler	PHD	M
Thindwa, Harriet	Malawi	TAM	Entomology	Teetes	PHD	F
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
Nunes, Maria E.	Mozambique	TAM	Breeding	Miller	MSC	F
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
Saadan, Hamis	Tanzania	MSU	Breeding	Gourley/Watson	PHD	M
Tarimo, Thadeo	Tanzania	PRF	Bird Control	Butler/Weeks	PHD	M

Name	Country	University	Discipline	Advisor	Degree	Gender
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
Kasalu, Helen	Zambia	UNL	Agronomy	Mason	MSC	F
Masi, Cassim	Zambia	UNL	Agronomy	Maranville	PHD	M
Mwale, Moses	Zambia	UNL	Plant/Soil	Walters	MSC	M
Ngulube-Msikita, Rachel	Zambia	UNL	Breeding	Moser	BSC	F
Siame, Anthony	Zambia	PRF	Food Science	Butler	PHD	M
Beta, Trust	Zimbabwe	TAM	Food Science	Rooney	MSC	F
Gono, Tigere Lawrence	Zimbabwe	KSU	Agronomy	Vanderlip	PHD	M
Mahuku, George	Zimbabwe	Guelph	Pathology	Hall	PHD	M
Makaudze, Ephias	Zimbabwe	TAM	FSR/Econ	Fuller	MSC	M
Mazhangara, Edward	Zimbabwe	PRF	FSR/Econ	Masters	MSC	M
Mtisi, Esther	Zimbabwe	TAM	Pathology	Frederiksen	PHD	F
Muza, Figuhr	Zimbabwe	UNL	Breeding	Lee	PHD	M
Nyakatawa, Ermson	Zimbabwe	UNL	Agronomy	Eastin/Schilling	MSC	M
Zvoutete, Petros	Zimbabwe	KSU	Pathology	Claflin	MSC	M

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	32,513	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
	World Bank - Training	1989	2.5 years	10,000	25,000
	World Bank/IDA	1989	1 year	4,500	4,500
	USAID/Bean-Cowpea CRSP	1990	1 year	27,000	27,000
					$ 71,500

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
					$ 282,000
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	33,000	66,000
	SADCC/ICRISAT Training	1989	1 year	21,000	21,000
					$ 435,498
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
					$ 633,419
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
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

INTSORMIL Buy-Ins

University/ Project No.	Buy-In	Year	Life of Buy-In	Annual Amount	Total
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.B.	INTSORMIL/Egypt/NARP	1991	3 years	156,727	$ 470,183
	Nebraska/Kansas St.				
Total Buy-Ins					$ 9,022,998

INTSORMIL Sponsored and Co-Sponsored Workshops 1979 - 1991

	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

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
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 Científico e Tecnologico
CNRA	National Center for Agricultural Research, Senegal
CRSP	Collaborative Research Support Program
DAR	Department of Agricultural Research, Botswana
DR	Dominican Republic
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

ELISA	Enzyme-linked Immunosorbent Assay
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuaria, Brazil
EMBRAPA-CNPMS	EMBRAPA-Centro Nacional para Maize e Sorgo
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
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 Ciencias Agricolas de la OEA
IITA	International Institute of Tropical Agriculture
INCAP	Instituto de Nutricion de Centro America y Panama
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 Sahelian 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
MOA	Memoranda 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
NU	University of Nebraska
OAU	Organization of African Unity
PCCMCA	Programa Cooperativo Centroamericano para el Mejoramiento de Cultivos Alimenticios
PI	Principal Investigator
PRF	Purdue Research Foundation
PSTC	Program in Science & Technology Cooperation
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
SAT	Semi-Arid Tropics
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
TAM	Texas A&M University
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