INTSORMIL

Annual Report 1990

SORGHUM/MILLET COLLABORATIVE RESEARCH SUPPORT PROGRAM (CRSP)

Fighting Hunger with Research ... a team effort

Funding support through the Agency for International Development

Grant No: DAN 1254-G-SS-5065-00

Cover Photographs
(top to bottom)

1. Dr. Gebisa Ejeta examines experimental plots of *Striga* tolerant cultivar 'SRN-39' and *Striga* susceptible local cultivars in Niger. (Photo courtesy of Dr. Darrell Rosenow).

2. INTSORMIL scientists discuss new sorghum variety performance with farmer on steep hillside farm in Honduras. (Photo courtesy of Dr. Darrell Rosenow).

3. Colombian Director of Research, Dr. Manuel Torregroza and INTSORMIL Principal Investigator, Dr. Guillermo Muñoz inspect new ICA/INTSORMIL acid/aluminum tolerant variety 'Sorghica Real 60'. (Photo courtesy of Dr. Bruce Maunder).

4. IER scientists Mdme. Coulibaly, Mr. Temé, Mr. N'Diaye, Mr. Sy and Mr. Traore make field selections in sorghum nursery in Mali. (Photo courtesy of Dr. Darrell Rosenow).

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Fighting Hunger with Research . . . A Team Effort

A Technical Research Report of the

Grain Sorghum/Pearl Millet

Collaborative Research Support Program (CRSP)

Funding support through

Agency for International Development

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INTSORMIL INSTITUTIONS

Kansas State University

University of Kentucky

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University of Nebraska

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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 and consumption in 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, INTSORMIL was created in 1979 by USAID and operates under the Bureau for Science and Technology. Over the past ten years, INTSORMIL has established a dynamic, multi-institutional and interdisciplinary collaborative research and training program. INTSORMIL links the expertise of 30 U.S. scientists from five 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 us 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, 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. Our 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 participating with INTSORMIL are:

Kansas State University
Mississippi State University
Purdue University
Texas A&M University
University of Kentucky
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 impertance 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 eleventh year of implementation. These eleven 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 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 year was a very busy but fruitful one for the ME, BOD, TC and EZC. Below are listed several major accomplishments for the year.

- Developed Grant Extension Proposal for the next five years of INTSORMIL activity. The Proposal outlined the INTSORMIL five year strategic plan and was approved at the optimal funding levels contingent on the availability of funds in USAID.

- Organized and implemented an important workshop on sorghum/millet protein quality at Purdue University. This workshop was highly esteemed for assessing current state of the art and orienting future quality protein work in sorghum.

- Presented CRSP activities to U.S. Congressional, World Bank, Environmental, AID, and USDA delegations in Washington. This initiative should result in higher visibility and recognition among important domestic and international groups.

- Successful at securing a $100,000 buy-in from the USAID Mission in Sudan. These funds will be used exclusively to complement the INTSORMIL core country budget for collaborative sorghum and millet research. Much thanks goes to the AID mission and Dr. Gebisa Ejeta, the INTSORMIL Sudan Coordinator.

- Developed 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.

- Funded, organized and hosted a major sorghum and millet workshop in Sudan. The workshop was well attended with participants from over 15 countries.

- Instrumental in the development of the CRSP Council, an integrated CRSP initiative that addresses the global concerns of agricultural production and sustainability, natural resource conservation, and environmental quality. The CRSP Council unites the resources and capabilities of the eight CRSPs, effectively creating a powerful international research network to service and support USAID missions and regional offices.

- Granted an additional $100,000 by USAID/S&T to be used in behalf of all eight CRSP programs for developing "Cross CRSP" activities.

- Negotiated U.S. $558,000 buy-in from USAID Egypt Mission. This three year buy-in will activate INTSORMIL projects in pathology and agronomy in collaboration with Egyptian scientists.

- Initiated and awarded $25,000 grant from USAID/S&T to co-sponsor Sorghum Utilization Symposium with ICRISAT. The Symposium highlights current state of the art technologies and focuses on future research directions.

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 covered by this report, 118 students from over 37 different countries were enrolled in an INTSORMIL advanced degree program. 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 totaled 20. An additional 19 students received partial funding from INTSORMIL. The remaining 60 students are funded from other sources but are working on INTSORMIL projects. A grand total of ninety-nine students were advised by INTSORMIL principal investigators in 1990.

Total student numbers remained constant with that of last year which has increased by 17% compared to 1988. However, 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. An even more significant factor is that budget flexibility for supporting training under INTSORMIL projects has been greatly diminished because of inflationary pressures. None of the INTSORMIL project budgets have been increased in the last five years.

The second phase of the SADCC/ICRISAT/INTSORMIL program was signed in 1989 and will run through September 15, 1993. The second phase calls for a two fold increase in volume and activity. An additional 60 scientists from the SADCC region have been identified and will be processed for training in the next two years. Increased emphasis has been given for the disciplines of food technology, economics, forages, and agroclimatology. As of June 30, 1990 INTSORMIL has processed a total of 48 SADCC students encompassing nine SADCC countries.

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 has collaborated with TROPSOILS in Mali and in Peru 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. INTSORMIL was awarded a $100,000 grant to initiate and foster inter-CRSP approaches to sustainable agricultural development.

Current Country Specific Activities

Botswana

The major constraint in Botswana is that of inadequate and poorly distributed rainfall. During the time INTSORMIL has been involved with research in Botswana there has been a drought seven of eight years. INTSORMIL is working with the Department of Agricultural Research, DAR, to develop macro and micro water encatchment systems. These systems, when used in conjunction with soil management techniques have been proven to double yields of sorghum in dry years. INTSORMIL also provides high quality, adaptable germplasm to the sorghum and millet breeding program and collaborates with the country's pathology and entomology components.

Progress was made in identifying resistance to the sugarcane aphid in sorghum lines. Resistant x susceptible crosses indicated that resistance is simply inherited and controlled by a single completely dominant gene. Different virulence within the Botswana and between the Botswana and Zim-

babwe sources of aphids suggests different biotypes exist among the populations.

Material from Texas A&M University collaborative nurseries demonstrated that good anthracnose resistance was available in introduced and improved local germplasm. Anthracnose virulence appears to differ from that occurring in India and the U.S. and may even differ within the SADCC region. Charcoal stalk rot, ergot, and other diseases were also characterized.

Dr. Naraine Persaud, INTSORMIL soil physicist continued work on the Botswana national tillage trials. Results from this research have shown that tillage performed as early as possible with the inception of rains can conserve sufficient moisture and give better rain use efficiencies. Addition of phosphorous furthered response and gave excellent yield increases.

Botswana students trained through SADCC/ICRISAT/INTSORMIL, INTSORMIL, and USAID/BOTSWANA educational/research programs are Lucas Gakale, Louis Mazhani, Chris Manthe, Dollina Malepa, Elijah Modiakgotla, Baikabile Motalaote, and Boi Sebolai. These scientists are providing an excellent scientific core staff to DAR. Currently there are four students being trained by INTSORMIL and others have been identified for future training.

Honduras

INTSORMIL works in conjunction with the National Research Institution, Recursos Naturales, the Pan American Agricultural School, EAP and The Soil Conservation Program, LUPE. 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.

Two varieties were developed and released through the program and recent impact studies show these technologies provide farmers with a real 15% net farm income increase and a 58% income increase if price policy was designed to avoid price collapse in good years.

Extensive on-farm testing of the new INTSORMIL varieties indicates that they produce higher grain yields than traditional maicillo criollos 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 and when seed treatment was combined with 60Kg/ha nitrogen. 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.

Improved local sorghum breeding lines performed very well in yield trials and the most promising have been advanced to extensive on-farm trials. These on-farm trials have revealed that the improved maicillo lines yielded slightly better than the traditional maicillo with traditional cultural practices. Some 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.

Hybrid maicillos have shown a large yield advantage over local maicillos varieties. Breeding for hybrid maicillos has become a priority breeding objective.

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. Development of high yielding, food type sorghums with these grain quality traits should have direct and significant application not only to Honduras, but to other countries in South and Central America

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.

Studies on biological control of the fall armyworm and stem borers have been completed, and an exotic parasite effective in controlling stem borers was mass reared and released in Honduras and El Salvador and apparently has become established at low numbers, in both countries.

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.

Colombia

The INTSORMIL program in Colombia has effectively engendered the support of the National Agricultural Research Institute, ICA, Columbian Universities, Private companies, CIAT, and Extension Organizations to form a dynamic program on sorghum improvement. Program focus

has been on the adaptation of sorghum varieties to the acid and aluminum saturated soils of the savannah region.

Two varieties, Real-40 and Real-60, were recently released 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 can not grow.

Selections were made in the different ecosystems from 500 F_4 lines sent by MSU-104. These short-stature lines have good yield capacity and are being evaluated in regional trials.

Twenty F_2 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.

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. The Mali program has focused on the development of sorghum varieties with acceptable food quality, headbug/mold resistance, drought tolerance and nutrient-use efficiency. Several seedling establishment screening techniques have been developed and are being used by the breeding programs.

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. This research showed that sorghum with hard endosperm and thick pericarps is definitely required for efficient traditional hand pounding.

The severity and persistance 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, with unacceptable texture and keeping properties.

Seven improved sorghum lines, Malisors, from the Malian program have been released. Malisor 84-7 has shown some advantages in multiple cropping systems and appears to be the only improved sorghum with head bug resistance. As such, it will be used extensively in sorghum breeding in Mali, and all across West Africa where head bugs are a very serious constraint. 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/TROP-SOILS 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 used.

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.

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. Seven 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 breeding, pathology, entomology, 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.

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

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 ARC/ICRISAT/INTSORMIL hybrid, 'Hageen Dura-1' was released in 1984 and is grown on over 15,000 hectares in the irrigated Gezira. This technology is in its initial stage of diffusion and has already shown a high rate of return to society of 32%.

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.

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.
- 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.

Agronomy / Physiology

Seedling Vigor and Stand Establishment of Pearl Millet

Project KSU-106
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Summary

In field studies seed size had an effect on percent emergence and the resulting yields from two different millet hybrids. These results indicate that there is an optimum seed size for pearl millet and that improved establishment can lead to higher yields.

In comparing yields and yield components of millet and sorghum at different planting dates and populations, results indicate that at the populations tested pearl millet showed no yield response to differing populations while sorghum yields increased with increasing populations. Increases in head number were primarily responsible for the ability of millet to compensate for differing populations. There was no effect of date of planting on millet yields. Sorghum yields were highest at the second date of planting.

Preliminary results indicate that the ability of the sorghum plant to tiller is dependent on temperature and its effects on dry matter accumulation.

Objectives, Production and Utilization Constraints

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.

Objectives

1. Investigate mesocotyl and coleoptile growth of different genotypes and from different seed qualities as they respond to temperature.

2. Compare planting date and plant population responses of sorghum and pearl millet.

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

Project Output

Current work at Kansas State University with millet stand establishment examines seed quality effects of sor-

ghum and pearl millet in both field and controlled environment studies.

1. Investigation of mesocotyl and coleoptile growth of different genotypes and from different seed qualities as they respond to temperature and planting depth.

A study was conducted to investigate establishment and seedling vigor response of two millet hybrids to varying environmental and management factors in the field.

Approach

This experiment was designed to quantify seed size and planting depth effects on the establishment and seedling vigor of two millet hybrids under field conditions. The design was a split plot with four replications. The two hybrids were 1056A x 9001 (large seeded) and Tift 23 DAE x 9001 (small seeded) from the Fort Hays Experiment Station. Planting depths were 4 and 8 cm. Four seed classes were used as shown in Table 1.

One hundred seeds were drill-planted in flat rows 6 m long and 0.76 m apart. There were two rows per plot, and percent establishment was determined from these rows. Two locations were used. At Manhattan the seeding was done on a Eudora silt loam (coarse-silty, mixed mesic, Fluventic Hapludoll) soil. The site at St. John was on a Naron loamy fine sand (fine-loamy, mixed, thermic, Udic Agriustoll). No fertilizer was applied at either location. Trials were planted on 7 and 15 June for Manhattan and St. John, respectively. At Manhattan, establishment and seedling vigor data were collected 14 days after planting, but due to severe chinch bug (*Blisssus lecucopterus*) attacks, the experiment was subsequently abandoned. At St. John, establishment was determined 20 days after planting. Data for yield and yield components were obtained including grain yield (kg ha^{-1}) adjusted to 12.5% moisture, number of heads per square meter, number of seeds per head, number of heads per plant, and seed weight in g/1000 seeds. Heads for determination of yield and yield components were harvested from the center 4.5 m of each row.

Results

There was a hybrid x seed size class interaction for percent establishment at St. John. For the large seeded hybrid the medium seed size class gave the highest establishment (52%). For the small seeded hybrid, the highest establishment came from the large seed size class (48%). For both hybrids the highest establishment was significantly higher than the establishment from the small seed size class (Figure 1). At Manhattan the highest establishment came from the medium seed size class, however, all size classes had extremely low establishment (<15%). These results suggest that there is an optimum seed size for pearl millet.

Table 1. Description of seed sources for the field establishment and seedling vigor study.

Characteristics and hybrid	Seed size class			
	Composite	Large	Medium	Small
Seed weight, g/1000				
1056A x 9001	12.9	17.8	14.7	10.5
Tift 23 DAE x 9001	6.2	8.3	7.2	5.3
Seed diameter, mm				
1056A x 9001	--	3.18	2.78	2.38
Tift 23 DAE x 9001	--	2.58	2.18	1.79

Table 2. Effect of hybrid and seed size on yield and yield components at St. John, 1989.

Factor	Variable			
	Heads per sq. m.	Heads per plant	Seeds per head	Grain yield 12.5%moist kg ha^{-1}
Hybrid				
1056A x 9001	15	1.6	1113	2220
Tift 23 DAE x 9001	22	2.9	1010	2413
LSD (5%)	2	.03	66	ns
Seed size class				
Composite	8.8	2.4	1001	2149
Large	10.1	1.9	1082	2446
Medium	9.9	2.0	1155	2513
Small	7.3	2.8	1007	2157
LSD (5%)	2.2	0.5	93	283

While the number of plants per square meter at St. John was affected by seed size, the number of heads per square meter was not (Table 2) because of the ability of pearl millet to compensate for low population. The smallest seed class had the fewest plants per square meter and the largest number of heads per plant. However, even with this compensatory ability, grain yield from the large and the medium seed was still significantly higher than from the composite and small seed size classes. The results indicate that steps to improve establishment in pearl millet need to be emphasized since millet's compensatory ability will not always attain maximum possible yields.

Hybrids did not differ in grain yield (Table 2). In contrast with seed size effects, the higher number of plants per square meter in the large seeded hybrid did not translate into higher grain yield.

2. Comparison of grain sorghum and pearl millet response to date and rate of planting.

In the United States, pearl millet has been grown mainly as a forage crop and unlike sorghum, millet grain still is absent in commerce. Some experts believe, however, that it will gain more attention in the future with interest in the crop for dryland areas. On this basis, research was conducted to

compare the effects of date and rate of planting between pearl millet and sorghum.

Approach

Two millet hybrids (81-1056 x 86-9001 and 81-1083 x 87-8025), a millet variety (Senegal Bulk), and a sorghum hybrid (DeKalb 39Y) were planted at 15,000, 45,000, and 135,000 plants ha^{-1} on three dates at Manhattan and St. John, Kansas. At Manhattan, the planting dates were 15 May, 7 June, and 29 June, and at St. John, 24 May, 15 June, and 5 July. The experimental design at both locations was a modified split plot, replicated three times. Dates of planting were main plots stripped across all replication while subplots were planting rate and variety combinations. Subplots were four rows, 7.6 m. long, with two border rows between each date. Interrow spacing was 0.76 m. All data were taken from a 4.57-meter section of the two middle rows.

Data taken included stand count, half-bloom date (day of the year), head number, threshed grain weight, percent grain moisture, seed weight (g/1000 seeds) and lodging (% of heads harvested). Yield was calculated based on threshed grain weight corrected to 12.5% moisture. Heads per plant were calculated by the number of heads harvested divided by the number of plants counted. Seeds per head were calculated based on yield, heads harvested, and seed weight.

Results

The study showed that in pearl millet, plant populations had no effect on yields (Figure 2 a, c, and d) while with grain sorghum, yield increased with increases in plant populations (Figure 2b). Sorghum yields were significantly greater than millet yields at high populations. However, this was not always true at low and medium populations , particularly when soil and weather conditions were unfavorable.

Yield components of millet, particularly heads per plant, made up the differences among populations. Millet head number per plant decreased as population increased. Sorghum, on the other hand, did not show any significant population effect on head number per plant (Figure 3). There was no consistent trend in number of seeds per head for millet at either St. John or Manhattan. However, the overall trend was towards a decrease in number of seeds per head as populations increased (Figure 4). Sorghum at St. John showed a significant decrease in seed number as population increased. However, at Manhattan there was no clear trend across dates (Figure 5). Seed weights for millet did not change significantly at either location across populations or dates (Figure 6). Sorghum seed weights at both Manhattan and St. John decreased significantly as populations increased. Sorghum seed weights were consistently greater than those of any of the pearl millet cultivars (Figure 7).

There was no significant date by variety interaction for yield at St. John. Millet yields at Manhattan were highest at the first date of planting and decreased with each succeeding date. Sorghum yields increased significantly between the 15 May planting and the 7 June planting and were lowest at the last planting date (Figure 8).

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

A study was initiated to determine and compare the tillering ability of sorghum cultivars of tropical and temperate origin under both field conditions and controlled environments and to investigate the relationships between growth rate and tiller number and between tiller number and economic yield.

Approach

A greenhouse study was used to investigate temperature effects on sorghum dry matter accumulation rates versus tillering ability. The sorghum hybrid Pioneer P-8500 was chosen based on its tillering ability. Experimental design was a split split plot with main plots consisting of two different temperature regimes, 25/20° C day-night for the high temperature treatment, and 20/15° C for the low. Subplots consisted of plant populations of 1, 5, and 10 plants per pot (20 cm. X 20 cm.), and within these subpots two treatments of no nitrogen and 40 g. of nitrogen per plot (44.6 kg ha^{-1}). The following measurements were taken: dry matter per plant, tiller number, leaf area, and leaf number.

Results

Preliminary results have indicated a temperature effect on tillering. At low temperatures Pioneer hybrid P-8500 exhibited a higher tiller number with a lower growth rate. At high temperatures none of the plants tillered even though the growth rate was significantly higher than the low temperature treatment. The high nitrogen treatment did not increase tiller number.

Publications

Mortlock, M.Y., and R.L. Vanderlip. 1989. Germination and establishment of pearl millet and a sorghum, of different seed qualities under controlled high temperature environments. Field Crops Res. 22:195-209.

Mohamed, A., F.L. Barnett, R.L. Vanderlip, and B. Khaleeq. 1989. Emergence and stand establishment of pearl millet as affected by mesocotyl elongation and other seed and seedling traits. Field Crops Res. 20:41-49.

Networking Activities

R.L. Vanderlip spent two weeks at the end of the 1988-89 growing season in Botswana working with the collaborating scientists in Botswana and investigating the possibility of a broader collaboration with the SADCC/ICRISAT program.

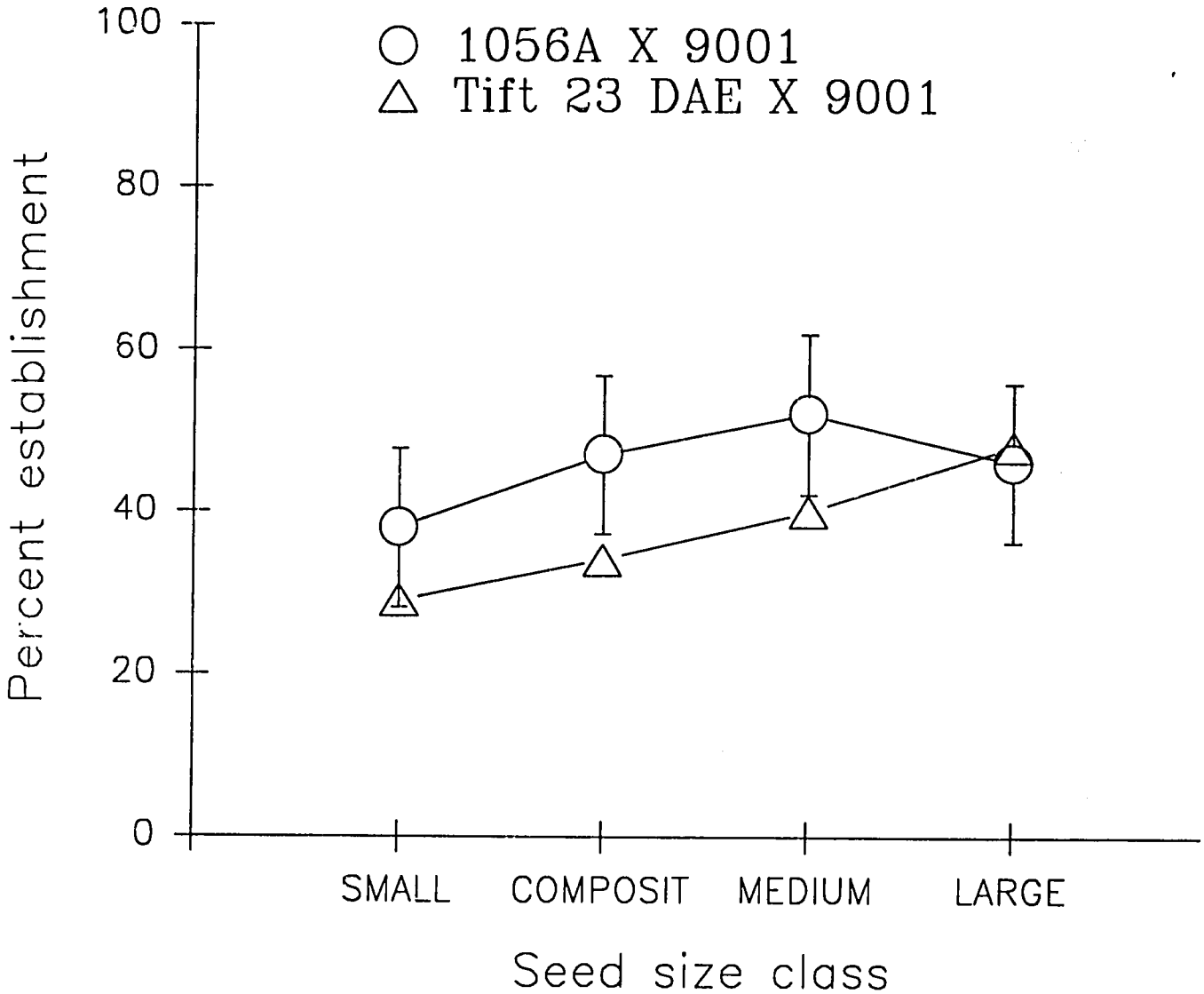

Fig. 1. Effect of hybrid and seed size on establishment at St. John. Bars show 5% LSD

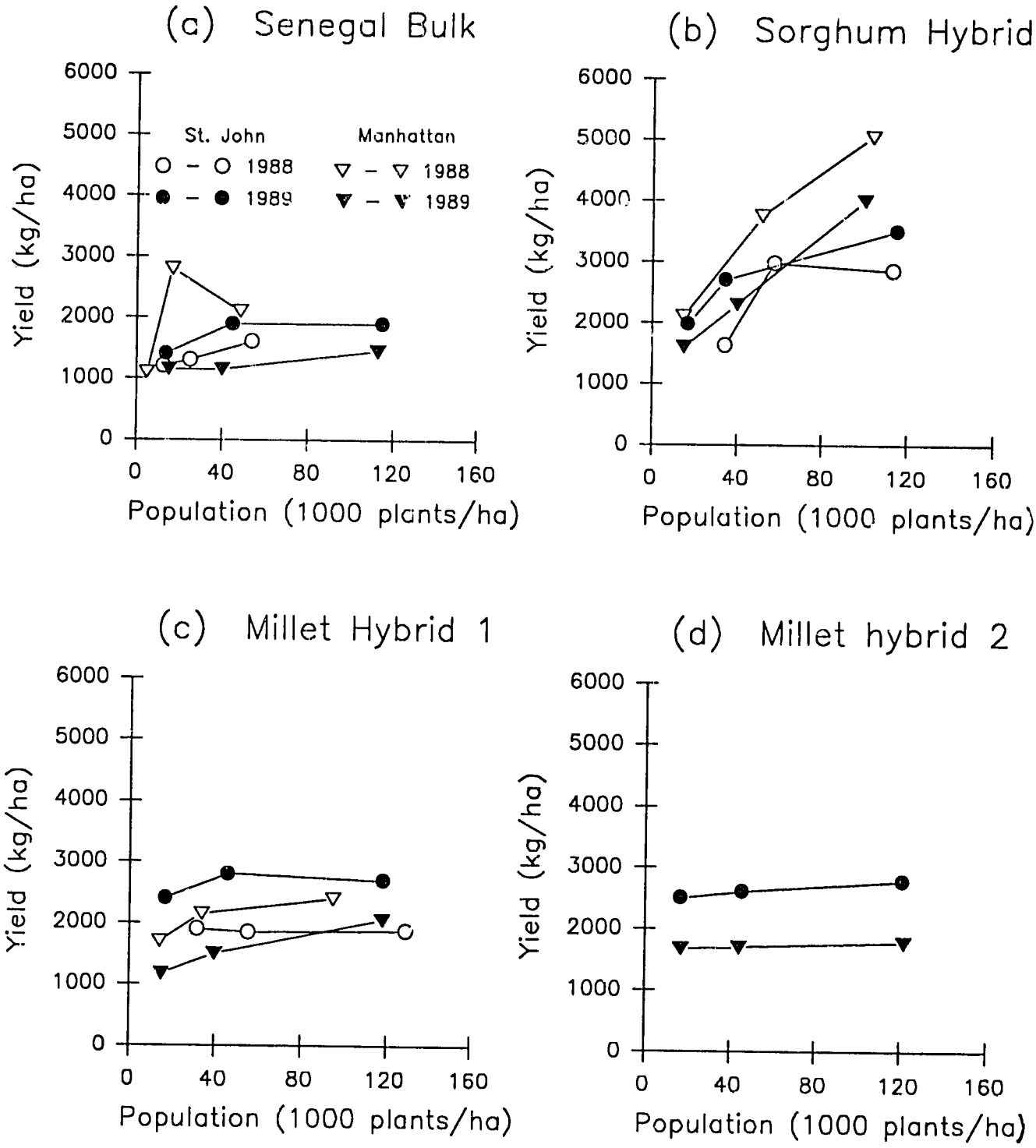

Fig. 2. Effect of variety X population on millet and sorghum yield at St. John and Manhattan in 1988 and 1989.

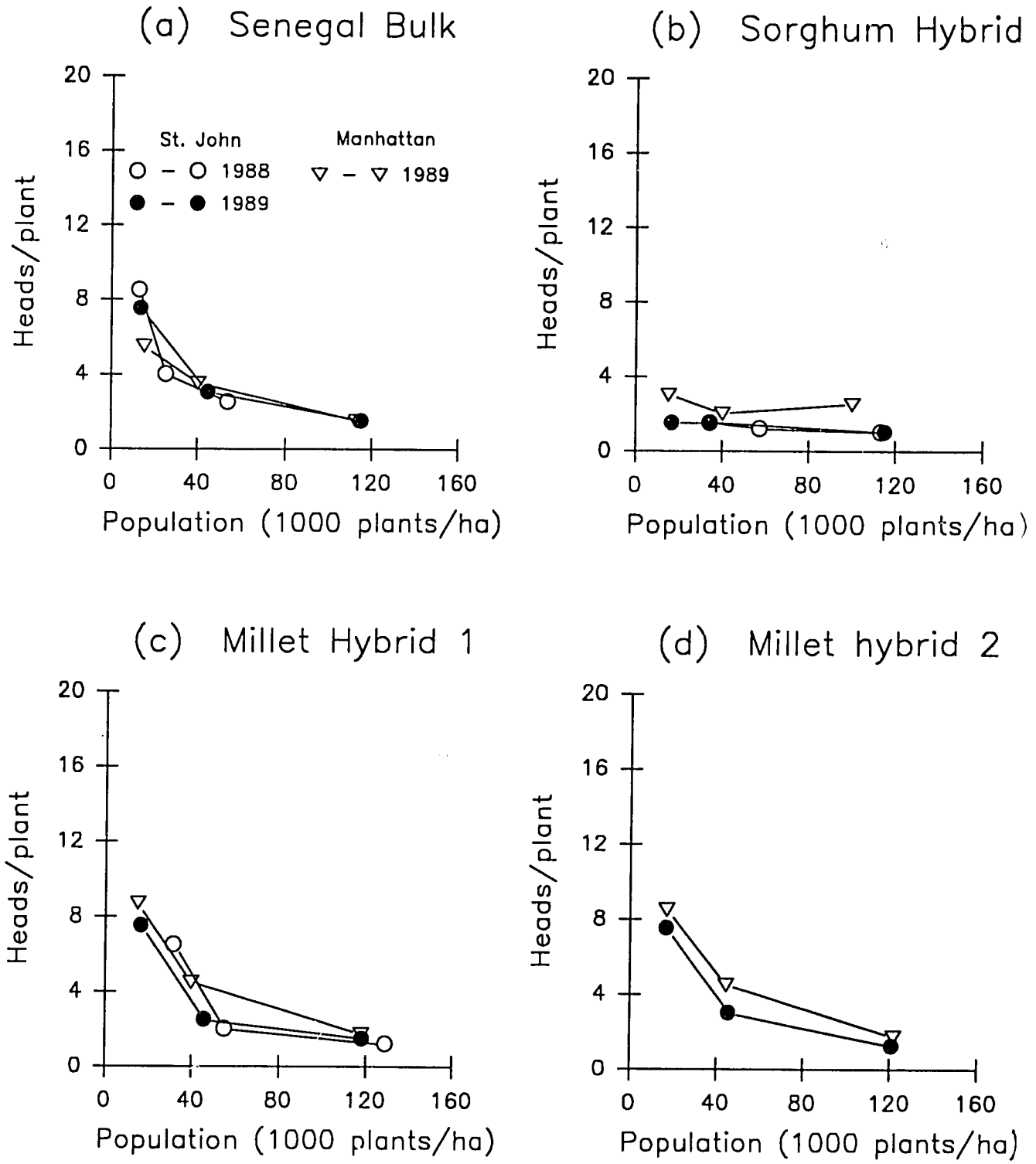

Fig. 3. Effect of variety X population on number of heads per plant at St. John and Manhattan in 1988 and 1989.

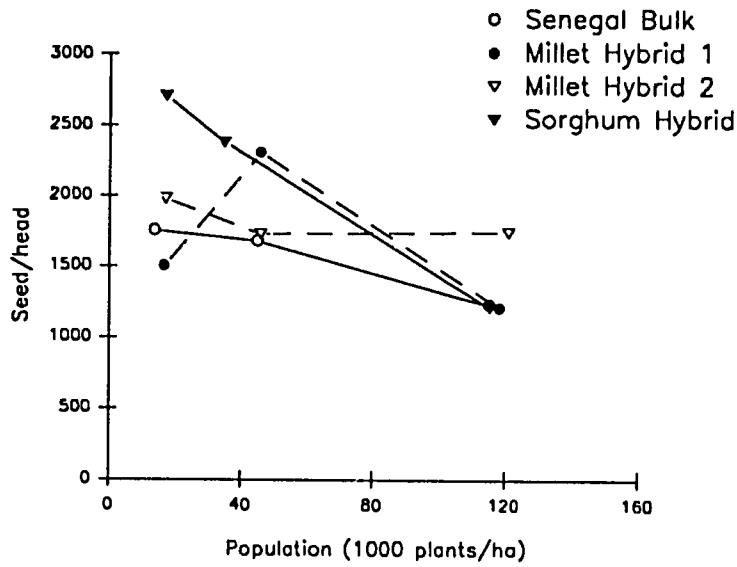

Fig. 4. Effect of variety X population on number of seeds per head at St. John in 1989.
LSD ($P < 0.05$) for comparison amoung populations = 597.

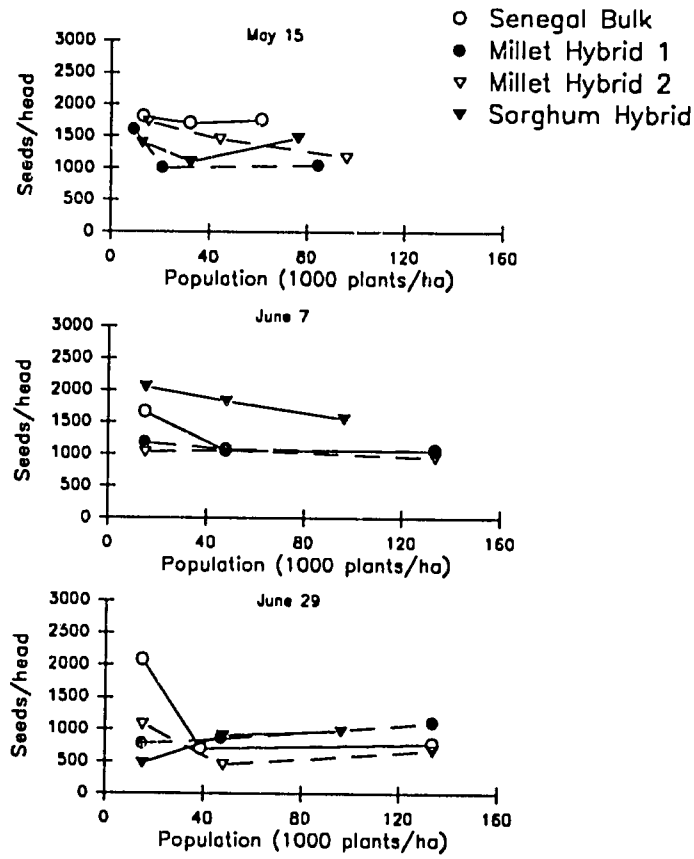

Fig. 5. Effect of date of planting X variety X population on number of seeds per head at Manhattan in 1989.
LSD ($P < 0.05$) for comparison amoung populations = 659.

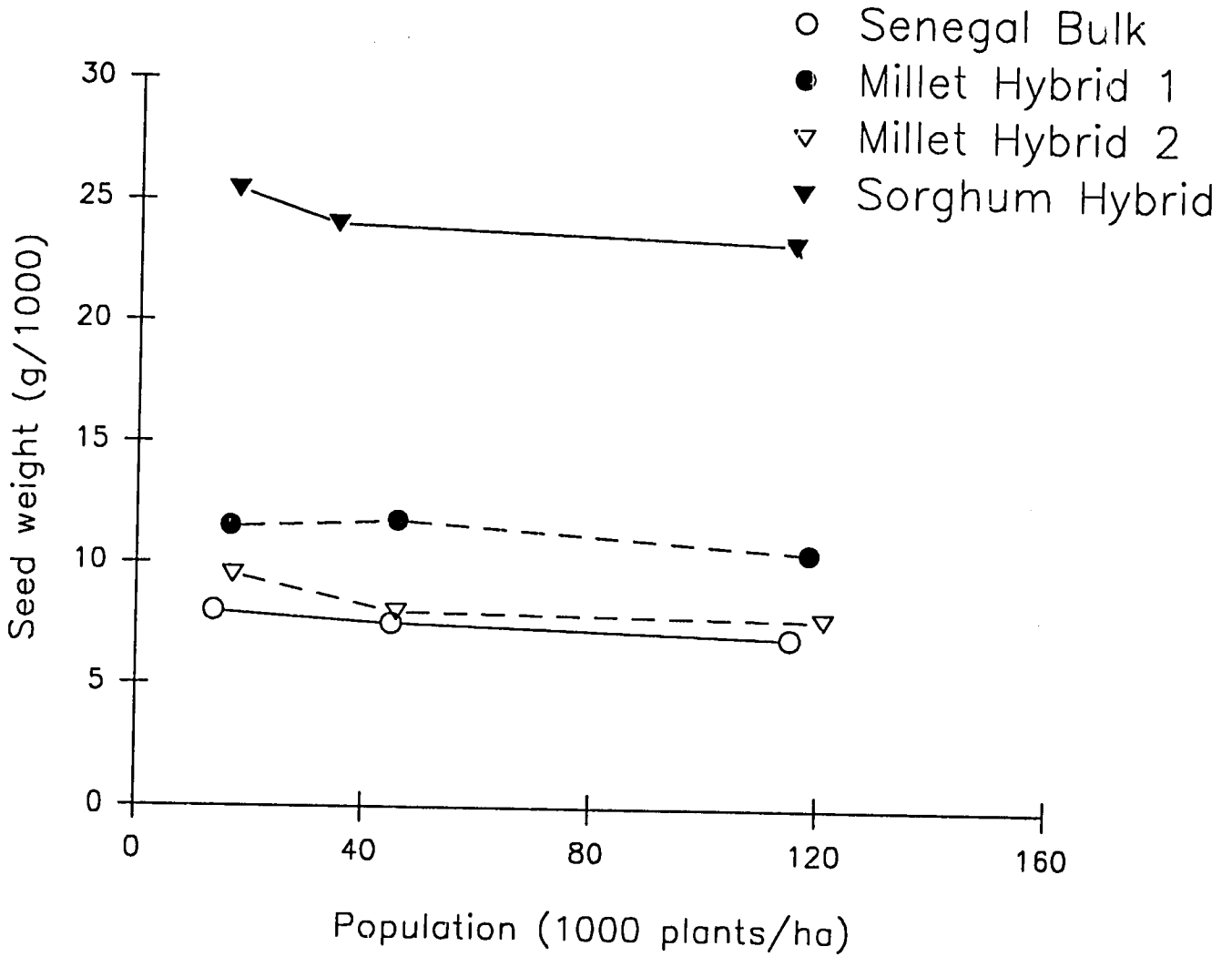

Fig. 6. Effect of variety X population on seed weight at St. John in 1989.

LSD ($P < 0.05$) for comparison amoung populations = 0.97.

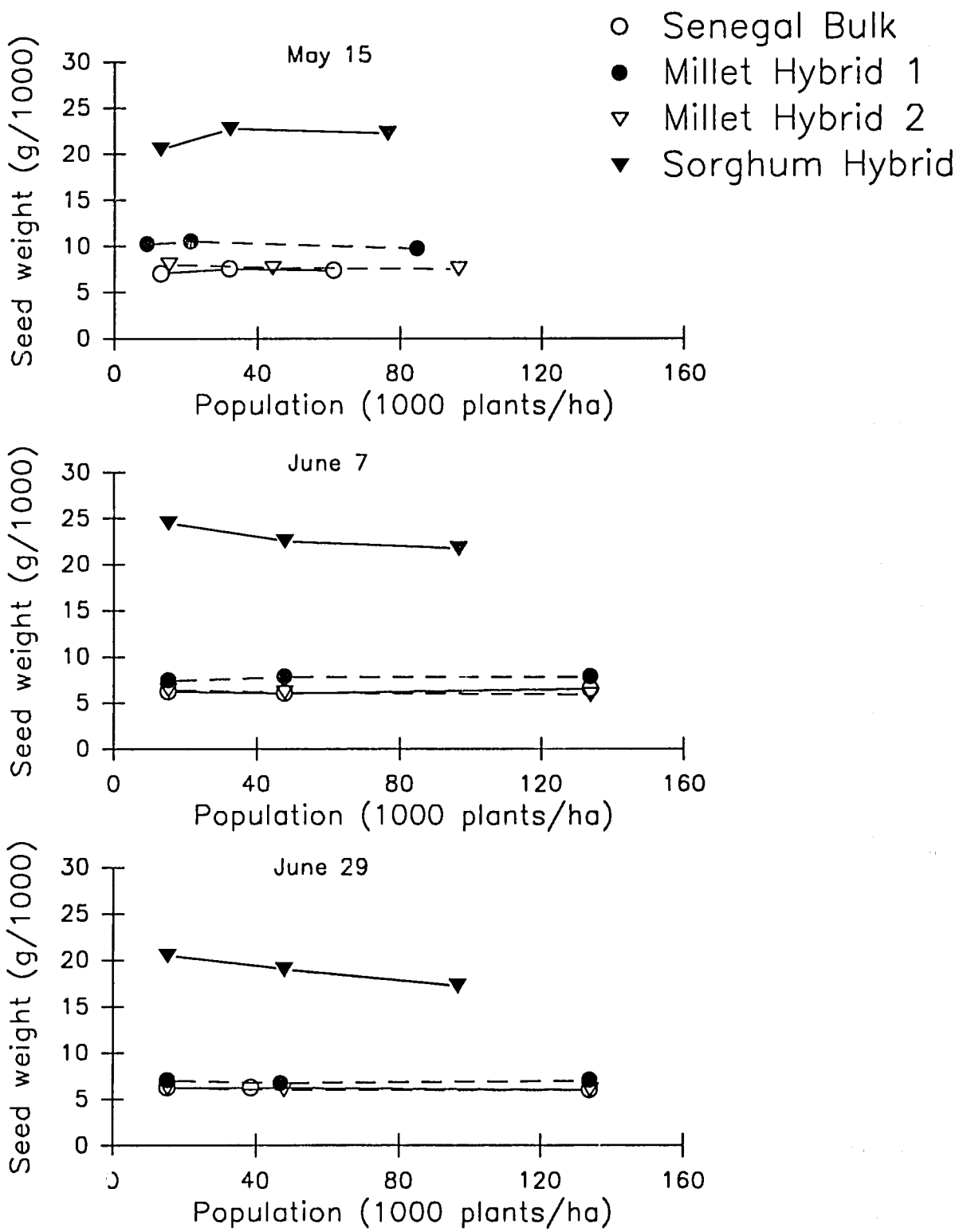

Fig. 7. Effect of date of planting X variety X population on seed weight at Manhattan in 1989.

LSD ($P < 0.05$) for comparison amoung populations = 1.6.

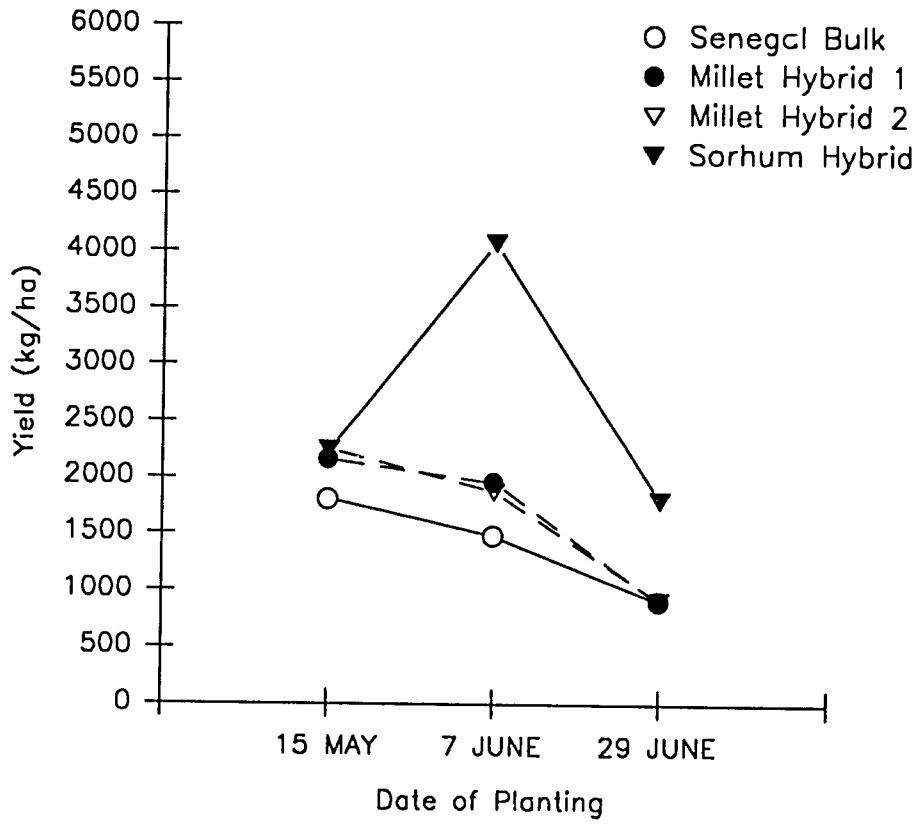

Fig. 8. Effect of date of planting X variety on yield at Manhattan in 1989. LSD ($P < 0.05$) for comparison among dates of planting = 543.

Botswana Agronomic Research

Project KSU-107
Richard Vanderlip
Kansas State University

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Summary

Food security continues to be the major goal for Botswana and other members of SADCC - the Southern African Development Coordination Conference. Since 1983 INTSORMIL - the International Sorghum and Millet CRSP - through Kansas State University's KSU-107, has sought to contribute to this goal by collaborative studies with Botswana's agricultural research scientists in their efforts to develop improved and sustainable agronomic practices for dryland sorghum and millet production. USAID/Botswana and the Ministry of Agriculture are supporting these efforts both financially and logistically. The value of their support over the past two years is estimated to be over 200,000 USD per year.

In developing their collaborative research program Botswana and INTSORMIL scientists recognized the primary need for practical and sustainable dryland production technologies to deal effectively with the twin primary constraints of soil-moisture and soil-fertility deficits. As a result their collaborative research program became integrated and centered around longterm studies on three main themes:

Rainfall harvesting.
Soil-moisture conservation tillage and soil fertility improvement.
Manure and crop residue management.

In implementing their collaborative program researchers utilize multilocational on-station and on-farm research sites. All sites are characterized to permit extrapolation and extendibility of the results. Research on these themes have produced significant achievements in development of improved technologies. For example:

On-farm studies of macrocatchment rainfall harvesting systems have shown that natural runoff can be used to triple sorghum yields by increasing seasonal soil-moisture availability.

INTSORMIL's in-country scientist serves as chairman and team leader of an effective MBO research working group organized to plan and implement a national agronomic research program on dryland cereal production. Under this program collaborative multilocational, on-farm and on-station trials are being conducted on several promising

soil-moisture conservation tillage/soil fertility improvement practices that can promote deeper moisture and root penetration, give better weed control, better crop establishment, and healthier crops. Preliminary results from these multilocational trials clearly indicate that tillage and fertilizer management can increase cereal yields and rain use efficiency in Botswana and needs to be comprehensively studied.

Crop residues used in conjunction with manure and fertilizers have been shown to have a favorable effect on crop growth by moderating the impact of environmental constraints. Yields can thus be stabilized at a higher level.

Objectives, Production and Utilization Constraints

Objectives

Improve and stabilize dryland sorghum and millet crop production by studying sustainable systems for improving rain and soil-water use efficiency through manipulation of the cropping system x cultural practice x soil interrelationships. Specifically:

- Evaluate on-farm rainfall runoff management systems.
- Evaluate crop response to various tillage systems and to fertilizer application across various rainfall conditions and soil types.
- Evaluate the effects of manure and crop residue management on crop yields and stability over seasons and sites.

Collaboratively support relevant national research efforts to improve and stabilize dryland sorghum and millet crop production. Specifically:

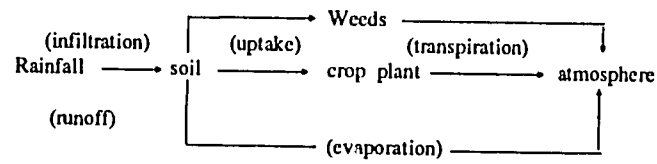
- Supporting studies on applications of agroclimatic data to sorghum and millet production.
- Assisting with the organization and management for development of a national dryland cereals research program.

Constraints

Dryland sorghum and millet production in Botswana is constrained principally by low, unreliable rainfall and low natural soil productivity. The low, irregular, and low-efficiency rainfall pattern contributes to a high risk of seasonal drought and crop stress. This rainfall pattern results in low, variable yields, low harvested-to-planted area ratios, and economically marginal cereal farm enterprises. Farmers traditionally invest a low level of labor and other resources because of the high risk and low yields.

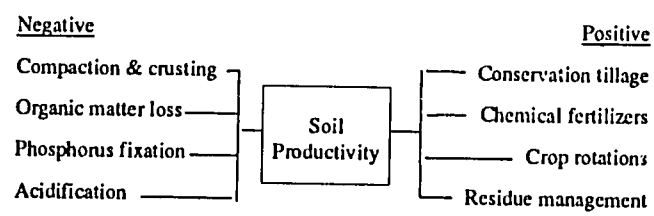
Sorghum is mostly grown on soils which have low organic matter, low N and P content, broadly graded sand fractions, and unstable surface structure. These last two properties result in a high bulk density, a massive hard structure when dry, and surface sealing and crust formation. At least one primary tillage operation is necessary to control weeds, improve soil structure and rainfall infiltration, and obtain good seedbed tilth, crop establishment, and crop stands.

Primary and secondary tillage operations are, and will continue to be, the most costly inputs for dryland crop production in Botswana. It is estimated that these operations annually cost Botswana's sorghum farmers close to 50% of the value of the national harvest for this crop. Tillage can be used to conserve and maximize available soil moisture utilization by crop plants in the following catenary pathway:



Lack of adequate P in the soil is a major limiting factor for crop growth in Botswana. Little is currently known about the levels of P and other nutrients that are needed to produce economically optimal yields of specific crops 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 indicate a need for continuing and comprehensive studies to develop sound fertilizer management practices for Botswana.

Together tillage and fertilizers help to maintain a favorable balance between the positive and negative influences on short-term and long-term soil productivity in Botswana as illustrated below:



The project addressed the above constraints through research on rainfall runoff management, tillage and fertilizer practices, and crop residue management.

Research Approach and Project Output

The overall goal of INTSORMIL KSU-107 is to achieve stable grain yields for sorghum at a significantly higher level than currently exists through improved and sustainable ag-

ronomic practices. Yields of at least one Mg/ha. every year will permit Botswana farmers to make more resource investments in arable activities. Research was continued during 1989-90 on tillage and fertilizer practices, crop residue management, and rainfall runoff management for dryland sorghum production. These efforts are detailed in the following sections.

Rainfall Run-off Management

Research Methods

Rainfall runoff management (RRM) is used to denote a range of rainfall runoff management schemes which seek to concentrate water for crop production. Various RRM investigations were conducted by ATIP, INTSORMIL, and LWMP at on-farm sites in Francistown, Mahalaype, and Sebele. This report briefly summarizes findings from collaborative research conducted by D. Carter and Dr. S. Miller of the LWMP on a macrocatchment system located on a farm near the Sebele Agricultural Research Station.

Research Results

Runoff from a natural drainage channel was directed via a delivery channel to a 0.5 hectare section of the field surrounded by a low perimeter ridge. The enclosed area was flood-irrigated as runoff frequency and amount allowed. A total of four runoff events occurred during 1989-90, however only two produced useful volumes of runon as shown below:

Rainfall and runoff amounts observed in 1989/90

Date	Rainfall (mm)	Runoff (m^3)
6 Nov.	31.0	273
25 Nov.	35.0	1649
27 Nov.	12.6	165
8 Dec.	28.6	745

Table 1 presents the yield and components of yield for sunflower, maize, and cowpeas within and outside of the runon area. Sunflower yields were higher with water harvesting whereas yields of maize and cowpeas were similar to the control. Similar maize yield results were obtained in a previous year, indicating maize may not be a good crop under these water harvesting conditions. Sunflowers appear suitable for further testing with water harvesting in rotation with sorghum.

Residue Management Study

Research Methods

In this, the final year of the study, the effects of applying 9 Mg/ha manure and 5 Mg/ha crop residues each year over four years on the soil's chemical and physical properties were assessed. Measurements were made on the two soil types, hardveld and sandveld, at three locations used in the studies. Measurements were made of modulus of rupture, Bray 2 P, organic carbon (OC), surface bulk density in 0-10 cm, 3-minute initial infiltration rate, and 60-minute cumulative infiltration.

Table 1. Yield and components of yield in the control and water harvesting plots.

	Crop					
	Sunflower		Maize		Cowpea	
	WH	Cntl	WH	Cntl	WH	Cntl
Plants m^{-2}	1.1	2.5	0.8	1.7	7.5	2.7
Heads m^{-2}	1.6	2.1	0.5	0.5	-	-
Stover (Mg ha^{-1})	0.8	1.0	1.2	0.9	0.3	0.4
Grain (Mg ha^{-1})	0.8	0.4	0.2	0.2	0.3	0.3
Water use (mm)	276	274	292	249	-	-

Research Findings

It was not possible to measure the modulus of rupture as the briquettes were too weak and broke apart despite several attempts and careful handling. The MOR of the few which did not collapse was between 0.6 and 1.5 bars. As shown in Table 2 the manure and residues resulted in some improvement in soil properties especially for the sandveld soil. Applying 9 Mg/ha manure and 5 Mg/ha crop residues is equivalent to applying 900 g manure/sq m and 500 g residue/sq m. Assuming a mean bulk density of 1.5 g/ml and a mean depth of incorporation of 15 cm these rates are equivalent to 4g manure /kg soil and 2.2 g residues/kg soil. A level

Table 2. Results of measurements of soil physical and chemical properties in plots receiving 9 Mg/ha manure and 5 Mg/ha crop residues each year for four years.

	SITE					
	Goodhope (sandveld)		Sebele-I (hardveld)		Sebele-II (sandveld)	
Property	+R	-R	+R	-R	+R	-R
Dry bulk density gm/ml	1.59	1.53	1.43	1.54	1.72	1.76
Initial 3-min. infiltration rate mm/hr	220	380	240	200	260	340
Cumulative infiltration after 60 min. mm	159	188	111	113	108	108
Organic carbon % dry soil						
00 - 15 cm	0.28	0.12	0.32	0.28	0.22	0.14
15 - 30 cm	0.25	0.20	0.38	0.30	0.16	0.10
Bray 2 P ppm dry soil						
00 - 15 cm	22.8	18.9	19.7	12.8	25.0	6.0
15 - 30 cm	16.6	8.4	15.4	8.3	25.1	2.5

of Bray 2 P of about 25 ppm is considered necessary for good plant growth. The rate of 4g manure/kg soil would supply this requirement if the available P content of the manure were 0.6%. Similarly the residue application rate would meet the requirement if the available P content were 1.1%. These P levels are much higher than were reported for kraal manure and sorghum stover in Botswana. The results of the manure and residue management studies in their entirety indicate that future investigations are needed to more fully quantify the effects of crop residues on soil nutrient status and availability.

Tillage and Fertilizer Research

Research Methods

In August 1988, with assistance from INTSORMIL, the Botswana Department of Agricultural Research delineated an agronomic research subprogram on dryland cereal production. It was decided to focus attention on tillage and fertilizer management practices in this subprogram. For the 1988-89 season, a single experiment was designed to evaluate several tillage systems on sorghum growth and yield. The trial was put out at eight on-farm and one on-station locations. At several sites preliminary studies on fertilizer P and N were initiated. Detailed reports on the results of these trials are available. Much technical experience was gained in the implementation of the 1988-89 trials. In addition, the program resulted in improved linkages and communication between the scientists in the Department of Agricultural Research, the Arable Lands Development Programme, and the Farming Systems Research teams.

In 1989-90, the program broadened its scope of activities to include other aspects of agronomic research on dryland cereals, but tillage practices and fertilizer for sorghum remained the main focus. In addition, the traditional broadcast/plough/plant system was added to give the following six core tillage treatments with and without fertilizer:

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/plow/plant: Broadcast seed at 5 kg/ha followed by a single mouldboard ploughing to at least 15-20 cm depth.

At several sites other treatments were added as appropriate to suit specific needs and objectives. These treatments were implemented by tractor and animal draught in separate experiments. For the animal draught experiment, treatment T5 was not implemented and T3, the deep rip treatment was replaced with chisel ploughing. The chisel plough treatment consisted of an early tillage operation with an animal drawn chisel on 150 cm centers to at least 25-30 cm. Crop was row planted on chisel lines to obtain 20,000 plants/ha + 10%.

In 1989-90, there were four experiments on tillage and fertilizer for dryland sorghum over nine sites as shown below:

E1: Tillage systems by tractor for sorghum on hardveld and sandveld, with and without fertilizer.

E2: Tillage systems by animal for sorghum on hardveld and sandveld, with and without fertilizer.

E3: Fertilizer calibration for sorghum on hardveld and sandveld.

E4: Weed control methods for sorghum with deep ripping tillage system on hardveld.

		Experiment			
Site	Code	E1	E2	E3	E4
Mathangwane 1	F1	x			
Mathangwane 2	F2	x	x		
Palapye	M5	x			
Mahalapye 1	M3	x	x		
Mahalapye 2	M4	x			
Sebele	S1	x	x	x	x
Mushopa	P3	x	x	x	
Tswidi	P2	x	x	x	
Sese	J1	x	x	x	

The same codes were retained for those sites that were used previously in the 1988-89 season.

Research Findings

Results from the 1988-89 trials showed that sorghum responded differently to tillage treatments from site to site. Generally, the double ploughing and plough + cultivate treatments tended to be better than the others at many of the sites but the differences were significant at the 5% level of probability at only two of the sites. At two sites where detailed water balance calculations were possible, these treatments also had the highest rain use efficiencies. The

conventional treatment performed better than the deep rip system at six of the eight sites. However, these differences were statistically significant at only two sites. There were no significant differences between the deep rip and the conventional + wide-row spacing treatments. These site to site differences were probably related to the rainfall, soil, and crop management factors but data collected were not sufficient to permit definite correlations and functional relationships.

The climatic, soil, and management factors at each site are integrated and expressed in the grain yield. The overall mean grain yield at each site was therefore taken as an index of the environmental conditions of the site. The mean yields for each treatment at each site were then plotted against these overall mean site yields and least squares regression lines were fitted through the plotted points. These analyses are presented in Figures 1 and 2 and permit comparison of the regression lines for double plough, deep rip, plough + cultivate and conventional + wide row spacing treatments with that for the conventional treatment in each case. They showed that at the lower overall-yielding sites there were little or no differences between the conventional and the other treatments. At higher overall-yielding sites, these differences tended to be greater, with higher yields from the double plough and plow + cultivate treatments and lower yields from the deep rip and conventional + wide row spacing treatments.

It was not possible to form general conclusions on the reasons for these observed effects. At Sebele, soil moisture in the plots was measured shortly before, and several weeks after, the first tillage operation. These data indicated that the plots with the early tillage operations, namely double plough, deep rip, and plough + cultivate treatments, lost less soil moisture. This may have contributed to the higher yields obtained with early mouldboard ploughing at most sites. In addition, various correlations were examined between grain yield, rainfall, and other measured crop variables such as productive plants and plant height. No patterns were found in these correlations and no general conclusion was possible regarding the crop factors responsible for yield differences. For example, at one site lower mean plant populations in the conventional and double plough treatment plots gave higher yields than the other three treatments with higher mean plant populations. The optimum plant population for a given treatment would increase as the yield environment improves. The convergence of the lines shown in Figures 1 and 2 at the lower overall-yielding sites may indicate that the optimum plant populations were being exceeded at these sites. Conversely, several outliers appearing in these figures at the higher overall-yielding sites may be the result of suboptimal populations for these specific treatment and site combinations. More data than were collected in these initial trials are needed to define more conclusively the relationships between grain yield, rainfall, and plant populations.

These relationships are hypothesized as follows for rainfall R in mm and population N in plants/ha:

a. kg DM/plant = f(R/N), where DM = above-ground dry matter.

b. (kg grain/ha)/(kg DM/ha) = Harvest Index = f(kg DM/plant)

c. kg grain/ha = R x RUE x HI, where RUE = rain use efficiency = (kg DM/ha)/R.

Data on soil moisture, surface dry bulk density, and infiltration rates, did not show that these properties were differently affected by the tillage treatments. These data also did not permit a definite conclusion as to whether the traffic lines harvested rainfall into the rip lines in the deep rip treatments.

The addition of 15 kg P /ha on a ferrallic arenosol with a Bray 2, P content of 0.2 ppm had a large, positive effect on yield for all tillage treatments. In separate studies on application rates for fertilizer N and P at two sandveld sites, P application also had a large, positive effect on yields as shown in Table 3.

Data for the 1989-90 trials are currently being analyzed. Table 4 presents the grain yield data for experiment E1 at several sites in these trials.

These activities have resulted in:

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

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

3. A clear indication that early tillage and P application can increase yields.

4. The initiation of modelling to more fully understand the mechanisms and to serve as a tool for transferring the results of these trials. Models developed by IBSNAT - the International Benchmark Sites for the Agrotechnology Transfer Project - have been acquired for this purpose.

5. Obligation of GOB funds through ALDEP to cover equipment and operational costs of the trials. USAID Botswana provided in-country support for INTSORMIL participation in these studies.

Miscellaneous Research Support Studies

INTSORMIL has continued support-relevant activities and interests of Botswana researchers. Support was provided to:

Figure 1. Plots of regression lines and data points for comparing mean yields of the conventional with those of the double plough and deep rip tillage treatments over the sites used for the 1988-89 tillage trials.

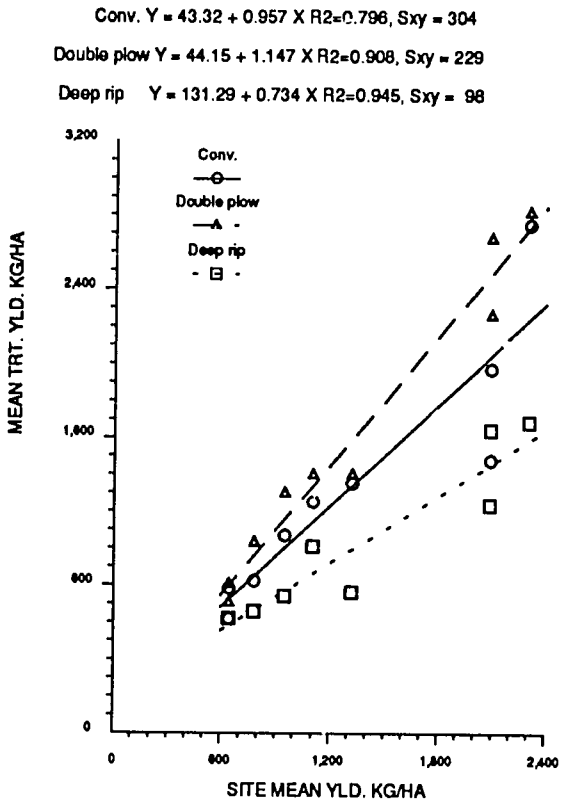


Figure 2. Plots of regression lines and data points for comparing mean yields of the conventional with those of the plough + cultivate and conventional + wide row spacing tillage treatments over the sites used for the 1988-89 tillage trials.

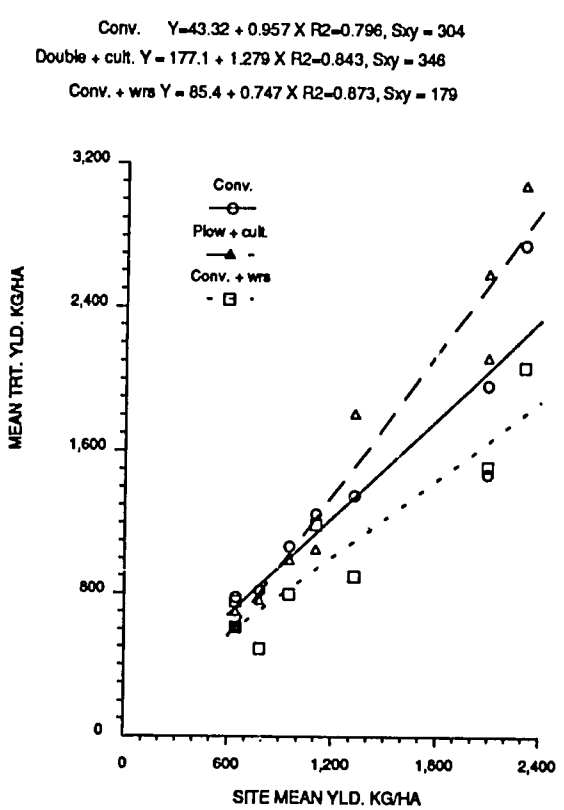


Table 3. Effect of N and P application rates on sorghum grain yield and P uptake in grain.

	Sandveld sites					
	SESE			TSWIDI		
P rate	grain	increase	P uptake	grain	increase	P uptake
	kg/ha	%	kg/ha	kg/ha	%	kg/ha
0	552	0	0.95	946	0	1.82
10	1567	184	3.13	1780	88	3.25
20	1903	245	4.21	1863	97	3.38
40	2435	341	5.89	2016	113	5.53
80	2787	405	7.03	1939	105	5.67
N rate	grain	increase	N uptake	grain	increase	N uptake
	kg/ha	%	kg/ha	kg/ha	%	kg/ha
0	1574	0	15.74	1822	0	18.20
20	1802	14	18.00	1508	-17	18.10
40	2021	28	20.20	1677	-08	16.89
60	1998	16	20.00	1791	-02	22.00

Table 4. Sorghum grain yields for various tractor draught tillage treatements in multilocational trials with and without applied fertilizer.

		Grain yield adjusted to 10% moisture						
		Treatment						
Site		Conv.	Double Plow	Deep Rip	Plow + cultivate	Conv. + wrs	Broadcast plow/plant	Mean
F1	-F	880	1087	917	939	736	983	924
	+F	794	1298	733	1187	738	644	899
Mean		837	1193	825	1046	737	813	912
F2	-F	44	1155	1561	585	62	14	570
	+F	236	1155	574	437	2	11	403
Mean		140	1155	1067	511	32	13	486
S1	-F	1633	1326	1198	1237	1364	-	1352
	+F	1190	993	1282	965	1547	-	1195
Mean		1411	1160	1240	1101	1456	-	1274
P2	-F	1019	1338	704	1374	934	491	977
	+F	1743	1739	978	1514	1350	1338	1444
Mean		1381	1539	841	1444	1142	914	1210
J1	-F	508	462	303	424	346	1127	528
	+F	868	818	1061	755	833	1428	961
Mean		688	640	682	590	590	1277	893

1. Meteorological Services researchers resulting in completion of a joint study to select an appropriate set of coefficients for use in calculating potential evapotranspiration with Penman's formula. The report on this study was printed by the Ministry of Agriculture and has been circulated to SADCC member countries by the SADCC Land and Water Management Research Programme.

2. Ms. Malepa for her Ph.D dissertation research on critical levels of macro and micronutrients for 12 soils of Botswana.

Publications and Presentations

Publications

Carter, D.C. and S. Miller. 1989. Crop production using water harvesting techniques. Bulletin of Agricultural Research in Botswana. Vol 7: 1-14.

Carter, D.C. 1989. Effects of four tractor draft tillage practices on soil moisture and sorghum yield. Bulletin of Agricultural Research in Botswana. Vol 7: 15-24.

Carter, D.C. 1990. Manure and stover management for sorghum and millet production in eastern Botswana. Part I. The effects of mulching two soils on soil moisture content and water use efficiency. Bulletin of Agricultural Research in Botswana. Vol. 8: In print.

Carter, D.C. 1990. Manure and stover management for sorghum and millet production in eastern Botswana. Part II. The effects of manure, mulch, and soil-incorporated stover on the physical and chemical properties of two Soils. Bulletin of Agricultural Research in Botswana. Vol. 8: In print.

Carter, D.C. and S. Miller. 1990. Three years experience with an on-farm macrocatchment water harvesting system in Botswana. Accepted for publication, Agricultural Water Management. May, 1990.

Persaud, N. 1990. Taking soil samples and examining soil profiles. In Farming Systems Research Handbook for Botswana, Chapter 8. Dept. of Agricultural Research, Pvt. Bag 0033, Gaborone.

Persaud, N., K. Monageng, A. McPherson, J. Siebert, B. Tilahun, G. Heinrich, D. Carter, D. Norman and L. Williams. Botswana National Tillage Research Programme. Proceedings of the 6th Regional Workshop of the SADCC/ICRISAT/ SMIP, Bulawayo, Zimbabwe, 14-19 September 1989.

Persaud, N., C. M. Sakamoto, W.D. Joshua, D. Lesolle, D. Dambe, and R. Vanderlip. 1990. Coefficients of Penman's formula for calculating evaporation and potential evapotranspiration in Botswana. Dept. of Agricultural Research, Pvt. Bag 0033, Gaborone.

Persaud, N. 1990. National Tillage Research Programme - Report on the 1988-89 National Tillage Trials. Part 1: Main Report. Department of Agricultural Research, Pvt. Bag 0033, Gaborone, Botswana.

Persaud, N. 1990. National Tillage Research Programme - Report on the 1988-89 National Tillage Trials. Part 2: Detailed Site Reports. Department of Agricultural Research, Pvt. Bag 0033, Gaborone, Botswana.

Youngquist, J.B., D.C. Carter, and M.D. Clegg. 1990. Grain and forage yield and stover quality of sorghum and millet in low rainfall environments. Accepted for publication, Exp. Agric. 26: 279-286.

Presentations

Carter, D.C., N. Persaud, R. Vanderlip, N. Mokete, and S. Miller. 1989. Three Years Experience with an On-farm Macrocatchment Water Harvesting System in Botswana. Presented at the annual meeting of the American Society of Agronomy, Las Vegas 15-19 October 1989.

Monageng, K., N. Persaud, D. Carter, L. Gakale, K. Molapong, G. Heinrich, J. Siebert, and N. Mokete. 1990. Tillage and organic matter management for dryland farming in Botswana. Presented at the international conference on Tillage and Organic Matter Management in the Humid and Subhumid Tropics, Antananarivo, Madagascar, 9 - 15 January, 1990.

Persaud, N., K. Monageng, A. McPherson, J. Siebert, B. Tilahun, G. Heinrich, D. Carter, D. Norman and L. Williams. 1990. Soil moisture conservation tillage systems for sustainable dryland sorghum production in Botswana. Presented at the annual meeting of the American Society of Agronomy, Las Vegas 15-19 October 1989.

Van de Griend, A.A., M. Owe, and D.C. Carter. 1990. Microwave Remote Sensing of Soil Moisture in Africa Using Nimbus-7/SMMR. Interna-

tional Symposium on Remote Sensing and Water Resources, 20-24 Aug. 1990. Enschede, The Netherlands.

Networking Activities

Workshops

Participated in SACCAR Conference on Land and Water Management, 2-6 April, Sun Hotel, Gaborone, Botswana.

Participated in the 6th Regional Workshop of the SADCC/ICRISAT/SMIP, Bulawayo, Zimbabwe, 14-19 September 1989.

Organized technical meeting to discuss components of Penman's potential evapotranspiration method and to determine the appropriate coefficients applicable for Botswana.

Initiated and obtained formal approval from SACCAR Board of Directors to organize an International Workshop on "Improving and sustaining the productivity of dryland farming systems in the SADCC region".

Research Investigator Exchanges

Joint soil moisture data collection and analysis with scientists from the Free University, Amsterdam, Netherlands and Goddard Space Center, Maryland, U.S.A.

Met with Dr. Michael Lee, UNICEF consultant, about water harvesting research in Botswana. Nov. 1989.

Met with Drs. E. Ikavalko and Rajet De as part of a review of the Arid Lands Development Project. Dec. 1989.

Met with Drs. H. Henderson and B. Hutchinson from the University of Arizona about research on the role of women in agriculture.

Hosted visit by Dr. J. Parr, Coordinator USAID/USDA Dryland Management Project, 19-24 February, 1990.

Research Information Exchange

1. Arranged and hosted consultancy 11 - 17 March 1990 by Dr. Upinder Singh to demonstrate to Botswana researchers the DSSAT models developed by IBSNAT - the International Benchmark Soils Network for Agrotechnology Transfer.

2. Organized three short courses on data collection procedures for field assistants monitoring the on-farm tillage and fertilizer trial sites.

3. INTSORMIL is a standing member of:

a. The National Committee for Agricultural Meteorology.

b. The Sebele based 'Agricultural Water Group'. This group's main function is to coordinate research in the area of rainfall, runoff, and water conservation.

4. The National Tillage and Fertilizer Research Group which coordinates research on tillage and fertilizer practices for dryland cereals. INTSORMIL in-country scientist serves as the chairman and team leader of this group.

Agronomy and Cropping Systems

Project UNL-113

Max D. Clegg and Stephen C. Mason
University of Nebraska

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Mr. Maman Nouri, INRAN, Niger
Dr. Chandra Reddy, INRAN/NAAR, Niger
Mr. Minamba Bagayoko, IER, Mali
Mr. Mirghani Mohamed, INTSORMIL/ARC, Sudan
Dr. Saeed Farah, ARC, Sudan
Dr. Francisco Gomez, Sorghum Program, Honduras
Dr. Daniel Meckenstock, INTSORMIL/Honduras
Dr. Gebisa Ejeta, Associate Professor, Purdue University, West Lafayette, Indiana
Dr. Jerry Eastin, Professor, University of Nebraska, Lincoln, NE
Dr. Richard Vanderlip, Professor, Kansas State University, Manhattan, KS

Summary

In Sudan rotation with phillipesara and clitoria resulted in sorghum grain yield increases of 20 and 39%. Nitrogen fertilizer application of 40 and 80 kg ha^{-1} further increased yields by 32 and 23% for phillipesara and 46 and 31% for clitoria respectively.

Grain sorghum genotype emergence studies showed great variation across years and across locations. The local Niger variety Bogoba emerged better than all breeding lines tested. In 1989, the genotype P1044 had consistently high emergence across locations. Data from studies on kernel weight, mesocotyl and coleoptile length, germination index under varying temperature and osmotic potential, and emergence through artificial crusts is being analyzed.

Grain sorghum-soybean studies in Nebraska show important two-year residual benefits of soybean cropping on grain sorghum yield and soil N status. Previous soybean crop resulted in 2 to 3 Mg ha^{-1} sorghum grain yield the first year and 0.4 to 1.4 Mg ha^{-1} the second year. Soil NO_3-N levels were 44 to 50 kg ha^{-1} the first year and 17 to 23 kg ha^{-1} more the second year. Soybeans in rotation also increased the protein content of the sorghum grain produced the following year.

Economic analysis based on 1979 to 1989 prices and input costs showed the highest return to be for continuous grain sorghum with 171 kg ha^{-1} applied N, however, this would change if fertilizer nitrogen costs rise. The sorghum-soybean rotation was the most stable production system when no fertilizer nitrogen was applied.

Objectives, Production and Utilization Constraints

Objectives

Determine the influence of residual effects of rotation and fertility regimes on sorghum and millet yields.

Determine water use efficiency of sorghum and millet following soybeans in rotation.

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 cowpeas harvested for forage and grain to millet. In 1990 this four-year study will conclude by looking at residual contributions.

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.

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

Complete the statistical analysis of data from sorghum and soybean intercropping studies with sorghum isolines of differing heights and complete a final report.

Establish collaborative research effort in Honduras and Mali.

Constraints

Environmental - This project deals primarily with limited availability of nitrogen for crop production, but its interactions with water, light, and temperature require consideration. In addition, difficulties in stand establishment of grain sorghum due to high temperature and moisture stress are addressed.

Research - Cropping systems research requires long-term commitments of trained scientists' time, availability of research funding, and linkage with scientists with similar interests. Also, improved production practices will result in substantial yield gains as many farmers produce less than 0.500 Mg ha^{-1} grain from sorghum.

Research Approach and Project Output

The principal investigators are involved in research on nitrogen and other contributions associated with cereal/grain legume rotational and intercropping systems. Dr. Clegg focuses his international efforts in the southern Africa prime sites, while Dr. Mason focuses on the western Africa prime site of Niger and Mali. Dr. Clegg is involved with the eastern Africa prime site through Sudanese graduate student Mirghani Mohamed's Ph.D. thesis research. The Central America prime site has expressed interest in UNL-113 assisting with maize/sorghum intercropping system along with use of legumes as nitrogen sources. Domestic research is focused on grain sorghum-soybean crop rotation in the Great Plains.

- Max Clegg - International

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

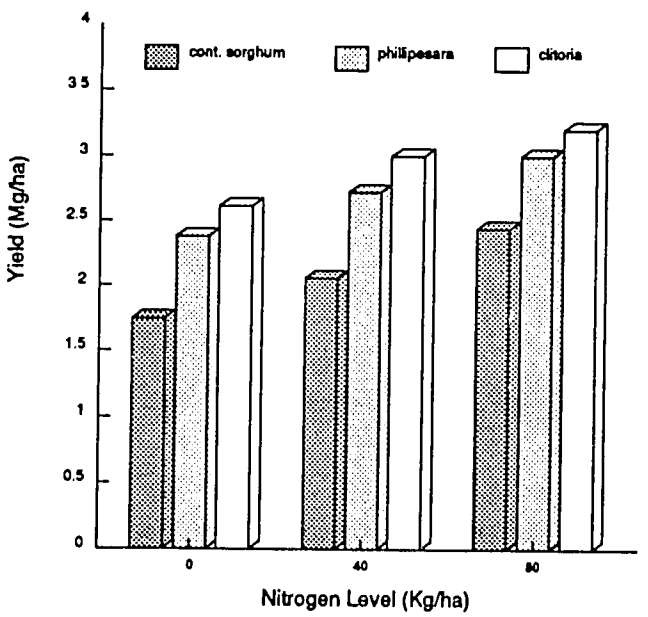
Research Methods

A rotation experiment was established at Wad Medani in 1988. Sorghum (*Sorghum bicolor* [L.] Moench) variety HD-1 was used. Since *Striga* is a problem, a resistant sorghum SRN-39 was used in 1989. The legumes 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. Yield, and yield components were determined on the grain harvested from the two center rows (4 meter) of each plot. Total soil characterization analyses were made. The soils were found to have a very high pH and may indicate iron deficiencies.

Research Results

The linear response of SRN-39 grain yield to nitrogen application was significant at the P=0.01 and the differences to previous crop were significant at the P=0.05 (Fig. 1). Fertilizer treatments increased yield 36 and 49% with application of 40 and 80 kg ha^{-1} respectively. Rotation with the legumes also had a pronounced effect on grain yield. Growing sorghum after phillipesara resulted in a yield increase of 20% and after clitoria an increase of 39%. Rotation and nitrogen fertilizer application resulted in an additive effect with greater grain yield increases.

Figure 1. Sorghum yield as affected by nitrogen fertilizer and previous crop.



- Stephen C. Mason - International

Grain sorghum emergence studies.

Research Methods

Niger, 1987. Twenty two grain sorghum genotypes comprised of breeding lines from INTSORMIL Project PRF-107 and local Niger cultivars were planted in dune sand and valley soils on June 25 and July 9 in a split-split plot experiment. Emergence was collected every two days until eight days after planting. Survival data were collected weekly until eight weeks after planting. The survival ability index was determined by dividing the percent survival by percent emergence.

Table 1. Emergence and survival of grain sorghum genotypes in Niger, 1987.

Sorghum Genotype	Emergence	Survival	Survival ability+		
			Valley	Dune	Difference
	---------- % ----------				
P898012	19	10	1.06	0.16	0.90
P1006	8	4	0.82	0.05	0.78
P954035	19	9	0.84	0.06	0.78
P1058	8	4	0.90	0.21	0.69
P1028	18	8	0.78	0.10	0.68
E55-1	15	8	0.85	0.17	0.68
P1041	20	12	0.90	0.25	0.65
P1029	21	11	0.81	0.23	0.58
P1056	27	14	0.96	0.44	0.52
P1055	42	18	0.78	0.26	0.52
HDF1	18	11	0.89	0.38	0.51
P1016	26	12	0.79	0.28	0.51
BG	18	11	0.92	0.41	0.50
P1044	34	20	0.86	0.41	0.45
P967083	13	8	0.91	0.47	0.44
P1004	24	13	0.79	0.40	0.39
P1052	9	5	0.79	0.40	0.38
BDF	31	16	0.71	0.35	0.36
El Mota	41	28	0.90	0.60	0.30
P1045	17	9	0.82	0.58	0.24
NGK	34	23	0.69	0.59	0.09
Bagoba	53	33	0.66	0.69	-0.03
LSD(0.05)	10	7			

+ Survival ability = Percent survival/percent emergence.

Table 2. Genotype by location interaction effects on percent seedling emergence of grain sorghum in 1989.

Genotype	Mean	Niger	Kansas	Zambia	Nebraska	
					July 10	July 24
P1044	63	35	85	44	69	84
P1056	61	28	79	40	73	86
P954035	61	39	73	56	56	81
P967083	57	27	81	37	[illegible]	76
P1041	56	29	86	38	52	74
P1045	55	31	81	37	50	78
P1055	55	29	77	38	53	77
P1006	54	38	70	31	54	78
P1052	49	34	65	29	54	65
P1058	49	26	72	32	49	67
P1028	45	11	70	22	56	64
P1004	41	19	58	25	39	63
P898012	38	26	43	27	38	54
P1016	37	24	40	27	31	63
LSD(0.05)	7	10	26	15	11	11
CV (%)	27	30	32	38	18	13

Multilocations, 1989. Grain sorghum emergence studies were conducted with 14 genotypes at Mead, NE (July 12 and July 24 planting dates); St. John's, KS; Mt. Makulu, Zambia; and N'Dounga, Niger in 1989. A randomized complete design with six replications was used. Emergence counts were taken 7 and 14 days after planting.

Research Results

Grain Sorghum Emergence and Survival in Niger, 1987. Analysis of variance indicated that planting date and soil type had no influence on emergence of grain sorghum genotypes. Genotype differences were present with the best genotype having an emergence of 53% and the worst with 8% emergence (Table 1). The local Niger genotype Bagoba had the greatest emergence followed by P1055 and El Mota. Genotypes P1052, P1058, and P1006 had emergence less than 10%. Sixteen of the 22 genotypes had emergence less than 30%. The low percent emergence in this study was partially attributed to soil temperatures above 40 C several days at 1400 hours.

Survival variation was attributed to the soil type X planting date interaction, and to grain sorghum genotypes. The survival of grain sorghum genotypes was lower on the dune sand soil than on the valley soil. For the June 25 planting date the survival was 7% lower on the dune sand soil, while for the July 9 planting date it was 13% lower. Percent survival was much lower than emergence for all genotypes (Table 2). To eliminate the confounding effect of genotypes with high percent emergence having more plants to survive, a survival ability index was determined. This index indicated that the genotypes P8988012, P1006, and P954035 had high ability to survive on the valley soil, but very low ability to survive on the dune sand soil. In contrast, the genotypes Bagoba and NGK had a lower ability to survive on the valley soil, but a much higher ability to survive on the dune sand soil. In fact, the ability to survive on the valley and dune sand soil was essentially the same.

Emergence in Nebraska, Kansas, Niger, and Zambia, 1989. The highest mean emergence across locations was 63% for the genotype P1044, while the lowest was 37% for P1016 (Table 2). However, a significant genotype X location interaction occurred. The genotype P1044 had consistently high emergence across locations, with it being one of the top three emergers at all locations. The genotype P1056 had the highest percent emergence for both planting dates in Nebraska, but it did not emerge as well in the other locations. Most genotypes percent emergence was inconsistent across locations. The genotypes P1016 and P898012 had very low percent emergence at all locations.

Overall, the Nebraska location planted on July 24 had the highest emergence while Niger had the lowest emergence. During the emergence study the Nebraska location planted on July 24 had the most desirable soil temperatures along with adequate soil water levels. The Kansas and Zambia locations had desirable day temperatures for emergence, but the night temperatures were lower than desired for grain sorghum. Low soil water levels during part of the emergence period in Kansas, Zambia and Nebraska planted on July 10 could have reduced percent emergence. The Niger location had the highest soil temperatures of all the locations. Shoot-fly (*Atherigona soccata* Rondani) damage to the plots in Zambia contributed to the low percent emergence at this location.

Present Study. Studies to evaluate kernel weight, mesocotyl and coleoptile length, germination under varying temperature and osmotic potentials, and emergence through artificial crusts have been conducted. At present the data are being analyzed in hopes of determining seed/seedling characteristics associated with the emergence differences among genotypes presented above.

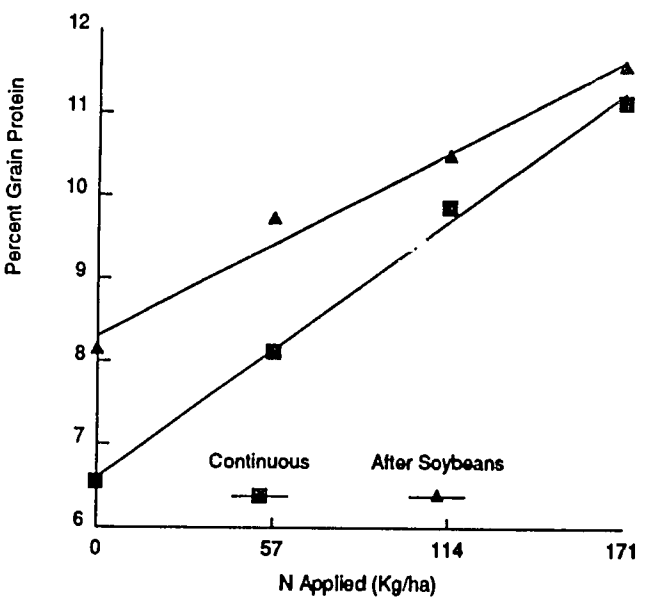
- Max Clegg - Domestic

Grain sorghum-soybean rotation.

Research Methods

Sorghum and soybean can be grown in rotation, a sustainable agricultural system. Although cereal yields are improved, other factors need to be considered when making management decisions. The objective of this study was to determine the protein concentration and the economic return to overhead, labor and management for the different treatments. A randomized complete block design with four replications was used. Plots were thinned to a uniform stand about two weeks after emergence and 0, 57, 114, and 171 kg N ha^{-1} was applied as ammonium nitrate to the designated sorghum plots. Yield data were taken from the two middle rows of six row plots. Percent nitrogen was determined on the grain. Yearly and mean returns ha^{-1}, skewness, standard deviation, C.V., and number years with a net return below \$50 ha^{-1} for the years 1979 to 1989 were determined.

Figure 2. The effect of applied nitrogen on the grain protein of sorghum grown continuously or after soybean.



Research Results

The effect of applied nitrogen and rotation on protein content is shown in Fig. 2. Percent grain protein is greater when sorghum is grown after soybean. Application of nitrogen increases percent grain protein linearly. However, it requires 57 kg ha^{-1} to obtain the percent grain protein at a level considered reasonable for sorghum. Continuously grown sorghum requires 114 kg ha^{-1} to reach a similar level. Quality as indicated by percent protein can be further increased with additional applied nitrogen.

Yearly and mean net returns, skewness of net return distribution, standard deviation, C.V., and number of years with net return below \$50 ha^{-1} for eleven years are shown in Table 3. Highest net return was from continuously grown sorghum with 171 kg ha^{-1} applied nitrogen. This was followed by continuously grown sorghum with 100 kg ha^{-1} applied nitrogen and then grain sorghum-soybean grown in rotation with 50 kg ha^{-1} applied in the sorghum cycle. The net returns due to applied nitrogen could change, especially if nitrogen costs would increase. Nitrogen applied in all systems tended to add economic stability as indicated by yearly net returns, the C.V., and number of years with a net return below \$50 ha^{-1}. The grain sorghum-soybean rotation was the most stable production system when no fertilizer nitrogen was applied. This reflects the fertility benefit the cereal obtains from being grown after the soybean.

- Stephen C. Mason - Domestic

Grain sorghum-soybean rotation.

Research Methods

A crop rotation experiment with eight years history of continuous soybean [*Glycine max* (L.) Merr.] and grain sorghum [*Sorghum bicolor* (L.) Moench], and soybean-grain sorghum and grain sorghum-soybean rotations combined with fertility treatments of control, nitrogen (45 kg ha^{-1} on soybean and 90 kg ha^{-1} on sorghum) and manure (16 Mg ha^{-1} dry matter containing 160 to 250 kg N ha^{-1}), was terminated in 1987. In 1988 and 1989 grain sorghum without fertilizer was grown on all plots to determine the residual effect of previous cropping history and fertilizer practices on soil mineral nitrogen, sorghum grain and stover yield.

Research Results

The results of this experiment indicated important one- and two-year residual effects of previous soybean cropping and manure application on soil NO_3-N, and sorghum grain and stover yield. At the beginning of the season in 1988, treatments with soybean as the previous crop had approximately 44 to 50 kg ha^{-1} more soil NO_3-N in the 150 cm soil profile than for continuous grain sorghum (Fig. 3). Two-year residual effect of previous soybean crop resulted in 17 to 23 kg ha^{-1} more soil NO_3-N than for continuous grain sorghum, while an increase of only 3 to 8 kg ha^{-1} more soil NO_3-N was observed the third year. Depending on the previous fertilizer application, yield increase due to previous soybean ranged from 2 to 3 Mg ha^{-1} more sorghum grain than continuous grain sorghum the first year, and 0.4 to 1.4 Mg the second year, while only a small yield increase was observed the third year. Similar trends were observed for stover yield. Sorghum grain yield increased by 1.0 Mg ha^{-1} one year and 0.7 Mg ha^{-1} two years after manure application. This study indicated that soybean in a crop rotation can increase soil NO_3-N and sorghum grain yield for two years. Fertilizer N application for grain sorghum with a recommended rate of 90 kg N ha^{-1} can be reduced by 50 kg ha^{-1} when following soybean, by 13 to 20 kg ha^{-1} the second year after soybean, and by 3 to 8 kg ha^{-1} the third year after soybean.

Publications and Presentations

Publication

Youngquist, J.B., D.C. Carter, and M.D. Clegg. 1990. Grain and forage yield and stover quality of sorghum and millet in low rainfall environments. Expl. Agric. 26: 279-286.

Presentations

Dr. Steve Mason presented seminars on INTSORMIL activities to Instituto Nacional de Investigacion Agricola (INIA) and Consejo Superior de Investigaciones Cientificas in Madrid, Spain.

Dr. Steve Mason presented a seminar on "N Contribution of Intercropped Cowpeas to Pearl Millet" to IER, Mali.

Dr. Steve Mason presented written research progress reports on "N Contribution of Intercropped Cowpeas to Pearl Millet" and "Stand establishment of Grain Sorghum Genotypes" to INRAN, Niger

Networking Activities

Internship

African Internship, Rockefeller Foundation (Mirghani Mohamed).

Assistance

Equipment Purchased; Computer, printer and software to Mali.

Funding transfer to Mali and Niger

Figure 3. Soil nitrate distribution in the 150 cm soil profiles as influenced by previous cropping systems in 1988 and 1989 (BS=Rotation, grain sorghum last crop; BB=Continuous soybeans; SS=Continuous grain sorghum; SB=Rotation, soybean last crop).

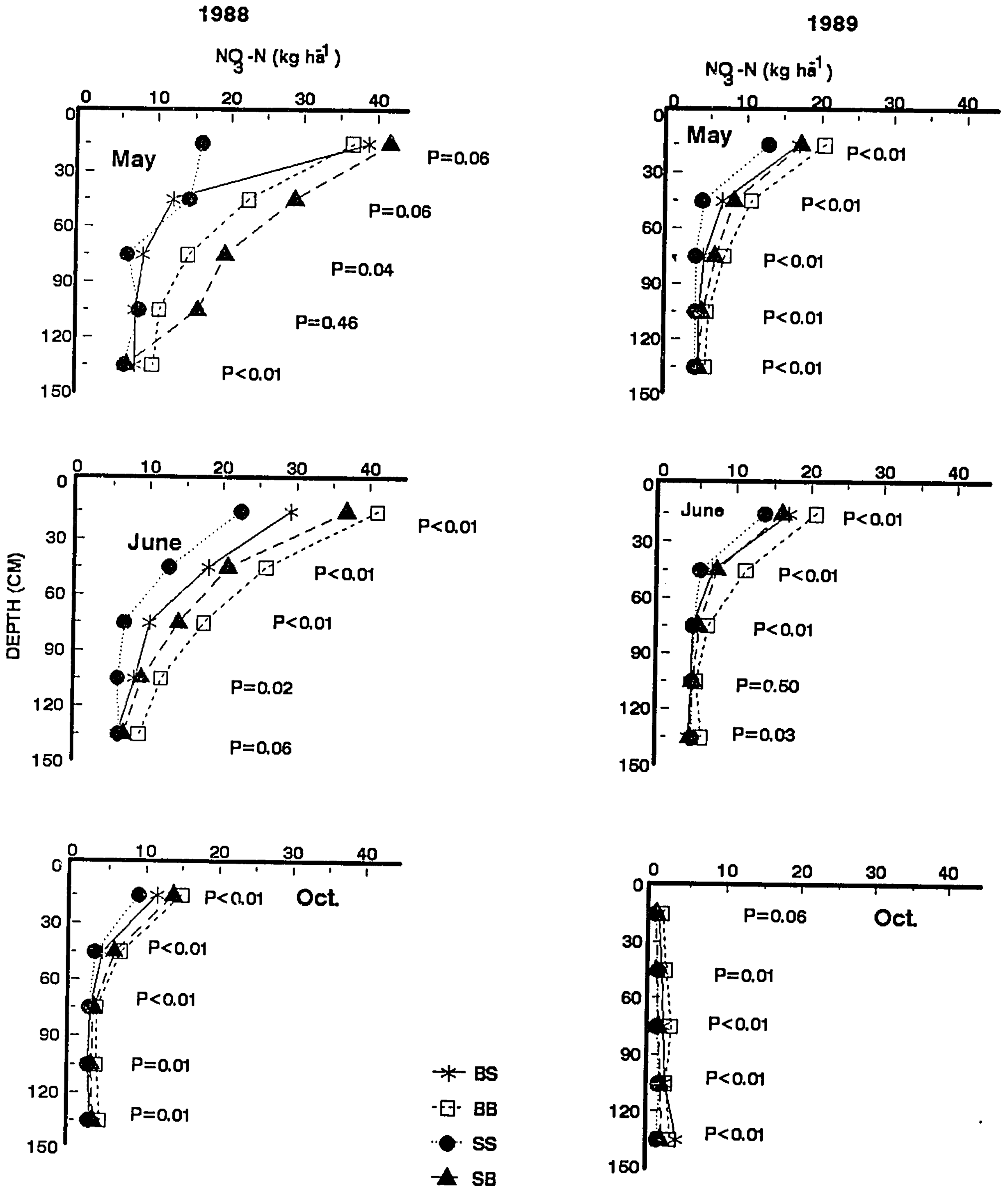


Table 3. Net dollar returns per hectare (return to overhead, labor and management), mean, skewness of net return distribution, standard deviation, C.V., and number of years with net return below $50/ha for the years 1979 to 1989.

System - - -	Continuous grain sorghum (CGS)				CGS and continuous soybean not rotated				GS - SB rotation				Continuous SB
Applied N	0	7	114	171	0	7	114	171	0	7	114	171	0
1979	178	289	321	333	307	363	378	384	419	363	415	381	436
1980	152	351	421	427	235	335	370	373	349	412	389	384	318
1981	139	225	282	275	129	172	201	197	251	253	229	232	120
1982	-237	-79	-86	-81	-62	17	28	16	38	39	8	37	114
1983	-93	126	203	227	-6	103	142	154	92	179	58	81	81
1984	-202	32	167	207	-107	20	77	194	-44	60	116	84	-13
1985	-128	-4	45	70	-43	19	43	56	72	72	68	108	42
1986	-19	121	140	136	37	106	116	111	160	130	123	155	92
1987	-101	8	28	17	-34	20	30	24	16	31	37	21	32
1988	2	124	153	188	-29	32	47	64	81	99	105	65	-60
1989	-38	89	127	94	-41	23	42	25	64	64	89	23	-43
Mean net return	-32	117	164	171	35	110	134	15	136	155	149	143	102
Skewness of net return distribution	0.229	0.455	0.122	0.032	1.245	1.358	1.287	0.982	0.979	1.107	1.282	1.166	1.354
Standard deviation	140	130	143	146	132	128	130	133	145	133	138	133	151
C.V.	439%	112%	87%	85%	378%	117%	97%	91%	107%	86%	93%	94%	149%
Number of years net return below $50/ha	8	4	3	2	8	6	5	3	3	2	2	3	5

Mineral Uptake and Utilization in Sorghum and Pearl Millet

Project UNL-114
Jerry W. Maranville
University of Nebraska

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Summary

Results from 1988 and 1989 trials for sorghum in Mali showed that adapted genotypes respond well to nitrogen fertilizer applied as urea. Two of three genotypes in tests at two locations produced maximum yields at 80 kg urea/ha, but one improved Malian type had increased grain yields through the 120 kg/ha rate. As expected, the local landrace type produces more stover while improved types produce more grain.

Regarding the timing of urea application, the results showed that some sorghum genotypes favor early application (at tillering) while others appear to favor a later application (at preboot) in terms of increased grain yield. There is also a strong year x genotype x nitrogen timing interaction which makes results from these early experiments difficult to interpret in terms of applied recommendations.

Nitrogen use efficiency was higher for grain production with the improved sorghum types over the local type. However, the local sorghum produced its total biomass (grain + stover) at a high level of nitrogen use efficiency.

Several alternative parameters were investigated which might be used to estimate nitrogen use efficiency in sorghum. These experiments were conducted at Nebraska utilizing three sets of material. It was determined that grain nitrogen content might be useful as a prescreening tool in estimating NUE in sorghum. By this method, about 70-80% of the material might be eliminated so that fewer numbers would need to receive complete nitrogen analysis for NUE determination and a substantial savings in time and resources would be realized.

Pearl millet studies in Niger and at Nebraska showed that this crop also responded favorably to moderate rates of nitrogen application. The most striking observation was that the crop gave a favorable grain yield increase due to nitrogen even when rainfall was as low as 535 mm per season.

Objectives, Production and Utilization Constraints

Objectives

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

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

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

Determine optimum nitrogen and phosphorus management practices for arid and 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

Essentially no constraints exist currently which would hinder UNL-114 from reaching its objectives in Mali with time. There is good enthusiasm for the research and enough equipment in place to accomplish the general field and laboratory experiments. Persons involved in the collaborative research are well trained.

Research in Niger could be potentially constrained by lack of trained personnel. There is also a need to put some priority on the UNL-114 collaborative research which appears lacking at this time. There is a definite need at Maradi for some research items which INTSORMIL could provide to accommodate the collaboration. These items are difficult to get to the intended research locations and expensive.

Research Approach and Project Output

International

Mali

Several experiments have been in progress during the past two years related to nitrogen (N) response of sorghum to timing and amount. Some of these results have been reported previously in former INTSORMIL annual reports. The following results and discussions are from N'Tarla location for 1988 and from N'Tarla and Samanko locations for 1989.

The 1988 N'Tarla experiments were planted according to normal practices in hills within rows 75 cm apart. Hills are overseeded and later thinned to two plants per hill. All experiments are dryland although the N'Tarla location usually receives sufficient rainfall compared to other locations that sorghum yields are satisfactory in most years. The soil type at this location also contains more loam and clay than areas further north where sand predominates. The first experiment consisted of three varieties: a local (CSM) which is a landrace type with tall growth, generally well adapted to stresses, S-34, an improved type which is shorter stature, and Malisor 7, another improved Malian type of stature shorter than the local. Three rates of N were applied at tillering in the first experiment, these being 40, 80, and 120 kg N/ha. Zero N served as a control.

Table 1 shows that all genotypes responded to applied N in terms of grain yield. For the local and S-34, the 80 kg/ha rate produced the highest grain yields while Malisor 7 responded to 120 kg/ha with another 6% increase over the 80 kg/ha rate. Both S-34 and Malisor 7 had increasing stover yields up through 120 kg/ha applied N. The local sorghum did not respond in stover yield over the 80 kg/ha rate.

Table 1. Stover and grain yields, and grain + stover N concentration in sorghum grown at the N'Tarla location during 1988 with four levels of applied N.

Genotype	N level	Stover yield	Grain yield	Grain+Stover N
	kg/ha	kg/ha	kg/ha	%
Local	0	11125	2186	2.46
(CSM)	40	11678	2459	2.59
	80	12504	2861	2.61
	120	11425	2887	2.42
	Mean	11696	2588	2.52
S-34	0	6523	2679	2.34
	40	7847	3045	2.41
	80	7467	3413	2.46
	120	8286	3378	2.25
	Mean	7473	3110	2.37
Malisor-7	0	3886	2079	2.42
	40	4290	2525	2.42
	80	4058	2631	2.57
	120	4846	2794	2.37
	Mean	4249	2497	2.45

When comparing genotype performance for biomass production at different N levels, the results show much of what would be expected in that the local produced significantly more stover than the improved types. However, only S-34 produced significantly more grain yield than the local (20%) while Malisor 7 was similar. Several factors come into play in interpreting this result such as maturity which influences the presence of head pests and of fungus. It is likely that Malisor 7 may have been subject to such stresses late in the season. The 1988 season was very good and N'Tarla received good rains. This is evident in the level of grain and stover yields produced this year.

In the second N'Tarla experiment, 46 kg/ha N as urea was applied at tillering and preboot stages in split application. Treatments included (a) 1/4 early, 3/4 later; (b) 1/2 early, 1/2 later; (c) 3/4 early, 1/4 later, and (d) a O N control. The same three varieties were chosen and fit this location best in terms of adaptation.

Table 2 shows that all varieties responded to N application in terms of increased grain and stover yields as well as increased grain N concentration.

Table 2. **Stover and grain yields and grain N concentration of sorghum grown at the N'Tarla location during 1988 with four different times of N application.**

Genotype	N timing	Stover yield	Grain yield	Grain N
		kg/ha	kg/ha	%
Local	0/0	9589	2093	1.88
	¼/¾	9860	2248	2.06
	½/½	9811	2191	1.97
	¾/¼	8988	2351	2.10
	Mean	9562	2221	1.88
S-34	0/0	6134	2132	1.89
	¼/¾	6703	2423	2.36
	½/½	6527	2487	1.96
	¾/¼	6854	3335	2.12
	Mean	6541	2456	2.08
Malisor 7	0/0	4231	2821	1.64
	¼/¾	4386	3077	1.92
	½/½	3814	2777	2.18
	¾/¼	3664	2621	1.77
	Mean	4023	2824	1.88

The local variety produced much more stover than S-34 or Malisor 7, similar to the N rate study although generally not of as great a magnitude. Grain yields of the two improved sorghums were again generally higher than the local with Malisor 7 being the best grain producer in this test.

Timing of N application varied according to genotype. Highest grain yield for S-34 occurred when the bulk of N was applied early although for Malisor 7, it occurred when the bulk was applied later at preboot. The local variety also appeared to favor the later application. This was similar to that previously reported for the Samanko location (see Annual Report, 1989). However, visual observations for the 1990 growing season appear to support application of N at tillering although yields are not available at this time. There is most likely an interaction with years in such experiments.

Similar experiments were conducted at Samanko and N'Tarla in 1989. At N'Tarla, however, genotype ICSV 1063, an improved ICRISAT type, was used in place of Malisor 7. Table 3 shows the results of the N timing experiment at the Samanko location. All genotypes responded to N application in terms of increased grain yield, but only Malisor 7 showed a definite response in terms of increased stover production. Both of the improved sorghums were greater producers of grain and biomass than the local when averaged over all N treatments.

Grain yields appeared to be higher for S-34 and Malisor 7 if the bulk of N was applied earlier at tillering, while the local appeared to favor later application. In the 1988 experiment, Malisor 7 responded best to a later application indicating a year x N timing interaction. Efficiency of biomass production (NE_1) and of grain production (NE_2) was highest for the improved types. This is not always the case for NE_1 since landrace genotypes often produce a lot of stalk, giving them high NE_1 values. The local in this experiment, however, did not produce high amounts of stover. The relatively higher grain yields for S-34 and Malisor 7 over the local is common for improved sorghums and generally always results in higher NE_2 values.

Table 3. **Grain and stover yields, NE_1 and NE_2 for sorghum grown at the Samanko location in 1989. NE_1 is g total DM per g N; NE_2 is g total grain per g N and are used as indicators of nitrogen use efficiency.**

Genotype	N timing	Stover yield	Grain yield	NE_1	NE_2
		kg/ha	kg/ha	g/g	g/g
Local	0/0	7544	1052	116	14
	¼/¾	7169	1310	116	17
	½/½	7122	1438	101	16
	¾/¼	7556	1140	96	12
	Mean	6905	1194	109	15
S-34	0/0	10377	1836	119	21
	¼/¾	9240	1918	108	22
	½/½	8795	1930	97	18
	¾/¼	12082	2146	125	27
	Mean	10123	1957	112	22
Malisor 7	0/0	7356	1427	118	20
	¼/¾	8187	1602	116	18
	½/½	8544	1947	99	20
	¾/¼	8906	1737	115	18
	Mean	8248	1678	112	19

Table 4 shows the 1989 rate of N application study at N'Tarla. All varieties showed good response to N application with ICSV having the greatest response to N application over control. This is very typical of improved types which are often selected to do best under high management. The best yields in all cases occurred at the 120 kg/ha rate of urea application which contrasted somewhat to the 1988 data. Again, the interaction with year is probably significant.

N efficiency values for grain and biomass production were much higher in this experiment than the N timing experiment. The local variety was also relatively high for these values in comparison to the improved genotypes and to what is normally expected, especially for NE_2. Further investigations are needed to clarify this response.

Niger

Experiments were conducted in pearl millet at the Maradi research station during the 1989 growing season by Mr. Cherif Oumarou to determine the response of three varieties to nitrogen rate. Varieties GP1, GRP1 and CIVT were planted in hills (1 m apart) on a grid July 6 in three replications and thinned to two or three plants per hill on July 18. Urea was applied July 24 (½ dose) and August 11 at rates

totaling 30, 45 and 60 kg/ha. Zero N served as a control. Plots were harvested on October 10. A total of 526.5 mm of rain was received during the season.

Table 4. Grain and stover yields, NE_1 and NE_2 for sorghum grown at the N'Tarla location in 1989. NE_1 is g total DM per g N; NE_2 is g grain per g N and are used as indicators of nitrogen use efficiency.

Genotype	N rate	Stover yield	Grain yield	NE_1	NE_2
		kg/ha	kg/ha	g/g	g/g
Local	0	5496	1327	159	31
	40	5892	1477	142	28
	80	6404	1607	147	30
	120	6276	1658	117	24
	Mean	6016	1517	141	27
S-34	0	6392	1304	123	21
	40	6824	1653	121	24
	80	6340	1709	106	23
	120	6916	1807	111	23
	Mean	6616	1618	115	22
ICSV	0	8552	948	145	15
	40	9444	1350	144	18
	80	10572	1332	137	16
	120	9112	1727	119	19
	Mean	9460	1355	136	19

Table 5 shows the grain yield and grain:stover ratio data. All varieties responded significantly to N application even though rainfall was not particularly high. Variety GP1 was the lowest grain yielder among the varieties and was the only one to respond linearly over the range of applied N. The higher yielding varieties GRP1 and CIVT reached a maximum yield with 45 kg/ha urea. Variety CIVT even had a 10% yield reduction with the higher 60 kg/ha rate.

Grain:stover ratios generally reflected the yield ranking among varieties and treatments. Nitrogen fertilizer obviously favored grain production over that of stover in all varieties. The best combination in this test was with variety GRP1 at the 45 kg/ha urea rate which produced nearly half as much grain as stover. The results of this test indicated that nitrogen application up to 45 kg/ha urea should significantly increase grain yields of certain millet varieties even when rainfall is moderate to low.

Domestic

Study 1

Determining N uptake and utilization efficiencies can be costly and time consuming. Whole plant samples must be ground and analyzed for N content. When several hundred or even a thousand individuals or treatments need to be evaluated, it may be difficult to obtain the necessary data for determining selections in time for the next season. A study was conducted by Drs. Joan Youngquist and Paula Bramel-Cox to evaluate alternative criteria for determining relative N use efficiencies in sorghum genotypes.

Table 5. Grain yields and grain:stover ratio for pearl millet during the 1989 growing season at Maradi.

Genotypes	Urea rate	Grain yield	Increase from control	Grain:stover ratio
	kg/ha	kg/ha	%	kg/kg
GP1	0	524		.27
	30	823	57	.32
	45	858	64	.35
	60	906	73	.32
	Mean	778		.32
GRP1	0	775		.39
	30	724	(7)	.36
	45	1195	54	.44
	60	1174	51	.43
	Mean	967		.41
CIVT	0	581		.27
	30	1017	75	.40
	45	1100	89	.40
	60	1003	42	.39
	Mean	925		.37

All experiments were conducted at the Agricultural Research and Development Center (ARDC), Mead, Nebraska and three sets of material were evaluated. The first set of material contained 36 genotypes; six parent lines and their 30 hybrid crosses planted in low and moderate N fertile soils. Each set was grown in two different years. The second set of material included 48 adapted dwarf varieties, 24 sorghum conversion lines, 10 adapted hybrids and 25 exotic varieties planted in a clay loam soil with two soil N levels, high N (120 kg N/ha) and low N (55 kg N/ha). The third set of material included 10 adapted dwarf varieties, 10 sorghum conversion lines, 10 exotics and 10 elite exotics. The moderate N fertility treatment had a residual soil nitrate level of 7 kg ha^{-1} to which was applied 80 kg ha^{-1} N fertilizer. The high fertility treatment was a loamy sand with a residual soil nitrate level of 30 kg ha^{-1} to which was applied 150 kg ha^{-1} N fertilizer.

Spearman rank correlation coefficients of PN, NE_1 and NE_2 with possible alternative criteria are presented in Table 6. Alternative criteria evaluated which had consistently low, nonsignificant or negative correlations with a N use efficiency trait are not presented.

When soil N is constant, uptake efficiency can be determined by measuring PN. PN and TDW have been found to be positively correlated. Larger plants tend to take up more N from the soil even though N concentration in the plant tissue may be less than that found in a smaller plant. Rank correlations of PN with TDW in the three sets of material evaluated ranged from 0.80 to 0.96 (Table 6). This agrees with other results where partial correlations between PN and

TDW were 0.87 and 0.93 for 40 elite breeding lines and 48 selections, respectively. Given the consistently high correlations and ease of measurement of TDW, this trait would be the best predictor of PN of all alternative criteria evaluated.

Total plant N and GN were also highly correlated. The high correlation was maintained in Set 2 where HI values ranged from 0.10 to near 0.50, indicating the relationship holds across genotypes with variation in partitioning of biomass. The lowest correlation of the three sets of material evaluated was in the 36 genotypes (Set 1) during year 2. The low correlation may result from environmental influences.

The high correlation between PN and GN indicates the possibility of using GN as an alternative parameter to PN in evaluating N utilization efficiencies. Analyzing for GN would allow faster, more economic evaluations, as sorghum grain can be analyzed as whole kernels in the Kjeldahl method. Of all the criteria evaluated, TDW/GN showed the most promise in predicting which genotypes would have high NE_1 values in both low and high N treatments. Set 1, year 1 evaluated in high N soil had a low rank correlation between NE_1 and TDW/GN. This is likely a reflection of the low correlation between PN and GN in this set of material. The danger in utilizing GN rather than PN is thus illustrated. If only grain is evaluated for N content, the relationship between GN and PN is unknown. If it were low, the effectiveness of using GN could be greatly diminished.

While the correlation between NE_2 and GDW/GN was high, the best predictor of genotypic performance for NE_2 was HI. Greater partitioning of photosynthate to grain, as indicated by a high HI, should result in higher NE_2 as well. Previous research showed that high yielding hybrids had lower N concentration in the grain and thus higher NE_2 values.

Depending upon the breeding program, the usefulness of the above alternative screening criteria may vary. While correlations tended to be high, exceptions were noted. This would suggest that the best use of the alternative screening criteria described would be as a prescreening tool. Eliminating genotypes with the lowest TDW, TDW/GN or HI would eliminate the poorest PN, NE_1 or NE_2 genotypes, respectively. To select the top 10% for any given N use efficiency trait, full plant N analysis could be conducted on only the top 20 - 30% which were selected using an alternative criteria. A substantial savings in time and resources as well as a fair level of confidence in the selections made would then be realized.

Study 2

A N response study was conducted in the greenhouse by Drs. John Settimi and Jerry Maranville during the 1989 growing season. This experiment consisted of six Malian millet genotypes and 15 Malian sorghum genotypes with a U.S. commercial hybrid check. The objective was to determine the increase in leaf area for these crops due to N application over the growing season. It has been determined that green leaf area and total water use by crops are highly and positively correlated. In dry areas of Africa such as the sub Sahelian areas of Mali and Niger, N fertility can result

Table 6. Spearman rank correlations ($P < 0.01$) between nitrogen use efficiency (NUE) traits and selected alternative screening criteria from three experiments.

		Experiment							
		Set 1				Set 2		Set 3	
	Alternative	Year 1		Year 2		Year 1		Year 1	
NUE trait	Criteria	Low N	High N	Low N	High N	Low N	High N	Low N	High N
PN	GN	0.74	0.86	0.53	0.49	0.57	0.83	0.98	0.93
PN	GDW	0.48	0.75	0.48	0.49	0.49	0.78	0.95	0.91
PN	TDW	0.80	0.83	0.83	0.93	0.93	0.90	0.96	0.93
NE_1	TDW/GN	0.59	0.62	0.69	0.31	0.87	0.85	0.82	0.70
NE_1	GDW/GN	0.73	0.78	0.38	0.64	ns	ns	0.61	0.58
NE_1	TDW/GN%	0.57	0.69	0.30	0.43	0.40	0.27	ns	0.58
NE_1	GDW/GN%	0.42	0.57	ns	ns	-0.40	-0.28	ns	0.43
NE_2	GN	ns	ns	0.65	0.80	0.61	0.60	-0.28	0.36
NE_2	GDW/GN	0.80	0.65	0.74	0.46	0.56	0.66	0.90	0.62
NE_2	TDW/GN%	0.52	0.50	0.47	0.45	ns	0.25	ns	0.35
NE_2	GDW/GN%	0.84	0.75	0.89	0.87	0.78	0.77	0.24	0.58
NE_2	HI	0.83	0.65	0.88	0.96	0.95	0.91	0.63	0.73

PN = uptake efficiency; NE_1-biomass utilization efficiency, TDW/PN;
NE_2 = grain utilization efficiency, GDW/PN; GN = grain N content; GDW = grain dry weight;
TDW = total plant dry weight; GN% = grain N percent; HI = harvest index

in lower yields due to a lack of water to supply the transpirational demand of the extra green leaf area. A knowledge of varietal response to N in terms of leaf area may help general management regarding varietal selection. Only two growth stages are presented for each crop. Millets were supplied by Dr. Omar Niangado (IER) and sorghums by Dr. Benanati (ICRISAT).

Figure 1 shows that the millets produced about 1000 - 2000 cm^2 of green leaf area per plant under limited soil N by the 10th leaf stage. Genotypes 88CZ-PN4 and 88CZ-Synth 2 responded the greatest to applied N although the former produced significantly more green leaf area at both high and low N. Both doubled their leaf area or more with applied N. Other genotypes increased only about 20% at best. By maturity, very little green leaf area increase occurred over that of the 10 leaf stage and some genotypes even lost green leaf area (Fig. 2). Genotypes 3-4 BM and 88CZ-PN4 produced the most green leaf area with high soil N while 88CZ-Synth 2 and TORONIOUCN the least. This is probably an indication of their capacity for water use with N fertility.

Sorghums generally produced less green leaf area than millets with low N, but about the same at high N (with one exception) by the 11th leaf stage (Fig. 3). Of all the varieties tested, only about four did not respond well in terms of green leaf area production due to applied N. Most compared favorably to a good U.S. hybrid. At the 18th leaf stage, sorghums differed from the millets in that all increased their green leaf area at the low N treatment (Fig. 4). This resulted in much less total response to applied N by maturity in this crop than the millets although most increases were still in the area of 100%. Few were lower than the U.S. hybrid. This is born out in Figures 5 and 6 which show the green leaf area increases over time for the two crops. The slope of the increase for high N was identical in each crop although the magnitude of values was less for millet than sorghum. The slope was much flatter for millet at low N (Figure 5). These kinds of studies supplement actual field data of these same genotypes which are being grown in Mali at the present time.

Study 3

Although pearl millet is known as a "crop with a high quality feed grain" compared to maize and sorghum, its response to high soil nitrogen is not consistent. An experiment conducted in 1988 at the University of Nebraska was repeated in the 1989 growing season by Mr. Abdoul Toure (M.S. student) with the objective of determining the effect of different levels of nitrogen and the timing of application on the development and yield of pearl millet as well as nitrogen use efficiency (NUE).

Four levels of nitrogen (0, 28, 56 and 112 kg/ha) applied at 25 and 50 days after emergence as a combination of emergence and sidedress were compared (Table 7). The 0 and 28 kg/ha levels were applied only at emergence while the 56 and 112 kg/ha levels were applied either entirely preplant or one half at preplant and one half sidedress.

Varieties ICTP-8203, an ICRISAT/TOGO selection without any breeding and 68A x MLS, a U.S. adapted hybrid were used. Three plants chosen randomly were harvested at the five leaf stage, flowering, milk stage and after physiological maturity to determine leaf area, biomass, nitrogen content and NUE.

Analysis of available 1989 data (Table 8) showed no differences among levels or nitrogen timing for most measured traits. However, genotypes varied for grain and stover yield and NE_1 (g DM per g N). Grain appeared to be more important in terms of biomass production for 68A x MLS while stover appeared more important for ICTP-8302.

A diagnosis of total N content in the soil, sampled before planting, will be useful in partially interpreting the response of pearl millet to N application and rate.

Table 7. Combination of rate and timing of nitrogen application per treatment (g).

N level	Timing of		Sidedress	
kg/ha	application	Emergence	25 days	50 days
112	4	112	0	0
	9	56	56	0
	10	56	0	56
	11	0	112	0
	12	0	0	112
56	3	56	0	0
	5	28	28	0
	6	28	0	28
	7	0	56	0
	8	0	0	56
28	2	28	0	0
0	1	0	0	0

Publications

Raju, P.S., R.B. Clark, J.R. Ellis and J.W. Maranville. 1990. Effects of species of VA mycorrhizal fungi on growth and mineral uptake of sorghum at different temperatures. Plant and Soil 121:165-170.

Raju, P.S., R.B. Clark, J.R. Ellis and J.W. Maranville. 1990. Mineral uptake and growth of sorghum colonized with VA mycorrhiza at varied soil phosphorus levels. J. Plant Nutr. 13:843-859.

Networking Activities

UNL-114 supplied Mali with $9000 operational money for collaborative research in nitrogen agronomy and physiology.

Table 8. **Effect of rate and application treatment on grain and stover yield.**

N rate kg/ha	Treatment	Grain yield kg/ha	Stover kg/ha	NE_1
112	4	1106	1.688	188
	9	850	4.651	70
	10	979	1.799	69
	11	1308	2.322	73
	12	820	2.066	60
	Mean	1013	2.504	92
56	3	769	1.597	78
	5	974	2.514	85
	6	912	2.415	104
	7	924	2.438	72
	8	960	2.365	77
	Mean	908	2.265	83
28	2	765	2.446	81
	1	907	2.074	89
Var ICTP 8202		725	2493	104
Var 68A MLS		1154	2234	70

Figure 1. **Leaf area of millet under two nitrogen levels at the 10th leaf stage.**

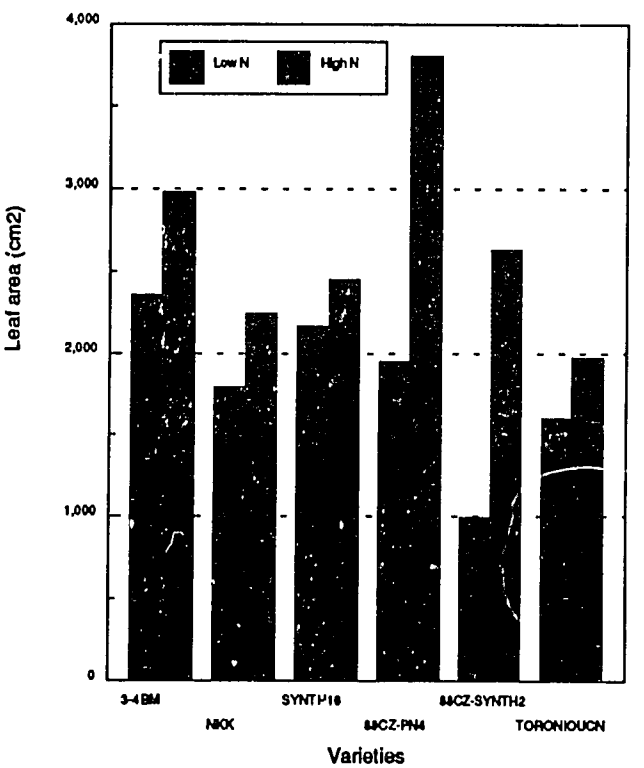


Figure 2. **Leaf area of millet under two nitrogen levels at the 18th leaf stage.**

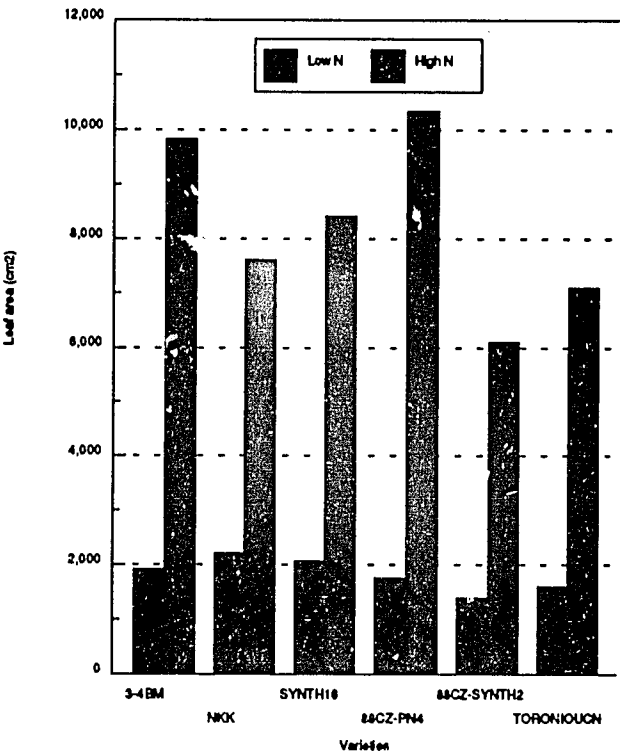


Figure 3. **Leaf area of sorghum under two nitrogen levels at the 11th leaf stage.**

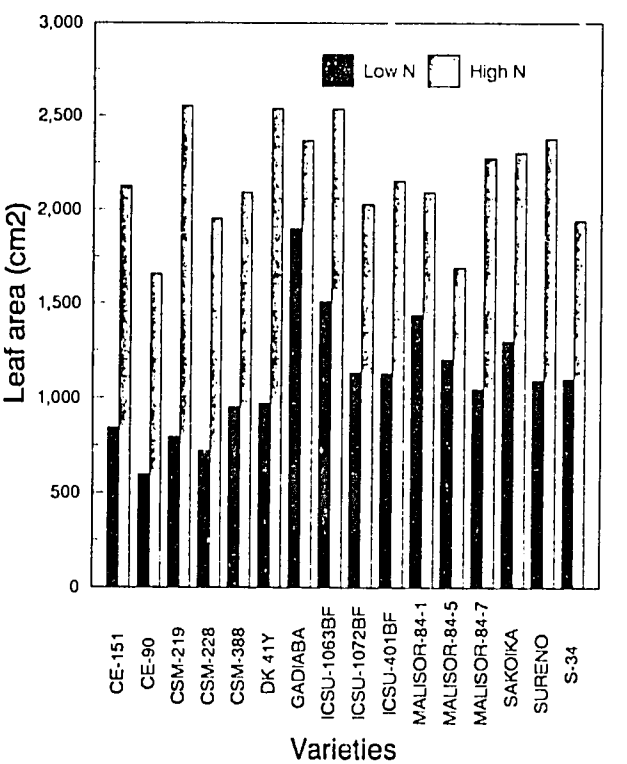


Figure 4. Leaf area of sorghum under two nitrogen levels at the 18th leaf stage.

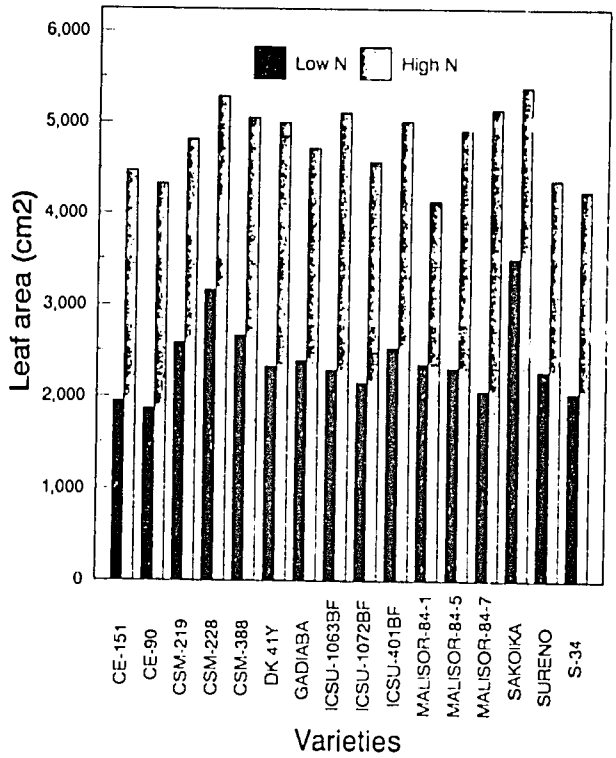


Figure 5. Leaf area of millet at four growth stages under two nitrogen levels. Averaged over six varieties.

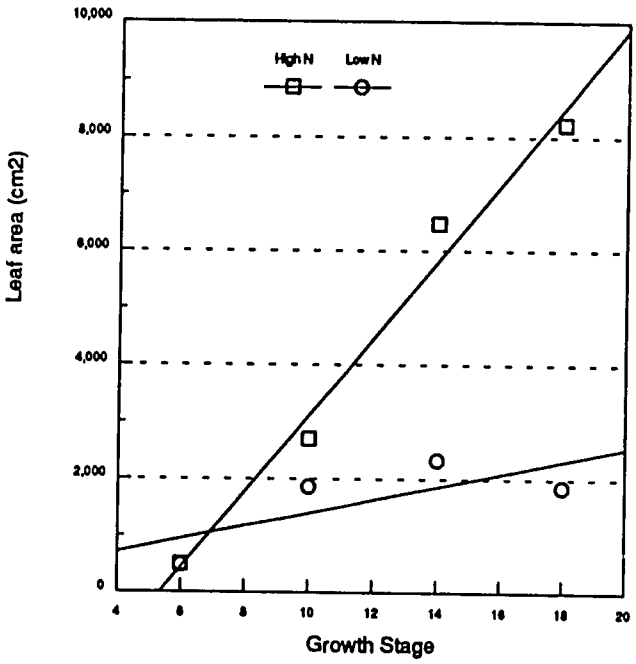
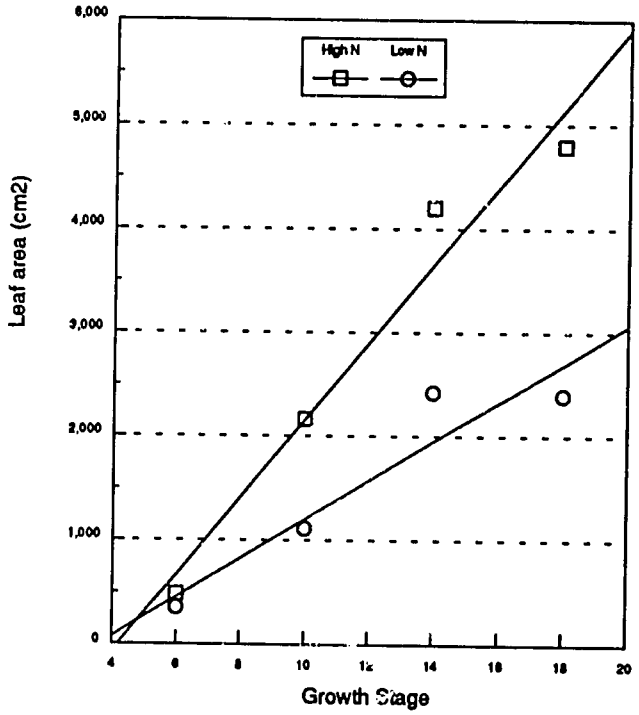


Figure 6. Leaf area of sorghum at four growth stages at two nitrogen levels. Averaged over 16 varieties.



Water and Temperature Effects on Sorghum and Millet as Related to Grain Production and Breeding

Project UNL-116
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Summary

A physiologically based field stress screening technique was developed in the late 1970's. Application of the technique in the early 1980's produced medium to tall high yielding, stress tolerant lines from Texas populations TP_2 and TP_3 and one ICRISAT population. An effort to improve or complement this stress screening technique involved measuring the differences between the canopy and ambient air temperatures (DT) of genotypes being tested. Limited testing shows that the higher yielding sorghums have cooler canopies than lower yielding ones. This tends to confirm the notion that stress resistant sorghums rely primarily on stress avoidance rather than stress tolerance mechanisms. A few sorghums had respectable yields with higher canopy temperatures, suggesting that they may have more stress tolerance mechanisms than the primarily stress avoiding genotypes being selected with the above screening technique. Even though yields are lower it appears that an effort should be made to identify stress tolerating sorghums using canopy temperature measurements and recombine them with the more common stress avoiding genotypes. Hopefully this would broaden the stress resistance mechanism base in commonly cultivated sorghums because they are grown in widely fluctuating environments.

Sorghum growing environments commonly range from very severe stress to very favorable conditions at the same location from year to year. Therefore, the farmer needs stress resistant (SR) sorghums for the bad years but they must be water responsive (WR) under good year conditions also. Most sorghums are either SR-NWR (not WR) or SS-WR. A very few are SR-WR. A higher percentage of SR-WR types are now coming out of this stress screening germplasm manipulation program. A few lines and bulks have been released for use in commercial operations. Larger numbers of germplasm genotypes and bulks have gone to Niger, Mexico, Sudan, Egypt, Botswana and Senegal.

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
High temperatures
Low temperatures
LDC infrastructures

Research Approach and Project Output

Research Methods by Objective (above)

1. Western Kansas midseason stress screening reviewed.

a) Overplant the optimal production population by 100% or more to establish a high water use canopy by panicle initiation (PI).

b) Withhold H_2O at PI or earlier to impose stress about two weeks after PI at floret differentiation (FD).

c) Maintain stress from FD to anthesis.

d) Relieve stress at anthesis if irrigation is available.

e) Full irrigation if possible.

f) Treatment combinations.

5 tests yield potential.

1-2-3 together compared to 5 expose yield and see # stability characteristics.

1-2-3-4 compared to 5 test seed size compensation capacity.

If irrigation is unavailable a low population (low stress) could be compared to high population (stress) performance.

Also an infrared thermometer was used to monitor the difference between the canopy and ambient air temperatures (DT) to determine which genotypes have good transpirational cooling near microsporogenesis. Maintaining cooler plant temperatures helps avoid floret abortion and correlated yield losses.

2. B line sterilization continues through normal backcrossing procedures.

3. Cultural practice research in Niger is continuing but will not be included this year in view of a heavy 1989 germplasm reporting emphasis.

4. Field photosynthesis, respiration and transpiration chambers have been developed to isolate crop canopies from soil CO_2 and water flexes. Methodology is under development to measure CO_2 and water flexes from the soil directly on an instantaneous basis. Combinations of such measurements can be used (1) to separate evaporation (E) from transpiration (T) in the ET component of WUE measurements and (2) to measure the influence of tillage and residue levels on E.

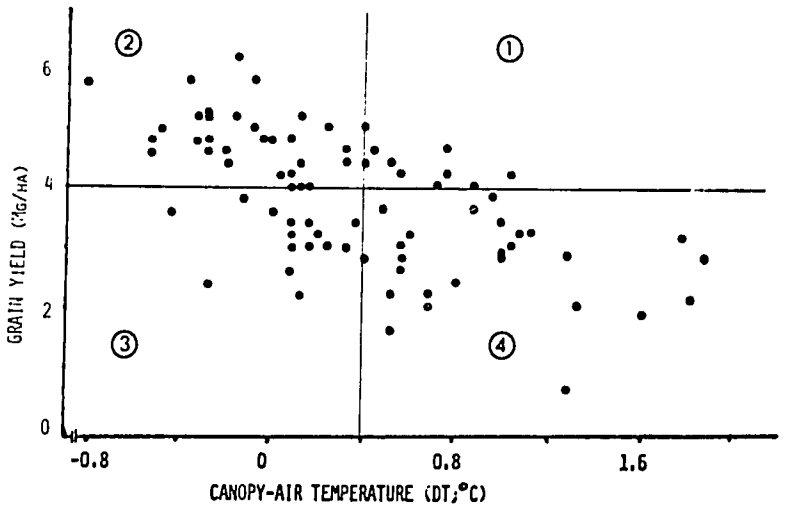
5. Cooperation is continuing on the USDA/OICD Dryland Agriculture Projects in India. They involve stress screening similar to 1 above and cultural practice research dealing with water-use-efficiency (WUE) and nutrient use efficiency in various cropping systems. Many of the WUE measurements are very similar to those in 4 above. A LiCOR 6200 is used to measure canopy photosynthesis and transpiration. Modification of that system is under development and will be used to measure evaporation and soil CO_2 fluxes directly.

Research Findings

The physiologically based field stress screening technique described above works quite well as per the 1987 INTSORMIL Report (p. 48). Additional supporting yield data will be cited later in this report. Nonetheless, constant technique improvement is desired. Therefore, the following experiment was conducted to help assess the potential of measuring canopy temperature to enhance stress screening. High relative water content and high water potential are positively correlated with yield. Low canopy temperature relative to ambient air temperature indicates the plants are transpiring and is a general indicator of both high relative water content and high water potential permitting good cell division and expansion. However, reported correlations between canopy temperature and grain yield are erratic.

The following experiment, conducted by P. K. Verma at Garden City, Kansas, used 81 genotypes in a 9 x 9 lattice with two replications at two water levels (dry and full water). Yield versus canopy - air temperatures is plotted in Figure 1 illustrating the general relationship between higher yield and cooler canopies relative to ambient air temperatures. Temperature measurements were made at critical periods near microsporogenesis and megasporogenesis when seed number and hence yield potential is set. The analysis of variance (Table 1) for yield shows a significant genotype component under both dry and wet conditions. However, canopy - air (DT) temperature was significantly different among genotypes in the dry treatment but not the wet treatment. The correlation between grain yield and DT (Table 2) is significant only under dry conditions. The -0.56 r value increases to -0.81 when variation due to genotypes

Figure 1. Grain yield vs canopy-air temperature (DT) in sorghum genotypes under stress.



is removed. Judging from these r values the yield vs DT relationship appears real and sufficient genetic variation exists to permit selection progress.

Table 1. Analysis of variance for grain yield.

Source	df	Mean squares Wet	Dry
Total	161		
Replication	1		
Genotypes (unadj.)	80	459.7**	282.3**
RCB error	80	65.8	187.8
Block within rep (adj.)	16	43.2	751.7
Intra block error	64	71.4	46.8
**Significant at P<0.01		16.6	13.4

The DT values appear to be reflecting the combined but unspecified effects of an unknown number of physiological properties contributing to grain yield. The physiological characteristics of the cooler plants might include more extensive root systems, root systems which develop at slower rates in order to conserve water earlier in the season, greater stomatal or other control of transpiration, differences in osmotic regulation at the stomatal, root, and/or seed (floret) differentiation levels, etc. The net effect is that the cooler plants are staying cooler by either extracting more water from the soil or are rationing water at earlier stages of development so that adequate water is available during the critical period when seed number potential is being set.

Table 2. Correlations of canopy-air temperature (DT) with grain yield in sorghum.

Correlation (r) between	DRY	WET
Grain yield and DT	-0.56*	-0.29
Grain yield and DT after removing variation due to genotypes	-0.81*	-0.11

*Significant at P<0.05.

The 81 genotypes included in this test were a mix of hybrids and lines from breeding programs in Texas and Nebraska plus commercial hybrid checks. Ten hybrids from this program outranked the best check under irrigation with the other four checks ranking numbers 26, 33, 47 and 51. Under stress the top ranked 20 genotypes were hybrids and lines from this program while check ranks were 28, 38, 42, 44 and 45. It appears that the selection procedure we are using is generating primarily cool plant types or drought avoiding types (Quadrant 2 of Figure 1). Possibly some consideration should be given to recombining some of the moderate yielding drought tolerating types (Quadrant 1) with the higher yielding drought avoiding types (Quadrant 2) to try to broaden the total number of stress resistance mechanisms of new genotypes.

The potential value of the DT technique cannot be fully determined from these limited data but results suggest further investigation is in order. If the system is eventually shown to be valuable it offers breeders in stress areas a convenient tool since the DT's are made before anthesis and can therefore be used to help determine crosses to be made in the same season.

Regarding screening techniques in general, it is not expected that DT or any other physiologically derived screening method will replace empirical selection for grain yield and/or yield testing. At best such methodologies will only complement actual yield testing or yield testing with a carefully trained eye in a stress breeding program. What does seem clear is that physiologically derived measurements will likely be the most successful if they reflect the net beneficial effects of several essential physiological processes or systems since a large number of processes must be involved. The DT measurement appears to be one such measurement and needs further evaluation which is beyond current budgetary limitations.

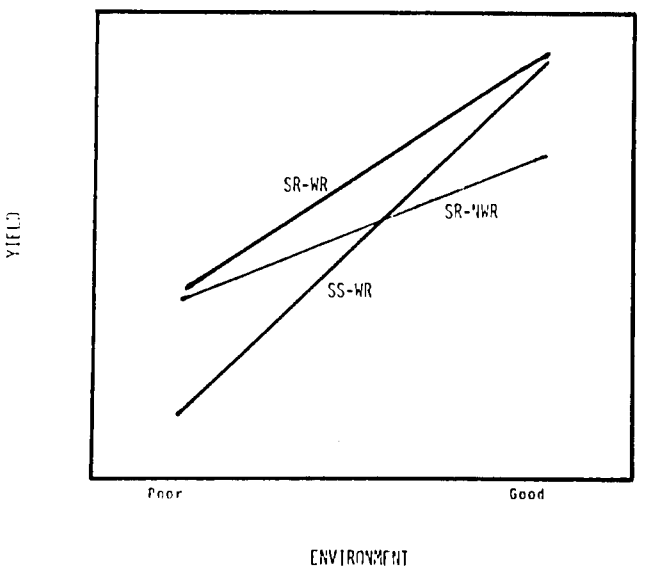
Restatement or reemphasis of our stress screening goals appears in order before considering the second stage of yield testing beyond the 1987 INTSORMIL report. The two most common characteristics among stress environments are (1) the variability in the plant developmental times (crop growth stages) at which the stresses hit from year to year at the same location and (2) the variability from year to year in the severity of the stress. Regarding point (1) making progress in screening against variability in the time at which stresses occur requires multiyear testing involving a range of environmental variability followed by suitable recombination of plants responding favorably in the different environments. Regarding point (2) the main emphasis needed is on the matter of screening for favorable response in both the good and bad environments which occur at the same location in different years.

It is possible to generate stress resistant (SR) germplasm which performs comparatively well under tough conditions. It is likewise possible to generate high yielding germplasm under good conditions but often such germplasm is relatively stress susceptible (SS). Such germplasm, though SS, is water responsive (WR) in good environments. Generating SR germplasm which is WR is difficult.

Figure 2 illustrates the SR, SS, and WR concepts graphically. Until fairly recently many commercial breeding programs were carried out under favorable water conditions and have yielded good SS-WR material. A smaller number of stress programs have yielded SR-NWR genotypes. The number of SR-WR genotypes available is meager indeed. One primary goal of this program is to generate SR genotypes with a fair percentage of those being WR in the good years. Farmers need good SR sorghums to provide production insurance during the stress years which also have adequate WR characteristics in order to capitalize on the extra water resources available in the good years.

Our screening approach to develop SR-WR genotypes relies primarily on selecting under stress for a relatively high, stable seed number (seeds m^{-2}). Under severe stress this can be done simply with a skilled eye. Moderate stress level screening has not been tried widely but probably would require more extensive testing plus seed weight (g 100^{-1}) and seed number (seed m^{-2}) determinations. Research on moderate stress level screening is in progress.

Figure 2. Idealized yield response curves of contrasting sorghum types grown in a range of environments. SR-stress resistant, SS-stress susceptible, WR-water responsive, NWR - not WR.



Screening results follow: Yield tests in the 1987 INTSORMIL report represent parent lines derived primarily from TP_2 and TP_3 (R lines) and an unspecified ICRISAT population received which turned out to be primarily a B line source. R line results in this report will also include a few food grain type lines (tan plants mostly) derived from an earlier maturity version of the TP24 population jointly released by F. R. Miller (Texas) and R. R. Duncan (Georgia). This population is sometimes referred to as a food grain population because of the generally tan plant color and light grain. The original version of this population was too late for Nebraska and was selected for earlier maturity for two years before substantive line selection was begun. Three subpopulations are being developed at this point. Line development begins with selection of 100 to 200 high yielding fertile plants in randomly mated populations at Mead, Nebraska, to insure a WR germplasm base. These fertiles are grown out in a winter nursery from which usually 500 to 1000 head selections are made. Resulting S_2 families are stress tested in western Kansas and other locations. The main subpopulation in this case was derived from stress testing at Garden City, Kansas in 1988. Approximately 900 S_2 families were stress tested there. Stress was severe enough so that about half the families did not set seed. Seed was collected from 100 of the remaining families and

Table 3. Regional 1989 Sorghum Dryland Yield test (be D.T. Rosenow) at Halfway, TX.

Pedigree	Height in	% Lodging	Days to bloom	Yield kg/ha	Drought desirability	Source
A1836 x 884159(fg)[5]	29	0	65	2760	1.9	1[1]
AN122 x 860899	28	5	65	2754	2.0	1
A1836 x M3-17668	34	3	63	2710	2.3	1
A1836 x 884117(fg)	31	0	63	2559	2.5	1
A46038 x N91	33	13	59	2559	1.9	1
A46031 x N91	33	1	60	2504	1.6	1
A1 x R2241	30	2	64	2493	2.9	3
A1 x Tx435	35	8	64	2476	2.1	3
A8201-2 x R6078	36	1	63	2472	3.5	3[3]
AN122 x 852468	33	10	60	2424	2.2	1
OK11 x N62	27	0	60	2411	1.7	2[2]
AN122 x 5008-1	28	2	65	2407	2.4	1
RS626	29	3	57	2374	2.9	--
A4R x Tx430	34	3	60	2369	2.5	3
A35 x Tx430	28	3	60	2358	2.3	3
DK46	36	3	61	2320	1.7	Dekalb
DK41Y	27	2	62	2271	2.3	Dekalb
AN122 x 3-17668	35	13	61	2250	2.4	1
Redlan x N62	29	1	60	2249	1.8	2
KS57 x N62	24	0	59	2157	1.7	2
1181-A x N62	26	<1	58	2071	2.2	2
ATx619 x N62	29	5	59	2065	1.9	2
Tx399 x Tx430	29	2	62	2054	3.2	3
ATx2652 x Tx430	29	4	62	2048	2.7	3
S4A x 884120	34	2	58	2022	2.3	1
AN30 x N62	26	0	60	1978	2.3	2
A2 x Tx430	29	3	62	1972	3.3	3
A1 x R6078	32	3	65	1941	3.4	3
Tx630 x R338Wx	37	2	64	1783	2.9	2
NS24 x N6..	24	1	60	1735	2.2	2
RS671	29	2	59	1734	2.7	--
Martin B	30	2	60	1724	2.9	--
A1181-1 x Tx2741	28	0	59	1719	3.3	3
AOK11 x Tx2737	29	3	63	1697	3.3	2
N122 x 3-17664	33	3	66	1697	3.4	1
ATx631 x R8505	32	6	63	1680	3.3	3
ATx3042 x Tx2737	27	2	60	1615	3.3	3
S1 x R3224	27	2	66	1506	3.6	3
S1 x TAM428	31	3	64	1453	3.7	3
A1181 x N75	25	<1	56	1323	1.3	2
A1 x 6017	29	0	66	1225	3.7	2
Avar x RTx435	32	0	66	661	4.1	2

[1]J.D. Eastin, [2]P.T. Nordquist, [3]D.T. Rosenow, [4]very good (1) very poor (5) [5]fg-food grain.

planted in a Mexico winter nursery. Sufficient genetic sterility remained so that two steriles were bagged per row and were subsequently pollinated by pollen collected from other rows. Equal quantities of seed were then mixed from the 200 crosses to form a population called the Nebraska S_3 food grain stress population (NS_3 fg). At the same time, the component lines were advanced a generation and some were crossed to test as early generation hybrids which will be referred to in Table 3 as fg (food grain) hybrids.

The six top ranked hybrids in the Halfway, Texas test (Table 3) were developed in this program. Two of the top six are fg hybrids even though this is a very small subsample of the lines available in some form from the 1988 Garden City (GC) stress screening. There is some reason for opti-

Table 4. Regional 1989 Dryland Sorghum Yield Test at Mead, NE (conducted by J. Pederson, USDA/ARS).

Genotype	Source	Yield (kg/ha)	Days to bloom	kg/day to bloom	Height (cm)
A46038 x 860903	4	9103	72.0	126	142
A46031 x N91	4	7973	73.5	108	142
Tx378 x Tx430	3	7471	74.0	101	127
A1 x R3224	1	7471	74.5	100	137
A Vart x Tx435	3	7345	81.0	91	127
Al x Tx430	1	7220	74.5	97	130
Al x R2241	1	7157	75.5	95	114
Al x R6078	1	7094	75.0	95	114
Al x TAM428	1	6969	74.0	95	122
RS626		6969	70.5	99	109
N123 x RTx8503	5	6969	71.5	97	112
A2752 x RTx430	3	6969	75.5	92	117
N122 x Tx8503	5	6906	74.0	93	112
A8618 x Tx434	3	6906	80.0	86	109
A1836 x 884117	4	6906	80.0	86	109
N122 x 5008-1	4,5	6906	78.5	88	122
ATx626 x R8503	3	6843	76.5	89	124
AUR x Tx430	1	6843	75.5	91	117
46031 x 852005	4	6717	77.5	87	109
N122 x Tx430	5	6655	74.5	89	114
N122 x 860899	4,5	6592	75.5	87	107
Tx631 x 8002241	3	6592	77.0	86	109
Tx631 x N91	5	6466	77.5	83	140
Tx399 x RTx430	3	6466	74.5	87	107
Tx631 x 88C2003	3	6466	77.0	84	124
A35 x Tx430	1	6404	75.0	85	119
1836 x 884159	4	6341	74.0	86	112
A8610 x Tx435	3	6215	76.5	81	132
Tx631 x R8505	3	6152	80.0	77	119
S4A x 884120	4	5964	69.5	86	132
ATx2752 x RTx433	3	5964	80.0	75	112
ATx630 x R3338wx	1	5901	74.5	79	112
ATx626 x R8617	3	5901	74.0	79	127
A1 x Tx435	1	5901	74.5	79	124
1836 x 3-17668	4	5776	75.0	77	109
46031 x 852005	4	5713	75.0	76	109
N122 x 3-17664	4,5	5713	75.0	76	107
A8618 x RTx435	3	5713	80.0	71	117
ATx626 x RTx433	3	5650	75.0	75	117
ATx631 x R8511	3	5587	80.0	70	164
AKS24 x RN62	2	5525	73.5	75	89
ARedlan x RTx432	2	5462	73.5	74	122
N122 x 852468	4,5	5462	75.5	72	109
Redlan x RN62	2	5462	75.0	73	91
A8201-2 x R6078	1	5336	74.0	72	114
A1181-1 x RTx2741	2	5274	70.0	75	99
A8606 x RTx435	3	5211	77.0	68	127
A155 x Dorado	3	5085	80.0	64	145
Y1 x RTx8503	5	5085	72.0	71	114
A8618 x R8618	3	4897	78.0	63	102
AKS57 x RN62	2	4834	74.0	65	84
AArg 34 x 80C2441	3	4520	80.0	57	107
AOK11 x RN62	2	4395	75.0	59	86
Martin	2	4385	74.5	59	97
ATAM619 x RN62	2	4143	76.5	54	89
ARedlan x RN75	2	3955	70.0	57	89
A1181-1 x RN62	2	3704	72.0	51	89
A1181-1 x RN50	2	2825	66.0	43	114
LSD .05		2007	2.5		13.5

[1]D.T. Rosenow, [2]P.T. Nordquist, [3]P.R. Miller, [4]J.D. Eastin, and [5]D.J. Andrews.

mism regarding utility of the lines being developed from the 1988 GC screening and the stress resistant NS_3 fg population being developed from that. Population samples and progeny tested by R. R. Duncan (summer 1990) did surprisingly well under drought in pH 4.3 soils with 50% aluminum saturation in Georgia. Plants selected will be advanced one generation in the Puerto Rico winter nursery, stress tested on acid soils in 1991 and released in bulk if stress resistance under acid soils holds. These observations are somewhat surprising since the population had never been tested on acid soils. In fact, the 1988 GC stress screening was on slightly alkaline soils. Possibly the physiological mechanisms conferring stress resistance are not quite as diverse as has been suspected and their application may be more universal than has been hoped for. Much investigation on the nature of these mechanisms is needed.

As pointed out earlier, the overall goal of this program is to produce genotypes which are both SR and WR. Evidence of at least limited success in this respect can be seen in Tables 3 and 4. The top two hybrids (A46038 x N91 and A46031 x N91) at Mead, Nebraska (Table 4) rank 4 and 5 at Halfway, Texas (Table 3). The mean of their yields under stress at Halfway is only 164 kg/ha less than the mean of the top four hybrids in the test (Table 3). These hybrids appear to fit the criteria of SR-WR hybrids and compare favorably with the commercial checks in the stress test. Space does not permit reporting on 20 additional Nebraska and Kansas tests which indicate favorable responses of a variety of other stress developed genotypes compared to commercial and public program checks. The assistance and counseling of commercial company breeders in this germplasm development effort is especially appreciated.

Cooperators in Mexico and Senegal report that AN96 hybrids are generally the highest yielding in their tropical tests. Performance of other genotypes from this program in Sudan, Niger and Botswana also is reportedly good but yield data are hard to get.

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Networking Activities

Workshops

Served on a panel on Genetic Sources of Stress Resistance at the XIII National Congress of Plant Genetics (Mexico) in September 1990. An invited paper was presented on the Response of Sorghum to Drought and Heat.

Coauthored two presentations at the Sudan Sorghum and Millet Workshop (see above) dealing with factors influencing water use efficiency.

Participated in setting up a new cooperative INTSORMIL project in Egypt funded by USAID Egypt.

Research is continuing in Niger, Sudan and India (in cooperation with the Indo-U.S. Commission.

Helped plan an Indo-U.S. Commission workshop on Climate Change Effects in Photosynthesis and Productivity to be held in India in January, 1991.

Research Investigator Exchanges

Numerous scientists from LDC's visited research plots in 1989 including those from Sudan, Mali, Botswana, and Mexico.

Germplasm

No formal releases were made this year. A number of stress tolerant breeding materials were distributed to Sudan, Niger, Botswana, Senegal, Egypt and Mexico.

CRSP Produced Technology

Millet-cowpea cropping system technology developed in Niger based on instantaneous WUE research and legume N fixation considerations has been used for altering the DECOR on-farm testing program. Chances are good that the simple changes (they appeal to farmers) suggested compared to current recommendations will have very favorable long term production effects.

Assistance Given

Equipment assistance has gone to Niger, Sudan, Mexico and India (about $3000).

Mechanisms of Drought and High Temperature Resistance in Sorghum and Pearl Millet

Project UNL-123
C.Y. Sullivan
University of Nebraska

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Dr. Jerry Maranville, Agronomy Department, University of Nebraska, Lincoln.
Dr. John Leslie, Department of Plant Pathology, Kansas State University, Manhattan.

Summary

Drought and high temperature stress is a major problem in West Africa. Collaborative research continued with Mali and was directed toward understanding some basic physiological factors involved in plant stress resistance and susceptibility as well as some of the cultural aspects. Metabolites such as proline and abscisic acid often accumulate in plant cells when they are exposed to drought and temperature extremes. Our basic research was aimed at elucidating the nature of the accumulation of these metabolites and how they may contribute to the stress resistance of sorghums and millets.

Inherent differences were found among genotypes in quantities of proline accumulation in response to drought stress. In stressed plants, proline increased up to nearly 30 times that of controls. It accumulated in roots, stems and leaves, but most in the leaves and differed among genotypes. Abscisic acid (ABA) also markedly increased when plants were stressed. There was some indication that quantities of ABA accumulation may be related to stress resistance. Proline accumulation was also studied in relation to plants inoculated with the pathogen *Fusarium moniliforme*. When plants infected with fusarium were water stressed, proline increased dramatically, but generally levels were lower than uninoculated controls - indicating that the fusarium may be utilizing the proline.

Measurements of several physiological characteristics of drought resistance revealed that stress reduced the height of local Malian sorghums more than that of shorter improved varieties, root mass decreased but depth of rooting increased, and the improved varieties had the greatest relative increase in rooting depth. Malisor-5 maintained water use efficiency when stressed better than other sorghums measured. Under post-flowering drought stress conditions of Bema, Mali, the local genotypes maintained higher yields than introduced or improved varieties, although Malisor-1 exhibited improved drought resistance.

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, or 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

Research Methods

Proline

In our previous report we showed that proline accumulated in sorghums when grown under drought stressed con-

ditions. Further experiments were conducted to determine possible variabilities in proline accumulation among sorghum genotypes. Proline concentrations in leaf tissue were again determined on plants grown under dryland field conditions. The second expanded leaf from the top was sampled and analyzed for proline as previously reported (1989 INTSORMIL Annual Report). In order to investigate the effects of water stress under controlled conditions, plants were grown in hydroponic solutions, in racks of cone-tainers. At three weeks of age, polyethylene glycol (Carbowax-8000) was added over a one week period to create a root media stress of -.3 MPa. Controls were grown identically without the addition of osmotica. After another two weeks growth, the plants were harvested, divided into leaves, stems, and roots and frozen immediately at -20°C. Samples were later analyzed for proline.

Abscisic Acid

The monoclonal antibody technique was perfected for analysis of abscisic acid (ABA) as related to stress resistance. Plant extraction of ABA generally followed the procedure described by Beardsell and Cohen (Plant Physiol., 56:207-212, 1975). The monoclonal antibody for free +ABA, the reported natural occurring form of ABA, was commercially obtained and the procedure for immunoassay was that of PHYTODETEK-ABA, as described by IDEATEK, Inc., San Bruno, CA. A standard curve was constructed for each assay with commercial ABA (Sigma Chemical Co.), ranging from .05 to 100 pico-moles per sample. Unknowns were compared to the standard. Plant leaves (second leaf from the top) were sampled in the field at the early grain fill stage of growth, except for the photosensitive Malian genotypes which remained vegetative. The samples were immediately placed in a cold insulated container and transported to the laboratory for analysis. The ABA research was performed primarily by a Malian graduate student.

Fusarium/Proline Relations

Research continued in cooperation with Dr. John Leslie, Kansas State University, on possible relations among sorghums susceptible to *Fusarium* sp. attack and proline accumulation. Dr. Leslie previously found that some fusariums grow well on proline media and it was hypothesized that there may be a relation to their growth in sorghums that accumulate proline. Fusarium cultures used in the study were supplied by Dr. Leslie. Sorghum plants were grown in hydroponic media in cone-tainers and inoculated at two weeks of age with *Fusarium moniliforme* by adding the culture suspended in full nutrient solution. Water stress was created by additions of osmotica, Carbowax-8000. Controls were treated similarly without fusarium. After two weeks growth plants were sampled and frozen immediately for later proline analysis.

Physiological Characteristics of Drought Resistance

A Malian graduate student continued to conduct research on physiological characteristics of Malian and other sorghums that may contribute to their differences in drought and high temperature resistance. One objective is to develop a stress index that will be indicative of severity of stress effects at a specific stage of growth. The research includes field, greenhouse, and growth chamber studies. Parameters measured included leaf number and leaf area, internode length, plant height, maximum root length, numbers of main roots, root weight, total dry weight, root:shoot ratio, water use, and water use efficiency.

Evaluation of Drought Adaptation in Mali

Fifteen varieties of sorghum were evaluated for various morphological and physiological traits and responses to biological and abiotic stresses at four locations in Mali. The locations were Cinzana (both heavy and sandy soils), Sotuba (insect and disease evaluations), Samanko (two fertility levels), and Bema (post-flowering drought, two seeding dates). The research at Bema was of particular interest to this project. The 15 sorghums planted were: CSM 219, CSM 228, CSM 388, Gadiaba, Malisor-1, Malisor-5, Malisor-7, CE 90, CE 151, E35-1, Sureño, S 34, ICSV 401, ICSV 1063, and ICSV 1079. Planting dates at Bema were July 22 and August 7, 1989. Each variety was planted in hills with five row plots, 5 m in length, 75 cm between rows, and 50 cm between hills, thinned to two plants per hill. Plots were uniformly fertilized with 100 kg ammonium phosphate at seeding and 50 kg urea at the first cultivation (about three weeks after planting).

Research Findings

Proline

Additional results showed that significant differences in proline accumulation occurred in dryland field grown sorghums. Table 1 gives the results of 12 genotypes. As previously found, sorghums NP9-272, 121 and NP9-9 had significantly higher accumulation of proline than 9040 and 103-S-11. And again, visual evaluation of the stress symptoms did not always correlate positively with accumulation of proline, indicating that inherent differences may exist among genotypes in proline accumulation in response to stress.

Four genotypes were grown under controlled conditions with water stress uniformly imposed by additions of osmotica to the root media, as indicated above. The unstressed controls had some apparent differences among genotypes, where Redlan had a higher proline level in the leaves, while in 121 it was higher in the stems and roots (Table 2). When stress was applied, there was a dramatic increase in proline. Accumulation was greatest in the leaves. In the leaves of Tx430, it increased about 28 times that of the controls.

Again, Redlan had the highest accumulation in stressed leaves, as it also had in the controls. The highest accumulation in the stems of stressed plants was in B35-6, while 121 and Tx430 had the highest accumulation in the roots of stressed plants.

These results demonstrate that accumulation of proline in water stressed plants differs among genotypes, even when the roots are subjected to the same stress with plants growing in the same media.

Table 1. Mean leaf proline content of dryland field grown sorghums, Mead, Nebraska

Sorghum	Proline (µg/gdw)
NP9-272	185.2 a*
121	178.0 a
NP9-9	175.6 a
Redlan	145.3 b
7078	136.4 b
B35-6	134.9 b
4104	133.5 b
SC-90	130.0 c
SC-283	128.9 c
Martin B	113.8 d
9040	97.0 e
103-S-11	96.3 e

* Values not followed by the same letter are significant at the 5% level according to Duncan's Multiple Range Test.

Abscisic Acid

We previously reported that applied abscisic acid (ABA) had a significant effect on drought tolerance, seedling survival, and even grain yield of drought stressed plants. Sometimes the response was less with local Malian sorghums than with selected U.S. varieties. This led us to surmise that there may be inherent differences in the endogenous levels of ABA in these sorghums, and among other genotypes. Considerable time was required for development of methodology for free ABA analysis in sorghum with use of a monoclonal antibody. Thus, only limited results will be shown at this time. Table 3 compares ABA levels in some sorghums grown under irrigation - without drought stress, and dryland, where drought stress was moderate to severe. Stress initiated a noticeable increase in ABA in all genotypes, as expected, except in the selection M35-1 x 8569. This selection is a drought stress resistant and desiccation tolerant genotype, selected and self-pollinated for five generations. The Malian locals and DK46 had a moderate increase in ABA, and the selection from CK60 x 4196, considered the least stress resistant, had the highest increase in ABA. The results tend to indicate that stress resistance is related to free ABA accumulation in sorghum leaves during stress, but the results are too few to make a conclusion at this time.

Table 3. Levels of free abscisic acid in leaves of U.S. and Malian sorghums when grown with irrigation or on dryland, 1989.

Genotype	Abscisic acid	
	Irrigated	Dryland
	(nano-g/gdw)	
CSM 63	598.3	929.4
CSM 207	576.1	1100.7
Sel. from (CK60x4196)	545.8	1241.5
Sel. from (M35-1x8569)	761.8	738.7
DK46 (DeKalb)	869.4	1061.1

Fusarium/Proline Relations

The outcome of these experiments has been variable with no definite conclusions reached. The results in Table 4 again show a marked increase in leaf proline when plants were uniformly drought stressed. When the roots were inoculated with *Fusarium m.* there was no large change in proline content, except with Redlan which had a noticeable reduction in proline when fusarium was present. However, with water stressed plants there was a trend toward reduction in proline when fusarium was present, except with Tx430. There is some indication that the fusarium within the plants

Table 4. Effects of Fusarium moniliforme and water stress on proline content of sorghum.

Genotype	Leaves			
	Control	Stressed	Fusarium	Stress & Fusarium
	(Proline µg/gdw)*			
121	200	1810	174	1522
B35-6	199	2737	180	1459
TX430	173	4838	185	5113
Redlan	350	5949	167	4652

*Values are means of three replications.

Table 2. Effects of water stress on proline content of sorghum leaves, stems and roots.

Genotype	Control			Stressed		
	Leaves	Stems	Roots	Leaves	Stems	Roots
	Proline (µg/gdw)*					
121	200	758	687	1810	1415	979
B35-6	199	410	559	2737	1986	623
Tx430	173	431	497	4838	1262	846
Redlan	350	455	474	5949	1582	644

*Values are means of three replications.

was utilizing the proline, but the variability of results make the conclusions indefinite.

Physiological Characteristics of Drought Resistance

The results of measurements of several physiological parameters for Malian sorghums CSM 63, Gadiaba and improved variety Malisor 5 are compared to CK60 in Table 5. It was noted that when water stressed, plant heights of the tall Malian sorghums were reduced proportionately more than the improved shorter varieties, due primarily to a reduction in internode length, while leaf numbers were reduced the same in all varieties. Rooting depth increased as a result of stress in all varieties, with the greatest relative increase in Malisor-5 and CK60B. Although root mass decreased when plants were stressed, the root to shoot ratio increased in stressed plants, except in CK60, which decreased with stress. Water use efficiency (wue) generally decreased when plants were water stressed, except for Malisor-5, which maintained the same wue when well watered or stressed. Local CSM 63 had the greatest decrease in wue when stressed.

Evaluation of Drought Adaptation in Mali

Table 6 compares means of several variables measured for 15 genotypes, with two dates of seeding, at Bema.

Post-flowering drought was most severe for plants seeded the second date, August 7, and of these CSM 219, Gadiaba, and Malisor-1 exhibited the best drought resistance by producing the highest grain yields. Local CSM 388 produced a large amount of shoot mass, but little grain yield. Varieties CE 151, S 34, and ICSV 401 did not greatly reduce in grain yield when subjected to post-flowering stress, but actual yields were lower. The post-flowering leaf area generally decreased with the late seeding date, but the degree varied among varieties. Some varieties maintained their leaf area better during the stress, namely, Sureño and Gadiaba. These results continue to show that the local sorghums have superior drought resistance, although some progress is being made with some of the improved Malisor varieties. It has been observed that germination is very good with seed produced at Bema. Whereas, seed produced at other sites (Cinzana, Samanko and Sotuba) are variable in their ability to germinate, and depends on the type of protection the panicles have had during grain filling (solid pollinating bags, nylon mesh bags, or no bags), that may influence effects from insects and diseases

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Thesis

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

Networking Activities

Research Investigator Exchanges

The P.I. visited Mali, September 16-25, 1989. The purpose of the trip was to visit collaborating scientists and other personnel, discuss the research in progress and plan for continued collaboration. Experimental plots were viewed at

Table 5. Means for some physiological parameters of Malian sorghums and U.S. check (CK60B).

Genotype	Watering level	Plant height	No. of leaves	Internode length	Maximum root depth	No. of main roots	Root mass	Root: shoot ratio	Total dry weight	Water use	Water use efficiency
		(cm)		(cm)	(cm)		(g)		(g)	(L)	(g/L)
CSM 63	Well-watered	95.7	16	6.0	46.7	35	7.6	.2147	43.0	6.91	6.06
Malisor-5	"	57.8	16	3.6	39.0	27	4.5	.1822	29.2	4.71	6.13
Gadiaba	"	79.9	16	5.0	43.7	31	6.7	.2204	37.1	6.48	5.52
CK60B	"	53.9	16	3.4	46.1	27	6.5	.3202	26.8	4.78	5.52
CSM 63	Water-stressed	56.3	14	4.0	58.5	29	4.3	.3007	18.6	3.41	5.41
Malisor-5	"	48.9	14	3.5	57.5	25	4.1	.2595	19.9	3.27	6.12
Gadiaba	"	54.2	14	3.9	59.4	19	3.9	.2617	18.8	3.63	5.20
CK60B	"	47.6	14	3.4	67.6	26	4.6	.2875	20.6	3.86	5.21

Table 6. Means of variables measured in evaluation of sorghum adaptation to drought at Bema, Mali, 1989.

	Variable									
	50% flower (DA)		Grain weight (g)		Dry matter (g)		Plant height (cm)		Leaf area+ (cm^2)	
	Planting Date									
Genotype	1*	2*	1	2	1	2	1	2	1	2
CSM 219	66	59	2300	1665	5865	3445	220	192	1804	1321
CSM 228	56	57	1865	1155	3062	2228	170	176	1188	744
CSM 388	109	71	655	725	14650	5230	292	217	1384	1544
Gadiaba	77	65	2905	1815	8328	3800	211	158	2109	1931
Malis-1	69	64	2410	1705	4235	2800	153	133	2515	1796
Malis-5	59	59	2515	1155	2750	1728	139	122	1569	1346
Malis-7	63	63	2515	1340	3385	1840	104	81	1830	1894
CE 90	65	65	2380	1195	3985	1633	140	110	1712	1560
CE 151	61	61	2225	1495	2253	1480	113	118	1704	1432
S 34	75	69	1875	1530	4703	2733	138	135	1917	1825
Sureño	77	72	1175	830	3152	2323	125	112	2473	2017
E35-1	81	76	810	1312	5528	4853	134	122	2737	2909
ICSV 401	61	68	1630	1472	2370	2033	134	112	1745	1734
ICSV 1063	70	68	2650	1585	5915	2593	157	136	2361	1970
ICSV 1079	59	65	2990	1395	4355	2213	166	123	2337	1752

* 1 = July 22; 2 = August 7
\+ Post flowering.

Samanko, Ntarla, and Cinzana Research Stations and field notes were taken. The program was reviewed with USAID and IER personnel concerning the continuing collaborative research program in Mali.

Assistance Given

Several pieces of equipment and supplies were purchased from this project for the physiology program in Mali. Also, membership for Dr. Traore in the American Society of Agronomy, including subscriptions to Agronomy Journal and Crop Science were acquired. Assistance was given in equipment operation, repair, maintenance, and recalibration.

Plant Breeding

Pearl Millet Breeding

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.

Several populations are being used as germplasm sources in the development of materials for northern low-rainfall areas of the Sahel. Three new dwarf populations are under development as sources of increased seedling length and stand establishment capability, bird resistance, and a togo type germplasm source of B_1 fertility maintainer lines. Final conversion from normal to dwarf plant heights was facilitated with glyphosate (Roundup) applied with a wick applicator to eliminate normal height plants.

Although the cytoplasmic male-sterile line 79-2068 is widely used in India, the breakdown of its downy mildew (DM) resistance restricts its use as a seed parent of hybrids to low-rainfall areas. A sister selection, 81-1163, may be a suitable replacement for 79-2068 as it has acceptable DM resistance and similar agronomic and grain yield responses in hybrid combinations.

Exchanges of breeding materials with ICRISAT and LDC's are increasing the genetic diversity of the Kansas State University breeding program leading to improved

grain yield potential, F_1 hybrid fertility restoration, drought tolerance, and lodging resistance.

Continued selection and screening for improved stand establishment is identifying inbred lines capable of rapid emergence and vigorous seedling development.

Fourteen hybrids using KSU seed parents were entered in the All India Coordinated Millet Improvement Project trials by Indian institutions. Commercial hybrids of 79-2068 are grown on more hectares in northwest India than hybrids of other male-sterile lines.

Objectives, Production and Utilization Constraints

Objectives

To develop widely adapted, early maturing pearl millet populations, lines, germplasms, and hybrids with: a) improved drought tolerance, seed size and density, seedling stand establishment, lodging resistance, and grain yield; 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 and farming systems 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

Standard breeding procedures for open-pollinated crops are used. The pedigree breeding method is used for the early development of nearly all materials entering the program, the advancement of elite lines, and lines extracted from populations undergoing recurrent selection. Mass selection, gridded mass selection, and the S_1 and S_2 progeny performance testing methods are used in population improvement. Screening and evaluation is conducted at several Kansas, Nebraska, and LDC locations.

New sources of breeding materials 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 inbred lines and superior F_1 hybrids (B x B and R x R) used as seed parents. Superior progenies and selections arising from these crosses are reintroduced into ICRISAT and LDC programs as elite F_2 families and germplasm pools, as F_3 to F_5 lines possessing desirable maturity and agronomic characteristics, and as components of populations. Advanced inbred lines and population selections are crossed to tester A, B, and R lines to determine combining ability in hybrid combinations and value as germplasm sources of desirable characteristics.

Seed and seedling characteristics affecting stand establishment are studied and evaluated under laboratory, greenhouse, and field conditions. Seed size and gravity table density separations are used to select lines to be evaluated for length of seedling radical, mesocotyl, and coleoptile structures. Length measurements of 10 randomly selected seedlings of each seed lot are recorded after germination in paper dolls at 30°C for eight days, allowing maximum elongation and emergence of the first leaf from the coleoptile. Selected materials are planted 100 mm deep in greenhouse soilbeds to obtain initial germination and emergence indices, seedling vigor, scores, and plant weights. Seedlings selected from superior lines are transplanted to pots and grown to maturity. Crosses are made between lines to generate new segregates and to tester lines to evaluate responses in F_1 hybrid combinations. 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 a depth of 75 to 100 mm to identify lines possessing superior emergence characteristics.

Research Results

Several KSU/INTSORMIL populations are being used as germplasm sources by cooperators in Niger and Senegal. Recent communications indicate that crosses involving se-

lections from these populations and West African lines are producing progenies that may be useful in northern, low-rainfall areas of the Sehel.

Three new populations are in various stages of development using random- mating and mass-selection procedures. A population of long-mesocotyl materials was formed by compositing a group of 68 F_2 families (D_1 and D_2 plant height) that have produced superior F_3 and F_4 segregates. This population is being advanced by planting the seeds to depths of 75 to 100 mm to eliminate short mesocotyl segregates followed by mass-selection for desirable plant characteristics.

The second population is a dwarf version (D_1 and D_2) of HMP-BR, a normal height, bristled population that has excellent resistance to depredation by several species of birds under Kansas conditions. Plant heights of the dwarf HMP-BR range from 0.7 to 1.9 m compared to the normal population with plant heights of 2.5 to 3.5 m.

A dwarf population has been derived from PI 185642, a "togo" or "iniati" type millet. This introduction has been our best source of germplasm in the development of cytoplasmic male-sterile inbred lines as the line is genetically diverse for several seed and plant characteristics. Since the mid 1970's we have advanced the material as a random-mating population with periodic mass-selection for large seed size and increased resistance to charcoal stalk rot and lodging. An introgression of the D_2 height gene into the population was maintained at frequencies of one to two percent for four cycles of random-mating and then increased to 50% in two cycles of selection. During the next two cycles of random-mating, glyphosate (Roundup) was applied to normal height plants prior to anthesis with a wick applicator to prevent pollen shedding, thus shifting the population to a D_2 dwarf height. This population is similar to the original normal height population in all characteristics except height. Its use as a direct source of new B-lines or as germplasm should eliminate much of the crossing and backcrossing necessary to develop new B-lines and reduce the sizes of F_2 families needed to recover superior segregates.

The cytoplasmic male-sterile line 2068A and its maintainer are being used extensively in Indian national breeding programs and as a seed parent of hybrids grown in low rainfall areas of India where the incidence of downy mildew (DM) is relatively low. Its use as a seed parent is restricted to those areas because its DM resistance became ineffective. ICRISAT/Patancheru personnel considered initiating a backcross breeding program to transfer resistance to 2068 but this would have required a considerable period of time. Therefore, 46 sister selections and early generation relatives of 2068 were sent to ICRISAT in 1988 to be screened for DM resistance. The male-sterile line 81-1163 received a DM resistance score of 90% in the initial screening trials and selections from this line are rated as 95% resistant. This level of resistance is adequate for most of the millet producing areas of India. ICRISAT entered two hybrids of 81-1163A in the 1990 AICMIP trials. In Kansas trials, the yield potential of hybrid combinations with 2068 and 1163 seed parents appears to be equal but there are differences in combining abilities with certain restorer lines. Some of the differences in characteristics of 79-2068 and 81-1163 are given in Table 1.

Table 1. Morphological characteristics and reactions to the greenbug aphid and zonate leaf spot, Fort Hays Experiment Station. 1989.

Character	79-2068	81-1163
Time to 30% bloom (d)	55	57
Plant height (cm)	97	94
Canopy width, 90 cm rows (cm)	61	46
Head length (cm)	18	15
Head diameter (cm)	2.85	2.54
Number heads/M^2	19	18
1000-seed mass (g)	12.5	11.4
Seed color	light grey	yellow
Greenbug aphid	susceptible	resistant
Zonate leaf spot	resistant	susceptible

Significant progress is apparent in improving the level of genetic diversity within the population of lines undergoing cytoplasmic male-sterilization as a result of continued exchanges and cycling of germplasms and lines with ICRISAT/Patancheru. Preliminary test cross results of new lines are identifying several that equal or exceed the performance of lines such as 79-2068 and 81-1163 in grain yield, drought tolerance, and lodging resistance.

Several thousand inbred lines have been tested in hybrid combinations with cytoplasmic male-sterile seed parents in the last 12 years. A large number of lines have produced hybrids with superior agronomic and grain yield characteristics and a significant number have equaled the yield potential of sorghum checks of similar maturity. However, we have had considerable difficulty in identifying lines with stable F_1 hybrid fertility restoration under environmental conditions in the central Great Plains. We now have selections from crosses between a KSU line and an ICRISAT line, Tift $239D_2B_2$/4*Serere 3A (81-2019)//B282/ 3/4 Ex Bornu (481-R80), that have produced hybrids with good fertility restoration responses at all locations in each of the last four years. Another set of five lines derived from other crosses of KSU/ICRISAT lines have had stable fertility restoration responses for three years.

Several of these hybrids have produced grain yields 60 to 90 percent as large as the sorghum checks on silty clay loam soils. In 1989, a test of 11 of these hybrids compared to a commercial sorghum hybrid at the KSU Sandyland Station, St. John (sandy loam soil), produced yields 4 to 76 percent (2480- 4210 kg/ha range) larger than the sorghum check (2390 kg/ha).

Progress continues to be made in the development and selection of materials possessing improved stand establishment characteristics. Within a group of 1050 F_3 lines selected for minimum seedling lengths of 100 mm, 47 had rapid emergence to stands of 90 to 100 percent from planting depths of 75 to 85 mm. An additional 130 lines emerged to stands of 80 to 90 percent. Arrangements have been made to test the best of these materials in the Mali IER soil crust screening nursery in 1991. Preliminary appraisals of these lines indicate several will have good potentials as germplasm sources for increased grain yield and drought tolerance.

We reported in the 1989 annual report that the Colorado State University Tissue Culture for Crops Project (TCCP) had terminated this work with several KSU millets because of budgetary constraints and difficulties in evaluation and seed production. A total of 1919 lines resulting from 5 to 18 passages through culturing medium were returned to KSU. Fifty of the 472 lines grown in 1989 were replanted in 1990 for additional screening and selection. Another group of 500 untested lines were planted in 1990. This group of lines had smaller seed sizes on average than the 1989 planting. Soil moisture and seedbed conditions were excellent at planting but fewer than one-half of the lines emerged to satisfactory stands. Only 16 of the lines were selected for replanting in 1991.

Publications and Presentations

Sullivan, T. W., J. H. Douglas, P. L. Bond, D. J. Andrews, J. D. Hancock, P. B. Cox, J. R. Brethour and W. D. Stegmeier. 1990. Nutritional Value of Pearl Millet for Food and Feed. Proceedings, International Conference on Sorghum Nutritional Quality. February 26 - March 1, 1990. Purdue University, West Lafayette, Indiana.

Stegmeier, W. D. Pearl Millet Improvement progress. Kansas State University, Fort Hays Branch Experiment Station Field Day. August 25, 1989.

Stegmeier, W. D. Breeding Pearl Millet for Grain Production in the Central Great Plains. Pioneer Hi-Bred International, Inc. Annual Conference. Plainview, Texas, September 6, 1989.

Networking

Workshops

International Conference on Sorghum Nutritional Quality. Purdue University, West Lafayette, Indiana. February 26 - March 1, 1990.

Investigator Exchanges

Drs. R. L. Vanderlip and F. Barnett brought three INTSORMIL sponsored graduate students to visit the pearl millet program. July 20, 1989.

The project was visited by Dr. Brian Hare, Millet Breeder and Director of Research and Mr. Neal Muller, Sorghum Breeder, Pacific Vegetable Seeds, a Division of Continental Grain Australia Pty. Ltd., Toowoomba, Australia. August 20-22, 1989.

Six pearl millet breeders and two sorghum breeders from Pioneer Hi-Bred International, Inc. visited the project. The pearl millet breeders are stationed in Sudan, South Africa, India, and Australia. September 12, 1989.

Dr. Lloyd Rooney, TAM-126, visited the program October 11, 1989.

Travel to Lincoln and Mead, Nebraska to visit the NU-118 millet breeding programs. October 20, 1989.

Germplasm and Research Information Exchange

Twenty-nine yellow and white seed color accessions from SADCC/ICRISAT/Bulawayo were grown under quarantine. A total of 775 accessions are in storage. Thirty-two inbred lines were received from UNL-118. A total of 84 lines, hybrids, and populations were sent to six U.S. Universities and Australia.

Assistance Given

A seed increase of a yellow-seeded hybrid was made in 1989 to plant a 0.6 ha production field in 1990. The grain harvested will be shipped to TAM-126 to be used in studies developing pearl millet-based food products with extended shelf life.

Seed lots of yellow and blue seed colors were produced for Dr. C. Klopfenstein for continued studies of the goitrogenic effects of flavinoid pigments in pearl millet.

Impact

Previous reports have indicated the KSU/INTSORMIL A-B lines 2068 and 2221 are used extensively in ICRISAT and Indian national breeding programs. Recent reports show a total of 13 experimental F_1 hybrids using 79-2068A and one hybrid using 79-2221A as seed parents were entered in the 1990 AICMIP trials by several Indian institutions. In the low rainfall areas of northwest India, particularly in Rajasthan, commercial hybrids using 79-2068A as the female parent occupy more hectares of production in 1990 than hybrids using other male-sterile lines.

Sorghum Breeding and Management of Insect, Disease, and Acid Soil Problems

Project MSU-104
Lynn M. Gourley
Mississippi State University

Principal Investigators

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Collaborating Scientists

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Dr. Dorance Munoz, Director Genetics and Plant Breeding, FEDEARROZ, Calle 72 #13-23 Piso 11, Bogota, Colombia.

Mr. Cesar Ruiz, Sorghum Breeder, ICA, La Liberted, Apartado Aereo 2011, Villavicencio, Colombia.

Mr. Luis de Angulo, El Alcaravan Foundation, Occidental de Colombia, Inc., Apartado Aereo 092171, Bogota, Colombia.

Dr. Fabio Polania, Technical Director, FENALCE, 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.

Drs. Vartan Y. Guiragossian and Sam Z. Mukuru, Sorghum Breeders, SAFGRAD/ICRISAT, P.O. Box 30786, Nairobi, Kenya.

Dr. Guillermo Munoz, Plant Breeder, MSU-111 PI, International Programs and Department of Agronomy, Mississippi State University, CIAT, Apartado Aereo 6713, Cali, Colombia.

Dr. Henry Pitre, Entomologist, MSU-105 PI, Department of Entomology, Mississippi State University, Mississippi State, MS.

Dr. Jerry Maranville, Plant Nutritionist, UNL-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.

Dr. Darrell Rosenow, Sorghum Breeder, TAM-122 PI; and Gary Peterson, Sorghum Breeder, TAM-123 PI, Texas A & M University Agriculture and Research Center, Route 3, Lubbock, TX.

Dr. Fred Miller, Sorghum Breeder, TAM-121 PI, Department of Soil and Crop Sciences, Texas A&M University, College Station, TX.

Summary

The primary collaborative research site of the germplasm enhancement conducted by MSU-104 in Year 11 was Colombia; however, a second site in East Africa was initiated. This was made possible through a buy-in by the USAID funded MidAmerica International Agricultural Consortium (MIAC) Kenya country project. The MSU-104 PI was assigned to Kenya for two years as a sorghum and millet breeding technical advisor. Based on their common latitude,

the Colombia and Kenya INTSORMIL Country Programs will complement each other. The sorghum and millet production constraints of infertile soils, drought and low-input crop management are common to both countries. Acid soils are also beginning to be recognized as a production constraint in Kenya, but they are not as severe or as extensive as those in Colombia.

The Kenya Agricultural Research Institute (KARI) has made the improvement of sorghum and millets (both pearl and finger millet) a research priority. All INTSORMIL research disciplines could find good KARI collaborators in Kenya. Regional transfer of sorghum and millet technology will be possible through active National improvement programs in the countries adjacent to Kenya and through the SAFGRAD/ICRISAT regional program based in Kenya.

Objectives, Production and Utilization Constraints

Objectives

Screen and evaluate sorghum and pearl millet, in the laboratory and field, for sources of tolerance to low soil phosphorus (P) content and availability, and aluminum (Al) and manganese (Mn) toxicities.

Enhancement of elite U.S. and LDC sorghum germplasm with sources of tolerance to 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 Acid Soils Research in Niger

Dr. Moussa Adamou, INRAN sorghum breeder, planted a sorghum combining ability study at Tarna, Bengou, and Konni stations in Niger during the 1989 growing season. The same study along with several dune adapted sorghum cultivars from Niger were evaluated in Al-supplemented nutrient solutions in the laboratory at Mississippi State University. Based on previous soil analyses, it was determined that soluble Al was probably not the acid soil constraint at the three sites in Niger. Very low cation exchange capacity (CEC), low water holding capacity, low organic matter contents, excess Mn and boron, drought and high temperatures during crop growth form a complex of production constraints that interact with low soil pH and reduce sorghum grain yields.

Germplasm used for the genetic study was selected based on performance results of lines and hybrids evaluated on infertile acid soils in Colombia. In the Colombian acid soils tests, it was felt that excess soluble Al was the primary sorghum production constraint and drought was not generally a limiting factor during the regular growing season.

Significant differences were found from the combined analyses of variance among genotypes, locations, and genotype by location interactions. Means for days to 50% bloom, plant height, and grain yield for the three test sites are shown in Table 1. For days to 50% bloom, hybrids were significantly earlier than parents at all three locations and the latest material was among the local check varieties. Heterosis for earliness exhibited by the hybrids was a positive trait, especially for the Sahelian regions where the annual rain period can be short and the rainfall very low. Hybrids were also significantly taller than the parental material, but shorter than the local checks at all locations.

Hybrids yielded more grain than both the parents and the checks at all locations. Hybrids with IA 28 and IS 3071C as male parents averaged higher grain yields at all locations than other hybrids. The trend was less clear with the female parents. The three females; Tx623, (AT1)-52-2-1-2-1, and Wheatland, all produced respectable yielding hybrids at Tarna and Wheatland hybrids yielded well at Bengou.

Combining ability was evaluated using the North Carolina Mating Design II fixed model. The variation among females and males was significant for all characters at all three locations except for grain yield at Konni. The interaction of females by males was significant for all characters at Tarna, and 50% bloom and plant height at Bengou and Konni. These results show that additive as well as nonadditive gene action was involved in determining the variability for most characters. The magnitude of the variances for grain yield, a quantitative character, showed that it was more governed by additive rather than nonadditive gene action.

Estimates of general (GCA) and specific (SCA) combining ability for grain yield are presented in Table 2. The best general combiners were the female, Wheatland, at Bengou; and the males IA 28 at Tarna and Bengou and IS 3071C at Tarna and Konni. Significant negative GCA effects were obtained with the female (AT1)-36-4-2-2-1 at Tarna, B-Yel PI at Bengou, and the males, IS 7254C at Tarna and Bengou, and TX432 at Tarna. Three specific combinations at Tarna

Table 1. Means of days to 50% bloom, plant height and grain yield of 40 sorghum genotypes evaluated at Tarna, Bengou and Konni, Niger.

Genotype	50% bloom			Plant Height			Grain yield		
	T	B	K	T	B	K	T	B	K
	------ days ------			------ cm ------			------ kg ha^{-1} ------		
1) IA 28	72	64	89	100	67	84	2827	1862	889
2) IS 3071C	78	77	90	112	84	80	813	312	389
3) IS 7254 C	62	60	70	129	118	136	1643	636	848
4) Tx430	66	66	79	110	82	91	3124	1507	634
5) Tx432	69	67	74	108	85	105	2538	1414	1133
6) B-Yel PI	62	60	80	95	73	91	1778	1084	828
7) Wheatland	59	59	71	94	63	85	2361	1028	1233
8) Tx623	64	65	92	124	91	102	2417	1362	395
9) (ATI)-36-4	64	62	81	106	86	96	2068	1188	705
10) (ATI)-52-2	64	56	79	98	80	85	1958	832	534
11) 6 x 1	65	61	74	122	89	111	3757	1830	1586
12) 7 x 1	63	54	74	112	86	100	3917	2621	1915
13) 8 x 1	68	66	78	148	112	132	4461	2076	1786
14) 9 x 1	65	61	73	135	108	138	3357	2176	2339
15) 10 x 1	63	58	76	129	98	129	4324	2585	3194
16) 6 x 2	66	64	75	154	128	139	3997	2005	2071
17) 7 x 2	65	58	70	150	126	130	3785	2741	2594
18) 8 x 2	68	68	75	199	182	169	4061	1593	1821
19) 9 x 2	64	63	74	198	161	179	4106	2039	3574
20) 10 x 2	62	62	74	181	155	151	3638	2241	2055
21) 6 x 3	63	62	72	141	130	140	3119	944	1331
22) 7 x 3	56	52	64	139	117	126	3267	1849	1689
23) 8 x 3	59	57	72	182	159	181	2513	1823	1634
24) 9 x 3	62	58	68	172	144	175	2743	1319	2092
25) 10 x 3	58	57	63	168	138	169	2170	1015	1767
26) 6 x 4	60	60	72	106	78	111	3258	1004	1007
27) 7 x 4	60	56	69	108	83	101	3882	2439	2214
28) 8 x 4	68	64	74	128	99	119	3579	1544	1557
29) 9 x 4	62	59	75	119	94	118	2507	1657	1874
30) 10 x 4	60	58	76	114	89	108	4322	2208	1271
31) 6 x 5	58	58	68	129	107	124	2732	2412	2248
32) 7 x 5	57	56	70	108	80	104	2719	2140	1190
33) 8 x 5	68	67	75	144	110	124	3502	1453	1260
34) 9 x 5	57	58	68	136	108	114	2528	2183	2038
35) 10 x 5	59	54	64	131	104	129	3324	1986	2613
36) H. Dura-1	66	64	83	125	98	112	2690	1564	1194
37) BDF	76	72	88	211	199	200	1614	859	984
38) NGK	68	69	86	212	246	225	1841	879	1001
39) L-30	78	75	92	232	243	189	1499	1121	511
40) 1/2 MSB	80	75	94	202	171	171	2003	653	902
Mean	64.6	62.1	76.1	140.3	116.8	128.9	2919	1605	1522
LSD (0.05)	3.2	3.8	7.2	11.5	13.2	17.5	836	703	1201

Adapted from dissertation of Moussa Adamou, Combining Ability of Acid Soil Tolerant Sorghum Germplasm in Niger, Mississippi State University.

and two at Bengou deviated significantly from expectations based on the average performance of the parents. Three of these combinations showed positive SCA effects.

In the Al-supplemented nutrient solution study (data not shown), parental lines IS 3071C and (AT1)-52-2-1-2-1 produced significantly higher root and shoot lengths and DM yields than other inbreds at the stress level of 222 uM Al L^{-1}. All of the local sorghum checks showed Al toxicity stress symptoms and reduced growth when grown in the high Al level nutrient solution.

Table 2. Estimates of general (GCA) and specific (SCA) combining ability effects for grain yield at Tarna, Bengou and Konni, Niger.

Males	Female					Male	
	B-Yel PI	Wheatland	Tx623	(ATI)-36-4	(ATI)-52-2	Means	GCA
	kg ha^{-1}						
Tama:							
IA 28	-156	-138	297	-232	228	3963	541**
IS 3071C	130	-223	-57	563	-412	3917	495**
IS 7254C	407	413	-450	355	-725*	2762	-660**
Tx430	-202	281	-130	-628*	679*	3510	87
Tx432	-179	-333	340	-58	230	2961	-461**
Female means	3373	3514	3623	3048	3556	3422	---
Female GCA effects	-50	91	201	-375**	133	---	---
Bengou:							
IA 28	-151	-79	36	-41	236	2258	342*
IS 3071C	288	142	-346	-77	-7	2157	241
IS 7254C	-301	49	683*	2	-434	1357	-558**
Tx430	-490	226	-9	-73	346	1771	-145
Tx432	654*	-338	-364	189	-141	2035	120
Female means	1639	2358	1698	1875	2007	1915	---
Female GCA effects	-276*	443**	-217	-41	92	---	---
Konni:							
IA 28	-278	-221	-41	-259	799	2164	215
IS 3071C	-52	199	-265	716	-599	2423	474*
IS 7254C	-72	15	269	-46	-167	1702	-246
Tx430	-278	657	310	-145	-545	1585	-364
Tx432	678	-651	-273	-267	512	1870	-79
Female means	1648	1920	1611	2383	2180	1949	---
Female GCA effects	-300	-28	-337	435	231	---	---

*, ** Significantly different from zero at the 0.05 and 0.01 levels of probability, respectively. Adapted from dissertation of Moussa Adamou, Combining Ability of Acid Soil Tolerant Sorghum Germplasm in Niger, Mississippi State University.

Aluminum Tolerance of Sorghum in Nutrient Culture

An effort was made to evaluate the effects of Al toxicity in nutrient culture on sorghum under ambient conditions at Mississippi State University. Polyvinyl chloride (PVC) pipes 101.6 cm in length and 15.24 cm diameter with a liquid capacity of 18.5 L were constructed as containers for growing the plants in this study. The frame used to support the PVC containers was constructed of angle iron and was 6.17 m^2 and 3.63 m in height. The frame contained eight racks with 62 cm between racks. The PVC containers were placed in the eight racks, 24 containers to a row. The nutrient solutions were 74 and 148 uM Al L^{-1}, 16 uM P L^{-1}, and pH 4.0. Air was constantly bubbled through the solution. Four A-lines and four R-lines of sorghum and their 16 F_1 progenies were evaluated in nutrient culture for Al tolerance using a North Carolina Mating Design II.

The toxic level of 148 uM Al L^{-1} produced differentiating effects among the inbreds and hybrids used in this study. Hybrid vigor was observed for all traits as evidenced by the significant parent by F_1's interaction from the analysis of variance. Means of the genotypes at the toxic level of Al and the ratio of these means compared with the control (148/74 uM) for root and shoot length and DM yield are shown in Table 3. Without exception, hybrids superior for root and shoot length and DM yield of the 31-day-old seedings were produced by males classified as Al tolerant (IA 28 and IS 7254C). For DM yield variables, hybrids produced by IS 7254C had the highest mean values. The trend among hybrids produced by female parents was less clear.

Results of the analyses of variance of the North Carolina Mating Design II showed significant mean squares for all variables for males and females except root length due to females. No significant male by female interactions were

Table 3. Means and ratios (148/74 uM Al L^{-2}) for length and DM yield of roots and shoots of sorghum parental lines and F_2 hybrids at 31 days of age grown in nutrient culture.

Genotypes	Root length		Shoot length		Root DM		Shoot DM	
	148	148/74	148	148/74	148	148/74	148	148/74
	- cm -	- % -	- cm -	- % -	- mg -	- % -	- mg -	- % -
1) Wheatland	30.2	56	36.7	81	360	55	700	57
2) Tx623	17.7	40	28.0	80	170	38	370	51
3) MS 36-4	22.4	49	29.8	71	250	35	540	53
4) MS 13-5	34.5	59	36.1	81	450	62	700	69
5) IA 28	35.7	64	42.6	90	680	94	1180	106
6) IS 7254C	44.2	109	46.9	105	820	108	1260	104
7) Tx430	36.5	59	31.8	71	300	40	510	47
8) Tx432	21.3	46	29.8	70	260	36	500	47
9) 1x5	55.6	91	48.4	90	830	81	1220	81
10) 1x6	44.5	65	49.7	100	850	83	1310	98
11) 1x7	32.0	58	35.0	75	370	47	660	50
12) 1x8	33.2	57	38.2	85	450	63	780	79
13) 2x5	36.9	74	40.4	82	550	71	940	71
14) 2x6	47.8	84	48.6	98	870	87	1390	92
15) 2x7	29.8	70	30.8	78	300	49	520	50
16) 2x8	31.4	65	30.2	73	250	42	460	49
17) 3x5	62.2	118	44.1	90	800	80	1100	75
18) 3x6	70.9	120	48.8	96	1010	95	1380	84
19) 3x7	39.2	63	38.6	87	560	60	900	68
20) 3x8	22.4	37	30.2	68	330	39	580	54
21) 4x5	56.5	74	48.4	94	770	73	1180	86
22) 4x6	50.2	73	50.2	102	880	95	1270	101
23) 4x7	37.6	65	35.4	76	490	53	780	60
24) 4x8	34.0	66	38.2	82	520	68	910	77
Mean	38.6	69	39.0	85	550	68	880	73
LSD(0.05)	17.0	--	5.3	--	210	--	280	--

Adapted from thesis of Osman Gutierrez, Combining Ability for Aluminum Tolerance of Sorghum in Nutrient Culture, Mississippi State University.

Table 4. Estimates of general combining ability (GCA) of 31-day-old sorghum F_1 hybrids grown in 148 uM Al L^{-1} nutrient culture.

Parent	Root length		Shoot length		Root DM		Shoot DM	
	Mean	GCA effect	Mean	GCA effect	Mean	GCA effect	Mean	GCA effect
	---------- cm ----------				---------- mg ----------			
Females:								
1) Wheatland	41.3	-1.45	42.8	1.87	620	10	990	30
2) Tx623	36.5	-6.27*	37.5	-3.46**	490	-120*	830	-130*
3) MS 36-4	48.7	5.91	40.4	-0.53	680	60	990	30
4) MS 13-5	44.6	1.82	43.1	2.12*	670	50	1040	70
Males:								
5) IA 28	52.8	10.05**	45.3	4.34**	740	120**	1110	150**
6) IS 7254C	53.4	10.59**	49.4	8.40**	900	290**	1340	380**
7) Tx430	34.6	-8.12*	35.0	-5.99**	430	-190**	720	-250**
8) Tx432	30.2	-12.52**	34.2	-6.75**	390	-230**	680	-280**

*,** Significantly different from zero at the 0.05 and 0.01 levels of probability, respectively.

Adapted from thesis of Osman Gutierrez, Combining Ability for Aluminum Tolerance of Sorghum in Nutrient Culture, Mississippi State University.

found at either Al level. Means and GCA effects of males and females for the stress level of Al are shown in Table 4. The SCA effects of hybrids were not calculated due to the absence of significant male by female interactions. The Al-susceptible inbred, Tx623, had significant negative GCA effects for shoot length. All of the GCA effects for males were significant.

For the seedling traits evaluated, IS 7254C proved to be the best and IA 28 the second best Al-tolerant males. In contrast, Tx430 and Tx432 had large negative GCA effects for the variables evaluated. This was an indication of their susceptibility to Al toxicity. Heterosis or hybrid vigor for all of the variables evaluated for Al tolerance was observed. Since male by female interactions were not significant, it must be assumed that this heterosis was due primarily to additive gene action. A final observation can be made. IS 7254C was highly Al tolerant and produced significant positive GCA effects for seedling traits; however, as can be seen in Table 2 it does not possess genes for high grain yield.

Breeding for Acid Soil Tolerance in the Tropics

Hybrids appear to offer the most promise for high grain yield in the stress environment caused by the acid soil complex. Tolerance to infertile acid soils is dominant to susceptibility and seems to be governed by only a few genes. Developing tolerant inbreds with high GCA would be the breeder's primary concern. Heterosis is observed in nearly all acid soil and nutrient culture genetic studies. Significant quantities of additive and nonadditive genetic variance to develop high yielding hybrids have been observed, depending upon the inbreds used in the study.

Near the equator, yields of photoperiod sensitive acid soil tolerant inbreds and their hybrids are usually superior to converted or temperate inbreds or hybrids. As you move farther away from the equator, the photoperiod sensitive inbreds or their hybrids become agronomically undesirable (tall plants and late maturity). Adequate rainfall and time of planting throughout the year become more important.

The lack of acid soil tolerant, tropically adapted A-lines with good combining ability has limited the movement of hybrids into the areas of severe acid soils in the tropics. Susceptible U.S. or ICRISAT A-lines produce acceptable hybrids with tolerant R-lines in the moderately severe (40-60% Al saturation) tropical acid soil areas. However, tolerance in both inbreds of the hybrid appears to have an advantage when fewer soil inputs are applied and/or when the Al saturation level is near the upper limit of tolerance in sorghum germplasm discovered to date.

Experimental Al-tolerant IS 7173C derivative A-lines are being used to produce hybrids with both susceptible elite U.S. R-lines and experimental tolerant R-lines developed in Colombia. These hybrid combinations are being evaluated in Colombian and African acid soil areas.

INTSORMIL Activities in Kenya

Efforts to restart the INTSORMIL program in Kenya were fruitful in Year 11. A buy-in by the USAID funded MidAmerica International Agricultural Consortium (MIAC) country project for approximately $231,500 was approved by the INTSORMIL Board of Directors and Mississippi State University. The services of the MSU-104 PI, for a two-year period (February 1,1990-March 30,1992), as a technical advisor in sorghum and millet breeding to the Kenya Agricultural Research Institute (KARI) were begun. This time frame also includes two months to complete graduate student and other INTSORMIL activities.

Seed for seven INTSORMIL trials and germplasm from MSU-104 and MSU-111 projects was given to KARI sorghum breeders for planting in Year 11. Some of the improved brown seeded lines from the INTSORMIL Colombian Project appear to be well adapted to western Kenya. This area of Africa shares a similar latitude with Colombia. A large quantity of sorghum germplasm from the previous Kenya INTSORMIL program directed by Dr. John Mann was removed from cold storage and planted in eastern Kenya.

One of the highlights of the long-rains season at Kiboko in eastern Kenya was the collaboration of Dr. Darrell Rosenow, INTSORMIL sorghum breeder (TAM- 122 PI) from Texas A & M University. Replicated sorghum drought tolerant variety and hybrid trials were planted in collaboration with KARI and ICRISAT. These dryland trials, as well as all of ICRISAT and KARI's nurseries, were heavily infested with aphids. Aphids are always a problem in Kenya during growing seasons with few rains. It is not the amount of rain, but the occurrence of rain that decreases the number of aphids (in this case probably yellow sugarcane aphids). These drought trials were designed to evaluate pre- and postflowering drought tolerance. When Dr. Rosenow evaluated the trials, he found that he could not differentiate among the entries based on drought tolerance. The combination of aphids and drought had masked the genetic potential for drought tolerance; however, two varieties were observed to be nearly immune to aphid attack.

Several conclusions can be drawn concerning these aphids and the nature of the genetic resistance of the tolerant sorghum genotypes. First of all, heavy aphid attack and premature killing of plants would have prevented genetic advance of selection for drought tolerance. Sorghum plants appeared to be damaged by a toxic response to the aphids. Upper leaves of susceptible plants could still be green; however, the panicles were sometimes dead and/or grain filling had ceased. Sorghum tolerance appeared to be near immunity (very few aphids were found on tolerant genotypes) and it probably was due to one or more dominant genes. Hybrids produced by aphid tolerant males and susceptible females were tolerant. This was an important ge-

netic find and should aid sorghum breeders in improvement programs for the semiarid areas in Kenya.

Publications and Presentations

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Flores, C. I., L. M. Gourley, J. F. Pedersen, and R. B. Clark. 1990. Genetics of leaf mineral element concentrations in grain sorghum grown on acid soil. In Abstr. Second International Symposium--Plant-Soil Interactions at Low pH. 24-29 June 1990. Beckley, West Virginia.

Flores, C. I., L. M. Gourley, J. F. Pedersen, and R. B. Clark. 1990. Inheritance of aluminum tolerance in grain sorghum grown on acid soil. In Abstr. Second International Symposium--Plant-Soil Interactions at Low pH. 24-29 June 1990. Beckley, West Virginia.

Networking Activities

Workshops

Participated in the Third Eastern and Southern African Regional Maize Workshop, Nairobi, Kenya, September 17-23, 1989.

Coauthored three papers which were presented at the American Society of Agronomy annual meeting, Las Vegas, Nevada, October 15-20, 1989.

Attended the National Conference on Plant and Animal Biotechnology, Nairobi, Kenya, February 25-March 3, 1990.

Participated in the National Striga Weed Workshop "Increase food production through Striga control", Kisumu, Kenya, June 18-21,1990.

Coauthored three papers which were presented at the Second International Symposium--Plant-Soil Interactions at Low pH, Beckley, West Virginia, June 24- 29,1990.

Member of the planning committee and participated in the 7th East Africa Regional Sorghum and Millets (EARSAM) Workshop, Nairobi, Kenya, June 24-July 2, 1990.

Partcipated in several EZC INTSORMIL meetings.

Research Investigator Exchanges

Consulted with the MIAC/KARI National Agricultural Research Project in Kenya about a buy-in for INTSORMIL and coordinated sorghum and millet breeding nurseries for the 1989 short rains season, September 7-21,1989.

Traveled to Niger to coordinate the sorghum harvest of Moussa Adamou's acid soil research with INRAN, September 23-October 4, 1989.

Traveled to Kenya to begin a two year assignment as sorghum and millets breeding technical advisor with MIAC/KARI, February 1, 1990.

Germplasm and Research Information Exchange

The book "Sorghum for Acid Soils" was printed in Spanish in Year 11. Copies have been distributed to authors, collaborators, and other scientists throughout Latin America.

The following sorghum germplasm was taken to Kenya and planted at one or more sites in Year 11:

2 All Disease and Insect Nursery-70 entries

1 Grain Weathering Test-40 entries

2 Int. Sorghum Tropical Adaptation Test-45 entries

2 Int. Food Sorghum Adaptation Trial-40 entries

1 Drought Line Test-81 entries

1 Drought Hybrid Test-49 entries

4 Zake's Combining Ability Trial-34 entries

Inbred A-B Pairs-Gourley-15 pairs

Misc. Inbreds-Rosenow-25 lines

Inbred Al-tolerant A-B pairs-Gourley-371 pairs

Aluminum tolerant R-lines-Gourley-825 lines

Armyworm tolerant lines-Gourley-83 lines

Brown-midrib forage lines-Gourley-50 lines

2 sets Al-tolerant hybrid observation nursery-Gourley-265 entries

Breeding germplasm (F_1-F_5 lines) from previous Kenya breeding project of Dr. John Mann-1480 lines or populations.

A comprehensive improvement program for sorghum and millets in Kenya was developed for KARI. This includes breeding and agronomic research for six research stations, two cropping seasons per year for most stations, and other on-farm trials.

Adaptation of Sorghum and Pearl Millet to Highly Acid Tropical Soils

Project MSU-111

Lynn M. Gourley and Guillermo Muñoz
Mississippi State University

Principal Investigators

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Mr. Luis de Angulo, Vice President Community Affairs, Arauca Project, Occidental de Colombia Inc., Apartado Aéreo 092171, Bogotá, Colombia.
Mr. César Ruíz, Sorghum Breeder, ICA, La Libertad, Apartado Aéreo 2011, Villavicencio, Colombia.
Dr. Fabio Polanía, Technical Director, FENALCE, Apartado Aéreo 8694, Bogotá, Colombia.
Mr. Eduardo Barragan, Sorghum Breeder, ICA, Nataima, Apartado Aéreo 527, Ibagué, Colombia.
Mr. Ricardo Ramírez, Farm Director El Alcaraván, Vereda Campo Alegre, Municipio de Arauquita, Colombia.
Mr. Walter, Rendón, Agronomist, ICA-FENALCE Agreement, Apartado Aéreo 2011, CRI-La Libertad, Villavicencio, Colombia.

Summary

The final release of two INTSORMIL lines of the world collection and the formation of the agronomic package represented the major activity of Year 11.

INTSORMIL acid soil breeding and screening research on sorghum and pearl millet in the Collaborative Site of Colombia has attracted funds from the private sector. The Alcaravan Foundation, a consortium of petroleum companies operating in Colombia, has supplied equipment to ICA and has funded sorghum and millet germplasm enhancement efforts in the Colombian Territory of Arauca. This five-year commitment has resulted in a 2:1 leveraging of INTSORMIL funds to support research in Colombia which is consistent with the mission of INTSORMIL. These buy-in funds are being used to help 11 Colombian students complete their B.S. degree thesis research on sorghum and millet. This allows INTSORMIL and ICA to conduct research at a very reasonable cost and to provide additional trained individuals to fill public and private jobs in the Colombian agriculture industry.

Objectives, Production and Utilization Constraints

Objectives

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

To screen and evaluate a portion of the world sorghum and pearl millet collections for tolerance to Al and manganese (Mn) toxicities, and low phosphorus (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 establish a regional program for the development of sorghum and pearl millet germplasm with tolerance to low pH tropical soils with phytotoxic levels of aluminum (Al).

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

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

Assist other INTSORMIL PI's in the conduct of research in Colombia.

Constraints

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 increased sorghum and pearl millet production in South America is soil acidity, and 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 an annual problem. 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 drought tolerance, pathology, 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 seven years of work in Colombia a great deal of effort has been put into the evaluation of acid tolerant lines from the world collection. ICA has been carefully evaluating the possibility for the release of two lines: MN-4508 (sorghica REAL 60) and 156-P5 Serere-1 (sorghica REAL 40).

Each year detailed annual workplans are developed among ICA, INTSORMIL, FENALCE, and El Alcaravan, and become a formal part of INTSORMIL's collaborative effort. An operating budget is developed to support the research to be conducted as formalized in the workplans.

In close cooperation with MSU-104 the main breeding and evaluation research was accomplished at CIAT-Palmira, CIAT-Quilichao, ICA-La Libertad, and Arauca, Colombia and at Mississippi State University. The breeding effort by ICA was conducted at Nataima and La Libertad with evaluation at La Libertad and other acid soil sites in the region. INTSORMIL breeding and screening activities were conducted via collaboration with MSU-104 winter nursery research in Colombia and other evaluation efforts in Africa.

Most of the research this year dealt with support for ICA to develop the agronomic package for release of future varieties, trying to develop minimum input technology systems for the evaluation and production of Al-tolerant lines grown on tropical savanna soils. Using lines of the world collection called the first generation, uniform regional yield trials were conducted at the following sites: Colombia-Quilichao, La Libertad, and Arauca; Venezuela, Peru, and Brazilian sites as determined by national program staffs.

Since there are quarantine problems with germplasm coming from Texas, the genotypes sent by Dr. Darrell Rosenow in 1989 were increased by Mr. Eduardo Barragan with INTSORMIL cooperation at ICA-Nataima. In cooperation with other INTSORMIL projects, drought tolerant sorghum germplasm (TAM-122) was evaluated in Motilonia (collaboration with FENALCE) on the Atlantic Coast of Colombia and at Nataima. Pearl millet germplasm (UNL-118 and KSU-101) was evaluated at regional test sites used for sorghum. Phosphorus efficiency research will in the future be conducted in cooperation with UNL-114. Studies concerning sorghum in food products involve direct consultation between ICA and INTSORMIL food quality projects. With the Alcaravan Foundation two projects were conducted for utilization of sorghum. One involved the chemical characterization and digestibility analysis of sorghum for monogastrics. High levels of protein (12%) and high levels of digestibility were found in sorghum grown at

10% Al saturation using the lines MN-4508, 156-P5 Serere-1, and IS-8577. In a cooperative experiment between the National University of Palmira, the Cassava Program of CIAT and INTSORMIL, sorghum was compared with cassava for feeding rabbits. Sorghum (PPQ-2) proved to be a more effective feed than cassava.

Breeding material was generated from crosses among AL-tolerant sources, agronomically elite lines, and new sources of tolerance. A different set of segregating material was sent from MSU-104 to be screened at Colombia. Dr. Teetes' sets have been increased at CIAT and tested under different levels of aluminum saturations with good results. Because some of the lines were not well adapted to Colombia growing conditions, great importance was given to screening for plant height and tolerance to head mold diseases. Since the lines of the first generation (coming from the world collection) are tall and late we tried to reduce height and have earlier lines, keeping the tolerance to head mold diseases. The lines of the world collection were divided according to aluminum tolerance capacity. Yield trials of the most agronomically Al-tolerant lines were conducted by ICA and El Alcaravan at different levels of aluminum saturation. An evaluation of the stability of these lines conducted by Javier Osorio showed that IS-8931 was the most stable line, according to the methodology of Digby (1979) with the modification of Granados.

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

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

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

Class 1, 0-35%, Subclass 0-20%, Vega

All susceptible genotypes could perform well under these conditions. The susceptible commercial hybrids and varieties have the ability to produce a grain yield above 3.5 t/ha. INTSORMIL material is tall under these conditions but has a grain yield of 4 t/ha.

Subclass 21-35

Aluminum saturation has an effect in this class for the very susceptible germplasm and most of the commercial hybrids will have reductions in grain yield. The most aluminum-tolerant hybrid will be the only one which will have reasonable production under these conditions. The INTSORMIL lines of the first generation do not suffer changes under these levels of aluminum saturation.

Class 2, 36-60%, Subclass 36-45%, Vega

None of the susceptible commercial varieties or hybrids will have economic yield under these conditions. The INTSORMIL lines of the first generation are the alternative. 156-P5-Serere-1 is planned to be released for this aluminum saturation level. The grain yield expectation for these conditions is about 3 tons, according to Walter Rendon (1988). An economic equilibrium point for Los Llanos Orientales of Colombia with 15% profit is 1.7 t/ha. 156-P5-Serere-1 is one of the shortest lines of the first generation and has excellent agronomic characteristics.

Subclass 46-60

Lines like MN-4508 and IS 9084 performed well under these conditions. More aluminum tolerance is necessary in these conditions. The lines of the first generation will reduce height in this subclass under 170 cm. Grain yield for the lines of the first generation will be about 2.5 t/ha.

Class 4, 61-90%; savanna, Subclass 61-75

Only one line of the first generation IS-8577 will have economic grain yield in these conditions. Height is extremely reduced and a drastic stress is evident in most of the lines of the first generation. IS-8577 yields about 2 t/ha in this subclass.

Subclass 75% and above

No germplasm now available will have an economic yield in this subclass. A great selection effort using the most tolerant lines both for varieties and hybrids is in process. Hybrids could be the genetic approach to solve this limitation.

Uniform regional yield trials were conducted at the following sites: Quilichao, La Libertad, and Arauca (Colombia); and sites determined by national program staff in Venezuela, Peru, and Brazil.

Considering that two varieties will be released in 1991, a great deal of effort was placed in semicommercial fields consistent with the specific levels of Al saturation where each variety will be released: MN-4508 between 40 and 60% and Serere between 20 and 40%. FENALCE has been and will continue to be in charge of these semicommercial fields. In collaboration with CIAT, INTSORMIL will increase basic seed for ICA. With the profit obtained from

basic seed production, INTSORMIL and CIAT will support programs from ICA.

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

Different approaches have been followed for research in Colombia. Over the last three years, regional trials have been the main effort of MSU-111 in the project for acid soils. In conjunction with ICA and the El Alcaravan Foundation, a full replication of all the work in La Libertad has been done in Arauca. La Libertad has a well-drained savanna ecosystem, while Arauca has a poorly drained savanna ecosystem. Twenty-five aluminum-tolerant lines were tested in these regional trials. As a result of these trials and additional related research, these acid soil savannas were divided into classes and subclasses according to the levels of Al saturation in the soil.

Sorghum Research in the Territory of Arauca

Since 1988 research has been conducted in collaboration with El Alcaravan Foundation which provided all the funds for the experiments. This was a new research area in Colombia for INTSORMIL and both normal and acid soils sites were used for sorghum and millet evaluations which enable the project to test selected advanced materials in acid and nonacid soils. Regional trials have been conducted with the first generation lines. In Arauca there were three sites with high levels of aluminum saturation, and five nonacid soils according to the levels of aluminum saturation that we are working for.

The Alcaravan Foundation has supported the B.S. thesis of Luisa Sánchez called Chemical Characterization and in vivo Digestibility Determination of 29 Sorghum Genotypes including lines of the first generation (Table 1). High levels of protein and digestibility were found. Also Al stability analysis of 25 INTSORMIL lines of five commercial hybrids was supported for the B.S. research of Javier Osorio.

Publications

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Networking Activities

Annually a workshop is organized by ICA, El Alcaravan Foundation, FENALCE and the Universities to share all the research results of the experiments done in Colombia. El Alcaravan has been supporting the publication of these proceedings.

It is an important meeting since in only one meeting a full actualization and a work plan is implemented with the participation of all the institutions involved in research. In 1990, the private sector began to get involved in this idea and in the future better results could be obtained.

An international meeting is planned to be held at CIAT, Colombia with the participation of all the Latin American countries. This meeting could provide the basis for a Latin American Sorghum Network. INTSORMIL is supporting to a great extent the realization of this event the third week of January, 1991. Another result of the meeting will be a closer approach between the INTSORMIL scientist and the Latin American scientist which will strengthen the possibility for better research in this area.

CIAT/INTSORMIL is increasing 10 ha of the line MN-4508 for certified seed before the possible release of this line by ICA.

This will make available at least 30 kgr of seed when the final decision for release has been taken. A Colombian Network of interchange of germplasm has been working between Alcaravan, FENALCE and ICA. One F_3 population selected from 1000 entries was sent from El Alcaravan to CIAT; 200 selections from ICA were sent to El Alcaravan; 1200 selections done in CIAT were sent to the acid soils projects of Arauca and 17 to La Libertad.

Table 1. Nutritive value[a] of different sorghum varieties included in the INTSORMIL collection and in commercial materials.

Variety[b]	% DM	CP	SP	NFE	SC	T	IVDMD	IVDMD*	GE	DE	Ca (%)	P (%)
IS-2765	85.02	8.42	50.50	81.07	1.60	0.80	97.20		4538		0.017	0.37
IS-3522	85.60	9.12	31.92	79.72	1.59	1.29	92.29		4610		0.012	0.38
IS-6944	85.23	9.64	56.20	76.30	1.74	0.80	91.36		4570		0.018	0.50
IS-7151	85.41	9.62	41.79	77.99	1.64	1.28	84.48		4634		0.017	0.53
IS-8577	86.23	11.35	45.00	78.42	1.45	0.82	78.33	88.40	4547	4.000	0.016	0.35
IS-8931	84.56	10.40	44.99	76.68	1.63	0.91	88.15		4558		0.018	0.48
IS-8996	85.68	9.02	43.51	78.78	1.93	0.92	85.26		4588		0.021	0.43
IS-9084	86.17	9.93	48.51	78.63	1.85	0.76	87.04		4609		0.018	0.47
IS-9938	86.29	10.56	42.99	80.00	1.49	1.29	85.54		4654		0.019	0.53
IS-9945	86.38	10.84	49.24	78.56	1.49	1.15	82.62		4506		0.014	0.39
IS-12152	86.95	11.06	45.69	78.68	1.52	1.25	79.92		4627		0.017	0.37
MN-4508	86.63	10.44	44.92	79.66	1.52	1.27	85.68	89.70	4528	4.035	0.016	0.41
PPQ-2	86.81	9.08	42.25	80.19	1.56	0.91	83.69		4516		0.020	0.43
Serere-1	84.87	11.87	50.87	78.18	1.34	0.65	82.30	88.04	4558	3.977	0.015	0.35
ICAIMA	87.23	8.78	35.80	83.24	1.30	0.87	77.07		4477		0.013	0.29
ICA-Nataima	86.66	11.00	55.74	81.03	1.05	0.65	70.37		4436		0.03	0.30

[a] DM = Dry Matter
CP = Crude Protein
SP = Soluble Protein
NFE = Nitrogen-Free Extract
SC = Soluble Carbohydrates
T = Tannins
IVDMD = In Vitro Dry Matter Digestibility (%)
IVDMD* = In Vivo Dry Matter Digestibility (%)
GE = Gross energy (Cal/g)
DE = Digestibility Energy (Mcal/kg)
Ca = Calcium
P = Phosphorus
b = Sorgum cultivated in savanna

Source: Luisa Sánchez Cortés, Zootec., 1990.

Development of Agronomically Superior Germplasm Including Varieties, Hybrids and Populations Which Have Improved Nutritional Value and Good "Evident" Grain Quality for Utilization in Developing Countries.

Project PRF-103A
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Summary

The major focus of this project is to develop high yielding sorghum varieties with acceptable food quality and good nutritional value for utilization in developing countries. A great deal of progress has been made in two areas.

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. Drought has plagued mankind since the early days of crop domestication. Recurring drought continues to be the major constraint on crop production in many regions of the world. One of the cereal grain species which man has relied on for drought resistance is sorghum. 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. The purpose of this research 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. 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 through the twenty-first century.

Drought resistance is a complex plant characteristic which may be governed by a number of discrete genes. The monocotyledon sorghum is unusually drought resistant. Although sorghum lines show significant variation in resistance to drought, these differences have not been fully characterized. We intend to follow the molecular and genetic characteristics of segregating sorghum populations derived from crosses between drought resistant and susceptible inbreds. We further propose to identify and characterize a series of single gene mutants of a drought resistant sorghum line which render the variety drought susceptible. These mutants will be created by chemical mutagenesis or by the use of transposable genetic elements and screened for drought resistance/susceptibility in arid environments in Mexico. These segregating populations and mutants will provide an exceptional source of germplasm for an interdisciplinary team of plant geneticists, physiologists and biochemists, and their graduate student trainees on the Purdue campus, to elucidate the underlying mechanisms responsible for drought resistance. This effort could lead to a detailed description of the major genes which contribute to the exceptional drought resistance of certain sorghum cultivars. Isolation of these genes may eventually permit their transfer to other cereal crops.

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 and Sudan with good adaptability, good grain quality, good drought and *Striga* tolerance, and improved yield potential.

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

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

Train LDC personnel in plant breeding and genetics.

Constraints

Nutritional value of sorghum has long been known to be different from other cereals. This includes the tannin problem, the protein quality problem, the protein digestibility problem, and the local processing methods involved in eliminating these problems in the diets of sorghum consuming people. We have made significant progress in cooperation with Dr. Larry Butler on the tannin problem, and Sam Mukuru has now proven in studies conducted in our laboratory that high tannin sorghums traditionally grown at high elevations in Eastern Africa are very satisfactory sources of digestible nutrients if the grain is processed adequately by traditional means. Protein quality improvement will be a major breeding objective during the next five years. We have identified good sources of modified quality protein sorghums which are comparable in yield potential and grain quality to quality protein maize as developed by CIMMYT. The basic high lysine gene P-721 opaque has been combined with sources of vitreous endosperm to give the QPS (Quality Protein Sorghum). The high yield potential has been demonstrated by Emmanuel Monyo and the modified vitreous endosperm characteristics have been recently documented. A major unresolved problem is the environmental stability of these modified endosperm sorghums. 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. This 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 may be responsible for low adoption rate of improved varieties. Joe Mushonga's research on developing rapid assays for diastatic power and studying inheritance of diastatic activity in sorghum cultivars will be continued. Second, Dr. 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 and 1988 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 of time, 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. 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 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. Secondly, we propose to generate many susceptible revertant lines by mutagenesis of drought resistant P898012 and P954035 sorghum. Seed of these pure line varieties will be mutagenized at Purdue in the summer of 1988 and M1 plants will be self-pollinated to provide M2 seed to screen for drought sensitive revertants in Mexico under water stress conditions. Stress sensitive revertants will also be obtained by using a controlling element system in sorghum for transposon mutagenesis and tagging. The "candy stripe" sorghum phenotype is analogous to the variegated pericarp controlling element system in maize. Candy stripe sorghum is now being backcrossed to drought resistant sorghum lines to produce a pure line drought resistant sorghum variety which contains the mutable gene system. When this is available, it should be possible to select for genetic events involving transposition of the controlling element away from the pericarp element by selecting seed from fully red sectors on the sorghum panicle. Plants grown from seed having red sectors will then be self crossed and their progeny screened for an alteration in drought resistance. Any drought resistant gene identified can then be cloned using as a probe the candy stripe controlling element we propose to clone. A genetic map of sorghum will be generated using restriction fragment length polymorphisms, and this will be employed to define specific chromosomal regions containing drought resistance genes and genes determining a range of morphological, physiological and biochemical characteristics of putative adaptive significance in terms of sorghum stress resistance.

Training M.S. and Ph.D. LDC students will continue as in the past.

Research Findings

We have recently identified mutants in one of the characteristics essential for drought resistance in sorghum. A series of 35 independently occurring mutants in the epicuticular wax genetic system in sorghum have been identified and will be studied with their normal counterparts to study how this waxy bloom trait in sorghum protects the plants against drought stress. Measurements of water use efficiency in mutant and normal plants will help us understand this mechanism of drought resistance in sorghum. Transposon mutagenesis is being used to identify the epicuticular wax gene in sorghum so that it may be cloned and transferred to other crop species as soon as suitable transformation systems become available. The objective is to learn more about the molecular basis of drought resistance in sorghum and use this knowledge to help develop improved screening techniques and methodologies which should lead to opportunities for improving drought resistance in other crop plants.

Sorghum breeding and genetics. A range of sorghum germplasm, including segregating progenies and inbred populations, has been generated through conventional crossing among selected drought tolerant and susceptible parental lines. Recombinant inbred line populations developed from one such cross are currently being evaluated for differential morphological reactions to drought under a rain-out shelter and field stress environments at Lubbock, Texas. This study will enable us to determine heritability of many of these drought associated traits. We also plan to place some of these traits on a detailed restriction fragment linked polymorphism (RFLP) map currently under preparation in Dr. Bennetzen's laboratory. Our recombinant inbreds will be subjected to RFLP mapping using an array of DNA probes available to develop association of certain drought related traits with molecular markers.

Candy stripe transposable element system in sorghum. The candy stripe phenotype, observed but not well documented in sorghum, is a mutable phenotype affecting the pigmentation of the pericarp and dried leaves. Through genetic studies conducted in the past year, the Y gene of sorghum has been identified as the mutable locus. A descriptive paper on the characteristics of the candy stripe phenotype will soon be written using our studies on the sorghum line. Currently, molecular studies are being carried out using heterologous maize color locus probes to identify DNA polymorphisms caused by the insertion of the putative transposable element in candy stripe sorghum. Once identified this transposon system will be used to "tag" the sorghum gene for epicuticular wax.

Sorghum tissue culture. We have developed a system for establishing embryogenic callus cultures from a wide variety of sorghum genotypes, beginning with explants of mature embryos, immature embryos, or immature inflorescence tissue. We can maintain these cultures indefinitely (in some cases two years or more) and still regenerate them into intact plants in good yield. These callus cultures, which are grown on solid media, are suitable for genetic transformation with a DNA-particle gun. We have further developed a system whereby calli which are small (but larger than fine suspension cultures) can be cultured in liquid media for at least two-three weeks (and transformed), then regenerated into intact plants in good yield. We have also developed fine suspension cultures, some of which grow fast (doubling time of no more than four days). These

suspension cultures are suitable for selection in culture of toxin- or desiccant-resistant clones or for genetic transformation. The regenerability of these suspension cultures is being tested.

We have been able to obtain embryogenic callus from cultures of two of the most drought tolerant cultivars (P898012) and P954035). Embryos of these two genotypes were cultured following a procedure developed in the laboratory of Dr. Larry Butler, Department of Biochemistry, Purdue University. Embryogenic callus was carefully selected during the initial stages of callus initiation and growth and embryogenic cultures were isolated. Somatic embryos and plants were easily obtained from the embryogenic cultures of both genotypes. Recently, preliminary experiments have resulted in transient GUS gene expression in embryogenic sorghum callus after microprojectile bombardment.

Physiology of drought resistance. Glycinebetaine is accumulated by many grass species in response to osmotic stress, and is thought to function as a compatible cytoplasmic osmotic solute or osmoprotectant. In order to determine the contribution of this metabolic trait to drought resistance, we have sought genetic variability for glycinebetaine accumulation capacity in both maize and sorghum. Over 20 betaine-deficient inbreds of maize have been identified. In maize, betaine deficiency is caused by a single, nuclear, recessive gene which confers a lesion in the capacity to oxidize choline -->betaine aldehyde in the betaine biosynthetic pathway. Betaine-deficient inbreds show no impaired capacity to oxidize betaine aldehyde to glycinebetaine, implying a lesion at the choline monooxygenase step (X) in the pathway:

choline --x--> betaine aldehyde ----> glycinebetaine

Similar genetic variability for glycinebetaine has recently been identified in sorghum. Among over 240 diverse sorghum cultivars screened, six betaine-deficient cultivars were identified. Work is in progress to determine the biochemical and genetic basis of betaine deficiency in sorghum (as in maize), and to test whether isogenic sorghum lines differing for stress-induced betaine accumulation exhibit differential susceptibilities to drought stress. All putative drought susceptible mutants of sorghum originating from the chemical and transposon mutagenesis programs will be screened for this trait, with the view to identifying additional mutations in this stress-modulated biochemical pathway which may contribute to the phenotype of drought susceptibility.

Over 31 bloomless and sparse-bloom independently occurring mutants of sorghum have been identified to date. These mutations may specifically alter cuticular wax load and hence cuticular resistance to desiccation, and are thus of specific interest in terms of drought resistance. Studies are in progress to determine the number of alleles responsible for the bloomless and sparse-bloom phenotypes, to determine the cuticular wax content and composition of the leaf sheaths and leaf blades of these mutants, and to determine the effects of these mutations on plant water relations.

Sorghum RFLP map. We have initiated and published [Hulbert et al. (1990) Proc. Natl. Acad. Sci. USA 87:4251-4255) the first restriction fragment-length polymorphism (RFLP) map of *Sorghum bicolor*. This is the first detailed genetic map of sorghum of any kind, having expanded the number of mapped sorghum traits from 35 to 100. This mapping study also demonstrated that the maize and sorghum genetic maps are largely colinear, although differing by a small number of chromosomal rearrangements. Since sorghum's genome is three- to four-fold smaller than that of maize, sorghum could serve as a model system for map-based cloning strategies (e.g., chromosome walking).

Publications and Presentations

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"Improving Sorghum Grain Protein Quality by Breeding." J.D. Axtell. Presentation at the International Conference on Sorghum Nutritional Quality. Purdue University, W. Lafayette, IN. February 26-March 1, 1990.

Networking Activities

Workshops

Participate in "International Conference on Sorghum Nutritional Quality". Purdue University, W. Lafayette, IN. February 26-March 1, 1990.

Participate in "The Third McKnight Conference on Plant Biology - Basic Research in Biology and Its Impact on Agriculture." Presentation entitled "Characterization of Morphological, Physiological and Biochemical Mechanisms Associated with Drought Resistance in Sorghum Bicolor." Minneapolis, Minnesota. May 3-5, 1990.

Organizer and participant of "The First Annual Purdue University McKnight Program Retreat." Presentation entitled "The McKnight Foundation Interdisciplinary Research

Project on Mechanisms of Drought Resistance." Turkey Run State Park, IN. November 30 - December 1, 1990.

Research Investigator Exchanges

INRAN staff, ICRISAT staff and INTSORMIL staff are regularly involved in exchange visits at Purdue.

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.

Breeding Sorghum Varieties and Hybrids with Improved Grain Quality, Drought Resistance and Striga Resistance

Project PRF-107
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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 11 we report on development and modification of laboratory assays useful in screening sorghum breeding germplasm with resistance to *Striga*, drought or grain mold.

A rapid gel assay which measures stimulation of germination of *Striga* seeds by a host root was developed. Using this assay we were able to demonstrate the separation of genotypes with known reaction to *Striga* infestation. We were also able to screen advance breeding progenies resulting from parental lines with resistance/susceptibility to *Striga*. This assay is expected to increase the efficiency of breeding sorghum for resistance to *Striga*.

Quick assays for traits controlling drought resistance are not likely to be found. We are currently studying the role of osmoregulatory compounds in drought resistance in sorghum. In a screening of a large set of sorghum genotypes we found significant genotypic variation for glycinebetaine, a known osmoprotectant. We will be studying the metabolic basis of betaine deficiency and its role in drought resistance.

In our grain mold research we confirmed our earlier finding that, among an array of physical and chemical kernel traits, the concentration of flavan-4-ols and/or 3-deoxyanthocyanidins correlate well with preharvest molding of sorghum grains.

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 techni-

cal 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 11 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 a high level 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 fungi that cause grain mold. 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 are 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

Drought

Traditional plant breeding strategies for drought tolerance -- selection for yield under optimal conditions, selection for yield in a dry environment, and selection for yield stability over many environments -- have proven time consuming and, in many cases, inefficient. Although drought tolerance in plants is a complex phenomenon, new technologies in the plant sciences offer the hope of faster progress in crop improvement for dry environments. Advances in genetics, biochemistry, and physiology have enabled researchers to probe the underlying mechanisms of drought tolerance, and sorghum's outstanding drought adaptation makes it a useful model in comparative studies of these mechanisms.

Certain metabolic traits may hold promise as selection tools in the screening of germplasm for drought tolerance. Such traits, acting as markers, might help to reduce the years of work traditionally required for yield gains since they are often simply inherited, in contrast to the quantitative inheritance of traits such as yield. Although several metabolites have been proposed as markers for increased drought tolerance, no single compound has yet proven to be worthy of inclusion as a sole selection index in breeding programs. One metabolite of interest is betaine (glycine betaine, N,N,N-trimethylglycine), which is known for its protective role during osmotic stress in bacteria. Betaine is accumulated to high concentration by many plant species, including sorghum, in response to osmotic stress, and it thus may serve a function in plants that is similar to its function in bacteria. During drought the sorghum plant is known to automatically adjust for declining water potential by accumulating certain metabolic compounds including glycinebetaine.

Of late, we have been studying the genetic variation of glycinebetaine in sorghum and its relation to drought stress adaptation. We screened over 230 cultivars initially during the summer of 1989 under rainfed conditions at West Lafayette, Indiana. Total betaine levels ranged from 0.1 mol/gfw to over 33 mol/gfw. Eight cultivars exhibited total betaine levels of <1.0 mol/gfw. We then reevaluated six high and six low betaine cultivars identified in the initial screen using the modified periodide assay. Agreement between the two tests of these twelve genotypes was excellent (r=0.989). In a subsequent greenhouse study we further tested some low and high-glycinebetaine cultivars under salinized and nonsalinized conditions to test the salt-inducibility of the betaine deficient genotypes. We found that a low betaine cultivar (IS 2319) showed no accumulation of betaine in either the salinized or nonsalinized environment. With a high betaine genotype (p-932290) high concentration was detected in young expanding leaves of salinized plants. This suggests that a strong genetic component existed between high and low betaine sorghum cultivars. The low betaine phenotype in sorghum behaves like that of maize, a well studied phenomenon. However, the genetic and metabolic basis of betaine deficiency in sorghum is yet to be studied.

A study was also undertaken to examine the association of betaine accumulation with agronomic performance in sorghum genotypes under preflowering drought stress; determine the mode of inheritance of stress-induced betaine accumulation; and elucidate the pattern of accumulation in response to varying levels of moisture stress and varying leaf age. Sorghum genotypes of known drought reaction were subjected to preflowering drought stress in the field and in a controlled-environment growth chamber, and leaves were sampled for betaine content. Betaine level showed significant correlations with days to flowering, leaf erectness, relative water content, and seed weight per panicle. Broad-sense heritability for the trait was 0.73. Parental genotypes differing in betaine level at nine weeks after field sowing showed no detectable difference when grown in a controlled-environment chamber and sampled at five weeks after sowing, thus preventing an elucidation of genetic control for the trait. Stress-induced betaine accumulation appeared to be highly sensitive to the rate of plant development, the rate of increase in moisture stress, and the relative age of the sampled leaf.

Striga

Considerable progress has been made in our *Striga* research at Purdue. With Dr. Larry Butler we are developing an interdisciplinary approach to the *Striga* problem. We have earlier reported on the identification of a superior source of *Striga* resistance in an enhanced germplasm line (SRN39), the genetic control of resistance in this line, as well as its stability and performance across different environments. We have involved SRN39 in an extensive intercrossing program deriving a range of elite progenies.

One of the problems associated with breeding for *Striga* resistance has been the lack of a reliable and rapid assay. Screening a large number of genotypes in *Striga* infested fields is often inefficient due to the complex interaction between host, parasite, and the environment that affects the establishment of the parasite as well as the host. *Striga* sick plots are rarely if ever uniform enough in level or intensity to permit reproducibility of results. Recently Dale Hess, working with L. Butler and me, developed a rapid gel assay that can separate sorghum genotypes on the basis of their capacity to stimulate *Striga* seed germination. In this assay, conditioned *Striga* seeds are spread over a petri dish with an agar medium in which a single germinating sorghum seed is also placed. As the sorghum root grows it produces a water soluble stimulant that will exude through the medium and trigger germination of the *Striga* seeds. Sorghum genotypes known to be susceptible to *Striga* all showed high stimulation while several resistant genotypes produced relatively little *Striga* seed germination. This test was found to be rapid, taking only some 48 hours to run a set of genotypes, and highly repeatable showing very small differences among replications of the same cultivars.

To check the usefulness and repeatability of this assay we tested advanced breeding progenies derived from intercrosses among resistant and susceptible parents but not previously tested for *Striga*. We found that some progenies were low stimulators while others had active germination activity suggesting that low germination stimulation is a heritable trait, although we are yet to establish the exact mode of inheritance. Crosses between two low stimulating lines produced all low stimulating progenies whereas progenies from low x high germination stimulating parents resulted in differing numbers of low and high stimulators. We also have modified the assay by using germination distance away from the host root as a variable as opposed to counting the percent germination of a volume of *Striga* seed in a microscopic field of the petri dish. The farther a *Striga* seed germinates away from the host root, the more susceptible that genotype may be. It is much easier and faster to measure such distances than counting germinated *Striga* seeds. To verify the practical utility of this test in breeding sorghums for *Striga* resistance, we conducted a field trial, under *Striga*, of progenies screened by our new bioassay. Our results show a very high degree of correspondence between *Striga* infestation and the amount of stimulant observed in the rapid bioassay. The implication of this is that with the use of this assay we can efficiently screen breeding progenies exploiting the low stimulation mechanism of *Striga* resistance. As we begin to look for protocols that would allow us to identify sorghum germplasm with other mechanisms of resistance, we hope to be able to pyramid sources of resistance genes with differing mechanisms. Such an approach should provide for a broader base of *Striga* resistance in sorghum than is currently available.

Grain Mold

Previously, we reported on our field screening of sorghum germplasm for resistance to preharvest molding. The warm fall weather in Lafayette, IN is conducive to mold development allowing us to discriminate between resistant and susceptible genotypes with reasonable confidence. We have also studied certain physical and chemical kernel characteristics associated with mold resistance. Certain low molecular weight phenols (Flavan-4-ols) were found to be strongly associated with resistance among non-brown sorghum. We are now examining whether certain metabolic products of Flavan-4-ols reported to be fungitoxic give better correlation with weathering resistance than do flavan-4-ols themselves.

In a developmental study where populations of different mold-causing fungi were monitored, we found that at the early milk stage overall type and population of fungi were small. As the season advanced the proportion of seed infested with fungi increased and the range of type of fungi also increased. In confirmation of our initial screening work, resistant genotypes are again found to be high in flavan-4-ol and/or 3-deoxyanthocyanidins.

Publications and Presentations

Shull, M., A. Chandrashekar, A.W. Kirleis and G. Ejeta. 1990. Development of sorghum endosperm in varieties of varying hardness. Food Structure 9:253-267.

Cai, T., G. Ejeta, J.D. Axtell and L.G. Butler. 1990. Somaclonal variation in high tannin sorghums. Theor. Appl. Genet. 79:737-747.

Cherif-Ari, O., T.L. Housley and G. Ejeta. 1990. Sorghum root length density and the potential for avoiding Striga parasitism. Plant and Soil 121:67-72.

Allrichs, J.A., G. Ejeta, V.C. Baligar, W.G. Smart, and T.G. Toulemonde. 1990. A three day screen for Al tolerance in sorghum cultivars and crosses. Agronomy Abstr. p. 52.

Ejeta, G., I. Nour El Din and A. Nour. 1990. Breeding sorghum for Striga resistance. Proc. Sudan Sorghum and Millet Workshop. (In Press)

Rosenow, D.T., O.E. Ibrahim and G. Ejeta. 1990. Breeding sorghum cultivars for drought resistance. Proc. Sudan Sorghum and Millet Workshop. (In Press)

Ibrahim, O.E., A. Nour, G. Ejeta and D.T. Rosenow. 1990. Breeding and evaluation of grain sorghum hybrids for Sudan. Proc. Sudan Sorghum and Millet Workshop. (In Press)

Networking Activities

Workshops and Conferences

Organized a workshop on sorghum and millet research in Sudan, Agricultural Research Corporation, Wad Medani, Sudan, October 29-November 2, 1989. In addition to Sudan and U.S. INTSORMIL PI's, the workshop was attended by SAFGRAD/West Africa and SAFGRAD/East Africa staff and NARS members from eight Eastern Africa countries, thus providing for a good networking opportunity.

Organized an international conference on sorghum nutritional quality held at Purdue University, West Lafayette, Indiana, February 27-March 1, 1990. The conference pooled together representatives of research organizations, donor agencies, private companies, and research scientists from around the world. Conference participants assessed the state of sorghum nutritional quality research and made projections about future research needs and priorities.

Attended the American Society of Agronomy Annual Meeting. October 15-20, Las Vegas, Nevada.

Provided technical assistance to sorghum breeding programs in Niger and Sudan, October-November 1989; June 1989.

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 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.

Breeding for Productivity in Sorghum

Project TAM-121
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Texas A&M University

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Dr. Dan Meckenstock, Sorghum Breeder, INTSORMIL/SRN,EAP, Zamorano, Honduras
Dr. R. Newton, Physiologist, Texas A&M University, College Station, TX
Dr. R. Frederiksen, Pathologist, TAM-124, Texas A&M University, College Station,TX
Dr. R. Toler, TAM-124, Texas A&M University, College Station, TX
Dr. L. W. Rooney, Cereal Chemist, TAM-126, Texas A&M University, College Station, TX
Dr. R. Waniska, Cereal Chemist, TAM-126, Texas A&M University College Station, TX
Dr. D.T. Rosenow, Sorghum Breeder, TAM-122, Texas A&M University, Lubbock, TX
Dr. R. R. Duncan, Sorghum Breeder, University of Georgia, Experiment, GA
Dr. A. Sotomayor-Rios, Geneticist, USDA/TARS, Mayaguez, Puerto Rico
Dr. G. Peterson, Sorghum Breeder, TAM-123, Texas A&M University, Lubbock, TX
Dr. G. Teetes, Entomologist, TAM-125, Texas A&M University, College Station, TX
Dr. R. Smith, Tissue Culturalist/Physiologist, Texas A&M University, College Station, TX
Mr. D.J. Andrews, Sorghum/Millet Breeder, UNL-115, University of Nebraska, Lincoln, NE

Summary

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 with adequate resistance to biotic and abiotic stresses. Successful crop production systems require genotypes with high yield levels per unit area and such genotypes need to possess a genetic potential which can be expressed over a wide range of environmental conditions.

In the drought resistance program a major effort is underway to understand drought mechanisms and their impact. One major dominant gene and one major recessive gene were found to control stay-green expressed as Green Leaf Retention in B35 and R4188 respectively. Validation of the visual rating, GLR, was R^2=.875 between GLR and actual green leaf area. The R^2 values for percent green leaf area and GLR, number of green leaves and percent green leaf area all showed high relationships. Furthermore, there appears to be a real relationship in sorghum for high nonstructural carbohydrates (NCS) and charcoal rot resistance. Those sorghums which suffer from a high and significant depletion of NCS just after anthesis appear to create substrate - limitations which allow invasion of the fungus, i.e., inhibition of defensive fungal degradative enzymes, triggering charcoal rot damage.

RTx285, the first publicly developed restorer conveying dominant immunity to Maize Dwarf Mosaic Virus was released from projects TAM-121 and TAM-124.

Forty inbred germplasm lines with widespread adaptation were developed and publicly distributed from this project. Tx2818 through Tx2857 were selected in Guatemala and Texas for tan plant color, white grain, and ability to withstand significant environmental fluctuations.

Harvest index estimates and grain yields were higher in more temperate environments than in tropical environments, indicating that selection for higher biological yields and harvest indices in more tropical locations are important selection criteria.

Cultivars with red pericarps and those having white endosperm in contrast to yellow endosperm, have higher diastatic activity, lower malt and dry matter loss, and higher germination.

Comparisons of hybrids with isocytoplasms A_1, A_2, and A_3 showed few lines with restoration to A_3 i.e., SC193-14E, SC399-14E, SC476-14E, and SC499-14E. Furthermore, heterosis in A_2 hybrids ranged from 62.5 to 71% while little difference was seen between A_1 and A_2 hybrids.

Several lines were identified which have a good agronomic performance and anthracnose resistance in Zambia and Zimbabwe. Food quality hybrids developed in the project continue to show high yield production in numerous LDC's and DC's. These food type sorghums evolving from the project are impacting U.S. sorghum as well. The benefits of white grain, tan plant color and vitreous round grain process well into food products and a superior poultry and livestock feed.

Many new germplasm lines were added to the project via introductions from collaborators. These have been crossed into our program materials and are being increased for distribution. A large amount of material 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.

Objectives, Production and Utilization Constraints

Objectives

Develop through breeding, selection, and appropriate evaluations stable, high yielding, agronomically desirable sorghums with high levels of disease, insect, and agronomic stress resistance, high grain quality with weathering resistance and resistance to environmental stresses.

Determine the heterotic germplasm pools (subspecies) within sorghum and characterize the constraints to yield improvement among West African cultivars (guinese types).

Determine the relationship between yield and photosynthetic ability.

Assessment and utilization of physiological measures of drought resistance to improve sorghum.

Develop specific germplasm pools and resources for use in impacting productivity in Latin America, South America, and Africa.

Distribute improved lines, hybrids, and early generation populations possessing superior productivity to collaborating LDC's.

Constraints

Yield of sorghum throughout the world is constrained by risks associated with unstable productivity and cultivars which are incapable of providing solutions to these constraints. The overall objective of this project is to reduce the risks through the enhancement of genetic potentials by creating germplasm pools, lines, and hybrids with 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 nutritional levels are at marginal levels of acceptability. The constraints to productivity which are addressed through this project are genetic limitations to yield, disease resistance, drought, inadequately developed germplasm resources, unimproved food quality, and unavailability of improved seeds.

Sorghum is the primary cereal of choice in several parts of the world because of its resistance to high temperatures and water stresses. In the north of Paraguay i.e., the Chaco, west and north Mexico, much of Honduras and El Salvador in Meso-America, conditions limit the production of maize. Sorghum fits the need well but the constraints of stability of yield, fodder, and grain (dual-purpose usage) utilization, as well as a grain quality adequate for tortilla production must be the focus of research. In West Africa, particularly in Mali, Niger, and Burkina Faso, Southern Africa, and much of Northeastern Africa temperatures and water stresses also present devastating production problems. Photoperioditic responsiveness must be added to the constraints, since sorghum for grain must mature outside the rainy season. Disease pressures exerted upon the germplasm are similar in many respects but are often different in regions and even small areas of production. In general, insect attack is not as specific. These items as a part of the total productivity system are constraints which limit successful sorghum growth.

Greater genetic diversity is an increasingly important goal for the maintenance of stability and productivity. Materials from the TAES/USDA Sorghum Conversion Pro-

gram have been crossed with elite higher yielding materials and have been selected to respond to the constraints described above. Higher stability of yield, greater stress resistance and pest resistance as well as food quality materials evolve from this project. As these elite more broad based genetically lines and hybrids emerge they are selected for use in Meso-America, South America, Africa or Asia. Successful crop production systems require genotypes with high yield and must possess a genetic potential which can be expressed over a wide range of environmental conditions.

Sorghum is a major food resource commodity in much of the arid and semiarid regions of the world. Very little is known about the genetics of objective food quality. Even though sorghum has been used for many thousands of years as a food source, selection for quality has been largely subjective. The renowned sorghum scientist H. Doggett said that sorghum will become more important as a food in the latter part of this century. Although the sorghum seed or caryopsis is well described, very little is known about those characteristics which impact quality, especially in the various food systems for which sorghum serves as the base raw material.

There is a continuous erosion of germplasm and a pressure to use new diverse sources of resistance to pests, diseases, and environmental stresses as well as increasing the superiority of end-products, hence there must be preservation and expansion of collections. Adequate evaluations of existing collections, new introductions, and converted lines are needed to determine usefulness in solving or impacting worldwide sorghum productivity constraints.

Research Approach and Project Output

Research Methods

Breeding materials in the existing program were crossed with converted or partially converted collections from the TAES-USDA Sorghum Conversion Program, or crossed with elite or advanced materials from other country(s) programs, screened, and evaluated for recombinations of disease resistance and grain quality in cooperation with pathologists and cereal chemists. Disease screening was done in large field nurseries with endemic natural infections at locations in south and central Texas, Honduras, Paraguay, Mexico, Puerto Rico, Brazil, and Georgia. Smaller nurseries for disease screening were in Africa and Asia. Artificial inoculation for downy mildew, anthracnose, charcoal rot, MDM virus and sorghum yellow banding virus was done also.

New breeding materials were generated from planned crosses among drought tolerant and susceptible cultivars and were evaluated in replicated yield trials at College Station and Lubbock, Texas as well as in greenhouse controlled environments to compare the relationships of non-structural carbohydrates and incidence of charcoal rot. Other trials were designed to describe modes and characteristics of drought resistance and their inheritance.

Crosses were made to generate populations among various disease resistant sources, agronomically superior lines, those possessing drought tolerance, and food quality potentials. These were distributed to Mexico, Paraguay, Honduras, El Salvador, Argentina, China and Southern Africa. These materials were screened for selection in field nurseries and in the laboratory. Replicated trials were used for critical evaluations, where possible.

Inbred lines and hybrids which differ in senescence rates, photosynthetic output, and yield have been evaluated in replicated field studies and laboratory measurements made to determine distribution of photosynthate in the plant. Selections have been made in the breeding nursery with increased seed number and high green leaf area at maturity.

Materials which were of different chronological age were compared for relative changes in grain to stover (harvest index) at different environmental sites. Replicated yield trials were carried for two years at three locations to obtain information on harvest index.

Materials from the TAES program which have shown differences in drought resistance genetically were evaluated in replicated field trials at College Station and Lubbock, Texas. These trials were designed to describe the inheritance of resistance previously identified in Sudan, Mali, and Texas.

Exotic sorghum introductions from Mexico, Paraguay, Argentina, China, Honduras, Zimbabwe, and India which possess grain quality traits, forage quality, photoperiodic sensitivity, disease, and insect resistance were made. After these plants cleared quarantine they were characterized in the winter nursery in Puerto Rico and crossed to elite Texas and U.S.lines for enhancement. Materials from these intercrossed introductions * U.S. elite lines have been sent as early generation materials to collaborating countries.

Research Findings

This project draws input from several other CRSP projects, germplasm resources from collaborating LDC's, and ideas and approaches from cooperative scientists and graduate students. Large field evaluation nurseries grown in areas of significant climatic variation are used to select the desired recombinations for yield, stability, drought tolerance, disease resistance, and grain quality. Major emphasis of this project has been placed upon tropically adapted genotypes with nonsenescence and high yield. Development of new germplasm pools with crosses involving identified materials from TAM-122 and TAM-124 has strengthened disease resistance and drought tolerance. With cooperation from

Table 1. Summary of desirabilities for selected lines of Sorghum bicolor (L.) Moench germplasm, originally selected in Guatemala and reselected in multiple locations from Weslaco to Halfway, TX, 1982 to 1988.

No.	Designation	Pedigree	Fertility reaction[1]	Desirability ratings by year[2] 1984	1985	1986	1987	1988	Mean
1.	Tx2818	(((Tx378 X Tx622) X Tx378) X Tx2792)-66-1-17-3-1	B	1.9	1.3	1.28	1.60	1.37	1.49
2.	Tx2819	(Tx430 X Tx2816)-1-1-5-3-bk	R	1.7	1.3	1.30	1.30	1.40	1.40
3.	Tx2820	(NSA954 X Tx430)-3-2-5-3-1-1	R	1.9	1.3	1.35	1.35	1.50	1.48
4.	Tx2821	((SC120 X Tx7000) X Tx7000)-10-4-6-2-1-3	R	1.7	1.4	1.35	1.25	1.50	1.44
5.	Tx2822	(Tx430 X Tx2816)-1-1-5-3-bk	R	1.5	1.5	1.35	1.25	1.35	1.39
6.	Tx2823	(Tx430 X Tx2816)-1-1-5-3-1	R	1.5	1.5	1.35	1.15	1.42	1.38
7.	Tx2824	(((Tx378 X Tx622) X Tx378) X Tx2792)-66-1-17-1-1	B	1.8	1.5	1.35	1.60	1.43	1.54
8.	Tx2825	((SC120 X Tx7000) X Tx7000)-10-4-6-2-2-2-2	R	1.9	1.5	1.38	1.30	1.40	1.50
9.	Tx2826	((SC120 X Tx7000) X Tx7000)-10-4-6-1-1-1	R	1.9	1.3	1.40	1.15	1.37	1.42
10.	Tx2827	((SC120 X Tx7000) X Tx7000)-10-4-6-2-1-2	R	1.9	1.3	1.40	1.25	1.47	1.46
11.	Tx2828	(Tx430 X Tx2816)-1-1-5-3-bk	R	1.7	1.4	1.40	1.30	1.57	1.47
12.	Tx2829	(Tx430 X Tx2816)-1-1-5-1-1	R	1.7	1.4	1.43	1.50	1.60	1.53
13.	Tx2830	((Tx378 X SC110-9) X Tx615)-4-3-5-2-1-2-bk	B	1.9	1.4	1.43	1.20	1.43	1.47
14.	Tx2831	((Tx399 X white kafir) X Tx2792)-66-1-1-1-1	B	1.9	1.5	1.43	1.50	1.47	1.56
15.	Tx2832	((SC120 X Tx7000) X Tx7000)-10-4-6-2-3-4	R	1.8	1.4	1.45	1.30	1.30	1.45
16.	Tx2833	(((SC120 X Tx7000) X Tx7000) X Tx430)-1-1-3-bk	R	1.9	1.4	1.45	1.50	1.47	1.54
17.	Tx2834	(((Tx378 X Tx622) X Tx378) X Tx2792)-66-1-20-3-1	B	1.9	1.5	1.45	1.40	1.50	1.55
18.	Tx2835	((Tx2816 X SC326-6) X Tx430)-3-1-1-6-3	R	1.7	1.7	1.45	1.40	1.37	1.52
19.	Tx2836	(Tx430 X Tx2816)-1-1-5-3-3	R	1.7	1.4	1.46	1.30	1.50	1.47
20.	Tx2837	((Tx430 X SC326-6) X Tx430)-1-1-2-2-2	R	1.7	1.5	1.46	1.45	1.60	1.54
21.	Tx2838	(Tx430 X Tx2816)-1-1-5-3-1	R	1.5	1.5	1.48	1.35	1.40	1.45
22.	Tx2839	(SC103-12 X Tx2536)-4-1-2-2-5	R	1.9	1.4	1.48	1.50	1.63	1.58
23.	Tx2840	(Tx430 X SC326-6)-3-2-5-4-3	R	1.9	1.3	1.50	1.65	1.70	1.61
24.	Tx2841	((SC120 X Tx7000) X Tx430)-10-2-3-3	R	1.6	1.5	1.50	1.55	1.60	1.55
25.	Tx2842	((SC120 X Tx7000) X Tx7000)-10-4-6 2-1-1	R	1.8	1.5	1.50	1.45	1.55	1.56
26.	Tx2843	((SC120 X Tx7000) X Tx7000)-10-4-6-2-3-2	R	1.9	1.6	1.50	1.65	1.43	1.62
27.	Tx2844	(77CS5 X Tx2817)-3-1-5-5-3	R	1.7	1.7	1.50	1.40	1.67	1.59
28.	Tx2845	(((SC120 X Tx7000) X Tx7000) X Tx430)-1-1-3-bk	R	1.8	1.4	1.53	1.55	1.63	1.58
29.	Tx2846	((SC120 X Tx7000) X Tx7000)-10-4-6-2-2-2-2	R	1.6	1.6	1.53	1.30	1.30	1.47
30.	Tx2847	((Tx2816 X SC326-6) X Tx430)-3-1-1-5-1	R	1.5	1.6	1.53	-	1.50	1.53
31.	Tx2848	((Tx2816 X SC326-6) X Tx430)-2-1-6-4-3	R	1.9	1.4	1.55	1.40	1.80	1.61
32.	Tx2849	(Tx430 X 77CS3)-1-4-7-2-2-2-1	R	1.9	1.4	1.55	1.65	1.67	1.63
33.	Tx2850	((SC120 X Tx7000) X Tx430)-10-2-7-3	R	1.8	1.5	1.55	1.50	1.67	1.60
34.	Tx2851	(Tx430 X Tx2816)-1-1-5-3-bk	R	1.7	1.6	1.55	1.35	1.43	1.53
35.	Tx2852	(Tx430 X SC326-6)-2-1-7-7-2	R	1.7	1.6	1.55	1.55	1.80	1.64
36.	Tx2853	((SC120 X Tx7000) X Tx430)-4-1-2-2-bk	R	1.9	1.7	1.55	1.50	1.76	1.68
37.	Tx2854	((SC120 X Tx7000) X Tx430)-10-2-7-3	R	1.8	1.5	1.58	1.55	1.47	1.58
38.	Tx2855	((Tx2816 X SC326-6) X Tx430)-3-1-1-5-1	R	1.5	1.6	1.58	-	1.30	1.50
39.	Tx2856	((Tx2816 X SC326-6) X Tx430)-2-1-6-3-3	R	1.7	1.4	1.60	1.75	1.55	1.60
40.	Tx2857	((AF28 X Tx2536) X Tx430)-1-1-1-1-2	R	1.5	1.6	1.63	1.45	1.40	1.52
(check)	RTx430		(R)	(2.0	1.8	1.80	1.70	1.70	1.80)

[1]B = maintainer and R = restorer in A1 cytoplasm.
[2]Desirability - overall performance value, where 1.0 = best, 2.5 = average, and 5.0 = very poor.

TAM-126 new sources of food quality grain were identified and placed in either crosses or nurseries for distribution.

In an attempt to develop wide ranges of adaptation in breeding stocks, a series of F_2 populations was grown in Guatemala in cooperation with ICTA (Institute de Cienciag Tecnologia Agricolas). In subsequent generations segregating materials were grown in lowland, highland- lowland sequences. Then selected superior materials were grown in six locations across the Texas (from subtropical to temperate) environments. Overall desirability ratings collected at all locations were summarized and mean performance calculated and used to advance the best, most widely adapted lines. The 40 items, Tx2818 through Tx2857, described in Table 1 were released and distributed in 1989/90. Among the 40 lines, there are 5 B-lines and 35 R-lines in the A_1 cytoplasmic genetic male-sterility system. There are 14 different pedigree combinations and 24 lines have tan plant color and white or white translucent seed color. These materials will contribute significantly to stability of productivity and provide excellent sources of disease resistance and leaf quality. In addition, these materials will provide germplasm for the new and growing white food grain market.

Because there appears to be a close association between levels of nonstructural carbohydrates (NSC) in the plant and charcoal rot a study using four inbred lines was initiated. Charcoal rot is one of the most serious diseases of sorghum

in dry areas or those areas where succulence is followed by severe drought. Significant differences were found between the four lines for *in vivo* disease response and for nonsenescence. Furthermore, significant differences were obtained for NSC content and partitioning between plant organs over time. Basal stem NSC depletion occurred in all the parents from anthesis to 15 days following anthesis and beyond. However, depletion rates (Table 2) 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 the reduction in critical NSC. In contrast, both NSC fractions were depleted in susceptible cultivars. Highest infection levels were obtained with inoculation at anthesis, i.e., infection followed by a period of rapid stem sugar depletion. Thus high depletion rates create substrate-limiting metabolic pathways that in turn inhibit defense fungal degradative enzymes.

Table 2. Rates of basal stem NSC change during grain fill in inbred parents grown during 1989 in the greenhouse at College Station, TX (experiment three).

Inbreds	Period[2]	Rates[1] Soluble NSC	Reserve NSC	Total NSC
		----------	%	----------
B35	A	- 19.0	+ 15.7	- 11.9
	B	+ 13.2	+ 20.8	+ 15.2
SC0599-11E	A	- 29.2	+ 58.8	- 15.8
	B	- 20.4	- 25.8	- 21.9
BTx378	A	- 64.0	- 36.7	- 57.7
	B	+ 30.2	+ 306.3	+ 125.5
BTx623	A	- 42.6	- 79.2	- 49.0
	B	- 16.4	+ 677.9	+ 32.8

[1] Rates were calculated using the following formulae:
for period A : $r = 100 * (NSC_{15DA} - NSC_{ANTH})/NSC_{ANTH}$
for period B : $r = 100 * (NSC_{PHMT} - NSC_{15DA})/NSC_{15DA}$

[2] Period A = from anthesis (ANTH) to 15 days after anthesis (15DA)
Period B = from 15DA to physiological maturity (PHMT).

Resistance to charcoal rot was determined to be under multiple genic control with dominant and recessive epistatic effects. The same conclusion was reached for inheritance of nonsenescence. It is suspected that expression of both resistance and nonsenescence genes depended on activation/signals coded for a common, external stimulus-sensitive, regulatory gene.

Stay-green is used to describe an important postflowering drought resistance trait in sorghum cultivated under water-limiting conditions. B35 and R9188 are known to possess high levels of stay-green and are expressed in the F_1 as dominant and recessive traits, respectively. When looking at the inheritance of these stay-green phenomena, a single major dominant and one major recessive gene were found to control stay-green expression as Green Leaf Retention in B35 and R9188 respectively.

Visual ratings which can be taken quickly in the field are very important to sorghum breeders. When drought resistance is sought, a visual reading is made of Green Leaf Retention (GLR) i.e., estimating the percent of total laminar leaf that is green at harvest maturity. When validation of this visual reading was made the relationship between GLR and actual green leaf area was found to be described by a fourth order regression equation, with R^2=.875. The R^2 values for percent green leaf area and GLR, number of green leaves and percent green leaf area all showed high relationships. GLR is a valid and useful estimator of drought tolerant as related to maintenance of green leaves under stress.

In a breeding study to compare both old vs. new developed parents and parents of diverse origin we attempted to determine yield gains and malting qualities. The first group was composed of lines as old as ATx378 (Redlan) and ATx399 (Wheatland), recent releases such as ATx630, ATx631, A_2Tx632, and the widely adapted line ATx623. Restorers represented a broad range of material from around the world. M35-1 is a traditional variety from India, CS3541 was developed in India from a Sudanese line, Sureño and Dorado were developed at ICRISAT and selected/released in Central America, IS9530 is from East Africa, SA3067, a feterita, is from Southern Africa, and RTx430, RTx432, RTx435, R8505 and R8509 are all elite lines developed in Texas from crosses involving partially converted sorghums from Ethiopia, Sudan, and Honduras. The ratios of GCA:SCA variances for female and male parents revealed that all traits were highly dependent on the additive genetic component. Additive effects from the males were higher than for females. ATx631 had the greatest impact on yield, ATx623 had the highest and most positive effect on harvest index. Among the males, Sureño, Dorado, and R8509 were superior combiners for grain yield, but for harvest index Dorado and RTx430 were the better parents. Harvest index estimates and grain yield were higher in more temperate climates, indicating that selection for higher biological yields and harvest indices in more tropical areas are important selection criteria. In general the most important parental lines were ATx631, ATx623, A_2Tx632, RTx430, R8509, Sureño, and Dorado.

In Africa sorghum beer is a traditional alcoholic beverage. However, the introduction of more productive hybrids has limited the sorghum beer industry which was dependent on sorghum malts already known to have high diastatic activity; and the parents ATx378 and IS9530 were superior parents. Hybrids usually had superior performance for all grain quality traits. For diastatic activity females were always inferior. Pericarp color apparently makes a difference when germination, malt loss, and diastatic activity are involved. Red grain was superior. Yellow endosperm geno-

Table 3. Summary of the results for grain and malt characteristics by type of genotype, pericarp color and endosperm color, College Station, TX, 1989.

	Germination %	Grain density g cm^{-3}	Malt density g cm^{-3}	1000 gr weight g	Malt loss %	Hard. index %	Diasta. activ. SDU g^{-1}	Dry matter loss %
				Type of genotype				
Females	80.00a[1]	1.348a	1.019a	26.14ab	24.68a	68.97b	8.38b	16.97b
Hybrids	82.31a	1.351a	1.044a	27.75a	19.93b	73.19a	18.14a	13.05c
Males	47.07b	1.353a	1.027a	25.15b	26.28a	72.70a	10.88b	19.14a
				Peric. color				
Red	86.37a	1.348a	1.051a	28.14a	19.82b	73.22a	23.62a	12.62b
White	66.62b	1.252a	1.028a	26.23b	23.28a	72.09a	9.93b	16.35a
				Endosp. color				
White	78.72a	1.351a	1.040a	27.01a	21.42b	72.95a	16.30a	14.38b
Yellow	18.40b	1.346a	0.991a	26.50a	28.45a	67.23b	2.33b	21.36a

[1]Duncan's multiple range test at 5% level of probability.

types had decreased malt properties when compared to normal white endosperm (Table 3).

A paper was prepared describing the origin, taxonomy, and ploidy of the millets and minor cereals (see list of publications). The paper attempts to bring together the various names, synonyms, ploidy, distribution, some breeding characteristics, taxonomy, and information on origin for each species. The finger, foxtail, and pearl millets are covered most extensively.

When A_1, A_2, and A_3 cytoplasms were compared for several traits no obvious differences were observed except for grain yield. A_1 hybrids were better than A_2 hybrids which were better than A_3. However, there were exceptions. A_2 hybrids with RTx432, SC56-14E, SC109-14E, SC237-14E, SC481-14E, SC491-14E, and SC599-14E were superior to A_1. A_3 hybrids with SC103-12E, SC118-14E, SC256-14E, SC258-14E, SC315-14E, SC317-14E, SC340-14E, SC396-14E, and SC563-14E were superior to A_1 in yield. Heterosis of hybrids with A_1 cytoplasm was 51.3 to 55.5%; A_2 the range was 62.5 to 71.0% and in A_3 the range was 47.7% to 57.4% for yield. SC193-14E, SC399-14E, SC426-14E, and SC499-14E showed fertility in A_3 hybrid combinations.

The following sorghum lines from this project grown in Zimbabwe and Zambia were good for anthracnose resistance and agronomic type: RTx434, BTx631, 84C9408, 86C2803, B.8610, 87EON109, 87EON125, 86C28011, B.8618, 84EON100, 80C2241, and R8505.

Sorghums from West Africa have a history of excellent stability of yield but low yield. Trials and studies are underway in Texas (multilocations) and in Mali to determine the genetics of stability and its correlation with higher yield; or the suppression of yield characteristics in these sorghums. The guineas have some desirable traits, but when crossed with other types of sorghum they lose combining ability, eliteness, and performance.

Food quality hybrids have been distributed to numerous collaborators in many LDC's. Yield and related performance has been very good among these new types of hybrids. For example, in Southern Africa A155*80C2241 yielded 12.66 T/ha; ATx631*80C2241 - 11.08; A8606*R8505 - 10.97; A8610*R8505 - 10.62; and G766W (Funk's) - 8.65. These same hybrids have topped yield trials in Argentina, China, Mexico, and the U.S.

In Paraguay in 1989/90 F_1 hybrid seed production by those Mennonites who live and work in the Chaco produced 140,000 kg of Fredy; 14,000 kg of Alex (ATx378*RTx434); 15,000 kg of Chaco-i, A.1844*R.doble prop. = 18,000 kg and Chaco 101 = 12,000 kg. All these seeds have been distributed within the country to grain and dairy farmers for utilization. Perhaps the most significant step in progress has been the installation of a wood fired seed dryer and associated seed treatment applicator and sized to handle the hybrid sorghum seed production now occurring in Paraguay.

The project has developed three international type nurseries; International Tropical Adaptation Trial (ITAT), International Food Sorghum Adaptation Trial (IFSAT), and International Sorghum Virus Nursery (ISVN). Table 4 lists part of the data obtained from the ITAT. The purpose of this trial is to determine the type of germplasm best adapted to various climatic conditions. This replicated trial was sent to 42 collaborators with 30 going to international sties in Mexico (6), Honduras (3), Paraguay (2), Argentina (2), Colombia (1), El Salvador (1), Guatemala (2), Mali (1), Zimbabwe (2), People's Republic of China (2), Ghana (3), Uruguay (2), Brazil (2), and Sudan (1). The trial contains both feed grain type hybrids and hybrids which possess food quality.

The IFSAT (food sorghum trial) has met with considerable acceptance. We have received requests from numerous LDC and DC collaborators for this trial which contains only tan plant color and white grain lines and hybrids. We distributed more than 45 sets of this trial which allows people to evaluate the sorghum for food products and have sor-

Table 4. Grain yield (kg/ha) selected sorghum parents and hybrids from several countries in 1989.

Entry No.	Designation	Texas (Col.Sta.)	Guatemala	Argentina	China	Colombia	Honduras	Mexico	Mean
1	BTx378	4364	2567	5942	7603	3632	1895	2504	4215
2	BTx623	4654	3377	5079	9297	4540	4491	4703	5163
3	BTx631	3771	2672	5244		3995		3295	3795
4	BTx626	4199	2973	5510					4227
5	RTAM428	2980	3472	5975	6159				4646
6	RTx430	4383	3121	4086	5735	3450	1656	3643	3724
7	RTx435	2392	2792	4857	3784		1560	2399	2964
8	RTx433	4806	3389	6069	4111	3723	2043		3744
9	RTx434	3882	3454	6031	8152	2906	2156	1865	4063
10	Sureño	7717	2533	4222	11568				6510
11	RS610	3325	3588	6641	7971	3390		4173	4848
12	ATx2752*RTx430	6903	3451	5387	6457	4449	1437	3825	4558
13	ATx378*RTx430	8135	3311	7255	11582	4298	6943	5380	6700
14	ATx623*RTx430	7124	4032	7406	12199	4540	3747	5176	6317
15	ATx2752*SC103-12E	5979	4056	6831	9728	5569	4667	3481	5758
16	ATx378*RTx7000	5436	3490	6404	5687		1444	2898	4226
17	ATx631*RTx435	7386	3571	5511	11609	2300			6075
18	A_2Tx632*SC599-11E	7680	2262	5571	9728	3390	3122	4910	5266
19	ATx631*80C2241	7193	3396	6317	10915	3390	4998	5864	6010
20	ATx629*RTAM428	6834	3510	5128	10519				6497
21	ATx629*RTx2817	5855	2287	5400					4514
22	ATx630*RTx435	7041	3464	6588					5697
23	ATx631*Dorado	9699	3064	5422					6061
24	A8606*RTx435	6613	4267	5288					5389
25	ATx631*R8504	6544	4019	5914					5492
26	ATx631*R8505	7763	3697	6277	7735	2906	3963	5092	5347
27	ATx631*R8606	6728	3808	6790					5775
28	A.Var1*80C2241	9175	3458	6146					6259
29	A.Arg34*80C2241	6245	3732	6759					5578
30	A.Arg34*R8504	5960	3634	6024					5206
31	A155*R.8509	9469	3285	6530	15949				8808
32	ATx378*RTx434	8168	3537	5580	9256	4722	4649	4457	5767
33	ATx629*RTx434	7956	3843	5950	10707	2482	3796	5251	5712
34	A.Var1*RTx435	8513	3590	7715					6606
35	ATx626*RTx433	6365	3283	6759	9755				6540
36	A8106*RTx434	6834	3733	7216					5927
37	A861[illegible]*R8617	7749	2807	7015					5857
38	A8618*RTx435	7386	4002	7324					6237
39	MR101-5	4995	4108	5638					4913
40	ATx2801*MR101-5	5270	3926	4224		3178	3903	4676	5862
41	A8610*RTx435	7276	3467	6845					4196
42	A1*RTx430	7662	4151	7257	10519	3087	5347	5145	6166
43	A1*R8505	7354	3207	7237		4358	5340	5519	5502
44	A1*RTx2817		3303	5219		2452	6089	4385	3351
45	ATx630*R3338wx	7225	3316	6990		4116	6987	5837	5753
	Mean	6431	3422	6083	9071	3537	3820	4200	5374

ghums which are made with higher yielding, more stable hybrids.

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Presentations

Miller, F.R. 1989. The sorghum conversion program and its impact on sorghum improvement. Keynote Address to III Reunion Nacional Sobre Sorgo. 25th aniversario de la Facultad de Agronomia. Universidad de Guadalajara. Oct. 2-5.

Miller, F.R. Production of sorghum in Paraguay. Farmers Union, Filadelfia, Paraguay. February 23, 1989.

Miller, F.R. Improvement of sorghum for productivity and food quality. INTA Research Center, Manfredi, Argentina. March 9, 1990.

Networking Activities

Developed field lectures for international exchanges in Beeville, Berclair, Corpus Christi, Weslaco, Lubbock/Halfway, and College Station. Provided field activities for delegations from Uganda, Nigeria, Burkina Faso, and China who travelled to College Station.

Developed and carried out collaborative work plans with Paraguay and Mexico. Obtained supplies and related support items for collaborators.

Increased, threshed, and otherwise maintained an array of old and new germplasm for distribution to collaborators. Distributed over 2,503 different sorghums to numerous requestors in the form of A/B or R-lines inbreds, composites, synthetics, F_2 populations, and partially inbred breeding stocks. In addition, 42 International Tropical Adaptation Trials, 45 International Food Sorghum Adaptation Trials, 5 International Food Sorghum Variety Trials, 12 International Sorghum Virus Nurseries, and 74 Modified Hybrid Evaluation Trials were distributed to collaborators.

Sorghum selections were made and entered into cooperative international trials including the ADIN, IDIN, GWT, IDMN, IAVN, UHSN, etc.

Participated in the release and distribution of 42 sorghums - R.Tx2858, GTPP7R(H)C5, and Tx2818 to Tx2857.

Acted as major professor for nine graduate students in plant breeding and served on graduate committees for nine other graduate students at Texas A&M University. Hosted two visiting scientists.

Research Investigator Exchanges

Dr. Noel Beninati, ICRISAT/Mali. August 21-25, 1989. Review of program and exchange of germplasm.

Mr. Leonel Herra R., University of Nuevo Leon, Mexico. August 23, 1989. Discussion of drought resistance and graduate studies in Mexico.

Dr. Brian Hare and Mr. Niel Mueller. September 1, 1989. Australia. Discussion of food quality sorghums and utilization.

Honduras. November 29 - December 2, 1989. Review of INTSORMIL/SRM collaborative research, and interacted with sorghum workers in Escuela Agricola Pan Americana (EAP).

Mr. Chen Yue, Liaoning Academy of Agricultural Sciences, Liaoning, People's Republic of China.

Mr. Lu Quin Shan, Liaoning Academy of Agricultural Sciences, Liaoning. People's Republic of China.

Breeding for Disease and Drought Resistance and Increased Genetic Diversity

Project TAM-122

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Principal Investigator

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Collaborating Scientists

Dr. Francisco Gomez, Sorghum Breeder and Head, Sorghum Investigations, SRN, Choluteca, Honduras
Dr. Dan Meckenstock, Sorghum Breeder, INTSORMIL/SRN/EAP, Zamorano, Honduras
Dr. Osman Ibrahim El Obeid, Sorghum Breeder, ARC, Wad Medani, Sudan
Dr. M.E. Hilu Omer, Pathologist, ARC, Wad Medani, Sudan
Dr. Moussa Traore, Physiologist, DAR/IER, Bamako, Mali
Dr. Noel Beninati, Sorghum Breeder, ICRISAT/MALI, Bamako, Mali
Mr. Mamourou Diourte, Pathologist, SRCVO/DAR/IER, Bamako, Mali
Dr. L. E. Clark, Sorghum Breeder, TAM-122 (Cooperating Investigator), Texas A&M University, Vernon, Texas
Dr. R.A. Frederiksen, Pathologist, TAM-124, Texas A&M University, College Station, TX
Dr. F.R. Miller, Sorghum Breeder, TAM-121, Texas A&M University, College Station, TX
Dr. L.W. Rooney, Cereal Chemist, TAM-126, Texas A&M University, College Station, TX
Dr. R.D. Waniska, Cereal Chemist, TAM-126, Texas A&M University, College Station, TX
Dr. G.N. Odvody, Pathologist, TAM-128, Texas A&M University, Corpus Christi, TX
Dr. G.C. Peterson, Sorghum Breeder, TAM-123, Texas A&M University, Lubbock, TX
Dr. G.L. Teetes, Entomologist, TAM-125, Texas A&M University, College Station, TX

Summary

The principal objectives of this project 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 resistance and the drought resistance breeding programs and the germplasm program continued to progress well. Several diverse disease resistant and drought resistant lines are ready to release to private companies. New cultivars were introduced into the U.S., evaluated, and used in crosses. Much new germplasm containing many desirable traits was generated by these crosses. A large number of germplasm lines and materials of all categories was distributed to LDC, other international, and domestic collaborators.

Excellent drought resistance ratings were obtained in Sudan and Texas with a large number of excellent sources of resistance identified. The line, B35, is the best source of postflowering drought tolerance ("stay-green") and performs well in hybrids. Four recently introduced sorghum varieties show an outstanding level of resistance to preflowering drought stress, Ajabsido and Koro Kollo from Sudan, El Mota from Niger, and Segaolane from Botswana. Two derivatives of the maicillos criollos from Honduras showed excellent drought resistance, indicating they may be a useful source of resistance.

A group of 40 diverse sorghum germplasm lines developed cooperatively with other Texas scientists were released to private breeders.

The white seeded, tan plant female parental line, A&B Var, obtained from ICRISAT/LASIP, as well as several other lines from ICRISAT, showed high levels of resistance to head smut. Since CS3541 is a common line in all pedigrees, it appears that it may be a unique source of resistance.

Malisor 84-7 continued to look outstanding as a source of resistance to head bugs in Mali. Breeding progeny of Malisor 84-7 looked excellent in both Mali and Texas.

The sugarcane aphid was determined to cause severe damage to sorghum in Kenya. Most genotypes are susceptible, ranging from super susceptible to moderately susceptible. A very few lines were found with very high levels of

resistance. It appears that the resistance is inherited as a complete dominant.

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 combinations of pre- and postflowering drought tolerance and lodging resistance for use in the U.S. and host countries.

Identify, in basic sorghum germplasm lines, new sources of drought tolerance and resistance to diseases of importance in the U.S. and in 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 in the world as well as in the U.S. 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. It has been shown that 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 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 parts of Mali. High yielding improved introductions often fail in West Africa due to the grain quality - head bug - grain mold complex, stand establishment problems, improper maturity or lodging, whereas the local sorghums appear well adapted. We believe that head bugs are a major constraint to the use on non-guineense type sorghums in much of West Africa. Head bug damage is often compounded by grain mold resulting in a soft and discolored endosperm, rendering it unfit for traditional food products. The early maturity of introduced types also compounds the grain deterioration problem. Therefore, head bug resistance, grain mold/weathering resistance, and proper maturity are essential. In the drier, northern areas of Mali and in Niger where drought stress is severe, earlier, less photosensitive material is needed, and the non-guinea sorghums generally perform well. In these areas, U.S. developed drought tolerant materials may have direct application. Diseases other than grain mold are also important, such as anthracnose and sooty stripes in portions of Mali, and long smut in the drier areas of both Niger and Mali.

In Honduras, diseases are a major constraint, including downy mildew, grain mold, weathering, foliar diseases, and acremonium wilt. The food quality-weathering resistance complex is also important. Drought is also important in Honduras and the Central American Region. Improvement in the photoperiod sensitive food-type maicillos criollos is a unique challenge, and most of the breeding and selection must be done under the daylengths and environment in the host country. Improvement in the nonphotoperiod sensitive combine-type sorghums used over much of Central America can result directly from introduction of Texas adapted germplasm.

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 Sudan, Mali, Niger, Honduras, El Salvador, Botswana and Senegal 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 F_2 and/or early generation bulks 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.

Breeding material was generated from crosses among various disease resistant sources, agronomically elite lines, and new sources of resistance. Advanced generations of breeding lines also were developed and selected in 1989. 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, as well as incorporated into standard replicated trials for extensive evaluation at several locations in Texas and host countries.

Converted and partially converted lines from the Sorghum Conversion Program, exotic lines, new introductions, and breeding materials were screened and evaluated in Texas for new sources of resistance to internationally important diseases and resistance to drought.

New sorghum germplasm was collected from several countries, introduced into the U.S. through the quarantine greenhouse, and evaluated in Puerto Rico and Texas for useful traits. Selected lines were selected for entry into the cooperative TAES-USDA Sorghum Conversion Program. Lines with known merit were incorporated into the regular breeding program.

Research Findings

The disease resistance breeding program continued with excellent field screening nurseries in south Texas. Major diseases screened for were downy mildew, head smut, grain mold, weathering, charcoal rot, and anthracnose. Some excellent new downy mildew resistant progenies were identified involving crosses with Sureño, M90318, and R7730. Many also possess resistance to several foliar diseases and head smut, along with good grain mold and weathering resistance, and also have white seed and tan plant color and excellent yield potential. Progenies derived from the lines 86E0361, 86E0362, and 86E0374, white, tan lines of pedigree ((Tx432xCS3541)xSC326-6), were also outstanding, with resistance to head smut, anthracnose, leaf blight, and rust.

The white seeded, tan plant female parental line, A&B Var, as well as several other white seeded, tan plant color lines from ICRISAT showed outstanding resistance to head smut, with resistance appearing to be dominant in nature. The one common parent in all these lines is CS3541, a partially converted line developed in India from IS3541, a zerazera originally from Sudan. We believe this line may possess a unique type of resistance to head smut. The line, IS3541, has been fully converted and released through the Sorghum Conversion Program and is known as IS3541C or SC798-14E.

Moisture and heat stress was extremely severe in the large sorghum breeding nurseries in south Texas in 1989, providing an excellent opportunity to select for resistance to drought. Outstanding data were obtained on resistance to both pre- and postflowering drought, depending on the nursery. Breeding lines involving the "stay green" line B35 showed excellent postflowering drought resistance. Under severe postflowering drought stress, hybrids made with A35 showed outstanding postflowering drought resistance with little if any premature death, along with excellent resistance to charcoal rot and lodging. Essentially all other experimental and commercial hybrids exhibited essentially 100% premature plant death, and lodging, along with extensive charcoal rot.

The line A Var showed some evidence of dominant stay green in hybrid combinations. This combination of postflowering drought resistance and head smut resistance in a widely adapted white-seeded, tan-plant female line should make this line extremely valuable for direct use and as a breeding line. Its hybrids are likely too tall for direct use in the U.S.

Four newly introduced photoperiod nonsensitive sorghums showed outstanding resistance to extremely severe preflowering drought stress in south Texas. These were the two Feterita lines from Sudan, Ajabsido, and Koro Kollo; the early Caudatum variety from Niger, El Mota; and the Kafir type variety, Segaolane, from Botswana. These were crossed to many other elite high yielding U.S. and international lines, and to stay green postflowering drought resistance lines to combine drought resistance with other desirable traits.

A large number of new converted and partially converted progenies were evaluated in south Texas, with several looking good, and seed bulked for inclusion in the uniform drought trials. Derivatives of Cacho de Chivo and Paquete showed very good resistance to preflowering drought stress, indicating that the maicillos criollos from Central America could be useful sources of drought resistance.

Several B35 derivative progenies showed outstanding lodging resistance at Lubbock. They apparently combine good stay-green drought resistance and charcoal rot resistance with some anatomical stem traits which impacts outstanding stalk and weak neck lodging resistance.

A group of 40 diverse sorghum germplasm lines were released to the private industry cooperatively with F.R. Miller (TAM-121) and L.W. Rooney (TAM-126). This germplasm contains a broad array of desirable grain quality factors, disease resistance, and plant types in good yielding genotypes. Many also have white grain and tan plant color.

Sudan

Over 220 genetically diverse drought tolerant sorghum varieties or breeding lines were evaluated under excellent drought stress at Wad Medani in Sudan. The material evaluated there represents the elite drought resistant sources identified, or developed, or collected through the drought resistance breeding program in TAM-122, which is cooperative with a large number of U.S. and LDC scientists. A large number of genotypes exhibited excellent resistance to drought, as indicated in Table 1. This nursery had an excellent combination of both pre- and postflowering drought stress, and data on the responses to both types of stress were taken. The preflowering drought rating is a combination of preflowering drought response and yield expression. Some genotypes showed excellent preflowering resistance but poor postflowering resistance, such as Tx7078 and Tx7000, while others such as B35 and B2-2 had a poor reaction to preflowering stress, but an excellent response to postflowering stress, or a good "stay-green" reaction. However, there were some genotypes which showed an excellent response to both types of stress, such as 82BD499, P898012, P954035, ICSV1002, SC701-14E, SC56-14E, and SC23-14E (Table 1). This nursery, planted and cared for by Dr. Osman Ibrahim, the ARC Sudanese sorghum breeder, provides some very useful information on diverse sources of resistance to drought that should have worldwide application. In most cases, the drought ratings correspond very well to the drought evaluations made on the same materials in Texas, indicating the direct application in LDC's to drought research in the U.S. Conversely, it indicates the direct applicability of drought resistant materials developed or collected in LDC's to the U.S. Additional converted lines, to those in Table 1, with excellent drought ratings are presented in Table 2. The converted lines evaluated in Sudan were all

Table 1. Drought ratings of selected sorghum lines from the drought screening nursery, Wad Medani, Sudan, 1989.[1]

Designation/Pedigree	Preflow drought rating [2]	LPD rating [3]
Tx7078	2.0	4.8
Tx7000	2.0	4.9
R9188	2.6	3.2
B35	4.0	1.5
1790E	2.5	3.2
80B2982	2.2	3.8
R4317	1.8	4.5
R6078	2.1	4.0
Tx430	2.0	3.5
R2241	2.3	4.9
R8503	2.2	3.5
R8507	2.5	3.5
B1	2.3	3.0
B2-1	3.5	2.5
B2-2	4.5	2.0
B2-2B	3.2	2.0
HL23/B4sis	4.3	2.5
B4	4.5	2.0
El Mota	1.8	4.0
Segaolane	2.0	4.8
Koro Kollo	1.8	3.8
Ajabsido	1.5	3.8
P898012	2.0	2.5
P954035	2.0	2.2
Malisor 84-7	2.0	3.9
B Var	4.0	2.0
82BDM499	1.2	3.0
(BTx399xB35	2.0	2.8
(BTAM618xB35)	2.5	2.0
(Tx7078x1790E)	2.0	2.6
CE151-262-A1	2.0	4.9
TnGbResW	1.8	-
86E0361	2.0	4.5
Tx2737	2.0	-
IRAT204	2.0	4.5
MR726	2.2	-
M91051	2.0	4.8
ICSV1002(82S-50)	1.8	2.5
TP4--5	1.9	3.2
CSM-63 Consp/Guin	2.0	2.5
SC265-14E(IS6705C)Consp/Guin	2.2	3.0
SC701-14E(IS3462C)Cau	2.0	2.5
SC38-14E(IS2558C)Dur	3.0	1.5
SC103-12E(IS2403der)Cau	2.2	4.5
SC56-14E(IS12568C)CauNig	2.0	2.5
SC23-14E(IS12543C)Dur	2.2	2.2
SC414-14E(IS2508C)CauKaf	2.5	-
SC118-14E(IS2801C)Cau	2.0	-
SC170-14E(IS12661C)ZZ	2.5	-
SC48-14E(IS2564C)ZZ	2.2	4.0
SC630-14E(IS1269C)Caff	2.0	2.5
SC35-14E(IS12555C)Dur	4.5	1.5
SC62-14E(IS12572C)CauNigConsp	2.5	-
SC502-14E(IS3498C)DurNig	2.2	4.5

[1] Ratings made Nov. 5, 1989. Selected entries and those with best ratings are from over 220 drought lines and converted lines planted in the drought nursery at the Gezira Research Station, Wad Medani, Sudan.

[2] Rating 1 to 5: 1=very good, 5=very poor. Rating is primarily an indication of response to preflowering moisture stress, based on head development, head exsertion, and yield expression.

[3] LPD Rating 1 to 5 on leaf and plant death due to postflowering moisture stress: 1=completely green, 5=dead. Ratings considered excellent except for entries with very poor head development due to preflowering stress. Signif. nt stalk lodging of the moisture stress charcoal rot type occurred in most entries with LPD ratings of 4.5 or higher.

Table 2. Other converted sorghum lines with excellent drought ratings, Wad Medani, Sudan, 1989.

SC number	IS number	Group	Preflow drought rating[1]
SC629	IS3404	Caff	1.8
SC762	IS5437	CauKaf	1.8
SC52	IS2501C	NigFet	1.9
SC329	IS3612C	Nigr	1.9
SC367	IS7340C	CauKau	1.9
SC346	IS7440C	Cau	1.7
SC396	IS7447C	CauKau	1.9
SC577	IS3072C	CauDur	1.9
SC336	IS3587	Cau	2.0
SC832	IS4585C	Dur	2.0
SC691	IS7088C	NigFet	1.7
SC348	IS7455C	CauKau	1.9
SC520	IS7595C	Consp	1.9
SC142	IS12633C	DurCau	1.9
SC609	IS1213	NervKoal	2.0
SC731	IS3487	Caud	2.0
SC781	IS7243	CauKaf	2.1
SC284	IS6729C	Consp	2.0
SC53	IS12567C	DurNig	2.1
SC202	IS1133C	Dur	2.1
SC337	IS7094C	Cau	2.1
SC144	IS12635C	DurCau	2.1
SC810	IS957C	CauDur	2.1
SC737	IS3441C	Cau	2.1
SC141	IS12632C	DurDoch	2.2

[1] Rating 1 to 5: 1 = very good, 5 = very poor.

selected by Dr. Ibrahim from a drought screening nursery in Texas in 1988.

The yellow endosperm breeding male parental lines developed cooperatively with Dr. Gebisa Ejeta of Purdue and Dr. Osman Ibrahim of Sudan performed very well under severe drought stress in Sudan, both as lines and in hybrid combinations (Table 3). They possess excellent preflowering drought resistance, but are susceptible to postflowering stress. Their hybrids with A35, however, generally had excellent resistance to premature death, charcoal rot, and lodging. Thus, the A35 type of dominant "stay-green" should be very useful in Sudan to impart improved charcoal rot and lodging resistance to hybrids. The line PT46-1 showed special promise, both as a line and in hybrids with both A1 and A35 (Table 3).

Table 3. Drought ratings of selected breeding lines and hybrids from drought screening nursery, Wad Medani, Sudan, 1989.[1]

Designation/Pedigree	Preflow drought rating[2]	LPD rating[3]	Lodging percent[4]
87PT33-1(Tx2794xK22/35)	2.2	4.9	15
87PT37-3(Tx2794xK22/35	2.2	5.0	80
87PT46-1(Tx2794xK22/35)	2.0	4.0	15
87PT69-2(Tx430xK22/35)	2.0	4..9	90
87PT40-1(Tx2794xK22/35)	1.8	4.5	0
87PT280-2(Tx2794xK22/35)	2.2	4.8	60
A1xPT33-1	1.8	4.8	15
A35xPT33-1	3.0	2.5	0
A1xPT37-3	2.2	4.8	15
A35xPT37-3	2.8	2.2	0
A1xPT46-1	1.7	4..0	0
A35xPT46-1	2.2	3.0	0
A1xPT69-1	2.0	4.9	45
A35xPT69-1	2.2	4.8	65
A1xPT280-1	2.0	4.9	80
A35xPT280-1	2.1	3.2	0
ATx623xKarper1597	2.2	4.9	-
A35xKarper1597	3.2	2.2	-
A1xKarper1597	2.2	4.2	-
A1xTx2794	2.6	3.5	10
A1xTx2737	2.2	4.9	80
Karper22/35	2.5	4.5	30
Karper1597	2.5	4.3	-
Tx7078	2.3	4.9	80
Tx7000	2.3	4.9	85
P954035	2.2	3.5	10
P898012	2.0	3.2	10
B35	4.9	2.0	0
BTx623	2.8	4.5	-
B1	2.6	3.8	-
Karper 669	2.5	-	-
Karper 443	2.3	-	-
Karper 22/22	2.5	3.8	-
Karper 22/39	2.5	-	-

[1] Ratings made Nov. 4, 1989. Nursery had moderate preflowering stress, but extremely severe postflowering stress.
[2] Rating 1 to 5: 1=very good, 5=very poor. Rating is primarily an indication of response to preflowering moisture stress, based on head development, head exsertion, and yield expression.
[3] Rating 1 to 5 on leaf and plant death due to postflowering moisture stress: 1=completely green, 5 = dead.
[4] Stalk lodging due to moisture stress and charcoal rot.

Mali

Malisor 84-7 continued to show excellent resistance to head bugs in Mali. It is the only sorghum of an improved agronomic, non-guineense type with a high level of head bug resistance. It has now also been selected by ICRISAT entomologists and breeders as the best and most useful breeding line to use in developing head bug resistant cultivars for West Africa. Malisor 84-7 has been crossed to numerous elite U.S. and international lines. The F_2 's of crosses with 87E0366, 84C7730, Sureño, Dorado, M50009, M90318, VG153, and R9708 were grown and selected in Texas and Mali, with a number of excellent appearing progeny identified. They appear to possess improved yield potential, excellent plant and head type, and the hard endosperm trait of Malisor 84-7. Other breeding lines identified in Mali which showed excellent potential in breeding crosses were S-34, S-35, ICS401, E36-1, ICSV1063BF, M36248, ICSV1002, CE151, Malisor 84-5, and Malisor 84-1. It appears that several sorghum lines developed by ICRISAT in Burkina Faso possess moderate levels of resistance to head bugs and can be useful in breeding crosses. Several breeding lines from Texas showed potential for disease resistance (sooty stripes and anthracnose) and for drought resistance.

Honduras

Breeding lines developed in Texas continue to be identified for their disease resistance, insect resistance, grain quality, drought resistance and yield potential in Honduras for use in the maicillo criollo breeding program. Also, some elite lines perform well when used directly in hybrid combinations, both in nonphotoperiod sensitive hybrids, and as females in hybrids with the improved maicillo crillio male parental breeding lines. The first evaluation of partially converted maicillos criollos from the Sorghum Conversion Program indicated the presence of some excellent drought resistance.

Kenya

The sugarcane aphid was determined to be a major constraint to sorghum production in the drier regions of Kenya with severe damage at Kiboko to most sorghum genotypes. However, a very few sorghum genotypes were identified with very high levels of adult plant resistance in the breeding nursery at Kiboko. These lines showed excellent tolerance to damage but also had very few aphids present, indicating a very high level of antibiosis or nonpreference. Table 4 lists the sorghum lines and hybrids with the best overall desirability rating and those with sugarcane resistance. Based on the hybrids made with TAM428 (previously identified as sugarcane aphid resistant in Botswana by Teetes and Manthe) it appears that the high level of resistance behaves as a complete dominant in F_1 crosses. It appears that a very wide range in reaction exists to the sugarcane aphid. Some genotypes appear super susceptible, failing to set any seed or dying prematurely. Others support large aphid populations, but appear to possess differing levels of tolerance to damage, and look rather normal. Then a very few lines such as CE151-262-A1, R3224(sh), and TAM428 support very few aphids and appear to have a very high level of either antibiosis or nonpreference. Several of the drought resistant materials from Texas performed very well under the drought pressure there, even though they were susceptible to the sugarcane aphid.

Publications and Presentations

Publications

Duncan, R.R., F.R. Miller, D.T. Rosenow, A. Sotomayor-Rios, and S. Torres-Cardona. 1990. Registration of GTPP7R(H)C5 white seeded, tan plant, and foliage disease resistant sorghum germplasm population. Crop Sci. 30:239-240.

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Presentation

Rosenow, D.T. Breeding for drought resistance in sorghum. Pioneer Sorghum Breeder Conference, Plainview, TX. Sept. 1989.

Networking Activities

Workshops

Participated in and presented invited paper at the Sudan ARC/INTSORMIL Sorghum and Millet Workshop, October 29-Nov. 8, 1989.

Participated in and presented two papers at the Seventh Annual CLAIS Meetings, CIMMYT, Mexico D.F. April 23-28, 1990.

Participated in the EARSAM Seventh Regional Workshop on Sorghum and Millet Improvement. Nairobi, Kenya. June 22-26, 1990.

Sorghum in the 90's Planning Committee, June 26-27, 1989, College Station, TX.

Table 4. Selected sorghum lines and hybrids with best desirability ratings grown under severe drought and high sugarcane aphid infestations at Kiboko, Kenya, 1990.[1]

Designation/Pedigree	Desirability rating[2]	LPD rating[3]	Sugarcane aphid rating[4]	Comments
CE151-262-A1	1.8	2.0		
R3224(sh)	3.2	2.0	1.0	very few aphids
TP4--5	1.9	2.8		
B1	2.0	3.0		
B2-1	2.1	2.2		
B2-2	2.0	2.0		
HL23/B4sis	2.2	1.8		late
P898012	2.2	4.8		
82BDM499/(SC173xSC414)	2.0	2.5		
R4244	2.1	3.0		
80B2982/(SC748xSC630)	2.1	2.5		
SC146-14E/IS12637C	2.0	1.8		
SC414-12E	2.3	4.2		
NSA440	2.3	2.5		
Tx430	2.3	2.0		late
B801	2.2	3.0		
88LDLON496/(SC173xSC414)	2.3	3.0		
PT37-3/(Tx2794xK22/35)	2.3	3.0		
PT46-1/(Tx2794xK22/35)	2.1	2.0		
SC762-14E	2.3	2.6		
BTx623	2.2			
Sureño	2.2	-		late
A1xTAM428	1.8	-2.0	1.0	very few aphids
A807xTAM428	1.7	2.0	1.2	very few aphids
ATx629xTAM428	2.0	-	1.0	very few aphids
ATx631xDorado	2.3	-		
ATx2752xSC103-12E	2.5	-		
AVarx80C2241	2.4	-		
AVarxTx435	2.4	-		
A8618xTx435	2.5	-		
A1xTx430	2.4	-		
A1Tx432	2.2	-		
AVarxR8505	2.3	-		
A1xR8503	2.2	-		
A1xTx2794	2.2	-		
A1x86E0361	2.1	-		
A1x87E0366	2.2	-		
ATx631x87E0366	2.1	-		
ATx623xSC103-12E	2.1	-		
A1xPT46-1	2.2	-		
A1xPT37-1	2.2	-		
A1xPT69-2	2.1	-	3.2	
A1xPT280-2	1.9	-	2.5	
A35xPT280-2	2.2	2.0	2.5	
A803xTx430	2.2	-		
A804xTx430	2.2	-		

[1] Data taken by D.T. Rosenow on 7/3/90 from DLT (Drought Line Test), DHT (Drought Hybrid Test), and ISTAT tests planted 4/10/90.

[2] Overall desirability rating 1 to 5: 1=very good, 5=very poor. Rating based primarily on head development, yield expression, grain development and adaptation.

[3] Leaf and plant death rating 1 to 5: 1=completely green, 5=dead. Premature leaf and plant death due more to sugarcane aphid damage than drought stress.

[4] Sugarcane aphid rating 1 to 5: 1=very few aphids and no damage, 5=killed. All those with no rating had large number of aphids on underside of leaves with extensive honeydew covering the soil, but with different amounts of leaf death as indicated by the LPD rating.

Research Investigator Exchanges

To Mali, Sept. 30-Oct. 10, 1989, to evaluate the INTSORMIL/IER collaborative research program, plan future collaborative research with Malian scientists, and coordinate research with ICRISAT/Mali USAID Program, and the ICRISAT West African Regional Sorghum Program.

To Sudan, Oct. 29-Nov. 8, 1989, to participate in the Sudan INTSORMIL/ARC Sorghum and Millet Workshop,

evaluate the collaborative INTSORMIL/ARC sorghum breeding program and plan future collaborative research with Sudanese scientists.

To Honduras, Nov. 29-Dec. 5, 1989 to evaluate INTSORMIL/SRN/EAP collaborative research program and plan future collaborative research with Honduran and INTSORMIL scientists.

To Mexico, April 23-28, 1990 to participate in the Seventh Annual CLAIS Meeting and discuss and plan future collaborative research in Central America with ICRISAT and national scientists.

To Kenya, June 22-26, 1990, to participate in the EARSAM Seventh Regional Workshop on Sorghum and Millet Improvement at Nairobi, and discuss sorghum research with national scientists from Kenya and surrounding countries.

To College Station July 10, 1989 to discuss Malian research plans with IER Director General, Dr. Oumar Tall.

To College Station Feb. 15-16, 1990 to meet with Drs. Moussa Traore and Yauouba Doumbia of Mali to plan 1990 research in Mali.

To Purdue, Sept. 27, 28, 1989 to tour breeding plots.

Lynn Wade (Australia), August 17, 1989
Roy Brengman (Australia, August 28, 1989
N.F. Beninati (ICRISAT/Mali), August 24-25, 1989
John Snape (UK), Sept. 25, 1989
G. Ejeta, October 12-13, 1989
L. Gourley, Ben Kanyenji, and John Mann, November 27-28, 1989

Other Collaborating/Cooperating Scientists

Cooperation or collaboration with the following scientists, in addition to those 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. 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, Mechakos, Kenya (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. Manuel Terregroza, Director of Annual Crops, ICA, Bogota, Colombia
Ing. Lindolfo Fernandez, Agronomist, SRN, Comayagua, Honduras
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, Mississipp State, MS
Mr. D.J. Andrews, Sorghum/Millet Breeder, NU-115, University of Nebraska, Lincoln, NE
Dr. J.D. Eastin, Physiologist, NU-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. C.W. Wendt,Soil Physicist, Texas A&M University, Lubbock, TX

Germplasm and Research Information Exchange

Germplasm Conservation and Use

Twenty-five new sorghum lines from West Africa (Mali, Burkina Faso, Mauritania, Ghana, Benin, Cameroon, Nigeria) and ICRISAT were collected, or acquired and introduced into the U.S. These include elite local varieties, elite breeding lins from Mali, ICRISAT, and Cameroon, and ICRISAT lines with sources of insect resistance. They were selected based on nursery observation and discussions with host country and ICRISAT scientists.

Six sorghums, including four new white seeded, tan plant A-B pairs were introduced from Sudan. The four new A-B pairs were selected by Dr. Osman Ibrahim, Sudanese sorghum breeder.

The 39 sorghum cultivars from Somalia which were introduced in 1988 were evaluatd in Texas and Puerto Rico, and seed was increased in Puerto Rico. Ten were selected for entry into the Sorghum Conversion Program.

Twenty nine sorghums from ICRISAT/LASIP were obtained from ICRISAT/CIMMYT and grown in the U.S. and seed increased. These were selected based on observations in Honduras and El Salvador and possess either good food type grain, disease resistance, or excellent yield and adaptation.

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 amounts of germplasm was distributed and the approximate number of items sent include: Mali (170), Sudan (220), Zambia (120), Kenya (200), Honduras (130), Zimbabwe (60), Brazil (60), ICRISAT/Mali (420), ICRISAT/Mexico (45), and Botswana (40).

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.

Increasing Resistance to Insects and Improving Efficient Nutrient Use by Genetic Manipulation for Improved Grain Sorghum Production

Project TAM-123
Gary C. Peterson and Arthur B. Onken
Texas A&M Univesity

Principal Investigators

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Dr. Arthur B. Onken, Soil Chemistry and Fertilizer, Texas A&M Agricultural Experiment Station, Route 3, Box 219, Lubbock, TX 79401

Collaborating Scientists

Dr. Francisco Gomez, Midge Resistance, 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, TAMU (TAM-125)
Dr. D. T. Rosenow, Sorghum Breeding, TAES/TAMU (TAM-122)
Dr. R. A. Frederiksen, Pathology, TAMU (TAM-124)
Dr. F. R. Miller, Sorghum Breeding, TAMU (TAM-121)
Dr. R. R. Duncan, Sorghum Breeding, Univ. of Georgia
Dr. T. L. Archer, Entomology, TAES/TAMU
Dr. B. R. Wiseman, Entomology, USDA-ARS, GA
Dr. A. Sotomayor, Sorghum Breeding, USDA-ARS, Puerto Rico
Dr. C. W. Wendt, Soil Physics, TAES/TAMU/TROPSOILS

Summary

Sorghum germplasm lines resistant to biotype E greenbug or sorghum midge were released. The lines (restorers in A1 cytoplasm) possess an improved level of resistance to the pest insect. In yield trials the greenbug resistant hybrids maintained excellent yield potential and exhibited less damage than susceptible hybrids when greenbugs were present. Midge resistant hybrids possessed no significant yield difference versus susceptible hybrids in two years of trials at Lubbock when the insect pest was absent. Some midge resistant hybrids outyielded susceptible hybrids although the difference was not significant. When the insect pest was present resistant hybrids produced significantly more than did susceptible hybrids.

Water and nutrient deficiencies are primary causes of low sorghum yields in Sahelian Africa. Our research has shown that sorghum genotype, water level and nutrient levels interact to affect nutrient and water use efficiencies (WUE). We have also determined that uptake, translocation and metabolic utilization are all important mechanisms affecting nutrient use efficiency (NUE). Water use efficiency has been found to be related to harvest index and shows promise as a screening tool for plant breeders. As a general rule, as WUE increases due to nutrient applications, NUE's are reduced. This relationship has been found to be highly genotype dependent. A field study has been initiated on the Cinzana Experiment Station in Mali to investigate the extent of the above interactions utilizing West African sorghum genotypes.

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 sorghums 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. The alleviation of plant stress through combining 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 particularily important as local production ecosystems (relative to cultivars and technology) experience induced change, with the natural balance between cultivars and biotic stress also being changed and insect damage becoming increasingly severe.

The sorghum midge is the only cosmopolitan sorghum insect pest and is probably the sorghum species most destructive insect. 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 at 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 obtained and evaluated for resistance to insects of economic importance in either large field nurseries or greenhouse facilities, depending on the insect mode of infestation, in a cooperative breeding/entomology program. Sources of germplasm are elite accessions from other programs (including ICRISAT), plant introductions, and partially or fully converted exotic genotypes from the sorghum conversion program.

New sources of resistance are included in a crossing program with elite breeding material. When possible, studies are conducted on the genetics of resistance and the resistance mechanism determined. 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 and stress resistance (disease resistance and/or drought tolerance) traits are incorporated into the germplasm whenever possible.

Elite lines and hybrids are provided to LDC cooperators for evaluation under their conditions. Cooperators evaluate the germplasm under their production systems (fertilizer, tillage, plant population, etc.) and obtain agronomic and yield data. TAM-123 will assist in evaluation at maturity. Additional, larger quantities of germplasm are provided to cooperators based upon initial observations.

For insects important in LDC's but not in the U.S., an array of germplasm is provided to the LDC cooperator. The cooperator will evaluate the germplasm for resistance to the specific insect. Based upon results of the experiments, 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 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

Germplasm, designated Tx2859-Tx2868, resistant to biotype E greenbug was released during INTSORMIL Year 11. The germplasm will be of use in regions where greenbugs are a production constraint. All of the lines, which possess excellent seedling stage resistance, restore fertility in A1 cytoplasm and represent unique genetic combinations not presently available. In yield trials where susceptible check hybrids sustained severe damage, resistant hybrids sustained little damage while maintaining green leaves and excellent yield potential.

Germplasm, designated Tx2869-Tx2890, resistant to sorghum midge was released. The lines possess significantly improved resistance and yield potential, when compared against previous sorghum midge resistant releases, and each will restore fertility in A1 cytoplasm. As a group this release significantly broadens the genetic base of agronomically improved sorghum with respect to sorghum midge resistant germplasm. Results of yield trials over several years and Texas locations (when midge density was suppressed) indicated that the lines produce excellent yielding, widely adapted hybrids which in some environments would outyield susceptible hybrids. Data from two years of tests at Lubbock did not reveal any yield difference between resistant and susceptible hybrids under late plantings in the absence of the pest insect. At College Station with midge infestation resistant hybrids produced significantly more grain than susceptible hybrids.

Evaluation of TAM-123 developed germplasm continued at numerous domestic and international locations. Results of trials containing advanced B- and R-lines indicated the lines possessed excellent resistance, wide adaptation, and are potentially useful at numerous locations. With each cycle in the selection and crossing program the level of resistance to sorghum midge, and agronomic type, improve. Sterilization of a number of potential new B-lines (seed parents) in A1 cytoplasm was initiated. Lines which produce good steriles will continue in the sterilization program. The lines represent an array of diverse pedigrees and agronomic characteristics.

Breeding material resistant to biotype E greenbug is being developed with improved levels of resistance to specific diseases. Lines resistant to biotype E greenbug and to one or more of the following diseases - headsmut, pathotype 3 downy mildew, anthracnose, and rust, - have been identified. A number of new restorer lines (A1 cytoplasm) were selected and crossed to elite females to evaluate hybrids for adaptation and yield potential. Some of the lines combine tan plant color, white epicarp, biotype E greenbug resistance, and anthracnose and/or rust resistance into a single genotype.

In Olancho state, Honduras, TAM-123 developed midge resistant germplasm is well adapted and appears to fit into the local production system. Midge trials were sent to Honduras but data had not been received at the time this report was completed. Sorghum midge resistant line and hybrid trials were also sent to Guatemala. Collaborative research on the sugarcane aphid in Botswana was in the final stages. Evaluation of lines provided by TAM-123 was completed and data were being summarized for analysis and reporting of results.

In addition to the midge line and midge hybrid trials, TAM-123 contributed germplasm to trials grown at numerous locations including the All Disease and Insect Nursery (ADIN), and the Tropical Adaptation Trial (TAT). Research to diversify the program genetic base continued, especially by combining multiple genes for resistance to sorghum midge and by 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 crop genotype.

Research has shown that nutrient deficiencies under rainfed conditions result in poor utilization of available water in both the African Sahel and Texas High Plains. It has been shown that five-fold increases in forage production can result from proper N and P fertilization. Water use efficiencies (biomass/ET) have been increased 8% under dryland conditions at Lubbock, Texas, with proper fertilizer practices. While research tends to indicate that biomass/unit of water transpired changes only in cases of severe nutrient deficiencies, research is lacking concerning plant nutrition requirements necessary to obtain maximum dry matter production per unit of water when water is limiting. It is well recognized that nutrient deficiencies, particularly N and P, greatly inhibit crop production in Sahelian Africa. Further, information is lacking relative to fertility level-water level interactions and the role newly identified nutrient use efficient cultivars might play in water use efficiencies.

A study was conducted in minilysimeters under a rainout shelter at Lubbock with the following objectives.

1) Delineate the interaction effects of sorghum genotype and available N level on nitrogen use efficiency and transpirational water use efficiency.

2) Determine factors necessary to define nitrogen use efficiency.

The study consisted of two sorghum breeding lines grown in 35 liter containers under a rainout shelter. After plant emergence the surface of the containers was sealed to prevent evaporation. The containers were weighed periodically to determine water loss and 100% of transpiration was replaced. The sorghum breeding lines were MB9 and B35. They are of similar maturity, but differ in drought and nutrient responses. The line B35 has the stay-green characteristic (postflowering drought resistance) which MB9 does not have and MB9 yields well under low fertility and low available water conditions. Applied N levels were 0, 20 and 80 mg/kg. Residual nitrate-N in the soil was 6 mg/kg. The plants, including roots, were harvested at physiological maturity, separated into various plant parts, dried, weighed and analyzed for total N. Water use efficiency (WUE) is defined as grain weight produced/liters of water transpired. The proposed definition of N use efficiency (Gw/Ns) is Gw/Ns = (Gw/Nt)(Nt/Np)(Np/Ns) where: Gw = grain weight, Nt = N in aerial plant tissue, Np = N in whole plant and Ns = available soil N.

Components of N use efficiency, N use efficiency and water use efficiency for the two sorghum breeding lines as affected by N rate are given in Table 1. There was a significant interaction between breeding line and N rate for each of the components proposed for N use efficiency. Both metabolic N use efficiency (Gw/Nt) and N uptake efficiency (Np/Ns) decreased with increasing N rate and significant differences existed between the two breeding lines at some N rates. Nitrogen translocation efficiency (Nt/Np) increased with increasing N rate, again with significant differences found between breeding lines at some N rates. Nitrogen use efficiency (Gw/Ns) decreased with N rate and significant differences were found between breeding lines for the two increments of added N. Transpirational water use efficiency (WUE) increased with each addition of N with MB9 having a higher WUE than B35 at each level of N. Thus, sorghum breeding line and N level interacted to significantly affect each of the proposed components for defining nitrogen use efficiency and strongly suggests that each must be considered to adequately define that important trait.

Water use efficiency was found to increase linearly with increases in harvest index for both breeding lines and each N level, Fig. 1. This relationship might be used as a relative screening tool by plant breeders.

Another important relationship to consider is the one between WUE and Gw/Ns. This is because most soils in semiarid regions where sorghum is a staple crop are deficient in both available nutrients and water. The data in Table 1 show that WUE increases with N rate while Gw/Ns decreases with increasing N rate. Thus, there is an inverse relationship between WUE and Gw/Ns, Fig. 2 However, there is a strong interaction with genotype which will be important to plant breeders as they try to improve these two traits. For MB9 the decrease in WUE was much less with increasing Gw/Ns and the level of WUE at each level of Gw/Ns was much higher than for B35.

A second study was initiated in cooperation with TROPSOILS in Mali. Previous studies indicated that P deficiency and Al toxicity were major factors limiting sorghum growth and yield in Grossarenic and Plinthic Paleustalfs of the Cinzana Agronomic Research Station, Mali (West Africa). Local resources (manure, Tilemsi rock phosphate, and Diamou lime) and selected sorghum genotypes are being tested to improve crop production in the above soils.

A common feature of each of the control plots in 1990 was that the percentage of planting hills displaying symptoms of poor early growth was very low. Percentages of 15% were very common (compared to 60% in 1986 and 1987). An explanation of this is that the research plots were located in a field plot that was abandoned (because of this soil problem), and therefore left in fallow for three years.

Selected sorghum genotypes (Babadia Fara, CSM 63, Malisor 84-7, and ATx631 x Dorado) are being tested in a

Table 1. Components of N use efficiency, N use efficiency and water use efficiency of two grain sorghum breeding lines as affected by N rate.

Line	N-rate mg/kg	Gw/Nt[1]	Nt/Np	Np/Ns	Gw/Ns	WUE
MB9	0	0.122 c	0.727 b	194.5 c	17.2 e	1.86 d
	20	0.096 b	0.862 c	88.1 b	7.2 c	2.20 e
	80	0.053 a	0.910 c	42.5 a	2.0 a	2.31 f
B35	0	0.061 a	0.643 a	219.2 d	8.6 d	0.95 a
	20	0.087 b	0.726 b	85.5 b	5.2 b	1.62 b
	80	0.055 a	0.846 c	37.0 a	1.7 a	2.04 c

[1] Means followed by the same letter are not significantly different (0.05 Duncan Test).

Figure 1. Relationship between water use efficiency for grain production and harvest index.

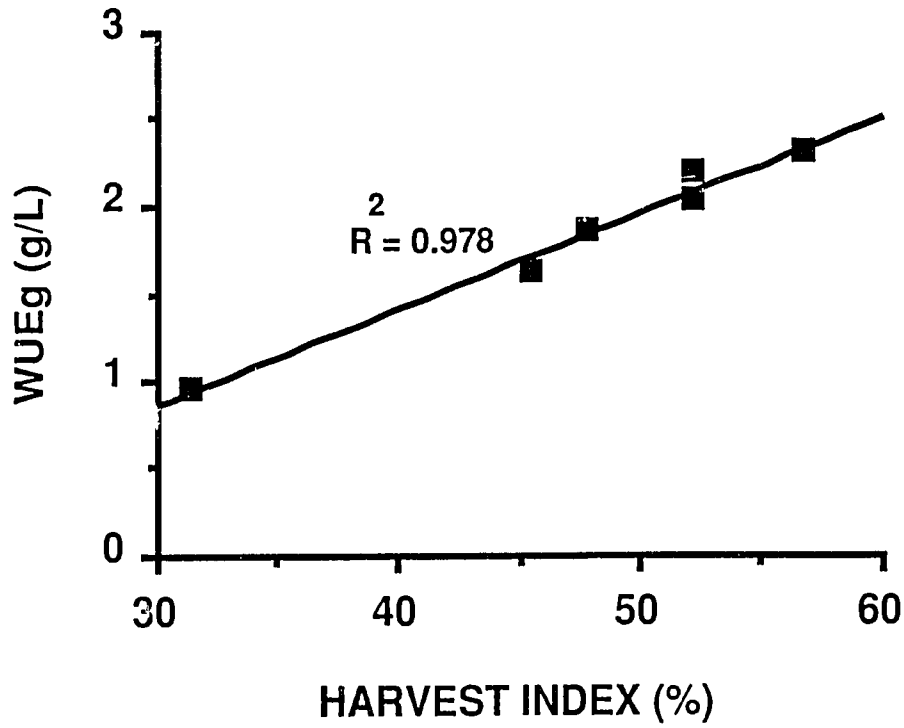
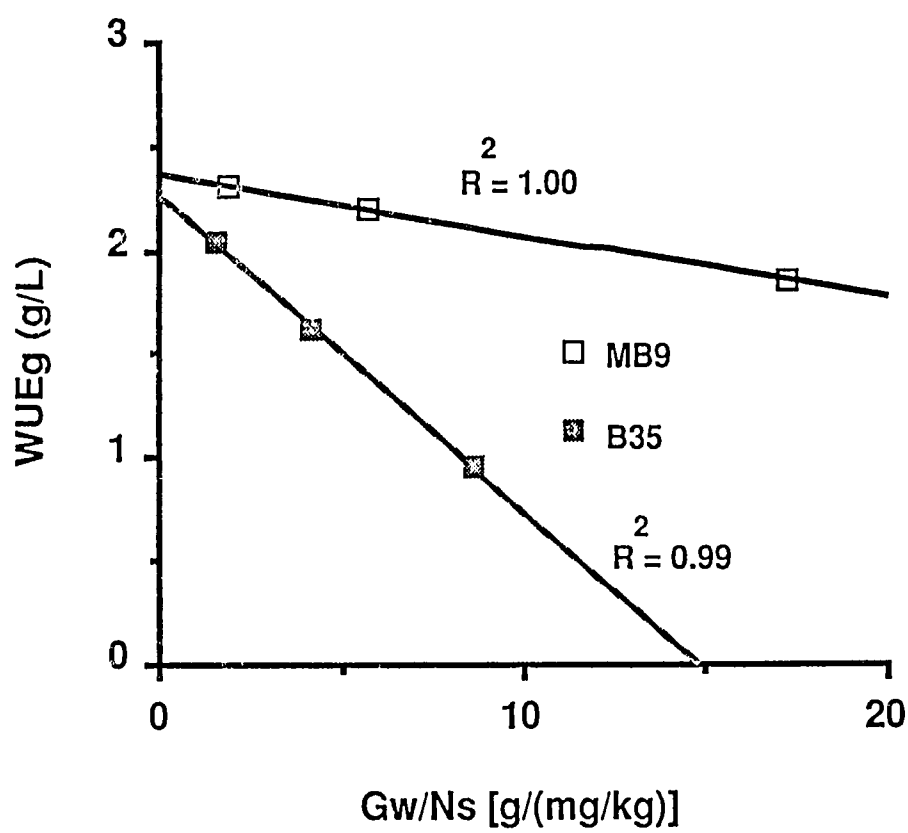


Figure 2. Relationship between transpirational water use efficiency for grain production (WUEg) and N use efficiency for grain production (Gw/Ns) of two grain sorghum genotypes.



factorial experiment with 0, 15, and 45 kg/ha of both N and P_2O_5. Each genotype established a very good crop stand by the growing point differentiation stage. The effects of the different N and P_2O_5 levels were observed for sorghum growth. Combining the two nutrients resulted in increased growth compared to applying either nutrient alone.

Different rates of corrective inputs such as manure, Tilemsi rock phosphate (RP), and Diamou lime were combined to different levels of mineral supplements (N and water soluble P_2O_5) in three factorial experiments. Malisor 84-5 (sensitive to the soil problem under study) was used. In the manure experiment, sorghum growth improved with increasing manure rates (0, 2.5, 5, 10, 15, and 20 tons/ha). In both Tilemsi RP (0, 20, 50, 75, 100, and 150 kg P/ha) and Diamou lime (0, 1, 2, 3, 4 x lime requirement) experiments, direct effects of these amendments were not observed on sorghum growth. In each of these three experiments, sorghum growth improved with increasing level of mineral supplements. Interactions were not clearly expressed on seedling growth. The plots were being harvested as this report was being written and yield data will be reported at a later date.

Publications and Presentations

Publications

Archer, T.L., A.B. Onken, E.D. Bynum, Jr. G.C. Peterson. 1989. Banks grass mite, Oligonychus pratensis (Banks), abundance on sorghum cultivars with different levels of nitrogen and metabolism efficiency. Exp. and App. Acar.

Doumbia, M.D., L.R. Hossner and A.B. Onken. 1989. Soil variability at the Cinzana Research Station, Mali (West Africa). Agronomy Abstracts. p. 52.

Onken, A.B., J.L. Mabry and C.W. Wendt. 1989. Interaction of nitrogen and water levels on water and nitrogen use efficiencies of two grain sorghum genotypes. Agronomy Abstracts. p. 249.

Peterson, G.C. and A.B. Onken. 1989. Correlation of chlorophyll content and iron deficiency chlorosis in grain sorghum. Agronomy Abstracts p. 95. 15-20 Oct. 1989. Las Vegas, NV.

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., T.L. Archer, G.L. Teetes, and J.W. Jones. 1991. Registration of biotype E greenbug resistant sorghum germplasm. Crop Sci. 30:(in press).

Peterson, G.C., G.L. Teetes, B.R. Wiseman, A. Sotomayor-Rios, J.W. Jones, and K. Schaefer. 1991. Registration of sorghum midge resistant sorghum germplasm. Crop Sci. 30:(in press).

Rosenow, D.T., L.E. Clark, F.R. Miller, G.C. Peterson, and A. Sotomayor-Rios. 1989. Utilizing exotic sorghum germplasm through genetic conversion. Agronomy Abstracts p. 97. 15-20 Oct. 1989. Las Vegas, NV.

Sow, A.A., L.R. Hossner and A.B. Onken. 1989. Transpirational water use efficiency as a function of P fertilization. Agronomy Abstracts. p. 253.

Presentations

Doumbia, M.D., L.R. Hossner and A.B. Onken. 1989. Soil variability at the Cinzana Research Station, Mali (West Africa). Presented at the American Society of Agronomy annual meeting, October 15-20, 1989. Las Vegas, NV.

Onken, A.B., J.L. Mabry and C.W. Wendt. 1989. Interaction of nitrogen and water levels on water and nitrogen use efficiencies of two grain sorghum genotypes. Presented at the American Society of Agronomy annual meeting, October 15-20, 1989. Las Vegas, NV.

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Sow, A.A., L.R. Hossner and A.B. Onken. 1989. Transpirational water use efficiency as a function of P fertilization. Presented at the American Society of Agronomy annual meeting, October 15-20, 1989. Las Vegas, NV.

Networking Activities

Research Investigator Exchanges

G.C. Peterson. Nov. 29-Dec 5, 1989. Honduras. Evaluate cooperative research with Recursos Naturales cooperators. Discuss workplan and research for the following year.

Germplasm and Research Information Exchange

Distributed germplasm samples for cooperative research or from specific requests. Seed was sent to several states, and to countries/programs including but not limited to Honduras, Guatemala, Botswana, Peoples Republic of China, SADCC/ICRISAT, ICRISAT-MASIP, Argentina, Australia, Hungary, Venezuela. Omitted from this listing are commercial seed companies, domestic and international, which requested seed of the germplasm lines released during INTSORMIL Year 11.

Increased seed of sorghum germplasm lines designated Tx2859-Tx2890 for release. All germplasm lines previously released by this project were planted for seed increase for 1)future use and 2)to provide seed of each line for the National Seed Storage Laboratory. All lines used for replicated trials were increased in addition to advanced breeding lines for which quantities of pure seed are needed.

Seed of the new germplasm releases, particularly Tx2859-Tx2868 for biotype E greenbug resistance, will in the near future be widely used as male parents in commercial hybrids.

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.

Sorghum Improvement in Honduras and Central America

Project TAM-131
Dan H. Meckenstock
Texas A&M University

Principal Investigator

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Agr. Manuel Santos, Sorghum Breeder, CENTA, San Andres, El Salvador, C.A.
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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. To accomplish this, the project focuses on *in-situ* conservation and enhancement of landrace sorghum populations. Honduras is an INTSORMIL prime site and research is conducted under an MOU with the MNR (1981) and the EAP (1988). The GOH and A.I.D./H provide local currency support for research activities in Honduras through the Title I PL480 program. Regional networking is conducted via exchange of information, germplasm, and scientific staff. TAM-131 collaborates with nine INTSORMIL projects representing four land-

grant universities. It also provides backstopping for students conducting research in Honduras. To date, seven advanced degrees have been completed and two are in process.

Ninety percent of the sorghum acreage in Honduras is planted on hillsides with landrace populations called maicillo criollo. Characteristically, this tropical sorghum is tall, late maturing, adapted to intercropping with maize, and produces low but stable yields. The specific task before TAM-131 is to sustain sorghum productivity on marginal lands. A three point plan that calls for 1) introduction and release of elite cultivars, 2) collection and enhancement of maicillo, and 3) on-farm testing has been put in place. High performance cultivars released to farmers who have adopted soil- and water-conservation structures promoted by LUPE have proven to be an efficient technology combination for increasing production and disposable income while reducing risk. Of three released cultivar introductions, Tortillero (1983), Catracho (1984) and Sureño (1985), the 2-dwarf variety Sureño has received the best acceptance. Roughly 28 percent of farmers in the South have tried Sureño, 43 percent of these have adopted it.

Initiation of on-farm testing of enhanced maicillo cultivars in 1989 marked the beginning of a new era in traditional farming systems in Honduras. These cultivars are 0.5 to 1.5 m shorter, two to three weeks earlier, and 30 to 50 percent higher yielding than their maicillo ancestors. Although the jury is still out, farmers are excited about their prospects. Already, enhanced maicillo cultivars are beginning to work their way into informal markets and promise to change the traditional sorghum landscape.

Supporting studies on the growth of enhanced maicillo indicate that photoperiod sensitivity can be managed to substantially increase phytomass. This factor may play a significant role in developing sorghum as alternative energy source for the tropics or as a means for removing CO_2 from the atmosphere. Evidence was also collected that suggests maicillo has a lower respiration rate than other sorghum. This character, if transferred to conventional hybrids, may produce higher yield plateaus.

Objectives, Production and Utilization Constraints

Overall Objectives

To improve the quality of life of rural families who produce sorghum through the conservation of biodiversity and enhancement of traditional sorghum varieties to reduce yield loss and increase their productivity and utilization.

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 training of local scientists.

To transfer new sorghum technologies through on-farm demonstrations and publication of research results.

Year 11 Project Objectives

Collect, evaluate, and conserve maicillo criollo germplasm.

Develop enhanced maicillo varieties and hybrids with improved yield potential, adaptation, insect and disease resistance, and acceptable grain and forage quality.

Develop a control strategy for the fall armyworm, *Spodoptera frugiperda*, and other early season lepidopterous pests which includes host plant resistance.

Constraints

Conservation and evaluation of maicillo diversity. Maicillo is the local name for landrace tropical sorghum found in semiarid regions of Central America. It 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 characteristics which were established in the course of its adaptation to traditional maize intercropping systems and local food processing customs. These changes have come about through natural selection 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 cultivars. This process threatens extinction of many useful genes before they can be identified and put to further use.

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 also the preponderant use of landrace populations called maicillo criollo which have low but stable yield. The inability of maicillo to respond to new technologies with increased grain yield is the primary constraint to sorghum production. Before new technologies like terracing and fertilizer can become economically feasible, the genetic potential of traditional varieties 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% of the sorghum planted in Honduras and El Salvador is late maturing landrace populations which are customarily intercropped with early maturing maize. Although maize is the preferred crop, it is generally intercropped with sorghum by small farmers in hot, dry regions as a hedge against drought. Maicillo's sensitivity to photoperiod and its ability to withstand shading are key to its adaptation to traditional maize intercropping systems, and introduced cultivars require genetic modification before they can be used in these systems. Study of sorghum-maize

intercropping systems is necessary for understanding how traditional farming systems work and for determining what changes can be made to increase their productivity.

Photoperiod sensitivity. Maicillo is very sensitive to photoperiod and day lengths of 12 h or less are required for floral differentiation. Attempts to grow maicillo in Niger and Mali show that it matures much later than indigenous varieties in those African countries. In southern Honduras, floral initiation occurs during the first fortnight of October regardless of spring planting date. Because of this short day requirement, maicillo fails to mature in the United States. Consequently, its improvement must be carried out in the region (between 12° to 15° N lat.).

Insect pests. An early season lepidopterous pest complex, collectively referred to as 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 for developing adequate control strategies.

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 of *Peronosclerospora sorghi* reported in the Americas which was discovered at Las Playitas Experiment Station, Comayagua, Honduras in 1986. This pathotype has been designated P5. 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 1980s was not a good decade for basic grains production in Honduras. Only the production of rice which increased from 29,000 to 41,000 metric tons (1980-87) grew faster than the population. During this same period, the production of maize (392,000 metric tons) and beans (48,000 metric tons) remained relatively constant, but the production of sorghum declined from 52,000 to 36,000 metric tons.

Three principal factors contributed to the stagnation of maize and bean production, and the decline of sorghum production. First, production emphasis was placed on nontraditional export crops. Because the agricultural sector produces more than 80% of Honduras' export earnings, it must finance Honduras' industrialization. Considering that the possibility of expanding the amount of arable land was small, basic grains had to compete with cash crops. Although traditional export crops like coffee and banana compete little with basic grains for land, there was a significant growth in nontraditional export crops like pineapple (25% per year, 1975-86) and cantaloupe (23%), and other agricultural products for domestic consumption like palm oil (19%), plantain (9%), and tomatoes (10%). Taken together, these and other crops displaced a significant proportion of land dedicated to basic grains.

Second, overvaluation of the national currency (lempira), which rose to more than 100% before its devaluation in 1990, reduced the incentive to produce basic grains. In effect, the overvaluation created a lower real price for grain compared to the increased real price of imported inputs like fertilizers, herbicides, and insecticides. This effect was further accentuated in good production years when grain prices collapsed (see socioeconomics PRF-105 chapter in this report).

Third, conflict of personal interests and the agrarian reform deterred larger farmers from producing grains. Although the agrarian reform deals with the agricultural restructuring of the country and ostensibly is oriented towards the production to satisfy the dietary needs of the population, some incentives and rules have limited the intensification of production on more than 360,000 ha of arable land which have been put into pasture. Comparing the production of maize with cattle, maize produces about ten times the labor per hectare and about twice the net income. However, the agrarian reform declares that land cultivated with basic grains can be expropriated. It also prohibits the renting of land to others who could use it more efficiently. According to the National Agrarian Institute, some 40,000 ha in the last three years were planted with crops protected by the agrarian reform (e.g., cotton, sugar cane, and coffee) and another 60,000 ha were given to cooperatives only to remain idle. In order to reverse the decline in basic grain production, the Honduran government approved in 1989 an emergency law which protects land planted to basic grains from expropriation.

Research Approach and Project Output

Conservation and Evaluation of Maicillo Diversity

Breeding programs based in regions where primitive cultivars exist have a special obligation to collect and conserve that diversity. Conservation of maicillo genetic diversity is a long term objective in which we propose to transform maicillo cultivars rather than replace them with "quick-fix" introductions. The idea is to develop a form of *in-situ* conservation in which both plant and man benefit. Those farmers who continue to use maicillos and/or their enhanced derivatives would in effect become village-level custodians of this gene pool. The bicolor species would benefit because its genetic diversity in Central America would be conserved and these genes would continue their evolutionary processes. Man would gain because he would have access to additional genes to defend against pathogens

and insect pests which in turn would reduce epidemics and sustain yields. Also, useful maicillo genes could be applied in sorghum breeding programs outside the region.

Conservation of maicillo begins with its collection and subsequent classification and evaluation. Acquisitions are placed in the maicillo criollo working germplasm bank which is maintained at the EAP. This germplasm bank is periodically grown in several locations and evaluated for resistance to biotic and/or abiotic stresses and agronomic performance. Since initiation of the Honduras prime site in 1981, resistance to fall armyworm (*Spodoptera frugiperda*) and diseases like *Cercospora scalariforme*, *C. sorghi*, *Colletotrichum sublineolum* (syn. *C. graminicola*), *Puccinia purpurea*, and *Ramulispora sorghicola* has been found. More recently, sources for restoring alternative male sterile inducing cytoplasms (e.g., A2) have been identified.

Promising accessions are then used in the Honduran breeding program and passed to other sorghum projects via the INTSORMIL collaborative scientist network. This network has proven to be a valuable means for extending evaluation and use of maicillo germplasm outside Central America. It has accelerated the discovery of useful traits like drought tolerance (e.g., SC1211-8, a derivative of Guatemalan Cacho de Chivo) and combined resistance to *C. scalariforme*, *C. sublineolum*, and *P. purpurea* (e.g., Billy/SC1370, Enano-23, Nance Dulce-79/SC1375, and Porvenir/SC1371). To date, 44 maicillo accessions have been placed in the TAMU-USDA Sorghum Conversion Program as an additional measure of conservation and to make this material available to breeders in the temperate zone.

Now that enhanced maicillo cultivars are being tested on-farm in Honduras, collection of maicillo has been linked to these demonstration plots. Participating farmers are routinely asked to contribute seed of their local varieties to the MC germplasm bank. Not only does this target the conservation of local varieties most likely to be replaced, but it also adds a dimension of cultivar performance to the collection.

Maicillo accessions are also shared among national programs. In December 1989, two unique photoperiod sensitive acquisitions were made in Guatemala with the assistance of ICTA counterpart Edgar Salguero. These were Maiz-Maicillo, an apparent 2-dwarf maicillo intercross that had been selected by a farmer, and Grano de Oro, a 2-dwarf large seeded, yellow endosperm kaura variety which probably was an introduction from the world collection in the mid 60s. Both varieties were seen growing in fields for the first time near Jutiapa and had begun to displace traditional cultivars. Not only do they exemplify the progressiveness of Guatemalan farmers to improve their crops through use of dwarf photoperiod sensitive cultivars, but they also remind us of the continual changes taking place in the genetic composition of local varieties.

In a similar effort, 62 maicillo accessions from national programs which had been passed to ICRISAT/Mexico for safekeeping, were received via Fred Miller. Although thirty were originally from the Honduran collection, six of these had been lost since their collection in 1975 and were restored; i.e., Cubano, Guanaco, Cabeza Apretada, La Paz Lado Oeste, La Paz Este, and San Bernardo I. Another seventeen were new acquisitions originating from El Salvador and Guatemala; i.e., Amarillo, Blanco, Chilazo Blanco, Chinanga, Criollo de Seda, Gringo, Guaymango, Jocoro, Maicillón, Mazatepeque Panameño, Piedra Parada, Pijón, Plano de Mazatique, Punta de Lanza, Texistepeque, and Viejo. Some of these obviously were named for the hamlet in which they were collected.

Presently, the maicillo accessions are being evaluated at the EAP for their reaction to A1, A2, and A3 male sterile inducing cytoplasms. This work began in 1988 and results are being used to group accessions and to match parents in the maicillo breeding program. Evaluation of these test crosses also give insight into maicillo height and testa genotypes as well as combining ability. Most maicillo cultivars have $Ma_1\ dw_2\ B_1$ genotypes (single symbols represent homozygosity at the indicated loci) which is the converse in the majority of elite lines used in the United States. These major gene differences have complicated the improvement of maicillo.

In 1989, 48 maicillo accessions were evaluated for their reaction to A1 cytoplasm and 42 accessions were evaluated for their reaction to A2 cytoplasm. The A1 tester was ATx623 and the A2 tester was A2Tx632. Paired crosses, male and F_1 hybrid, were planted in adjacent head row plots. A late planting date, 13 Sep., was used to reduce plant height and synchronize flowering between pairs for backcrossing. Ten panicles were bagged in each F_1 plot before anthesis to determine percent seed set at maturity.

Results indicate that five accessions were male-sterile in A1 cytoplasm; i.e., Caturra-68, Chocolate-204, Corona-195, Apretado-187, and Coludo-110. Of these, Chocolate-204 and Corona-195 were also tested in A2 cytoplasm, but were partial sterile. Another 15 accessions restored both A1 and A2 cytoplasms; i.e., Gigante-16, Lerdo-104, Liberal-3, Liberal-6, Liberal-94, Maicillito-86, Norteño-71, Norteño-72, Paquete-197, Paragüe-8, Paragüe-135-6, Piña-61, dwMC-19, dwMC-31, and San Bernardo III. These sources may be used to develop elite male lines that restore more than one cytoplasmic system. Development of superior males that restore multiple cytoplasms will add flexibility in hybrid breeding programs and facilitate the establishment of alternative cytoplasms that will reduce genetic vulnerability. A summary of results to date is presented in Table 1. One maicillo, Liberal-63, restored A3 cytoplasm in tests conducted in 1988, but this reaction has not been confirmed.

Table1. Profile of maicillo reaction to three male sterile inducing cytoplasms as of 1989.

Cytoplasm	n	Sterile	Partial sterile[1]	Fertile	Segregating
A1	78	11	26	31	10
A2	57	3	27	25	2
A3	17	13	3	1?	0

[1] 5% to 75% seed set

Maicillo Enhancement

Cultivation of uniform varieties and hybrids over vast areas reduces genetic variability and increases the risk of crop loss. The introduction and release of elite cultivars adds to this problem when landrace populations are displaced. In an effort to conserve maicillo genetic diversity, the Honduran sorghum improvement program has focused on the introgression of exotic genes into maicillo populations rather than replacement of local varieties. This process is called maicillo enhancement and provides several advantages in sustaining sorghum production. First, it preserves traditional sorghum-maize intercropping systems upon which many subsistence farmers depend. Second, maicillo genetic diversity is increased. Third, enhanced maicillo cultivars provide a broader genetic defense against insect pests and diseases because they are buffered with genes that have coevolved with these indigenous populations.

Specific breeding objectives. Traits being transferred to maicillo include tan plant color (*ppqq*) for improved tortilla quality; resistance to *Cercospora sorghi, Puccinia purpurea*, and *P. sorghi* for greater yield stability and improved forage quality; and reduced plant height for higher yield potential. Maicillo traits maintained include sensitivity to photoperiod, shade tolerance, and cereal properties for tortilla utilization. Photoperiod sensitivity is essential for traditional intercropping with early maturing maize.

Because of height, maturity, and testa genetic differences between maicillo and U.S. cultivars, large F_2 populations are required to select desirable phenotypes. In order to increase selection efficiency, another objective has been to develop the enhanced maicillo germplasm bank which consists of maicillo x exotic derivatives. Currently, this gene pool has 115 entries, each is designated with a dwarf maicillo variety (DMV) number. Entries are primarily 2- and 3-dwarf photoperiod sensitive varieties consisting of 25 to 75% maicillo germplasm. The DMV varieties bridge the gap between maicillo and exotic materials and increase the probability of selecting desirable phenotypes. Like the maicillo accessions, they are being evaluated for their reaction to A1 and A2 cytoplasms plus their height and testa genotypes. This will permit more efficient use of these materials.

Selection methods. Multilocation testing is used to select breeding materials for wide adaptation and resistance to multiple diseases. This past year, early generation materials were evaluated in head row plots at La Lujosa (4237 plots), Las Playitas (4625 plots), and Rapaco (5940 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, shade tolerance, and MDMV were selected at Rapaco.

In order to select for shade tolerance, the F_3 enhanced maicillo nursery was intercropped with maize at Rapaco. The F_3 generation was used instead of the F_2 because it permitted evaluation on a head row basis. This reduced the probability of selecting individuals which escaped competition due to a gap in the maize row. The native maize population, Maicito, which is shorter and earlier than commercial maize hybrids was planted 12 days before the sorghum nursery. The F_3 lines were then sown on 20 June 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. An increased incidence of viral diseases in Rapaco was evident and this was attributed to the presence of maize which attracted insect vectors. Selection of this nursery was based on maturity, plant stand, yield and white seed color.

Observation of F_2 populations revealed that substantial progress can be made with enhanced maicillo intercrosses. This is because segregation for height, maturity, and testa genes is reduced, thus allowing a greater number of desirable plants to be evaluated for other traits like resistance to foliar diseases, drought tolerance, and yield potential. Several outstanding, white seeded, tan plant populations with fairly uniform height and maturity were produced from maicillo intercrosses. These food-type populations were: [81EON31(81LL691*Billy)-9]DMV180, DMV171(81EON69*SBIII)-15, and DMV180(81EON69*S.B.III)-15. Other noteworthy food-type populations were 82EON112*DMV193, Dorado(CS3541*Liberal)-6, and (77CS1*Billy)*IS3443. The zerazera line IS3443 was one of 29 downy mildew resistant sources introduced from ICRISAT Center in 1987. Not only is this line resistant to pathotype 5 of *P. sorghi* at Las Playitas, but it also has excellent grain quality, resistance to foliar diseases, and combining ability. Its use in the breeding program will be extended.

CLAIS nursery. In an attempt to get these materials and others into the hands of national collaborators, 165 F_3 lines representing 63 families were placed in the 1990 CLAIS dwarf maicillo nursery. This is a Salvadoran, Guatemalan, and Honduran collaborative nursery created for the purpose of distributing photoperiod sensitive breeding material between national programs. El Salvador contributed 100 lines and Guatemala 147 lines. The number of entries was kept low so as not to overburden the modest budgets of national programs. Inspection of pedigrees indicates that both El

Salvador and Guatemala are incorporating a substantial amount of Honduran materials into their programs.

Cultivar performance. In addition to providing early generation materials that can be selected according to each country's agenda, advanced materials were also distributed via the International Improved Maicillo Yield Trial (IIMYT). This trial features the best enhanced maicillo cultivars developed to date and extends their evaluation for adaptation and yield into environments in El Salvador and Guatemala. The 1989 IIMYT consisted of 40 treatments, 14 of which were new enhanced maicillo varieties (DMV188 and above), and five were new experimental hybrids. One copy of this test was distributed to each national program in El Salvador and Guatemala.

Results of the 1989 IIMYT were obtained from five locations: El Zamorano, La Lujosa, Las Playitas, and Rapaco in Honduras and Jutiapa in Guatemala. The Salvadoran location was not harvested because of an outbreak of guerilla hostilities which prevented researchers from traveling to the fields at harvest. As in previous years, TAM428*Porvenir and TAM428*San Bernardo III derivatives showed superior yields which ranged from 3.9 to 4.3 t/ha (Table 2). However, the top of the test was the photoperiod sensitive hybrid A(Redlan*Coludo 110)-3*DMV194 which yielded an average of 4.6 t/ha. Both parents of this hybrid were maicillo derivatives which suggests photoperiod sensitive hybrids are a viable alternative for maximizing yields in the tropics.

Grain samples from the 89IIMYT grown at La Lujosa were sent to the Cereal Quality Laboratory at TAMU for analysis. Several properties were evaluated, but only the laboratory report for kernel hardness, nixtamal color, and protein content is presented in Table 2. Based on visual evaluation of the dry nixtamal, the tan plant cultivar DMV195, with pedigree (SPV346*Gigante Pavana)-1-1-2 F_7, was judged as having the grain with the best tortilla quality. Because this variety also comes close to meeting other breeding objectives like increased yield potential, disease resistance, and tortilla quality, it will be increased for on-farm demonstration plots in 1991. Experimental hybrids (Redlan*Coludo)*DMV194 and ATx631*DMV180 are also scheduled for increase for on-farm evaluation in 1991.

Growth analysis. There is a prevailing consensus among agricultural scientists that the big advances in yield have not come from increased production of photosynthate, but rather from its redistribution in which seeds received more and stalks less. One breeding objective that we have pursued aggressively has been the reduction of plant height which in effect reduces the size of the stem sink relative to the grain sink. Numerous field tests have shown that maicillo grain yield can be increased 30 to 60% by simply shortening plant height from a 1- to a 2-dwarf genotype (a 1-dwarf genotype has a recessive gene pair at one of the four known height loci, whereas a 2-dwarf has two recessive gene pairs). However, the question of whether crop growth rate (CGR) was affected by this conversion has not been investigated.

In an effort to elucidate the growth of maicillo, Patricio Gutiérrez conducted his Ingeniero Agronomo thesis on this topic at the EAP. Three sorghum cultivars were used: the enhanced maicillo variety DMV 143 with pedigree (TAM428*San Bernardo III)-23 F_8, its maicillo parent San Bernardo III (SBIII), and the commercial grain sorghum hybrid DeKalb DK64. Because we were also interested in the effect of maize intercropping on sorghum growth and development, these cultivars were evaluated in both pure stand and *casado*. *Casado* means "married" in Spanish and is a common intercropping system in southern Honduras which derives its name from the simultaneous sowing of maize and sorghum in the same hill. Maicito was the landrace maize population used in the *casado* treatment.

Significant genetic differences between the sorghum cultivars begin with their height and maturity genes. These are major growth regulatory genes. DMV143 is a 2-dwarf (dw_1 Dw_2 Dw_3 dw_4) photoperiod sensitive (Ma_1) variety, SBIII is a 1-dwarf (Dw_1 dw_2 Dw_3 Dw_4) photoperiod sensitive (Ma_1) variety, and DK64 is a 3-dwarf (dw_1 Dw_2 dw_3 dw_4) photoperiod insensitive (ma_1) hybrid.

The experimental design was a randomized complete block arranged as a split-plot. The intercropping system was the main plot effect, with sorghum cultivars as the split-plot. Each treatment combination was replicated four times. Because of the intercropping treatment, the sorghum plant population was established at three plants/hill (75,000 plants/ha) and maize was established at two plants/hill (50,000 plants/ha). Hills were planted at 50 cm intervals on 80 cm row widths. The surface area for each main plot was 554.4 m^2 (21 x 26.4 m), while the area for each split-plot was 184.8 m^2 (21 x 8.8 m). Two adjacent hills in each split-plot were sampled weekly at random to determine total dry matter. Grain yield was calculated from a 3.2 m^2 sample taken after maturity from each treatment. A logistic growth curve was used to model the phytomass accumulation and CGR of each treatment combination. Due to a 25 percent incidence of SDM in SBIII, comparison of growth parameters between SBIII and the other cultivars which were resistant will not be made.

Results of this study reveal several interesting aspects about maicillo growth. First, SBIII sustained its total phytomass and grain yield in *casado* (Table 3). Landrace populations are generally characterized as having low but stable yield, and in this study SBIII was no exception. Its phytomass and CGR_{max} remained about the same, regardless of the system (Table 3). Interestingly, SBIII sustained its phytomass in *casado* by delaying the day on which CGR_{max} occurred (Table 3). This flexibility is due in part to its

Table 2. Performance of the 1989 IIMVT.

DMV	Pedigree	Grain[1] t/ha	Flower date	Height m	P1[2] %	P5[2] %	Rust[3] J	GLS[3] CM	Kernel[4] Hardness	Color[5] 1-5	Protein[6] %
F_1	A(Redlan*Coludo 110)-3*DMV194	4.6	17-Oct	3.0	0	6	4.0	2.8	78.8	3.5	9.6
184	(TAM428*Porvenir)-30-1 F10	4.3	24-Oct	2.1	0	1	1.8	2.6	81.5	4.0	11.1
198	(TAM428*Porvenir)-29-1 F9	4.0	28-Oct	2.3	0	1	1.5	2.1	83.5	2.0	10.9
137	(TAM428*Porvenir)-29-2 F8	4.0	22-Oct	2.1	0	1	1.5	2.8	81.4	4.0	9.9
165	(TAM428*San Bernardo III)-3-1 F8	3.9	16-Oct	2.7	2	7	1.8	2.1	77.0	3.5	11.0
143	(TAM428*San Bernardo III)-23 F8	3.9	26-Oct	2.3	0	1	2.5	2.2	87.6	4.0	11.8
F_1	ATx631*DMV180	3.9	8-Oct	2.4	0	2	1.5	1.9	85.2	-	12.4
189	(81LL691*Porvenir)-16-3 F9	3.8	31-Oct	2.1	0	3	1.5	1.8	88.7	1.0	9.5
F_1	A(Tx623*Pespire)-1*(CS3541*Lib.)-6	3.8	9-Oct	2.8	0	1	3.5	2.0	83.2	2.5	11.0
check	Peloton	3.8	8-Nov	3.1	7	11	3.0	2.9	50.8	4.0	8.6
177	(San Bernardo III*TAM428)-6 F9	3.7	28-Oct	2.5	0	1	2.0	1.7	78.8	3.5	12.5
191	(D71020*Pespire I)-5 F9	3.6	29-Oct	2.4	0	3	2.0	2.2	71.8	1.0	9.8
195	(SPV346*Gigante Pavana)-1-1-2 F7	3.6	31-Oct	2.6	0	2	1.8	1.8	88.6	1.2	11.7
197	(SPV346[81LL691*Billy]-7]-32 F7	3.6	30-Oct	2.6	3	2	1.5	2.3	80.2	3.5	10.3
107	(81LL691*Porvenir)-16-1 F7	3.4	4-Nov	2.4	0	1	2.0	1.8	85.9	1.5	10.6
F_1	A(Redlan*Coludo 110)-2*Peloton-99	3.4	28-Oct	3.5	2	5	3.5	2.4	84.3	4.0	10.0
169	(Billy*CS3541)-1-1-6 F3	3.2	20-Oct	2.0	0	2	1.5	1.9	74.6	2.6	11.9
192	(Peloton*TAM428)-3 F9	3.2	1-Nov	2.5	0	1	3.5	2.6	83.1	3.0	11.1
162	(TAM428*Peloton)-1-4-3 F8	3.1	23-Oct	2.0	0	0	2.0	2.8	78.8	4.0	13.3
002	Lerdo Ligero, Guatemala	3.1	4-Oct	2.6	2	0	-	3.2	76.0	5.0	13.2
check	Porvenir	3.1	9-Nov	3.3	24	25	3.0	2.5	78.6	3.0	10.9
194	(SC414-12*Piano Namasigue)-53 F8	3.0	31-Oct	2.4	0	1	3.5	2.5	79.3	3.5	11.6
196	(SPV346*Pelotón-99)-14-2-3 F7	3.0	3-Nov	2.3	0	2	1.8	1.6	88.5	3.0	9.7
check	San Bernardo III	2.9	27-Oct	3.0	25	31	3.5	2.8	83.4	3.0	9.9
201	[ICSV151(TAM428*Porvenir)]-18 F4	2.9	18-Oct	2.0	0	0	1.5	1.8	75.8	3.5	12.4
F_1	A(MB9*Lib.)-17*(SC326*Lib.)-22	2.8	21-Sep	2.4	0	0	3.8	2.3	80.8	4.0	13.0
200	[Gigante 16(Tx432*CS3541)]-8 F4	2.8	27-Oct	2.1	0	1	1.5	2.2	82.8	3.5	13.2
188	(79HW207*Liberal)-11 F8	2.7	21-Oct	2.2	12	29	3.0	2.2	78.8	4.0	11.2
109	(BTx623*Pespire)-1 F5	2.7	28-Oct	2.3	0	5	3.0	1.8	88.5	2.0	11.8
004	ES727, El Salvador	2.7	7-Nov	3.1	7	0	-	2.7	57.4	4.5	11.2
003	Variedad Blanca, Guatemala	2.7	15-Oct	3.6	0	1	3.0	2.1	89.8	2.6	10.7
171	(D71020*Billy)-48-2-3 F9	2.5	1-Nov	1.9	0	0	2.0	2.0	74.2	1.2	12.3
180	[(TAM428*GPR148 BC1)Billy]-24 F8	2.5	29-Oct	2.4	0	3	1.5	2.3	79.4	3.0	12.3
001	San Miguel #1, El Salvador	2.4	30-Oct	2.4	11	37	3.0	2.5	73.2	3.0	11.9
166	[(TAM428*S.B. III)Billy]-7 F8	2.4	6-Oct	1.7	0	0	3.0	2.3	70.9	4.5	12.1
182	(TAM428*Peloton)-8 F8	2.3	24-Oct	2.0	0	0	2.5	2.8	75.0	3.0	12.5
199	(Tx2803*MC40)-3 F5	2.3	21-Oct	2.3	0	3	4.0	3.3	87.7	3.5	12.8
190	(CS3541*Liberal)-4 F8	2.0	10-Nov	2.2	0	1	2.0	2.1	70.7	1.3	11.5
193	(San Bernardo III*TAM428)-1-6 F9	1.8	31-Oct	2.1	1	1	2.5	1.9	81.2	2.0	13.4
153	(SC414-12*Peloton)-2-2-bk	1.8	5-Nov	1.7	2	7	3.5	2.9	82.0	5.0	11.4
	Mean	3.1	25-Oct	2.4	8	6	2.4	2.3	79.4	3.1	11.4

[1] Mean of five locations: La Lujosa, Choluteca; El Zamorano, Francisco Morazán; Rapaco, El Paraíso; and Las Playitas, Comayagua (CM) all in Honduras, and Jutiapa (J) in Guatemala.

[2] Percent infection of systemic sorghum downy mildew caused by pathotype P1 of P. sorghi at El Zamorano, Terrace #7, and the more virulent P5 at Las Playitas, Comayagua.

[3] Based on a scale of 5, where resistant = 1 and susceptible = 5. GLS = Grey leaf spot caused by Cercospora sorghi.

[4] Percent weight removal after milling of 20 g sample for 4 min. in a Tangenitial Abrasive Decorticator equipped with a 12 hole base.

[5] Subjective evaluation of dry nixtamal using a scale from 1 = light, clean yellow to 5 = dark, dirty yellow color.

[6] Protein (N x 6.25) is expressed in dry weight basis.

photoperiod sensitivity or dominant maturity genes. Because most subsistence farmers are adverse to risk, they tend to select for yield stability rather than increased yield. This artificial selection for stability, coupled with maize intercropping, probably best explains why maicillo has evolved into some of the latest maturing sorghum in the world.

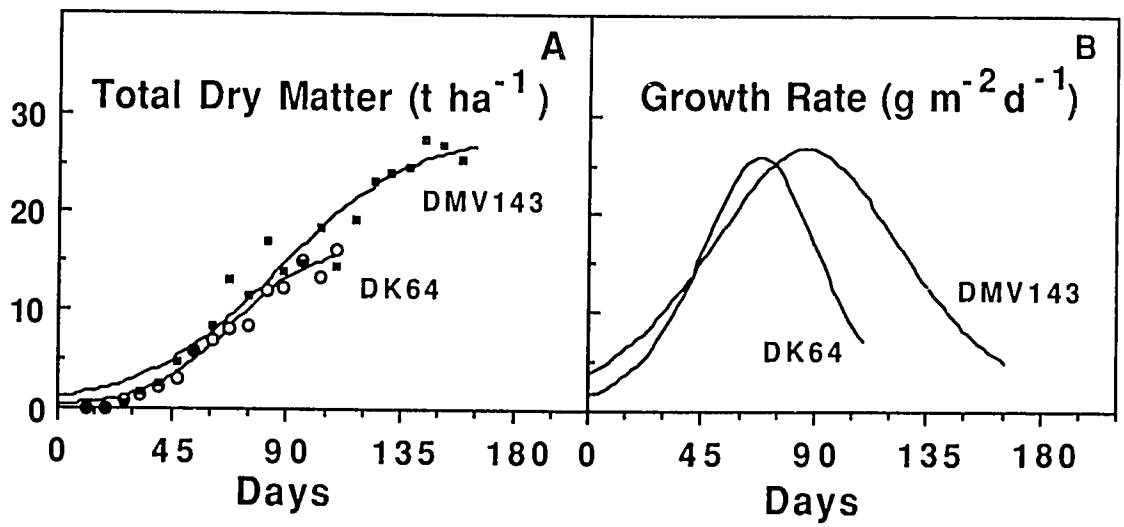
Second, there was no evidence under the conditions of this study that suggests the enhanced maicillo variety (26.5 g m^{-2} d^{-1}) has a greater CGR than the commercial hybrid (25.7 g m^{-2} d^{-1}) in pure stand. Even though total phytomass of DMV143 (28.0 versus 16.6 t/ha) was greater (Fig. 1a), this was attributed to its photoperiod sensitivity which sustained a high CGR for a longer period of time (Fig. 1b). Considering that production of phytomass by photoperiod

Table 3. Total dry weight, maximum crop growth rate, and the day of its occurrence for three sorghum cultivars in pure stand and casado intercropping systems.

	Grain yield		Total dry weight		Days to CGR_{max}		CGR_{max}	
Cultivar	Pure stand	Casado	Pure stand	Casado	Pure Stand	Casado	Pure Stand	Casado
	----- t ha^{-1} -----		----- t ha^{-1} -----		----- days -----		----- g $m^{-2}d^{-1}$ -----	
DK64	4.54 ab[1]	1.56 c	16.6 d	6.6 e	69 e	68 e	25.8 a	9.5 d
SBIII	3.34 bc	2.69 bc	22.2 b	21.9 b	98 c	117 a	20.0 b	19.9 b
DMV143	6.39 a	3.96 b	28.0 a	17.5 c	87 d	104 b	26.5 a	19.1 c

[1] Means within a parameter followed by the same letter are not significantly different at a probability of 0.05 according to Fisher's LSD.

Figure 1. Dry matter accumulation and crop growth rate of a photoperiod sensitive variety (DMV143) and insensitive hybrid (DK64) in pure stand in Zamorano, Honduras.



insensitive types is restrained by partial plant coverage of the ground during a relatively short growing season, photoperiod sensitivity can be managed in the tropics to extend the duration of the full crop canopy. Effectively, this would increase the net amount of solar energy captured, reduce the net amount of CO_2 in the atmosphere, and increase total phytomass produced. Considering the growing need to identify alternative sources of energy, photoperiod sensitivity in sorghum may open the door to farming sorghum for fuel in the tropics.

Third, both maicillo cultivars attained a CGR in *casado* which was twice as high as DK64 (Table 3). Since growth depends on the photosynthetic activity of the whole plant exceeding its total respiratory load, this is the first quantitative evidence reported that supports our claim that maicillo has a lower respiration rate than other sorghum. Previously, it was assumed that maicillo had a lower respiration rate because of its unique ability to withstand shading in maize intercropping systems. Contemplated studies include screening the MC and DMV germplasm banks in maize intercropping to identify superior shade tolerant materials and measurement of respiration rates of selected materials under controlled conditions.

If maicillo does indeed have a lower respiration rate, then it would be possible to increase the growth rate by reducing respiration. The introgression of these genes into commercial hybrids could conceivably create a new generation of sorghum with a higher yield plateau, just as the introgression of yellow endosperm germplasm into parental lines did in the late 60s. The impact on yield of yellow endosperm germplasm has been attributed to lengthening the duration of grain fill.

Hybrid Maicillo

Performance of maicillo hybrids in multilocation yield trials (Table 2) indicates that photoperiod sensitive hybrids will increase sorghum productivity over local varieties. Maicillo hybrids contrast strikingly with conventional hybrids; particularly, in appearance and management. They are taller, later maturing, and consequently have a greater largeness in scale and production of 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 current breeding goal is to create 2- and 3-dwarf photoperiod sensitive parental lines that make use of complementary height genes to restore acceptable plant height in hybrids. Once developed, height genotypes will be identified and field tests will be conducted to determine which 2-dwarf height combinations optimize yield. Conventional female parents make excellent hybrids when crossed to enhanced maicillo males; but, due to their insensitivity to photoperiod their hybrids are too early. Therefore, 3-dwarf, photoperiod sensitive, A1 and A2 male-sterile lines with tan plant color are being developed. Use of these females will increase farmer acceptance and will make commercial seed production economically feasible. Also, development of male-sterile lines in A2 cytoplasm will diversify the germplasm base and reduce genetic vulnerability; i.e., the threat of an epidemic occurring when the host population becomes a selective factor for the pathogen population.

Breeding methods. A paired progeny backcross method is employed to develop male-sterile lines and an off season nursery (Jan-May) is utilized to complete two generations per year. In addition to making three to five paired backcrosses per line, 10 to 12 female panicles are bagged before flowering to determine percent sterility at harvest. Lines with partial seed set are discarded. Test crosses are also made with the 3-dwarf lines, AN23 (Dw_1), ATx631 (Dw_2), ISIAP Dorado (Dw_3), and SC40-9 (Dw_4), to determine height and seed color genotypes.

Discussion. Sterilization of elite maicillo derivatives began at the EAP in 1986. Of the 151 A-lines that completed five backcrosses in 1989, 32 were selected for additional testing. These females were derived from the families: BTx623*Pespire I (n = 3), MB9*Liberal (n = 8), and Redlan*Coludo-110 (n = 21). They will be grown at El Zamorano (820 meters above sea level) and La Lujosa (45 meters above sea level) during the 1990 regular season and evaluated for stability of sterility. Test crosses will also be made with two enhanced maicillo males [DMV194 and (CS3541*Liberal)-6] to obtain seed for a combining ability test. Release of several A-B pairs will follow once merit is proven. Other B-lines are also being sterilized; these include 60 A1 BC_1 pairs, 34 A2 BC_1 pairs, 26 BC_3 pairs, 59 BC_4 pairs, and 65 BC_5 pairs.

In addition to testing five maicillo hybrids in the 89IIMYT, another five hybrids were evaluated in the 89CLAIS regional yield trials. Two of these hybrids were top of the test at El Zamorano. Their pedigrees were A(Tx623*Pespire)-1*[81EON31(81LL691*Billy)]-1 (4.7 t/ha), and A(MB9*Liberal)-17*(Criollo*CS3541)-10 (4.3 t/ha). Third on the list at El Zamorano was DMV179 with 4.3 t/ha. As mentioned above, this variety will be tested on-farm in 1990.

On-Farm Research

The purpose of our on-farm research is to introduce farmers to new technologies that will increase sorghum productivity. However, this activity also plays an integral role in maicillo conservation. It is through on-farm research that enhanced maicillo varieties are returned to the field. Once adopted, conservation *in-situ* begins. Unlike cold storage gene banks, conservation *in-situ* is dynamic. Genotypes change because of spontaneous mutation, outcrossing, and farmer selection; thus, evolution continues. The Guatemalan variety Lerdo Ligero is an example of how *in-situ* conservation works. Lerdo Ligero is a 2-dwarf photoperiod sensitive hegari type that was first seen in farmers' fields in 1985. It is believed to have originated from a maicillo outcross with Guatecau, which was released in 1974. Both Guatecau and Lerdo Ligero share a common marker gene, the recessive spreader (s). This allele has yet to be found in maicillo accessions. Likewise, its name is testament to its origin. In Spanish, Lerdo Ligero means late-early. Farmers call it Lerdo Ligero in reference to its maturity which is later than introduced varieties but earlier than maicillo. This characteristic is indicative of maicillo outcrosses with introduced varieties. Jokingly, researchers in Guatemala call it the "contradiction"; but all things aside, its name reflects a special intimacy that subsistence farmers share with their plants.

Methods. Much of our on-farm success depends on the human resources and infrastructure of the extension agencies of the MNR and LUPE. The HSP works with these agencies as a catalyst by providing seed, technical expertise, and coordination. This approach has worked reasonably well during the last two years and has reduced duplication of effort and increased efficiency. Evelyn Oviedo coordinated the 1989 on-farm activities with the MNR extension service. Unfortunately, LUPE did not participate fully, because it was in transition from the Natural Resource Management project to LUPE. Its absence greatly reduced the number of demonstration sites.

Because farmers have different attitudes towards risk, demonstration plots with graduating levels of technology were used to obtain crucial information for determining potential impact at different technology levels. The 1989 on-farm trials consisted of four treatments: T1 = local variety and traditional practices; T2 = improved variety and traditional practices; T3 = improved variety and insecticide seed treatment (furathiocarb); and T4 = improved variety, seed treatment, and urea applied at floral differentiation. Treatments were planted in 144 m^2 plots. Replications within sites were not used in order to maximize the number of sites.

Three enhanced maicillo lines were tested in southern Honduras: DMV134 = (TAM428*Porvenir)-20-2-6, which was selected for its resistance to SDM; DMV143 = (TAM428*SBIII)-23, selected for its yield potential; and DMV150 = (81LL691*Porvenir)-16 which was selected for its tan plant color and cereal quality.

Discussion. This was the first year in which enhanced maicillo cultivars were tested on-farm. Consequently, it marks the beginning of a new era for traditional sorghum in Honduras. In general, these cultivars are 0.5 to 1.5 m shorter, two to three weeks earlier, and 30 to 50 percent higher yielding than their maicillo ancestors.

Yield data were obtained from 16 sites and as expected variability between sites was high (Table 4). In part, this was due to differences in management practices and environments. There is a popular belief that improved cultivars do well only under favorable conditions and that they require the use of inputs. The design of the on-farm trials allows us to look at this question, and results indicate that the enhanced maicillo cultivars performed just as well, if not better, than the local variety under the same low input conditions (T1 vs T2, Table 4). However, the magnitude of their yield advantage increased when seed was treated with a systemic insecticide, as in the case with DMV134, and when 60 kg N/ha was applied at floral differential, as in the case with DMV143. These results demonstrate the superiority of improved germplasm at both ends of the input scale and strike a blow against the persistent belief that improved germplasm does not perform as well as traditional varieties when grown under traditional management. The DMV150 variety did not preform as well as hoped. In part , this was because it was planted in locations where *Luecaena* spp. was being promoted as a source of firewood. Between the shading of the maize and the *Luecaena* trees, its performance was restrained as well as the local variety's.

For the most part, farmers like the enhanced maicillo cultivars. Many of them saved seed to plant in 1990, some even sold seed to neighbors who were interested in planting it as well. Because enhanced maicillo has begun to work its way into informal markets, it promises to change the traditional sorghum landscape. One case in point is Dionedes Paz who lives along a gravel road near El Carreto, Alianza. He was one of Hector Portillo's collaborators in the population dynamics study of the langosta complex. From his small test plots, which were planted to a (TAM428*Porvenir) derivative, he harvested 6 qq of grain. He used the grain to make "good" tortillas and to feed his pigs and chickens which were kept around the house. He also saved enough seed to plant 1 ha in 1990. He liked the yield potential of the enhanced maicillo and the fact that it was slightly earlier which enabled him to sell the grain while the price was still high. Other farmers have said they like the shorter stature because the entire family could help harvest.

Fall Armyworm and the Langosta Challenge

The lead INTSORMIL project for developing a control strategy for the langosta complex is MSU-105. Both Keith Andrews (MIPH/EAP) and Dan Meckenstock have become adjunct associate professors at MSU in order to serve as committee members for MSU-105 graduate students conducting research in Honduras. A two pronged attack based on development of host plant resistance and study of the biology and population dynamics of the insect pests has been put in place to address the langosta problem. Most of the research is conducted in Honduras by Honduran graduate students. This past year, MSU donated a Chevrolet model S10 pickup to the EAPs sorghum project so that graduate students would have better access to on-farm sites in southern Honduras. Local currency obtained through the PL480 Title I program is used to support their research in Honduras.

Antibiosis to the fall armyworm. Antibiosis is the adverse effect of the plant on the biology of the insect and entails reduced fecundity, decreased size, abnormal length of life, and/or increased mortality. In 1986, MSU graduate student Marco Castro discovered that some maicillo accessions (San Bernardo III/SC1207, Hilate-179, Lerdo-104/SC1384, and Piña-61/SC1385) manifest antibiosis to the fall armyworm through reduced pupal size and therefore reduced fecundity. He characterized their effect as different from that of AF28 which worked through increased mortality. Currently, MSU graduate student Julio Lopez, is following up Marco's work and is trying to identify AF28 and San Bernardo III combined sources of resistance.

In 1988, Julio screened 62 (AF28*San Bernardo III) F_3 lines for resistance to fall armyworm in the field at the EAP.

Table 4. Farm level performance of three enhanced maicillo varieties compared to traditional varieties and practices in southern Honduras, 1989.

Technology level	DMV134		DMV143		DMV150	
	Grain	C.V.	Grain	C.V.	Grain	C.V.
	t/ha	%	t/ha	%	t/ha	%
T1: Traditional variety and practices	1.1	47	0.8	--[1]	0.6	47
T2: Enhanced variety with traditional practices	1.3	17	1.2	64	0.5	57
T3: T2 with seed treatment	1.5	27	1.2	63	0.5	52
T4: T3 with 60 kg N/ha, urea	1.6	40	1.8	35	0.5	61
	n=9		n=3		n=4	

[1] Insufficient data to calculate, traditional variety harvested only at one site..

This test was repeated in 1990 on 56 F_4 bulk selections of the same material. In both years, lines were replicated in 3 m row plots with an average of 21 plants per row. The bazooka method was used to artificially inoculate plants with approximately six fall armyworm larvae (first and second instar) per whorl. Visual leaf damage ratings, based on a scale of 10, were made once maximum damage was observed in the susceptible check Cacho de Chivo (Table 5). In 1988, plants were inoculated 35 and 50 days after planting and mean leaf damage ratings of the two inoculations ranged from 1.4 to 4.1. The test was repeated in 1990 on F_4 bulk selections, and inoculations were made about 17 and 24 days after planting. A native maize population, Maicito, was added to the 1990 test as an additional check. Mean leaf damage ratings ranged from 2.5 to 7.7. These ratings were higher than those obtained in 1988 and are attributed to younger plant age at time of inoculation. Based on two years data, (AF28*San Bernardo III)-23 showed the best and most consistent resistance. This line and others will be selected for larval feeding trials to determine if resistance has been combined. Ideally, genotypes with combined sources of resistance will produce a higher larval mortality rate and lower pupal weight than either parent.

Table 5. Subjective leaf damage rating of fall armyworm on a scale of ten.

Pedigree	1988(F_3)	1990(F_4)
(AF28 x SBIII)-28-bk	1.8	2.5
AF28 (resistant check)	2.1	4.4
San Bernardo III (resistant check)	2.6	6.1
Cacho de Chivo (susceptible check)	2.9	6.5
Maicito (maize check)	--	7.5
mean	2.7	5.5
n (includes checks)	69	70
Root MSE	0.9	1.8
range	1.4 - 4.1	2.5 - 7.7

Population dynamics. Hector Portillo, also an M.S. degree candidate at MSU, is studying the population dynamics of the langosta on-farm in southern Honduras. The occurrence of the lepidopterous pest complex or langosta on sorghum and maize creates the illusion that the component species exist conjointly. However, population dynamic studies carried out in 1988 and 1989 of the four insect species on both weeds and crops indicate that the complex is the product of a fine-grained mosaic of different microhabitats, each supporting a well adapted successful species (see the entomology MSU-105 chapter in this report for more details). Except for *S. frugiperda*, sorghum and maize apparently serve as a sink habitat where the net lepidopterous population decreases, and survival and population increase depends on nearby noncrop source habitats. Because of the geographical and biological diversity involved, controlling the langosta is a formidable challenge. Although many farmers spray their crops after the langosta has arrived, this has little effect on the core population of *S. eridania* and *M. rogenhoferi* 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 must 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 insect pests in the source habitat, but it is unlikely that subsistence farmers will forego these costs.

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 is the case with weed control which reduces the population of *M. latipes* but increases the population of *S. frugiperda*, a greater understanding of the ecology behind the complex is required before an effective technological control package can be developed. Strategies that include host plant resistance, seed treatment, and weed control are currently being evaluated on-farm. Other areas of on-going research include host oviposition preference of moths, feeding preference studies including young and old plant tissues, and parasitization of larvae.

Control of Sorghum Downy Mildew

Sorghum downy mildew presents a real threat to the sustainability of sorghum production in Honduras. Control of this disease is based on monitoring "hot spots" for changes in virulence and development of resistant cultivars. Monitoring of pathogen virulence is conducted with the SDMVN test which consists of ten differential lines provided by TAM-124. To date, pathotypes 1 and 5 have been identified in Honduras. In 1989, this nursery was planted at Argelia, El Zamorano, Las Playitas, and Rapaco. Pathotype 1 (as defined by Tx7078 and Tx2356) was predominant at Argelia, El Zamorano and Rapaco, but the more virulent pathotype 5 (as defined by SC414-12E) was predominant at Las Playitas. No change in pathogen virulence was apparent. This is the first time that pathotype had been determined at Argelia and Rapaco. Argelia is situated in the Jamastrán valley of El Paraíso. Downy mildew was first observed in Rapaco in 1988.

Commercial Hybrid Performance Test

Privatization of the seed industry in Honduras has caused a proliferation of seed companies and an increase in the number of hybrids available. In an attempt to promote the use of these hybrids and to increase sorghum production, the NSP initiated a statewide commercial hybrid performance test in 1989. This test was coordinated by Francisco Gomez and consisted of 24 hybrids produced by six companies (Agridec, Asgrow, Dekalb-Pfizer Genetics, Delta & Pine, Pioneer International, and the MNR). The test was conducted at the agricultural experiment stations in Choluteca, El Paraíso, Comayagua, and Olancho which are situated in major sorghum production areas. Field days were held at several of these locations so that sorghum producers could become familiar with the production potential of these hybrids. Results were published in the technical report SRN/EAP-1 *Comportamiento de Sorgos Graniferos, 1989* and 1,000 copies were distributed to vendors, extension agents, and MNR officials.

It was evident from this first year that the performance test plays an integral role in increasing sorghum production in Honduras. First, it acquainted farmers with available hybrids and identified local seed dealers. Second, it supplied farmers with unbiased information for choosing the hybrid that best suited their needs. Third, fledgling seed companies used it to select brand name hybrids for importation that were adapted to conditions in Honduras. Fourth, it provides quarantine officials with current information on resistance to downy mildew.

Forage Sorghum

One major environmental concern in Latin America has been the deforestation resulting from government and private programs to resettle farmers and to increase livestock production. In an effort to assist the intensification of land use which would help relax this trend without reducing livestock production, the HSP is working on the release of Ganadero, a SDM resistant sorghum-sudangrass hybrid with pedigree ATx623*Tx2784. In 1989, the EAP produced 169 qq of Ganadero seed which was sold to farmers in order to test their acceptance.

Star grass (*Cynodon nlemfuensis*) is a popular pasture in Honduras, and cattlemen frequently ask how Ganadero compares to star grass. In an effort to determine the carrying capacity of Ganadero and its feeding value, Guillermo Miranda conducted his *Ingeniero Agronomo* thesis on this topic at the EAP. Pastures of 2.1 ha were established for each species and then fenced into four lots/replication of equal size. Eighteen month old Brahma x Beef Master and Holstein x Brahma crossbred calves were used. The average initial weight was 270 kg. Because this study was performed under dryland conditions, insufficient rainfall caused premature termination of the star grass component. However, under moisture stress conditions, Guillermo determined that the carrying capacity of Ganadero was 6 calves/ha for three pasturing cycles. The total forage dry matter production of Ganadero was 6.7 t/ha which contained an average of 7.5% crude protein with 62% digestibility. The average weight gain was 0.47 kg/day/animal.

Publications and Presentations

Publications

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Vargas, R.E. 1990. Economic analysis of the effect on plant density and level of fertilization on sorghum hybrid DK64 (In Spanish). Ing. Agro. Thesis. Panamerican Agricultural School, El Zamorano, Honduras.

Presentations

Gomez, F. Cultivation and improvement of sorghum in Honduras. Presentation at the 7th Annual CLAIS Meeting, 24-27 Apr. 1990. CIMMYT, El Batán, Mexico.

Networking Activities

Workshops Attended

Participated in the seventh annual CLAIS Meeting, 24-27 Apr. 1990. CIMMYT, El Batán, Mexico.

Research Investigator Exchanges

Both Julio Lopez and Hector Portillo, M.S. degree candidates at Mississippi State University (MSU-105), were employed by the EAP for three months (May-Aug. 1990) to collect data for their research problems. Mr. Lopez worked on fall armyworm antibiosis and Mr. Portillo worked on the langosta lepidopterous pest complex.

Meckenstock traveled to Guatemala 14-19 Dec. 1989 to meet with Edgar Salguero and take notes on the 89IIMYT and Honduran entries in the 89CLAIS nursery which were planted in Jutiapa.

Several team visits to Honduras were received: First, the ICRISAT team, 19-23 Nov. 1989, was welcomed and shown research sites in Choluteca, Comayagua, El Zamorano, and Rapaco. Team members were Tom Hash (Mexico), Louis Mughogho (India), Tunde Ovilana (Zimbabwe), Compton Paul (Mexico), and René Clará (Mexico).

Second, the INTSORMIL team visit, 29-Nov. to 5 Dec. 1989, was welcomed and reviewed research sites. Members included Max Clegg (UNL-113), Delroy Collins (TAM-124), Fred Miller (TAM-121), Gary Peterson (TAM-123), Darrell Rosenow (TAM-122), and Tim Schilling (ME). Craig Anderson, USAID/ARDO officer, also attended the field trip to Choluteca.

Third, the Purdue team visit by John Sanders and Miguel Lopez, 22-24 Jan. 1990, was received. The purpose of this visit was to follow up Miguel's research and present his findings to LUPE and MNR administrators and extension agents. Agricultural officers in A.I.D/H were also informed of Miguel's results.

Germplasm and Research Information Exchange

Germplasm Exchange

The following basic seed was sent to Francisco Gomez for use in the 1990 on-farm demonstration plots:

Designation	Pedigree	Gen	kg
DMV 179	(SPV346*Gigante Pavana)-1-1-2	F_8	10
DMV 180	{[(TAM428*77CS3)GPR148]Billy}-24-1-2	F_9	3
DMV 197	(TAM428*Porvenir)-29-1-1-bk-bk-1-bk	F_{10}	10
DMV 106	(81LL691*Porvenir)-16-bk	F_{10}	3

Ten pounds of DMV143/(TAM428*San Bernardo III)-23 seed was sent to Hector Portillo for use in the validation of new technology for the control of langosta in Valle, Honduras.

Eight pounds of ATx623*SC414-12 F_1 seed was sent to Lindolfo Fernández to be used as the spreader row in the sorghum downy mildew nursery at Las Playitas, Comayagua.

Ten pounds of Ganadero seed was sent to Guillermo Miranda for his *Ingeniero Agronomo* thesis. Ganadero is an experimental sorghum-sudangrass hybrid that is in its final stages of testing before release.

Breeder quantity seed of 10 maicillo accessions and 10 enhanced maicillo cultivars was sent to Lynn Gourley for evaluation and use in Kenya. Likewise, three maicillo accessions and three enhanced maicillo cultivars were sent to Keith Schertz for evaluation in A2 and A3 cytoplasm.

Seed Production

Basic seed of the following cultivars was produced: ATx623 (12 kg), BTx623 (1 lb), ATx631 (55 lbs), BTx631 (18 lbs), SC414-12E (1 lb), ATx623*SC414-12 F_1 (17 lbs), DMV106 (40 lbs), DMV143 (25 lbs), DMV179 (25 lbs), DMV180 (18 lbs), DMV197 (40 lbs), San Bernardo III (20 lbs), and Porvenir (17 lbs). TAM428*Porvenir/DxN/ (25 lbs).

Assistance Given

Travel was provided Francisco Gomez (MNR) and Alejandro Palma (EAP) to attend the 7th Annual CLAIS Meeting, 24-27 Apr. 1990. CIMMYT, El Batán, Mexico. Dr. Gomez was elected president of the CLAIS Steering Committee, Meckenstock was named as an advisor to the Committee.

Travel was provided Lindolfo Fernández to visit TAMU 6-18 May 1990 to learn downy mildew inoculation techniques. He also observed sorghum nurseries in south Texas.

A remote telephone was procured for the La Lujosa experiment station. This will improve communications with Francisco Gomez who is stationed at La Lujosa.

An annual subscription to CAB Sorghum and Millets Abstracts and the following two books were donated to the EAP Library for student reference: *Sorghum* (1988, 2nd ed.) by Doggett, and *El Sorgo*, 1982 by L. House. Several reports and student theses were also sent to the EAP and MNR libraries.

Graduate Student Research and Training

Project TAM-131 cooperates with INTSORMIL PI's by providing ground support for graduate students conducting research in Honduras. This past year, Julio Lopez (MSU-105) and Hector Portillo (MSU-105) worked on various aspects of their research in Honduras.

Likewise, Patricio Gutierrez conducted his Ingeniero Agronomo thesis research with the sorghum project at the EAP on sorghum-maize intercropping systems.

Breeding Sorghum for Developing Countries

Project UNL-115

David J. Andrews
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Mr. Gilles Trouche, Sorghum Breeder, CNRA, Bambey, Senegal
Dr. Tom Hash, Sorghum/Millet Breeder, ICRISAT/CIMMYT Mexico
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
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Dr. J. D. Eastin, Physiologist, UNL-116, University of Nebraska, Lincoln, NE 68583-0817
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Summary

This project aims to use the variability created from crosses between two complementary germplasm groups--recently bred high yield tropical food quality sorghums and elite U.S. lines--in collaborative projects with LDC scientists and to produce lines for domestic use. Research commenced on the best type of tester to use to identify superior B-lines.

The collaborative breeding project has continued in Botswana, where progeny of crosses with drought tolerant Segaolane (and other similar varieties) and U.S. B-lines have succeeded through four years of selection including three years of severe drought. These progeny have potential as varieties per se or as seed parents, the production of hybrids being a supported objective of the national program. The progeny from these and other crosses are being further selected in the U.S., and tested for drought/heat tolerance. Segments of this material will support breeding programs in collaborating countries, and be released in the U.S. A range of INTSORMIL breeding material was tested in Senegal in a collaborative project with ISRA funded by USAID/Dakar.

The exotic introductions used in crosses were also selected and tested as varieties and hybrids and nurseries were provided to Botswana, Mexico, and Zimbabwe. Though generally taller and later maturing, the best of this material has yield potential at least equivalent to U.S. commercial hybrids but with superior food or feed grain quality.

Objectives, Production and Utilization Constraints

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, is supplied for selection in collaborative projects.

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. 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.

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 is 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 nonrestorers will be considered for producing new seed parents. Well adapted partial inbreds/lines are released as germplasm stocks/parental lines for use in the U.S.

The introductions are also tested for per se performance and in hybrid combinations for possible dissemination in international nurseries. However, these nurseries will eventually contain hybrids made with lines derived from the exotic x U.S. crossing program.

The research program provides opportunities and material for 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

U.S.

Breeding continued with the principal objective of producing a range of food quality seed parents. Evaluation commenced of their resistance to drought stress and combining abilities through test crossing. New genetic variability is being developed for the project through crosses with new exotic varieties from Senegal, large seeded accessions from the World Collection, and other leading INTSORMIL lines.

Hybrids made using maintainer lines of the potential seed parents were evaluated in a test on how best to determine combining ability. Yields indicated that the new lines do have good potential as seed parents for hybrids. Yields of 26 hybrids, using TX2721A_2 as a tester, ranged from 3500 to 5800 kg/ha compared to 5300 kg/ha for the best commercial hybrid check, while the average of four commercial hybrid yields was 4500 kg/ha. Heterosis of the hybrids over the lines tested averaged +34%. Other testers will be compared to determine the comparative worth of different types of testers.

Seventy-two potential B-lines were compared in a collaborative project with Kansas State University over four locations in Nebraska and Kansas, including an irrigated/dryland comparison at Garden City, Kansas. The general correlation of genotype performance over locations was not high, but certain individual genotypes did perform more consistently over locations. The results permitted the identification of 16 superior lines for inclusion per se and as hybrids in 1990 tests. An additional result of this collaboration with Kansas State University and because of the severe infestation of chinch bugs in 1988 and 1989, was the identification of two lines with good resistance to this widespread midwest pest.

Botswana

The process of developing adapted drought resistant seed parents from UNL-115 material continued as an integral part of the Department of Agricultural Research sorghum breeding program at Sebele. Eighty percent of the test crosses made on this material were male sterile. Lines being developed from other sources as varieties also gave good restorer reactions. The basis has, therefore, been developed to produce both male and female hybrid parents in the Botswana sorghum breeding program.

Dr. Louis Mazhani's Ph.D. dissertation research on the stability of different groups of sorghum genotypes in Botswana showed that single cross hybrids as a group, or blends (of hybrids, topcross hybrids and varieties, as groups) were higher yielding and generally more stable in performance across environments than topcrosses alone or composites, varieties and parental lines. The best two individual genotypes across the five diverse locations compared to variety Segaolane which averaged 2870 kg/ha, were a hybrid, SPL23A x SV1 at 3,640 kg/ha, and the blend of four hybrids at 3400kg/ha. The two hybrids were equivalent in yield to Segaolane in poor conditions but superior in better conditions with more moisture. The yield of the hybrid blend was higher than the average of the four component hybrids grown separately and this blend showed the best stability of performance across environments.

Senegal

Research support from INTSORMIL to ISRA's sorghum and pearl millet program continued as a component of the Senegal Agricultural Research Project (Grant No. 685-0957) from USAID-Dakar administered by Michigan State University. Results of sorghum research are reported in more detail in the Senegal country report. Briefly, sorghum varieties, hybrids and hybrid parent lines were supplied from Nebraska projects UNL-115 and 116 and Texas A&M projects TAM-121 and 122 for evaluation both in dryland experiments at Bambey and in two seasons in the Senegal river valley, where crop diversification is being sought from rice monoculture. Segregating populations were also supplied from project UNL-115 for selection at Bambey. Elements of all material supplied proved useful and were retained by the ISRA sorghum breeder for further testing. The principal conclusions from the first year's testing were that INTSORMIL seed parents can probably give higher yielding hybrids with Senegalese restorers, and that INTSORMIL germplasm has parental worth to diversify and improve the genetic base for sorghum breeding in Senegal. In the river valley, an existing line CE151-262 was confirmed as worth releasing when research on cultural techniques is finalized.

Networking Activities

Senegal, Planning Mission. University of Arizona/USAID-Dakar July 28-August 6, 1989.

Senegal, Collaborative breeding with ISRA. October 7-13, 1989.

MSU Mississippi. MS final examination November 28-30, 1989.

INTSORMIL EZC meeting, Kansas City, January 2, 1990.

San Juan de Abejo, Mexico, winter nursery breeding, January 14- February 2, 1990.

Malawi, SADCC/ICRISAT TAP Meeting, Lilongwe, March 12-15, 1990.

Botswana, collaborative breeding with Department of Agricultural Research, Sebele and Francistown, March 16-22, 1990.

Germplasm and Research Information Exchange

Four accessions were acquired, 482 are in storage, 30 lines in germplasm amounts were supplied domestically.

A total of 242 lines in germplasm amounts were supplied to Botswana, Mexico and Zimbabwe.

Discussion with LDC scientists on breeding methods and parental material to use appropriate to their program objectives leads to more productive breeding programs.

Breeding Pearl Millet for Developing Countries

Project UNL-118

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Dr. Anand Kumar, Millet Breeder, ICRISAT, Sahelien Center, Sadore, Niger.
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Drs. J. D. Axtell and J. Clark, PRF-103, Department of Agronomy, Purdue University, West Lafayette, IN 47907.
Dr. Lloyd W. Rooney, Cereal Chemist, TAM-126, Department of Food Science, Texas A&M University, College Station, TX.
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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 Project UNL-118 has been the continued development of elite inbred lines which will be used in both custom crosses with host country varieties and also to produce parental lines and varieties for the U.S.

One thousand five hundred F_3- F_8 lines from tropical x early parent crosses were evaluated and selfed in 1989, and backcrossing continued on 230 male sterile testcrosses and backcrosses. Selection was continued for lodging resistance. Backcrossing, selfing and hybrid production was continued on 180 elite lines sent to the winter nursery. Introductions and crosses to 50 breeding lines from the ICRISAT Sahelien Center were made in the winter greenhouse.

Recurrent selection continued through modified mass selection on the Nebraska Dwarf Pearl Millet Population and on testing varieties EDS and MLS produced from it. Yield tests in 1989 confirmed that producing topcross hybrids with population varieties on a seed parent can increase yields by 20-30%. Such topcross hybrids have distinct advantages for LDC conditions and are easy to develop and produce. New versions of EDS and MLS were selected.

Postgraduate research continued on the use of parental tests in predicting performance of synthetic varieties. Two M.S. students, Mr. F. P. Muuka from Zambia and Mr. Karim Traore from Mali, were graduated during the year.

A pearl millet regional test containing grain hybrids from Georgia, Kansas (KSU- 101) and Nebraska (UNL-118) plus

sorghum checks was grown at five locations in the U.S. Top millet yields ranged from 2590 to 4170 kg/ha compared to sorghum at 2810 to 5080 kg/ka. Pearl millet grain averaged 1.1 percentage points higher in protein content than sorghum and was higher in calorific value. In three experiments, chicks grown on pearl millet diets grew as well as on corn or low tannin sorghum diets.

Trips were made to participate in breeding work in Botswana, Mali, and Senegal.

Objectives, Production and Utilization Constraints

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 between stocks known to perform well in the region concerned, and 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 useful in identifying parents for varieties (synthetics), and possibly for indicating parental worth, which will be important in generating collaborative material for selection.

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 testing of hypotheses about the relative potential of various types of varieties and hybrids and parental breeding procedures, and enables 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. Further populations being developed using newly generated parental stocks are being evaluated. Besides information, improved lines and varieties will result from this process. Both the above approaches provide opportunities and material for postgraduate student theses.

3. Training LDC personnel in plant breeding and genetics is an important objective.

Research Approach and Project Output

Research Methods

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.

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 line is possible, the effect of controlled amounts of this on hybrid performance is being measured. In developing countries, where such protogyny hybrids (pro-H, 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 female self

pollination. Pro-H hybrids will also avoid the additional sensitivity to ergot commonly associated with hybrids made with any cms seed parent.

Since pearl millet is a cross-pollinating crop, population improvement is a relevant breeding approach, particularly for LDC conditions where selection is needed simultaneously for many adaptive traits and heterozygosity must be maintained. Research into the utilization of recurrent selection is 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

The main thrusts in breeding at Mead, NE were a) the continued development of inbreds and the production where possible, of cms seed parents and b) an investigation into the potential of new inbreds for making pro-H hybrids. Additional areas of activity were continued recurrent selection on the Nebraska dwarf population, synthesis of five new populations, graduate thesis research on producing synthetics and effects of chlorophyll mutants, conducting the 1989 pearl millet regional tests, and collaboration on investigations into the food and feed values of pearl millet.

Inbreeding continued in 1320 lines between F_3 and F_8 and 225 pairs, some now in the third backcross, were further backcrossed in the A line development program. Test crosses were made in the winter nursery to evaluate these.

In West African varieties, many traits, including those causing weedy off types, are carried recessively. In a simplified analogy, Mr. Karim Traore in his M.S. thesis studied the effects of a recessive virescent yellow chlorophyll trait. This was shown to be due to a single gene causing about a 50% reduction in total chlorophyll content, with a disproportionate reduction in chlorophyll b. In segregating families virescent plants tended to have more leaves, smaller heads and grain, and be later flowering than both homozygous and heterozygous normal green plants. Heterozygous normal plants were significantly taller and tended to be earlier flowering and have heavier heads than their normal green homozygous siblings.

Phenotypic traits associated with lodging in pearl millet were investigated by Mr. F.P. Muuka in his M.S. thesis. Generally peduncle lodging was more severe than stalk lodging. Rind thickness which was well correlated with stalk crushing and breaking strengths, and stem diameter were important in imparting strength to stalks and peduncles. However, lines derived from pearl millet by napier grass (*P. purpureum*) crosses, though they had great stalk strength in basal internodes, had weak peduncles. Although there was heterosis for increased stalk and peduncle strength in testcrosses, increased height, tillering and yield often caused more lodging. Good combiners were identified for stalk diameter and thickness, and for peduncle rind thickness.

Twenty-eight hybrids made between eight potential pro-H inbred parents and their topcrosses to tester variety EDS were compared. The average yield of the topcrosses was 3310 kg/ha, 46% more than variety EDS. The average yield of the individual crosses was 3000 kg/ha, but since the variance between them was greater, the top yielding hybrid in the experiment was the single cross 553 x 554 at 4000 kg/ha. This hybrid was less then 1 meter tall. Observations recorded at flowering showed that on the main head the period of protogyny can vary between 1.5 to 6 days on different inbreds. Thus there is considerable variability for this trait as also exists for the number and time to flower of tillers other than the main stem, all of which can affect the utility of inbreds as female pro-H parents.

Two experiments were conducted with various controlled percentages of selfed parental seed mixed with hybrid seed to determine the effect of any female selfing in the production of pro-hybrid seed. A singlecross pro-hybrid between two inbreds of similar height, 554 and 556, was used in the first experiment, while a topcross hybrid, 68A x MLS, where the variety pollinator (MLS), is taller than the seed parent, was used in the second experiment. In both hybrids 40% selfed seed in 60% hybrid seed resulted in a significant reduction in yield (see Figures 1a and 1b). However, at the 20% level of selfing the loss in yield was small, 6%, and not significant.The yield (3630 kg/ha) of the 80:20 hybrid/inbred mixture of 68A x MLS was still 12% more than the variety MLS (3240 kg/ha). It would be expected that with the choice of parents that 'nick' well, the level of selfing when making pro-hybrids could be kept well below 20%.

Figure 1a. Pearl Millet Pro-Hybrid 554x556. Effect of seed parent selfing on hybrid yield.

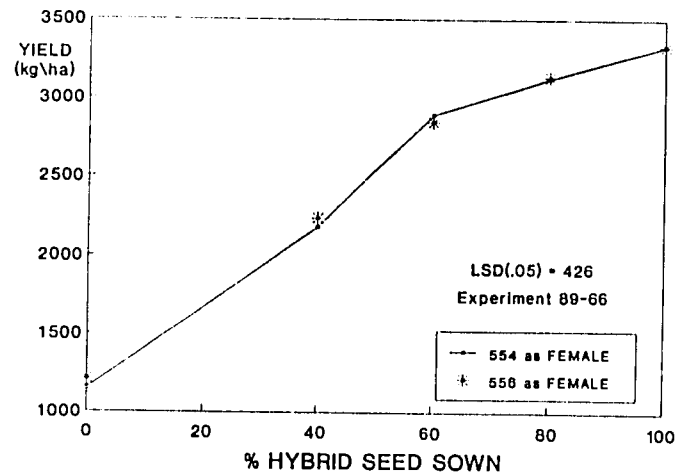
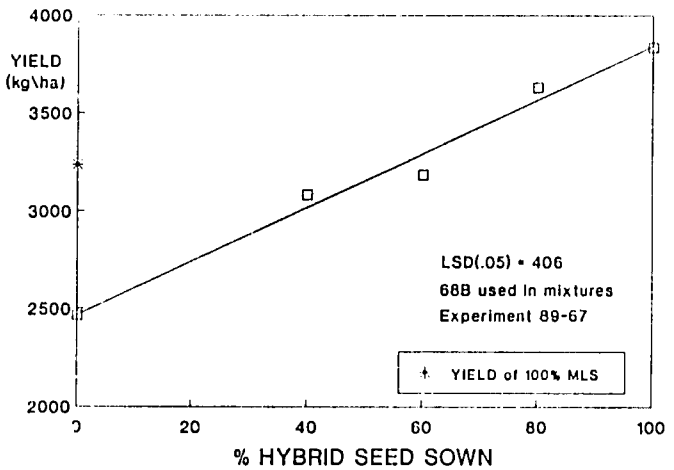


Figure 1b. Pearl Millet TC-Hybrid 68AxMLS. Effect of seed parent selfing on hybrid yield.



The pearl millet regional test containing entries from KSU Hays, KS, USDA Tifton, GA and UNL Mead, NE was grown at five locations in 1989 (Table 1). Pearl millet exceeded the yield of the sorghum checks at Tifton and in Mississippi (where bird damage was excessive on sorghum) but the best millet entry gave 92, 63, and 82% of the best sorghum check at Purdue, Hays and Mead respectively. Yields of the two topcross hybrids 68 A x EDS and 68A x MLS exceeded the yields of their respective pollen parent varieties (made from random mating populations) by 43 and 32 % respectively. Across three locations average sorghum grain protein content was 9.5% while millet averaged 10.6%. The protein content in the best millet hybrid, 68A x MLS tended to be higher than in the parent variety MLS.

Three chick feeding tests were carried out, two in conjunction with the Animal Science Department at the University of Nebraska, and one in conjunction with Kansas State University, to compare the feed value of pearl millet, sorghum and corn. In each case chicks grew as well or sightly better on pearl millet diets as on corn and low tannin sorghum diets. Pearl millet grain had higher protein and calorific values and the grain to feed ratio tended to be higher with pearl millet. Pearl millet samples were supplied to TAM 126 for research on millet food products. Seed stocks of white grained lines are being increased following the finding that more attractive 'milri' can be produced from this color grain.

Publications and Presentations

Andrews, D.J. 1989. Cereal breeding in Africa. Seminar for Summer Institute for African Agricultural Research, Univ. of Wisconsin-Madison, July 10-29, 1989. pp. 21.

Andrews, D.J. 1989. The role of intercropping in increased production in Africa. Seminar for Summer Institute for African Agricultural Research, Univ. of Wisconsin-Madison, July 10-29, 1989. pp. 14.

Andrews, D.J. 1989. Developing a collaborative pearl millet breeding program. ARC/INTSORMIL Sudan Sorghum and Pearl Millet Workshop, Wad Medani, Sudan, October 28-November 2. pp. 19.

Schilling, T.T., J.R. Settimi, J. W. Maranville, and D. J. Andrews. 1989. An in vitro technique for sorghum seedling emergence through a crusted soil. Agron. Abstr. p. 98.

Andrews, D. J. 1990. Crops and drought mitigation. Drought Disaster Mitigation Workshop. Office of U.S. Foreign Disaster Assistance. April 30-May 2, 1990, Maryland.

Sullivan, T. W., J. H. Douglas, P.L. Bond and D. J. Andrews, 1990. Nutritional value of pearl millet in broiler diets. Poultry Sci. 69:Suppl. 1, p. 132.

Table 1. Grain yield (kg/ha) of the ten entries in 1989 Pearl Millet Regional Test at five locations.

Pedigree	Source	Location				
		Mead, NE	Hays, KS	Purdue, IN	MSU, MS	Tifton, GA
		kg h 1				
KSU # 1 (1)	KS	4170	2510	2740	2060	3010
KSU #2 (2)	KS	3550	2030	4010	2590	2690
DK 39Y	(2)	5080	3960	4370	----(3)	2870
EDS	NU	2690	1450	2490	1300	1460
68A x EDS	NU	4020	2000	3690	1600	2110
MLS	NU	3390	1920	3410	1160	1450
68A x MLS	NU	4030	2770	3750	1450	2980
552 x EDS	NU	3420	2120	3660	2410	2500
H23DAE x 77	GA	2340	1150	830	980	3050
F 2233	(2)	5020	3710	4260	----(3)	2810
LSD (0.05)		489	753	961	986	1062

(1) KSU #1 = 81-1056/86-7907
KSU #2 = 79-2068/87-8025

(2) Sorghum hybrid checks.

(3) Excessive bird damage on sorghum.

Networking Activities

Collaboration was continued with Botswana, Mali, Senegal, Sudan and Zambia. Visits were made to breeding programs in Botswana, Mali and Senegal.

In Botswana selection continues among half sib families in the second cycle of millet population Botswana Serere 6A, which visually show a good improvement over Cycle O. A synthetic variety will be produced from selfs made in the best half sib families.

In Mali the F_2's of crosses between principal Mali varieties and UNL-118 lines were too early and had insufficient adaptation. In anticipation that this might be the case the F_9's of these F_2's have been crossed to complementary Mali varieties to create better segregates. It was noted, in reference to the potential of pro-H topcross hybrids being investigated in the U.S. program of UNL-118, that the highest yielding material in the Mali program both in Cinzana and Koporkeniepe appeared to be the topcrosses of tall varieties made on dwarf varieties. Such hybrids could be improved by selecting for combining ability within the dwarf varieties, which could be added to the per se progeny selection currently being undertaken on the dwarf varieties.

The millet breeding work in Senegal is reported in detail in the Senegal country report. Dwarf hybrids from KSU-101 and UNL-118 yielded more grain in a shorter time than local Senegalese varieties under irrigated conditions in the Senegal river valley where cropping alternatives are needed from rice monoculture, however better moisture control is required to obtain economic yields from nonrice crops in that area.

In the dry land millet program at Bambey 40 F_1's, 15 F_2's and 10 introductions of UNL-118 material were evaluated. Surprisingly four of the introduced lines showed apparent recovery resistance to downy mildew. Crosses were made with these to Senegalese stocks. Fourteen F_1's were kept for F_2's and selections made within seven of the F_2's.

One hundred seventy-one lines supplied to the Sudan were lost as the 1989 millet program failed completely due to drought. As many as possible were resupplied for 1990 planting.

Twenty-five F_2's generated between UNL-118 and Zambia stocks were supplied for selection at Kaoma research station.

Travel

Senegal July 28-Aug. 6 1989. Planning mission. Univ. of Ariz/USA-Dakar.

Mali Oct 1-7 1989. Collaborative research with IER at Cinzana and Koporokeniepe.

Senegal Oct 17-23 1989. Collaborative research with ISRA at Fanaye and Bambey.

Mexico Jan 25-Feb 14, 1990. San Juan de Abajo, Nayarit. Winter nursery breeding operations.

Malawi March 12-15, 1990. SADCC/ICRISAT Technical Advisory Panel Meeting, Lilongwe.

Botswana March 16-20, 1990. Breeding program, DAR, Sebele.

Zimbabwe March 22-26, 1990 Millet programs at DRSS Harare and SADCC/ICRISAT Bulawayo.

Germplasm and Research Information Exchange

Germplasm

Fifty new accessions were acquired, 457 are in storage and 21 samples were exchanged domestically.

Two hundred eighty-one germplasm lines/segregating populations were sent to Mali, Mexico, Senegal and Zambia.

Breeding

Breeding strategies were planned with breeders in Botswana, Mali and Senegal.

Entomology

Biological and Ecological Investigations and Management of Insect Pests on Sorghum

Project MSU-105
Henry N. Pitre
Mississippi State University

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Summary

The insect complex damaging or destroying sorghum and corn stands in many areas of Honduras and referred to as "langosta" by subsistence farmers was previously identified. But aspects of the biology and ecology of the lepidopterous pests related to the occurrence of populations of each species are generally unknown. This information is critical to the development of practical cultural crop and insect pest management strategies for use on subsistence farms. Seasonal occurrence of the pests and partitioning of damaging effects on the crops by the four important species was elucidated. The biological relationships of the pests with noncrop vegetation was shown to be significant in the build up of insect infestations prior to feeding on the crops. Oviposition, feeding and development studies with two species (*Spodoptera latifascia* and *Metaponpneumata rogenhoferi*) were conducted. These two species developed through only one generation on these crops.

Host plant resistance studies in Honduras with landrace sorghums included laboratory assays and field screening trials to examine levels of preference or nonpreference and antibiosis resistance to fall armyworm. Some lines exhibited the same level of antibiosis as the resistant AF-28 sorghum. New selections will be evaluated on-farm for adaptability, yield and acceptance. In the U.S., the meridic diet technique was used to measure differential developmental responses of *S. frugiperda* on converted sorghums. Resistance appeared to be a morphological nonpreference type expressed in the form of lack of sustained colonization of the larvae.

Partial life tables were constructed for sorghum and maize. Sixty-five percent of total mortality was attributed to insects, 20% to lack of germination, 10% to abiotic factors, 2.5% to disease and 2.5% to unknown causes. A research validation study including agronomic and plant protection technologies (host plant resistance, weed control, chemical protection of seed and whorl stage plants) was conducted on subsistence farms.

Objectives, Production and Utilization Constraints

Objectives

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

Evaluate sorghums for resistance to specific insect pests.

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

Constraints

Grain sorghum is one of the world's most important feed and fiber crops. The value of sorghum has steadily increased in the United States, especially in the southeast over the past two decades. Insect pest management, however, remains a great concern in agricultural systems. Annual loss estimates due to just one insect, the fall armyworm, exceeded $300

million in the U.S. in one year in the late 1970's. Yield losses and costs of control attributed to the complex of insect pests (e.g., stalk borers, sorghum midge, webworm, and corn earworm) on sorghum in the southern United States are considerable, considering that this one insect, the fall armyworm, can be responsible for this high level of expense in production of the crop. Crop and insect pest management systems 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.

Many of the insect pest constraints to sorghum and maize production in Honduras have been identified. Insect pests in the soil damage and/or destroy sorghum seed, lepidopterous pests damage or destroy seedling plants, stem and stalk borers weaken and/or kill maturing sorghum and head feeding species destroy the seed; all are important in reducing crop yields. Therefore, a range of insect pest management tactics have been evaluated to determine the effective practices that have application in 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 influence of these populations from specific geographical areas upon the population densities and crop damage by the pests in other geographical areas.

Research Approach and Project Output

Studies were conducted on biology, ecology, behavior and population dynamics of two lepidopterous pests (*Metaponpneumata rogenhoferi* and *Spodoptera latifascia*) that constitute an important component in the complex of insects that damage or destroy corn and sorghum plant stands in areas of Honduras where replanting is limited due to finances or lack of seed. The 1989 investigations were expansions of studies conducted in 1988 to identify and measure seasonal populations of lepidopterous pests and to construct partial life tables of sorghum and maize intercropped in southern Honduras. In 1988, two treatments were established on three farms on the plains and three in the hills. One treatment represented the farmer's technology and the other the farmer's technology plus weed control. Insecticide applications were made on both treatments when considered necessary by the farmer. Landrace sorghum and maize populations commonly grown by subsistence farmers were used on all farms. In 1989, four treatments were established on three farms on the plains and two in the hills. Two of the treatments were established as in 1988, and the other two consisted of farmer's technology with no insecticide and farmer's technology plus weed control and no insecticide. In this year the improved sorghum variety TAM428 * Porvenir was planted on all farms and landrace maize continued to be used.

The fall armyworm, *Spodoptera frugiperda*, a third lepidopterous species in the complex (this species studied in previous years) was the predominant species found throughout the growing season in both years; populations were higher in plots with weed control. Significant differences between treatments were observed only during mid-late season in 1988, but no differences were observed in 1989. This may be attributed to differences in weed infestation between treatments, where weed control and farmer's technology were not as extreme in 1989 as they were in 1988. Populations of fall armyworm on sorghum in 1989 were lower than in 1988, suggesting that the improved variety used has some antibiosis characteristics.

Spodoptera latifascia and *Metaponpneumata rogenhoferi* were found only early in the season, and populations disappeared by mid- to late June in 1988. Neither of these two species were recorded in 1989 in the experimental plots, although *M. rogenhoferi* was collected on broadleaf weeds around the production fields. Populations of these two species were also significantly higher on maize than on sorghum.

Mocis latipes, the grass looper, a fourth lepidopterous species, was found mainly during mid- to late season, and although populations of this species were constantly higher in plots with farmer's technology than in those with weed control, no significant differences were observed. Populations of this species were equally distributed on sorghum and maize.

All species in this lepidopterous complex (commonly referred to as "langosta" by the farmers) were observed feeding on noncrop vegetation in and around the fields. *M. rogenhoferi*, when not feeding on sorghum or maize, was observed on *Thrianthema portulacastrum* L. (Aizoacea), *Cassia leiophila* Vogel (Leguminosae), *Ipomoea* sp. (Convolvulacea), *Melampodium divaricatum* (Rich. ex pers) DC (Compositae) and *Amaranthus spinosus*, L. (Amaranthaceae), some of the most common broadleaf weeds in southern Honduras. *S. latifascia* was observed feeding on the above weeds as well as on other grasses like *Ixophorus unisetus* (Pres L.) Schlecht, the most common grass on the plains. This grass was the most common host for *S. frugiperda* when this pest was not feeding on sorghum or maize. *I. unisetus* and *Echinocloa colonum* (L.) Link were observed to be the primary food source for *M. latipes*; this

species migrated to neighboring sorghum and maize plants once the grasses were depleted.

Laboratory feeding preference studies were conducted with *S. latifascia* and *M. rogenhoferi*. *S. latifascia* neonates from an established laboratory colony were used and *M. rogenhoferi* larvae (less than 100 mg) were collected from broadleaf weeds in the field. The diets *Thrianthema portulacastrum*, *Cassia leiophila*, *Ipomoea* sp, *Melampodium divaricatum*, *Amaranthus spinosus*, *Heliotropium indicum*, *Ixophorus unisetus*, sorghum and maize were tested in a randomized complete block design. Larvae of *S. latifascia* fed *Amaranthus*, *Melampodium*, *Thrianthema*, or *Cassia* had significantly higher weight at day 15 than those fed any of the other diets. Significantly higher larval survival was observed for larvae fed *Amaranthus*, *Thrianthema* or *Melanpodium* and larvae fed *Ipomoea*, *Thrianthema* and *Amaranthus* took significantly longer time to develop to the pupal stage. None of the larvae fed sorghum, maize, *Ixophorus* or *Heliotropium* developed to pupa. Higher pupal weights were obtained when larvae were fed *Amaranthus* and *Cassia*. Only about half of the total pupae emerged to adults and no eggs were laid, suggesting that this species may be univoltine. These results indicate that sorghum and maize are not the most suitable diets for these two lepidopterous species, and that changes made by man in the agroecosystem are forcing them to temporarilly feed on these two crops. But, even when other plant species are available to these insects in the field, they disappear when the corn and sorghum are still suitable host plants.

The disappearance of *S. latifascia* and *M. rogenhoferi* from the areas in southern Honduras has not been elucidated. Collections of these insects were made and reared to quantify the influence of natural enemies. A maximum parasitization of 36% was recorded on *M. rogenhoferi* and 56% on *S. latifascia*. The most common parasitoides found in both species were the nematode *Hexamermis* and an unidentified virus. Tachinid flies were recorded in low incidence on *S. latifascia*. This suggests that natural enemies have some influence on the populations of these two species, but does not provide enough evidence to indicate that they are key to the disappearance of the species. Further studies are needed.

Preliminary studies were conducted with *Spodoptera latifascia* to determine crop and noncrop host oviposition preference and host plant and plant phenology feeding preference measured as a function of larval developmental time, larval and pupal weight, pupal development, sex ratio, adult life span, fecundity and fertility. Results have not been analyzed.

Development of Host Plant Resistance to Insect Pests

The best alternative to using insecticides for controlling insect pests in agriculture is to use insect-resistant crop varieties. The concept of host plant resistance capitalizes on the natural defense mechanisms developed by plant species during their evolution against various herbivorous enemies. The development of resistant germplasm is a necessity for the success of the overall scheme of integrated pest management (IPM). As new collections of germplasm become available, they need to be tested for phenological adaptability in different ecosystems and for resistance to the major agricultural insect pests at different stages of plant growth in order to determine their possible use in breeding programs. MSU-105 has emphasized both leaf- and panicle feeding resistance to fall armyworm larvae.

Plant resistance has been reported to be one of the most effective and ideal methods for controlling crop pests. The uses of a resistant cultivar for management of the pest 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 period of time would sharply increase. In sustainable agriculture, or any agricultural system, the use of the resistant cultivar should be the foundation or "hub" of any crop protection scheme where damage from insect pests is a major concern.

Today, probably more than 500 cultivars with resistance to more than 50 insect species or biotypes have been developed and released worldwide by plant resistance scientists for use by growers. Some of these cultivars have high levels of resistance and are used as the sole method for controlling the insect pest or as components of IPM. Whether the production of crops, large or small, is called 'organic', 'regenerative', LISA, or any other name, the resistance cultivar can be fine-tuned and used to limit insect damage or losses in most, if not all, situations. Thus, plant resistance to insects has a key role in "sustainable" or any other type of agriculture.

Experiments were conducted at Tifton, Georgia, to compare differential developmental response of fall armyworm after feeding on milk-stage spikelets of converted sorghums incorporated into a meridic diet. Larvae fed diet supplemented with spikelets of 'International Sorghum (IS) 12592 Converted (C)' were significantly smaller compared with the resistant check 'Northrup King Savanna 5'. Feeding on the genotypes 'IS 134)C', 'IS 2246C', 'IS 2569C', 'IS 7498C', 'IS 12617C', and 'IS 12683C' resulted in a significantly longer fall armyworm duration of larval stage compared with the resistant check. Pupal weights of fall armyworm fed a diet supplemented with 'IS 2403C', IS 2569C, IS 7498C, IS 12617C, or 'IS 12657C' were significantly less compared with the resistant check. The relationship between fall armyworm development and sorghum

spikelet characteristics also was determined. No significant relation was established between weights of fall armyworm larvae and the concentrations of tannin, lignin, neutral detergent fiber (NDF), or the ratio lignin/NDF. Weights of larvae were positively correlated with higher concentrations of crude protein.

The concentrations of lignin were in inverse correlation with the duration of larval development of fall armyworm. The concentrations of tannin and the ratio lignin/NDF were negatively correlated with the duration of larval development in the resistant genotypes, but positively correlated in the susceptible genotypes. No significant relations were found between weights of fall armyworm pupae and the sorghum spikelet characteristics evaluated.

Early maturing converted sorghum genotypes were evaluated at two stages of plant growth for resistance to whorl-stage feeding by larvae of the fall armyworm. Infested and noninfested plots were compared for the number of days to anthesis, sorghum grain yields, and grain test weights. 'International Sorghum (IS) 7273 Converted (C)', 'IS7444C', 'IS12573C', and 'IS12679C' were all more resistant to damage by fall armyworm than the resistant check CIMMYT (CM) 1821 at 14 days after artifical infestation (DAI) in the first experiment, and at both 7 and 14 DAI in the second experiment. Fall armyworm infestations significantly reduced sorghum grain yields in all genotypes except for the resistant check CM1821. The test weight of seeds produced by the main (primary) plant was significantly reduced by fall armyworm damage for IS12573C in the first experiment, and for IS7444C and IS12679C in the second experiment. Tolerance appeared to be the major mechanism of resistance in CM1821. The significantly accelerated rate of growth of the converted sorghums vis-a-vis the check did not permit a sustained infestation by larvae of the fall armyworm. Whorl-stage fall armyworm resistance in these converted sorghum genotypes appeared to be a morphological nonpreference type expressed in the form of lack of sustained colonization of the larvae.

Host plant resistant studies in Honduras with landrace sorghums developed in the INTSORMIL TAM-131 in-country program included laboratory assay and field screening trials to examine levels of plant resistance to fall armyworm. In one study, 11 landrace sorghum varieties were tested for antibiosis resistance using a meridic diet technique developed in Georgia (MSU-105, Wiseman). Results suggest that the sorghum varieties tested showed about the same levels of antibiosis to fall armyworm as the resistant AF-28 sorghum. Eighty percent of the sorghums showed greater than 30% larval mortality, plus different levels of pupal mortality. Also, pupal weight is related to adult fecundity; this relationship is presently being investigated.. These are characteristics to be included in a sorghum breeding program for host plant resistance.

In the field, 72 lines of (AF-28* San Bernardo III) sorghum crosses (with indicated level of antibiosis resistance in parents) were evaluated under artificial infestation with fall armyworm larvae. Lines showing low percent damage (2-4 on scale of 10) included (AF-28* San Bernardo III) -9, (AF-28* San Bernardo III)-16, (AF-28* San Bernardo III)-28, (AF-28* San Bernardo III)-21, (AF-28* San Bernardo III)-45, -59, -67, -63, -64, -54, and -13. New selections are to be made with those sorghums showing highest levels of resistance to feeding by fall armyworm. The new selections will be evaluated in farmers' fields to evaluate adaptability, yield and acceptance by the farmer.

A study to evaluate nitrogen levels in the landrace sorghum (San Bernardo III), a sorghum with some resistance to fall armyworm, was not completed due to inadequate germination of seed. Additional studies are needed to validate the hypothesis that "high nitrogen level in sorghum plants results in increased susceptibility to fall armyworm."

Development of Pest Management Systems

Partial life tables were constructed for sorghum and maize in 1988 and 1989. The most important mortality factors observed were lack of germination, wireworms feeding on seeds and early seedlings, cutworms, *Elasmopalpus lignosellus*, *Listronotus dietrichi*, *Diatraea* sp., mechanical damage, drought, diseases and unknown causes. No significant differences in percent plant mortality caused by any of these factors in any year were observed among treatments. Overall 65% of the total mortality of plants in sorghum and maize stands was attributed to insects, 20% to lack of germination, 10% to abiotic factors (drought and mechanical damage), 2.5% to diseases and 2.5% to unknown causes. Total crop mortality ranged from 25% to 95% in maize and from 3% to 32% in sorghum.Sorghum had significantly lower percentage of plants cut than maize, and in 1989 the percentage of sorghum plants cut was much lower than in 1988, suggesting that the variety TAM428 * Porvenir may have contributed to that reduction.

Methods to protect sorghum from insect pest feeding on the seed and seedling pests are essential. The efficacy of several granular and seed treatment insecticides, including kerosene, as a farmer's check, was tested. The sorghum hybrid Catracho was used in monoculture on farms on the plains and at the Experiment Station. The treatments tested were furathiocarb (Promet 40 sd) applied to the seed at three rates, 25, 50 and 75 ml/kg of seed; kerosene at 80 ml/kg of seed, furathiocarb granular (Deltanet 10g) 0.5 gr/hill, carbofuran granular (Furadan 10g) 1 gr/hill, terbuphos granular (Counter 10g) 0.5 gr/hill and the control with no insecticide were established as a randomized complete block design. Furathiocarb on the seed at rates of 50 and 75 ml/kg and terbuphos had significantly fewer seeds damaged and removed by insects, and a higher number of plants in stand 20 days after emergence. Kerosene was not significantly dif-

ferent from the control in the number of seeds damaged by insects, but had lower number of seeds removed by insects.

A research validation study was conducted in 1988 and 1989 on subsistence farms. The study was conducted during the first growing season on the plains and in the hills in southern Honduras to evaluate the effectiveness of different agronomic and plant protection technologies on the control of the major insect pests in the sorghum-maize system. The technologies tested were host plant resistance, weed control and chemical protection of seed and whorl stage plants. These new technologies were compared to traditional farmers' practices. Results of this study have not been analyzed at this writing.

Publications and Presentations

Publications

Castro, Marco T., Henry N. Pitre, and D.H. Meckenstock. 1989. Populations of fall armyworm, Spodoptera frugiperda (J.E. Smith) larvae and associated natural enemies in sorghum and maize cropping systems in southern Honduras. Tropical Agriculture. 66: 259-264.

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Trabinino, Carlos R., Henry N. Pitre, Keith L. Andrews and Dan H. Meckenstock. 1990. Soil inhabiting phytophagous arthropod pests in intercropped sorghum and maize in southern Honduras. Turrialba. 40:2 (Accepted).

Wiseman, B.R. 1990. Plant resistance: A logical component of sustainable agriculture. Plant Resistance to Insects Newsletter 16:40.

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Wiseman, B.R., and F.M. Davis. 1990. Plant resistance to insects attacking corn and sorghum. Fla. Entomol. 73:446-458.

Presentations

Pitre, Henry and N. Sharaf El Din. 1989. Approaches to Management of Insect Pests on Sorghum. Presented at INTSORMIL/SUDAN Sorghum/Millet Meeting. Wad Medani, SUDAN. Oct. 26-Nov. 7, 1989.

Pitre, H.N. 1990. Insect Pests on Sorghum in Eastern Africa: Approaches to Management. Presented at 7th East Africa Research on Sorghum and Millet (EARSAM) meeting. Niarobi, KENYA. June 24-June 30, 1990.

Pitre, H.N. 1990. Insect Pests on Sorghum. Presented at Panamerican School of Agriculture. El Zamorano, HONDURAS. July 25, 1990.

Networking Activities

Workshops

Sudan. INTSORMIL/SUDAN Sorghum/Millet Workshop. Wad Medani, Sudan. Oct 26-Nov. 7, 1989.

Kenya. Seventh East Africa Research on Sorghum and Millet. Niarobi, Kenya. June 24-June 30, 1990.

Germplasm and Research Information Exchange

Impact of CRSP - Produced or Recommended Technology

Methodologies such as those reported in the "proceedings of the International Symposium on Methodologies for Developing Host Plant Resistance to Maize Insects" and "Methodologies Used for Screening Resistance to Fall Armyworm in Sorghum," which was published in the proceedings of the International Workshop on Sorghum Stem Borers, are examples of direct transfer of plant resistance technology to underdeveloped Third World countries. The techniques and procedures developed by plant resistance scientists in the U.S. can be readily adapted to most programs of the Third World.

The information and sources of resistance to fall armyworm found in the converted sorghums can be readily used since those sorghums are inbreds that have wide environmental adaptability. Resistance to whorl-stage feeding by fall armyworms has been found in 20 of the 343 entries tested. Panicle-stage resistance has been shown in both milk-stage and hard dough stage of plant development. All three mechanisms of resistance have been discovered: tolerance, nonpreference, and antibiosis. Additionally, two sorghum germplasms genetically engineered through tissue culture are being registered in Crop Science.

Assistance to Collaborators

Pentax K1000 camera with accessories (Vivitar, macro focusing zoom lens and macro telephoto lens with filters) was shipped to collaborators in Honduras for use in capturing on film research situations, agricultural practices, magnified pests, etc. Each year INTSORMIL students that travel to Honduras to conduct research transport supplies from Mississippi State University for the conduct of their studies in the field and laboratory. These supplies are used by collaborators as well.

MSU-105 will continue linkage relationships with scientists in Agricultural Research Corporation (ARC) in Sudan. MSU-105 is involved as part of the Purdue University INTSORMIL program, working with collaborator entomologists in that country. Principal collaborators in Sudan have been Dr. Nasr Eldin, entomologist, ARC, Gezira Research Station, Wad Medani, Sudan and Dr. El Hilu Omer, Plant Pathologist (ARC, Gezira Research Station, Wad Medani, Sudan. A student from Sudan is enrolled in the Entomology Department at Mississippi State University to study insect pest management. The student's program is supported by FAO. Although the student is not working on objectives in INTSORMIL, he will be redirected at the Ph.D. level to conduct research on sorghum.

Development and Evaluation of Systems for Controlling Insect Pests of Sorghum/Millet by Integration of Resistant Varieties, Cultural Manipulation and Biological Control

Project TAM-125
George L. Teetes and Frank E. Gilstrap
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Dr. D. Meckenstock, INTSORMIL Plant Breeder, Escuela Agricola Panamericana, El Zamorano, Honduras.

Summary

The Texas Sorghum/Millet Entomology Project is conducting on-site collaborative research in Botswana, Mali, Niger, and Honduras, and technology support and graduate student training research in Texas to develop insect pest management strategies based strongly on plant resistance to insects and biological control that are compatible with sustainable sorghum/millet production. The insect pests on which major effort was made for developing insect resistant cultivars included sorghum midge, greenbug, yellow sugarcane aphid, sugarcane aphid, and panicle-feeding bugs. Insect pests of major focus for biological control were sorghum and millet stalk borers, the millet head girdler, the fall armyworm, and aphids.

Sorghum lines identified as resistant to the sugarcane aphid in Botswana include TAM428, SC170, SC109, SC173, and SA1469. Of all lines tested, TAM428 had the highest and most stable resistance, and it appeared to be dominant. The population dynamic of the major species of panicle-feeding bugs, *Eurystylus marginatus/(immaculatus)* showed two peaks in seasonal abundance which represented two generations. Bugs of the second generation severely damaged late planted sorghum. Numerous sorghum lines were screened and methods used to determine a simple, practical way to test sorghums for resistance to bugs. Parameters measured included bug damage ratings, mold rating, seed weight, germination, vitrosity, and numbers of floating seed. Malisor 84-7 has good bug resistance. Research conducted in Niger on the millet stalk borer included investigations on its host plants, natural enemies, oviposition behavior, effects on crop loss, survival in excised millet stalks, and population dynamics. Population dynamics were also described for another stalk borer species and the millet head girdler.

Honduran research consisted of evaluating predation by fire ants and earwigs on fall armyworm to develop manipulation tactics to improve biological control of fall armyworm on local sorghum varieties. The research concluded that naturally occurring earwig densities are not great enough in the field to reduce armyworm or aphid infestations. However, densities of earwigs were doubled by attaching artifi-

cial structure to plants. One earwig per plant provided useful levels of predation.

Graduate student training is in progress and several students have returned to research positions. 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: The objectives are to screen sorghums for resistance, determine resistance mechanisms, study inheritance of resistance, and assess the efficacy of biological control agents attacking the aphid complex on sorghum.

Mali sorghum panicle-feeding bug research: The objectives are to develop practical techniques for screening sorghums for resistance to head bugs; relate resistance to glume, kernel, and grain texture characteristics; and relate head bug abundance and kernel damage to pathogen infection, grain deterioration and food quality.

Honduras fall armyworm, and sorghum stem borer research: The objectives are to assess natural enemy efficacy of stem borers, fall armyworm and other pests of sorghum, and to optimize the use of effective enemies in production of local sorghum crops.

Niger millet head girdler (MHG) research: The primary objectives are to identify one or more potential biological control agents for field trials, and conduct field studies evaluating conservational and augmentational biological control strategies.

Technology support and student training research: The objectives of research conducted in Texas are to provide a mechanism for graduate student training programs, and to identify and evaluate sorghums resistant to insect pests in the U.S., determine resistance mechanisms, investigate plant-pest ecological responses and determine economic injury levels, identify potential biological control agents for use against sorghum and millet pests, and integrate effective biological controls with local production practices.

Constraints

Insect pests of sorghum and millet are an important component of the many stresses that contribute to reduced, unstable yields in developing countries, and to higher production costs because of insecticide use in the U.S. The role of insect pests as deterrents to sustainable agriculture is a constraint that must be dealt with in a biologically/ecologically sound manner. In traditional farming systems, the negative impact of aphids, panicle-feeding bugs, stem borers, armyworms, the sorghum midge, and the millet head girdler is dramatically increased when improved agricultural production is attempted through plant breeding and changed cultural practices. The public mandate in the U.S. is for safe food, clean water, and wildlife conservation and requires insect pest control strategies less dependent on insecticides. The species of insect pests that infest sorghum and millet vary geographically, and in severity and persistence. Sorghum and millet in different production areas encounter at least one key insect pest species, and several occasional insect pest species. Minimizing losses from these insects requires an integrated approach using several control tactics. The Texas Sorghum/Millet Entomology project focuses on developing insect control technologies applicable to subsistence crop production and to modern, high-input 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. Collaborative research in Southern Africa (Botswana and Zimbabwe) deals with sorghum aphid pests (sugarcane aphid and greenbug) by identifying resistant sorghum lines and biological control agents. The collaborative research in Mali is on damage assessment and plant resistance to the sorghum panicle-feeding bug complex. The collaborative research in Niger is focused on implementing biological controls of the millet head girdler, and in Honduras biological controls of the fall armyworm. 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; developing and evaluating greenbug and yellow sugarcane aphid resistance sorghums; and developing theory and technology for using biological controls in annual crops.

Research Approach and Project Output

Botswana sugarcane aphid research: The research element of this collaborative project has been completed with part of the research conducted at Matopos, Zimbabwe. Activities during part of this reporting period were limited to preparation of a Ph.D. dissertation. For this report, a summary of the research findings is presented. Research approaches were those commonly used for plant resistance research. Greenhouse cultured aphids were used to screen converted exotic sorghum lines, local varieties and ICRISAT entries. Sorghums were planted in rectangular plastic pots in a soil mixture, and three-day old seedlings were infested with aphids of mixed developmental stages by brushing aphids onto the soil surface and allowing aphids to move onto the seedlings. Damage ratings were taken when

the susceptible check showed evidence of aphid damage, usually in about seven days, and evaluations continued at seven-day intervals until the susceptible check was killed. Nonpreference was determined by providing aphids with choices of resistant and susceptible sorghums. Tolerance resistance was determined by comparing aphid number to subsequent plant damage. Antibiosis was measured by recording survival and rate of reproduction. An abstract of the research findings is as follows: Four hundred and fifty-eight sorghum lines were screened for resistance to *Melanaphis sacchari* including 431 Texas lines, seven from Botswana, seven from South Africa, and 13 ICRISAT lines. Among the lines, TAM428, SC170, SC109, SC173, SA1221, and SA1469 had high levels of resistance to the sugarcane aphid. There was variability in virulence within the Botswana and between the Botswana and Zimbabwe aphid populations towards TAM428, SC109, SC173, and SC110. TAM428 resistance was most stable. SC110, SC109, and SC173 resistance was moderately stable. These findings suggest different biotypes exist among populations of the sugarcane aphid. Antixenosis and antibiosis were present in highly resistant lines. Screening progenies of TAM428 and SC170 crossed to susceptible parents indicated that sorghum resistance to sugarcane aphid is simply inherited and controlled by a single, completely dominant gene.

Mali sorghum panicle-feeding bug research: A number of experiments were conducted as part of this collaborative research effort. At Sotuba, an assessment was made of the bug species composition. Also, the population dynamics of *Eurystylus marginatus* was monitored and compared in time and to grain development. A screening nursery of 100 sorghum lines from U.S., West African, and ICRISAT sorghum breeders was assembled and planted at Sotuba. Panicle-feeding bug abundance, kernel damage, kernel weight, vitrosity, mold, germination, and a number of floating kernels from bug protected and unprotected (naturally infested) panicles were rated or measured to compare resistance levels. A trial consisting of 13 selected sorghum entries, planted on two dates, was used for detailed evaluation as a means of determining screening techniques appropriate for breeders. In a split-plot design with three replications, panicles were allowed to be naturally infested, or protected from bug infestation using bags or insecticide. Bug damage to kernels and kernel weight, germination, and decortication were the parameters measured to determine levels of resistance. Surveys and collections were made of panicle-feeding bugs and bug damage in farmers' fields on improved and traditional varieties. The report of the research is a lengthy document and has recently been translated into English; however, only a summary of the results is presented here. A final report is being prepared and considered for publication.

Of the injurious bug species collected, *Eurystylus marginatus* (based on recent findings the species name may be *immaculatus*) comprised over 90% of the specimens collected. The first adults of *E. marginatus* appeared on sorghum panicles around September 15, 1989. Adults and nymphs were most abundant at two times during the season, late September and the last 10 days of October. Nymphs were more abundant than adults. During November, nymphs and adults were limited in number on ratoon and off-season sorghum. Very early planted sorghum (7-4-89) was not severely damaged by bugs. First generation bugs appeared between 9-20-89 to 10-15-89 during the late milk and beginning maturity stages of kernel development for early planted sorghum. The second bug generation appeared between 10-20-89 to 11-19-89. For the later sorghum planting date, this generation coincided with earlier stages of kernel development. The later planted sorghum was consequently more severely damaged than early planted sorghum. One hundred sorghum varieties tested showed differences in head bug damage. There was a relationship between bug abundance and damage and sorghum maturity. Bug numbers ranged from six to 218 per five panicles. The variety 87-CZ-CC-P23-2 was most heavily infested. Sorghums with the least infested panicles were 85-F4-164, 85-F4-107, CS630 and B-VAR1. Very early varieties such as CS566, SC630, Segolone, and CS560 were not severely damaged. At maturity, grain mold severity was evaluated. The number of punctures was independent of the number of bugs present. Malisor 84-1, 87-SB-F4-232-3, 87-SB-F4-16-1, 87-SB-F-129-1, 87-SB-F4-16-4, IS13518, OH/84-7/26/1, IS27454, ICSV1143-BF, ICSV1002 and Tx2536 had more than 60% of their grain damaged due to head bugs. Sorghum lines with less than 10% kernel damage included IS16123, IS20740, IS-27477, A2821, and Bagoba. Protected panicles had the highest kernel weight (4.40g/200), and unprotected panicles had the lowest (3.5g/200). Sorghum lines BTx632, BTx631, 87ED, 366 and TP21RB02-181-1-1 were severely damaged by molds (50%+). Varieties 84-QGH-12, IS16357, IS17610, IS20740, IS21444, IS27063, IS27466, A2821, A7081 had the least mold damage (1-10%). Kernels from protected panicles had a mean germination of 78%, while kernels of unprotected panicles had 55%. Similarly, kernels of protected panicles had only 18.5% floating seed, while unprotected had 66%. Kernels from protected panicles had better vitrosity and decortication values than kernels from unprotected panicles. These results are important to defining the relative amount of damage bugs cause to sorghum kernels and illustrate the parameters to be measured in determining resistance and susceptibility.

Thirteen sorghum lines were evaluated closely for resistance using protected and unprotected comparisons. Protecting panicles with cages was better than protecting panicles with insecticide. SC283 and SC34 were the sorghum lines with the greatest amount of kernel damage. Malisor 84-7 was the least damaged sorghum line based on visual rating. Surveys and collections made in farmers' fields on improved varieties and traditional varieties showed that bug

abundance was high in some localities and low in others. Also, traditional varieties were sometimes heavily infested and damaged.

Niger millet stem borer and head girdler research: The research aspect of this work was completed in the spring of 1988. Activities reported for 1989-90 are the result of Dr. Ousmane Youm completing his Ph.D. dissertation in entomology. His research was conducted in Niger, and he is now employed as a Research Entomologist by the International Crops Research Institute for the Semi-Arid Tropics, and is on site in Niamey, Niger conducting research on millet.

Dr. Youm's studies were conducted in Niger from 1986 through 1988 on the millet stalk borer (MSB), *Haimbachia ignefusalis* (Lepidoptera: Pyralidae) and included investigations on its host plants, natural enemies, oviposition behavior, effects on crop loss, survival in excised millet stalks, and population dynamics. Population dynamics were also described for *Sesamia calamistis* Hampson and the millet head girdler (MHG), *Heliocheilus albipunctella* de Joannis (Lepidoptera: Noctuidae). Effects of planting dates on population densities of MSB and MHG were assessed. Life-fertility tables were described for *Bracon hebetor* Say (Hymenoptera: Braconidae).

MSB was collected from 14 alternate host plants and was parasitized by a complex of parasite species on millet and seven of the alternate host plants. A model describing interactions between MSB, host plants, and natural enemies was developed. Mean numbers of surviving MSB in field cages excluding natural enemies were not significantly different from mean numbers of MSB that survived in field cages where natural enemies had access. These results suggest that natural enemies did not control MSB on millet. MSB oviposition was mostly associated with green millet stalks with leaf sheaths, leaf sheaths being the most preferred oviposition sites. Millet grain weight was negatively correlated with numbers of MSB larva holes. Numbers of diapausing MSB larvae and MSB larva holes increased from lower to upper stalk internodes. Many diapausing MSB larvae died during the dry season; however, a substantial number survived due to the stacking of millet stalks. MSB population densities were not reduced by adjusting millet planting dates, but were affected by millet growth stage. *Platytelenomus* sp. (Hymenoptera: Scelionidae) was the most common parasite of MSB on millet. Parasitism of MSB larvae and pupae was rare. *S. calamistis* was a minor pest of millet in Niger, and was rarely parasitized. MHG population densities were reduced by delaying millet planting dates. *Bracon hebetor* was the most common parasite of MHG. Life-fertility tables for *B. hebetor* developing on MHG showed that on the average, mated parasite females lived 24.7 days, oviposited for 22 days, and produced 173.7 adult progeny with a ca. 1:1 sex ratio. The estimated innate capacity of increase (r_c) and net reproductive rate (R_o) were 0.26 and 86.5, respectively. The mean generation time was 17 days.

Honduras fall armyworm biological control research: The research aspects of this work was completed in the fall of 1988. Activities reported for 1989-90 are the result of Ms. Lorena Lastres, a citizen of Peru who completed her Master of Science degree in the spring of 1990. Ms. Lastres conducted research for her degree at the Pan American School of Agriculture (PAE) in Honduras, and has since returned to Honduras where she is employed under the auspices of PAE. Her current research assignment is to develop improved pest management tactics for curcubit crops.

Ms. Lastres' M.S. research was conducted in 1988 in Honduras and consisted of evaluating predation by *Solenopsis geminata* and *Doru taeniatum*, primary predators of the whorlworm (WW), *Spodoptera frugiperda*. The general goal of this program is to develop manipulation tactics to improve biological control of WW on local sorghum varieties. Ms. Lastres studies included studies on the impact of *S. geminata* and *D. taeniatum* on WW mortality, and a cage study on predation of second instar WW by *S. geminata*. Naturally occurring earwig densities are not great enough in the field to reduce WW or aphid infestations. Thus, research was done on tactics for manipulating *D. taeniatum* to improve biological control of WW by using whorl-like structures to increase *D. taeniatum* field densities. These structures served as artificial refuges for *D. taeniatum*. Field work showed that population densities of *D. taeniatum* can be doubled by attaching the artificial structures to plants. In field cage studies, *D. taeniatum* at densities of about one earwig per plant provided useful levels of predation on second instar WW at two weeks after plant emergence. Predation of second instar WW by *D. taeniatum* was more influenced by plant size than by prey density. Field studies on *S. geminata* indicated that predation by *S. geminata* is an important source of mortality to WW larvae when fire ants densities exceeded $10/m^2$. *Solenopsis geminata* also reduced *Listronotus* sp. infestations and cutworm damage to seedling corn plants.

In laboratory studies, short-day photoperiod (11L:13D) stimulated diapause in *D. taeniatum*. Photoperiod, relative humidity and diet were important in regulating the development of *D. taeniatum*. Short-day photoperiod delayed developmental time of individuals and low relative humidity promoted nymphal mortality and prevented normal egg tending behavior of females. *D. taeniatum* developed the fastest on corn pollen, and the slowest on pelletized dog food. WW eggs seemed to delay development and induce mortality of *D. taeniatum* nymphs.

Technology support and student training research: The following information is a summary presentation of the technology support and student training research that complements collaboration.

Ten biotype E greenbug resistant sorghum lines were released and Crop Science registration is being sought. All lines are restorer (R-) lines in A_1 cytoplasm, produce excellent hybrids of medium-late maturity with good resistance in seedling and adult plants, and are resistant to head smut and rust. Efforts continue to develop additional biotype E greenbug resistant lines, especially female (A-) lines with resistance to sorghum diseases. Newly discovered sources of resistance to biotype E greenbug are being used to develop agronomically improved parental lines. Recent economic assessments indicated that biotype E greenbug resistant sorghum hybrids using RTx2783 provides a yield advantage of 50 (0.6%) and 600 (5.0%) pounds per acre, and a $2.09 and $2.47 per acre reduction in insecticide costs over greenbug susceptible hybrids grown dryland and irrigated, respectively.

Twenty-one sorghum midge resistant sorghum germplasm lines were released and Crop Science registration is being sought. Resistance of the lines was derived from TAM2566, AF-28, or SC423. All lines are restorer (R-) lines. Four of the lines produce hybrids which in certain environments outyield sorghum midge susceptible lines in the absence of midges. Current effort is to produce sorghum midge resistant female (A-) lines. Several maintainer (B-) lines are being sterilized. They represent the best effort and the most immediate solution to this lingering problem of the lack of A- lines. Genes from several old and new sources of midge resistance are being pyramided/stacked into single lines to elevate the resistance level. Progress remains slow, but encouraging. Extremely dry weather during this year and last at Corpus Christi has greatly hampered progress. Most progress has come from the College Station nurseries. It is likely that several additional midge resistant lines will be released soon.

Research to determine greenbug biotypes by sorghum variety response at different temperatures revealed that the tolerance level of TX2783, a greenbug resistant sorghum line, was increased at 30°C to nearly twice the level as at 21°C. TX2737 which is resistant to biotype C and susceptible to E became more resistant to C and more susceptible to E with this magnitude of increase in temperature. At this high level, temperature also considerably increased the preference of TX430 by biotype E and decreased that of TX2783. Temperature also greatly influenced antibiosis resistance. Reproduction of both biotypes was reduced by 50% or more at 30°C compared to 21°C and 26°C. At lower temperatures, biotype E was more reproductive on TX430 and TX2737 than was biotype C on these lines. Research to determine DNA composition of greenbug biotypes revealed that the range of DNA content in the population of greenbugs sampled from sorghum, wheat, and johnsongrass hosts was 0.78-1.24 picograms (10^{-12}) of DNA per cell. The mean was 1.05. Literature shows the range of DNA content in insects to be 0.1-7.5pg/cell. This means that at a mean of 1.05, the DNA content in greenbug populations sampled fall at the lower end of this range. Differences in DNA content were obtained among some of the greenbug clones isolated from populations found on the three plant hosts.

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.

Research was initiated to determine the differences in the habits, behavior and biology of sorghum midges within florets of resistant and susceptible sorghum lines. Preliminary results indicated that sorghum midge eggs are laid in a number of places on the sorghum floret, but within the glumes was the preferred site. Close observations of developing midge larvae within the floret showed that most midges develop by feeding on the developing ovary/kernel; however, some larvae developed feeding on other floret parts such as the glumes. Some larvae develop within the sessile floret which does not produce a kernel. A second objective of this research, using electron microscopy technology, will be to determine how sorghum midge larvae damage an ovary or developing kernel.

In cooperation with Temple TAES scientists, data were collected from nine sorghum fields in Nueces and Hill counties of Texas to validate a sorghum midge/sorghum plant model. Midge adult infestation levels were assessed in each 40 acre field at 10, 50, and 100% anthesis. Damage was rated at maturity, and yields were quantified. Midge abundance in Nueces county was very low compared to previous years because of drought conditions during June. Midge were more abundant in Hill County, but damaging infestations occurred later than normal, again due to dry conditions. The data gathered have not yet been applied to the model; however, the abnormal year will likely cause unusual results. The validation process will continue next year.

Experiments to use cultural management to increase the effectiveness of sorghum midge resistant sorghum hybrids were undertaken. Trials at Corpus Christi were complete failures because of lack of rain. At College Station, data were collected from a trial using different proportions of resistant and susceptible plants in mixed plantings. Data were collected on adult abundance, damage, per panicle yield, and per plot yield. The data are in the process of being summarized, and are not available for this report.

Sorghum lines were screened in the greenhouse for resistance to biotype E greenbug. This is standard procedure to

support field research. Selections taken based on agronomic performance are evaluated for resistance in greenhouse screening trials.

A similar program was conducted using yellow sugarcane aphid in a search for resistance. At least two lines have been confirmed to be resistant and will be the basis for a M.S. thesis for Mr. Ephraim Musonda, a recently arrived student from Zambia.

Biological control of millet head girdler has progressed sufficiently to begin studies on optimizing the suppressive impact of girdler enemies. This activity will be the M.S. or Ph.D. research element for the student selected for graduate training at Texas A&M University. The student will be encouraged to begin studies in the spring of 1992. Initial studies were completed by Dr. O. Youm. Plans for this research were initiated with Dr. Youm of ICRISAT in 1990, and research will begin during the growing season of 1991. Youm and Gilstrap will sponsor a student training program, with Youm providing on-site support for the student research and Gilstrap representing the graduate training aspects at Texas A&M University. The immediate research activity (see objectives) begins in January 1991, and continues until March 1991. Key elements of this project are 1) cooperative research activities shared by the Institut National de Recherches Agronomiques du Niger (INRAN), ICRISAT, and INTSORMIL, and 2) identification of a citizen of Niger who can obtain a graduate degree in entomology at Texas A&M University.

Biological control of fall armyworm has progressed sufficiently to begin work on armyworm enemy manipulation. Three key enemies have been identified and researched. These enemies are excellent candidates for implementing tactics of biological control. Thus, discussions were held in 1990 with Dr. K. Andrews of the Pan American School of Agriculture. Steps are now in progress to identify and engage a Honduran student for graduate training at the Ph.D. level. When identified, this student will seek to consolidate and complete development of biological controls based on research results of the prior three M.S. programs.

In continuing support of the INTSORMIL charge to provide training and technical support, three foreign students in biological control are routinely engaged in support of domestic programs of biological control. These activities include participating in the day to day activities of domestic programs developing concepts and tools for biological control of annual crops, and working with cultures of plants, hosts and biological control agents used in these domestic programs.

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Networking Activities

Research Investigator Exchanges

Fifteen LDC scientists visited the sorghum entomology program at Texas A&M University. George L. Teetes traveled to Mali to review research progress on panicle-feeding bugs, and Dr. Y. Doumbia visited Dr. Teetes at Texas A&M University to review research progress and plans for next year's collaborative research. Frank E. Gilstrap traveled to Niger to initiate a collaborative research program with INRAN and ICRISAT, and to begin the process of identifying a student for graduate research and training at Texas A&M University.

Germplasm and Research Information Exchange

Seed requests were received from eight LDC scientists, and these were forwarded to Dr. Gary C. Peterson, Sorghum Breeder, Texas Agricultural Experiment Station, Lubbock. Publication reprints or copies related to sorghum entomology were sent to 54 LDC scientists. Research supplies and equipment were sent to Mali to support on-site research activities. Material for cages, bags to cover panicles, insect-collecting supplies, insect-preservation supplies, computer software, and other research related supplies were provided.

Important collaborative linkages were maintained with Dr. K. F. Nwanze, Principal Cereals Entomologist; Dr. H. C. Sharma, Entomologist, ICRISAT, Patancheru P.O., Andhra Pradesh 502 324; Dr. D' Alain Ratnadass, Entomologist, IRAT-ICRISAT, B.P. Bamako, Mali; Dr. O. Youm, Entomologist, ICRISAT Sahelian Center, BP 12404, Niamey, Niger; and Dr. K. Andrews, Entomologist, Escuela Agricola Panamericana, El Zamorano, Honduras.

Food Quality and Nutrition

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 ARC in Sudan and INRAN in Niger during the past year. Achievements in Sudan included work on a technique for measuring fermented kisra batter consistency as a means of predicting kisra quality. In Niger we assisted the Cereal Quality Laboratory with food quality trials of three improved sorghum cultivars developed by the INRAN breeding program. The improved sorghum cultivars, SEPON 82, SRN 39, and ATx632xMR732 F1 were compared to local sorghum varieties for tuwo quality at four different locations in Niger. Statistical analysis of the sensory data from these trials showed that the improved sorghum cultivars produced tuwo that was equal to or better than the local sorghums.

Our work on the alcohol soluble storage proteins called kafirins was continued. The kafirin proteins are located in structures called protein bodies found in the endosperm of sorghum seeds. We have proposed a nomenclature system for the kafirin proteins based on a commonly used nomenclature for the zein storage proteins in maize. This system classifies the kafirins into alpha-, beta-, and gamma-types on the basis of their solubility characteristics, amino acid composition and cross reactivity with antiserum made against the zein-type proteins. Antibodies have been made against purified alpha-, beta-, and gamma-kafirin. We have used an immunocytochemical technique to determine how gamma-kafirin is distributed throughout the endosperm and within the protein bodies. We found that gamma-kafirins are evenly distributed throughout the protein body, and that a similar distribution of gamma-kafirin exists in the protein bodies from both the peripheral and central endosperm. We feel that the distribution of gamma-kafirin may be linked to sorghum protein digestibility and grain hardness. We have shown that when sorghum is cooked the protein digestibility is reduced. An examination of the *in vitro* pepsin-indigestible proteins from cooked sorghum revealed that the predominant proteins are kafirins. This year we found that the kafirin proteins are also the least digestible proteins when cooked sorghum was fed to rats. These findings confirm that kafirin proteins become less digestible after cooking and we must now find ways to reverse this.

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

Developing a bank of information on the food and nutritional quality of sorghum grain is of major importance in

developing countries and the U.S. Factors that affect milling properties, food quality, and nutritional value of sorghum grain critically affect other efforts to improve the crop. If the grain is not accepted by consumers, then efforts to improve grain yield, disease and insect resistance, and drought tolerance as well as other aspects of 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 milling, food, and nutritional properties of sorghum. With this knowledge we hope to develop improved methodologies for screening sorghum germplasm for end-use quality and develop processing techniques to make the grain more nutritious.

Research Approach and Project Output

Kisra Quality

Kisra is a thin, pancake like Sudanese bread made by fermenting whole grain sorghum flour. It is a staple in the diet of most people living in the sorghum production regions of Sudan. Kisra is prepared by mixing sorghum flour and water to make a thick batter. A backslop from a previous kisra fermentation is added and then fermented at ambient temperatures for 12 to 16 hours. The natural acidic fermentation gives the batter a very sour taste. Just before baking, the thick fermented batter is diluted with water to adjust its consistency for easy spreading on a hot metal baking sheet or griddle. The thinned batter is placed on the hot griddle, quickly spread into a large thin sheet, and baked for 30 to 45 seconds. A critical step in the kisra making process is the consistency of the thinned batter as this determines the ease of spreading, thickness of the kisra sheet, and the ease of removing the baked kisra from the griddle. An experienced kisra maker is able to judge whether the thinned batter will make acceptable kisra by simply running a hand through the batter. This we believe is a subjective evaluation of the homogeneity and consistency of the fermented batter. Thus, we have used the Bostwick consistometer to measure the consistency of kisra batter as a means of predicting the kisra making quality of different sorghums (1989 INTSORMIL Annual Report).

Work on the Bostwick consistometer method in 1990 was to standardize the test for measuring kisra batter consistency and to determine the effect of water/flour ratio on batter consistency. Bostwick readings were found to increase linearly for batters with water/flour ratios from 1.400-1.667. The straight line relationship (r=0.995), indicated the possibility of predicting flow behavior of batters of different water/sorghum flour ratios from a knowledge of the amount of flour in the measured suspension.

A water/flour ratio of 1.45 was used to compare the behavior of fermented and unfermented suspensions of five sorghum flours milled in Sudan. All the flours exhibited an increase in Bostwick consistency (became more fluid) after fermentation, however, those with the lowest unfermented values increased more after fermentation than samples with higher Bostwick values (Table 1).

Table 1. Bostwick consistometer readings at 15 seconds on unfermented and fermented sorghum batters with a water/flour ratio of 1.45.

	Unfermented Batter		Fermented batter[a]	
Variety	pH	Bostwick, cm	pH	Bostwick, cm
Dabar 1:1	6.03	10.3	3.93	13.7
Hageen Dura-1	6.15	7.3	3.89	15.6
Abu 70	6.11	19.7	3.91	20.2
Gadam Elhamam	5.90	18.8	3.92	17.8
D.W.W. Milo	6.14	20.2	4.04	21 3

[a] Fermentation time was 12 hr at 30°C

Kisra was prepared in our laboratory using the five sorghum flours from Sudan. A sensory panel consisting of six Sudanese students was asked to rate the quality of the kisra in terms of its smoothness, stickiness, and chewiness. Definitions for these three parameters were provided to the panel and a scale of one to six was used for scoring the panel responses. We found that the panel member responses were highly varied and poorly correlated with Bostwick readings. We feel that these results were due to the small number of panel members used and to the difficulties we encountered when preparing the kisra. This points out the need to have this type of sensory work done in the country where the food product is normally consumed.

Tuwo Quality

Moussa Oumarou from INRAN's Cereal Quality Laboratory conducted consumer food quality trials on three improved sorghum cultivars developed by the Nigerian breeding program. These cultivars are being considered for release to farmers. The agronomic characteristics of the sorghums are given below.

SEPON 82 - a high yielding variety suitable for either rainfed or irrigated production systems.

SRN-39 - a *Striga* resistant variety for production in those areas where *Striga hermonthica*, a very serious parasitic weed pest of sorghum, is a constraint to sorghum production.

ATx632xMR732 F1 - a hybrid for rainfed and irrigated production systems with both stable and high yield characteristics.

These three cultivars plus a local check were evaluated for food quality at four locations in Niger (Maradi, Konni, Tillabery, and Bengou). In brief, the food quality tests at each location were conducted on four successive days. Each day local women were hired to decorticate the sorghum, mill the decorticated grain into a fine flour, and prepare the local thick porridge called tuwe with the flour. During the preparation process product yields, water absorption, and time required for each unit operation were recorded. Each day

tuwo acceptability was evaluated by a ten member all male consumer panel. Sensory data on taste, texture, and overall acceptability of the tuwo's were collected. The sensory data were analyzed using the analysis of variance and LSD procedures at Purdue. As seen from the results shown in Table 2, the improved sorghum cultivars were in general given better color, texture and overall acceptance ratings than the local checks. Thus it appears that these improved sorghums should have acceptable food quality properties as judged by consumer tests.

Table 2. Tuwo sensory evaluation done at four locations in Niger.

	Means*		
Cultivar	Color	Texture	Overall acceptance
Maradi			
Sepon 82	0.71[a]	-0.08[bc]	-0.02[b]
SRN 39	-0.09[c]	0.20[ab]	0.17[ab]
ATx623xMR732F1	0.24[b]	0.31[a]	0.34[a]
Mota Maradi (local check)	-0.85[a]	-0.43[c]	-0.47[c]
Konni			
Sepon 82	0.93[a]	0.41[a]	0.26[a]
ATx623xMR732F1	0.14[b]	0.16[ab]	0.14[a]
SRN 39	-0.06[c]	-0.12[bc]	-0.13[ab]
Mota Ja (local check)	-1.01[d]	-0.45[c]	-0.27[b]
Tillabery			
Sepon 82	0.42[a]	0.32[a]	0.23[a]
SRN 39	0.28[a]	0.06[ab]	0.02[ab]
ATx623xMR732F1	-0.12[b]	-0.18[b]	-0.09[ab]
Mota Ja (local check)	-0.60[c]	-0.20[b]	-0.17[b]
Bengou			
Sepon 82	0.43[a]	0.06[b]	**
SRN 39	0.66[a]	-0.33[c]	**
ATx623xMR732F1	-0.66[b]	0.53[a]	**
BKC (local check)	-0.43[b]	-0.25[bc]	**

* Means with same letter are not significantly different at 0.05% level
** No significant difference between cultivars

Sudanese Sorghum Fermentation

Many foods and beverages are made from fermented sorghum in Sudan. The most popular fermented sorghum food in Sudan is called kisra, which is prepared daily in Sudanese households. As reported previously, sorghum flour obtained from Sudan was fermented naturally for 24 hours at 30C under aseptic conditions to produce a backslop or starter. It was found that the bacterial population increased with the increasing fermentation time and reached a plateau at 18 hours. The microflora of fermented sorghum flour consisted of lactic acid, coliforms, and other acid producing bacteria and yeasts/molds. The lactic acid content increased with fermentation time and at the end of fermentation it amounted to 0.8% which resulted in a pH drop from 5.95 to 3.73.

In sorghum flour that was fermented by adding a backslop from a previously fermented sorghum (traditional fermentation) for 24 hours, the bacterial population also increased with fermentation time. However, the fermentation plateaued at 9 hours. The bacterial population consisted mainly of lactic acid bacteria. The yeast and mold counts increased with fermentation time but were low, consisting mostly of yeasts. Coliform growth was suppressed by the other organisms. At the end of 9 hours of fermentation, the lactic acid content was 1.5% and pH was 3.73.

When three consecutive fermentations were carried out using a backslop from the previous fermentation to start the next batch, similarly the bacterial population increased with the fermentation time and reached a plateau by 9 hours and was dominated by lactic acid bacteria. Yeasts/molds also increased with fermentation time but were dominated by molds.

Eighty-five and fifty presumptive lactic acid bacterial colonies were isolated at random from countable plates during the 24 hours of natural fermentation, third and fourth transfers, respectively. According to morphological and biochemical tests the lactic acid bacteria included, *Pediococcus pentaceausus*, *Lactobacillus confusus*, *Lacto-bacillus brevis* and *Streptococcus faecium*. *Pediococcus pentaceausus* was found to be the dominant organism, especially during the second, third, and fourth transfers. A plasmid profile of *Pediococcus pentaceausus* showed that all isolates belong to one strain. The other acid producing bacteria belong to the family *Enterobacteriaceae* and were identified as *Erwina ananas* and *Klebsiella pnaemonioe*. Coliform members were identified as *Enterobacter cloacoe*. More yeast colonies were isolated and further identified as *Candida intermedia* and *Debarymces hansinii*. Using cultural and morphological characteristics, molds were identified as *Penicillium* spp., *Aspergillus* spp., *Fusarium* spp., and *Rhizopus* spp. These molds were found in the unfermented grain and throughout the fermentation. However, *Rhizopus* spp. was found throughout the fermentation and dominated the mold population by the third and fourth fermentation.

A starter culture from the above isolated organism is being formulated and its activity will be tested in sterile flour and compared to that of a backslop technique for making kisra.

Sorghum Protein Digestibility

The prolamins are the principal storage proteins in sorghum. These proteins are called prolamins due to their high concentration of the amino acids proline and glutamine. Prolamin proteins are synthesized in the endosperm of the developing seed in an insoluble form to form organelles called protein bodies. The prolamin or storage proteins of sorghum are called kafirins.

We have shown that when sorghum is cooked the solubility of the proteins is altered, in particular the alcohol-soluble kafirin proteins. An examination of the *in vitro*

pepsin-indigestible proteins from both uncooked and cooked sorghum by polyacrylamide gel electrophoresis revealed that the predominant proteins were alpha- and beta-kafirins. Recently we showed that the kafirin proteins are also the least digestible protein when cooked sorghum was fed to rats. These findings confirm that kafirin proteins become less digestible after cooking.

Using gel filtration chromatography, we found that cooking sorghum caused the formation of high molecular weight (Mr 10-20 million D) disulfide linked protein polymers. This protein polymerization did not occur when sorghum was cooked in the presence of a reducing agent. These protein polymers formed by cooking may be associated with the protein body proteins and thereby limit kafirin digestion. It was observed, using scanning electron microscopy, that sorghum cooked with water and an aqueous solution containing a reducing agent caused no visible disruption of the protein body structure. When changes in the *in vitro* pepsin digestion of uncooked and cooked sorghum (with or without a reducing agent) were observed by scanning electron microscopy, it was found that the protein matrix (non-kafirin protein) surrounding the protein bodies was more readily digested than protein body proteins or kafirins. It was found that the mode of protein body digestion with pepsin was similar in uncooked and reducing agent cooked sorghum, i.e., protein body pitting was first observed after 15 and 30 minutes of digestion, respectively. Whereas the digestion of protein bodies cooked in water proceeded by decreasing in size and losing their spherical shape without any observed pitting even after 120 minutes of pepsin digestion.

Sorghum proteins react differently than proteins of other cereals. Their digestibility is most negatively affected by the cooking process and most improved by the addition of reducing agents. As cooking in the presence of a reducing agent makes sorghum proteins more digestible and prevents the formation of high molecular weight polymers, oxidative formation of disulfide bonds during the cooking process must play a role in creating the less digestible proteins in sorghum porridges. As we know that kafirin proteins are the least digestible protein fraction, it appears that these proteins are in some way involved with the formation of disulfide linked polymers during cooking. A likely candidate for this involvement is gamma-kafirin, which is the Mr 28 kD polypeptide with as much as 7 mole percent of cysteine.

Kafirin Nomenclature

The endosperm of sorghum seeds contains a group of alcohol-soluble storage proteins called kafirins. The various kafirins are resolved into six polypeptides of 28, 25, 23, 20, 18, and 16 kD by SDS-PAGE. An updated nomenclature system has been adopted for sorghum kafirins which divides the polypeptides into three groups: alpha-, beta- and gamma- kafirin (1989 INTSORMIL Annual Report). This nomenclature is based on an existing zein nomenclature and emphasizes the similarities in molecular weight, solubility, and structure between kafirins and zeins. Structural similarities between kafirins and zeins were determined by immunological methods. Polyclonal antisera specific for alpha-, beta, and gamma- zeins were obtained from B. Larkins, University of Arizona. Sorghum kafirins were separated by SDS-PAGE and reacted with the antisera by western blot analysis. Reactivity of antisera with different polypeptides indicated structural similarities between the antigens. Alpha-kafirins correspond to the 25 and 23 kD components. They are electrophoretically similar to alpha-zeins, have similar extractability (40-90% alcohol), and react with alpha-zein antiserum. The beta-kafirins correspond to the 20, 18, and 16 kD components. These are similar to the beta-zeins in molecular weight, extractability (10-60% alcohol) and reactivity with the beta-zein antiserum. Finally, the gamma-kafirin corresponds to the 28 kD component. Similar to the gamma-zein, it is extractable in 10-80% alcohol in the presence of a reducing agent and reacts with gamma-zein antiserum. A nomenclature system for sorghum is greatly needed to provide a common terminology among researchers. Use of a common nomenclature which imitates corn zeins reflects the numerous similarities between the two grains.

Gamma-kafirin Localization

Kafirins are synthesized in sorghum endosperm tissue by membrane-bound polyribosomes and transported into the lumen of the endoplasmic reticulum where they assemble into protein bodies. The various kafirins are resolved into six protein bands by SDS-PAGE. Alpha-, beta-, and gamma-kafirins correspond to the 25 and 23 kD; the 20, 18, and 16 kD; and the 28 kD components, respectively. The localization of gamma-kafirin is of interest due to its high cysteine content and its ability to solubilize in both water and alcohol in the presence of a reducing agent. Knowledge of the distribution of gamma-kafirins within the protein bodies located in different parts of the endosperm may be of considerable importance toward understanding the decrease in digestibility that occurs in sorghum. Previous research has shown that during cooking an increase in disulfide bonding occurs in the protein fraction of the endosperm. The distribution of gamma-kafirin in sorghum endosperm is important due to its ability to disulfide bond.

To determine how gamma-kafirin is distributed throughout the endosperm and within the protein body, immunocytochemical techniques were employed. Three varieties were used to observe how varietal differences may affect protein body composition. SC283-14 (hard), P721N (intermediate), and NSA740 (soft) sorghum samples were collected 20 days after half bloom (DAHP). Gamma-kafirin was purified as described in the 1989 INTSORMIL Annual Report. Purified gamma-kafirin was injected into rabbits for antibody production. After six weeks rabbits were sacrificed and antiserum was collected. Both light microscopy and transmission

electron microscopy were used to observe localization of gamma-kafirin. Sections were incubated with anti-gamma-kafirin antibodies. Goat anti-rabbit/colloidal gold on light microscopy sections were silver enhanced while transmission electron microscopy (TEM) sections were post-stained. Immunocytochemical controls were performed by replacing the primary antibody with a similar dilution of preimmune serum.

Western blot analysis showed the anti-gamma-kafirin antibodies reacted exclusively with the Mr 28,000 kafirin polypeptide. There was no observable reactivity between anti-gamma-kafirin antibodies and purified alpha-kafirin protein. Microscopy results showed that higher concentrations of protein bodies exist in the peripheral endosperm than in the central endosperm. Gamma-kafirin existed throughout the endosperm; however, due to the higher concentration of protein bodies in the peripheral endosperm there was a higher concentration of gamma-kafirin. TEM revealed that gamma-kafirins are evenly distributed throughout the protein body, and that gamma-kafirin existed in both the dark and light staining regions of the protein bodies. A similar distribution of gamma-kafirin exists in the protein bodies from both the peripheral and central endosperm regions. For unknown reasons, the antibodies appear to react more intensely with protein bodies from harder varieties than soft varieties.

Sorghum and corn are grains which appear to be very similar, however important differences exist. While corn remains highly digestible after cooking, *in vivo* and *in vitro* tests show sorghum flour to decrease in digestibility by 40% after cooking. Our research shows that gamma-kafirin was distributed throughout the protein body. This is in contrast to corn where the gamma-zein, also a high cysteine protein, was localized at the periphery of the protein body. The distribution of gamma-kafirin throughout the protein body may result in the formation of disulfide bonding throughout the protein body during cooking. This may explain the decrease in protein digestibility. Further work must be done to study the distribution of the alpha-, beta-, and gamma-kafirins to understand how these proteins are laid down during seed development.

Isolation of Alpha-kafirin and Beta-kafirin

Total kafirin was extracted from sorghum flour using a solution consisting of 60% 2-propanol, 2% 2-mercaptoethanol, (2-ME). To this extract, one volume of water and 0.02 volume of sodium acetate were added to precipitate the alpha-kafirins and beta-kafirins. Gamma-kafirin remained in solution and was discarded after centrifugation. The alpha-kafirin/beta-kafirin pellet was redissolved in 60% 2-propanol, 2% 2-ME. Alpha and beta fractions were separated by adding two volumes of 100% 2-propanol. Most of the alpha-kafirin remained in solution while beta-kafirin was precipitated. Column chromatography (Sephadex G-75, 100 cm x 3.5 cm, buffer: 1 mM Tris, 6 M urea, 1% SDS, 0.1% dithiothreitol (DTT). (pH 8.0) was used to remove residual contaminating proteins from the alpha and beta fractions. Column fractions were analyzed by SDS-PAGE. Those containing isolated alpha- and beta-kafirin were dialyzed and then freeze dried.

While column chromatography gave good separation of the alpha- and beta-kafirin types it did not sufficiently separate the individual beta-kafirin bands so an electrophoretic technique was employed. Total kafirin was extracted from sorghum flour using 60% 2-propanol plus 2% 2-ME. This extract was mixed with sample buffer and loaded onto a 13% SDS-PAGE gel. The 20 kD beta-kafirin protein band was visualized by soaking the gel in ice-cold 0.25 M KCL, 1 mM DTT immediately following electrophoresis. The 20 kD band was cut from the gel and protein was eluted by grinding and extracting the gel piece in elution buffer (0.1% SDS, 0.5 M Tris, 0.1 mM EDTA, 5 mM DTT). The eluted protein was dialyzed against water and freeze dried.

The isolated kafirin proteins were subjected to amino acid analysis and differences in the amino acid content of these proteins are shown in Table 3. Alpha-kafirin contains high amounts of glutamine and leucine with very little cysteine and methionine. However, beta-kafirin contains relatively high amounts of methionine and cysteine, making it more similar to gamma-kafirin which is also high in sulfur-containing amino acids. All of the kafirin groups appear to be low in lysine residues.

Table 3. Amino acid compositions of alpha-, beta-, and gamma-kafirins.

	Mole %			
Amino acid	Alpha-kafirin (25,000, 23,000)	Beta-kafirin (20,000, 18,000, 16,000)	Beta-kafirin (20,000)	Gamma kafirin (28,000)
ASX	5.6	3.3	5.5	0.6
THR	3.2	4.6	3.8	4.2
SER	5.8	4.6	5.1	5.0
GLX	21.8	17.7	17.9	13.8
PRO	8.9	9.7	8.8	22.6
GLY	4.1	6.8	5.8	8.6
ALA	15.2	13.4	13.0	6.3
CYS/2	1.1	4.9	5.6	6.9
VAL	4.8	5.2	5.5	5.8
MET	0.6	5.7	6.1	1.0
ILE	4.4	2.3	3.3	2.6
LEU	15.1	12.0	13.4	9.0
TYR	2.3	3.0	3.2	2.1
PHE	4.0	1.9	3.5	1.8
HIS	1.2	0.9	1.5	6.9
LYS	0.4	0.5	1.5	0.4
ARG	0.8	2.7	3.1	2.0

Using the isolated kafirin proteins, polyclonal antibodies were produced in chickens. These antibodies are being used

for both immunocytochemical localization of kafirins in sorghum protein bodies and in the development of an ELISA assay. ELISA assays will enable us to determine the alpha-, beta-, and gamma-kafirin content of different sorghum varieties. This assay will be a very useful tool for determining the relationship between alpha-, beta-, and gamma-kafirin content and properties of the sorghum such as grain hardness and protein digestibility.

Publications and Presentations

Abstracts

Shull, J. M., A. Chandrashekar, and A. W. Kirleis. 1989. Endosperm development of three sorghum varieties: An SEM study. Cereal Foods World 34:774.

Shull, J. M. and A. W. Kirleis. 1989. Localization of a- and b-kafirins in Sorghum bicolor. Cereal Foods World. 34:784.

Journal Papers

Watterson, J., J. M. Shull, A. a. Mohamed, V. Reddy, and A. W. Kirleis. 1990. Isolation of a high-cysteine kafirin protein and its cross-reactivity with gamma-zein anti-serum. J. Cereal Sci. 12:137-144.

Shull, J. M., A. Chandrashekar, A. W. Kirleis, and G. Ejeta. 1990. Development of sorghum (Sorghum bicolor (L. Moench) endosperm in varieties of varying hardness. Food Structure. 9(3):253-267.

Ph. D. Thesis

Reddy, V. 1990. Protein composition and in vitro protein digestibility of developing Sorghum bicolor (L.) Moench kernels with different endosperm texture. Ph.D. Thesis, Purdue University, West Lafayette, IN.

Presentations

The two abstracts listed above were from papers presented at the American Association of Cereal Chemists 74th Annual Meeting, Washington, D.C. October 29-November 2, 1989.

Kirleis, A. W. and L. Monawar. 1989. "Nutritional Quality of Sorghum." ARC/INTSORMIL Sudan Sorghum and Millet Workshop. Wad Medani, Sudan. October 29 - November 2.

Monawar, L., P. Bureng, S. H. Badi and A. W. Kirleis. 1989. "Traditional Processing and Food Quality Evaluation of Sorghum and Millet." ARC/INTSORMIL Sudan Sorghum and Millet Workshop. Wad Medani, Sudan. October 29 - November 2.

Kirleis, A. W. 1990. The Prolamins of Sorghum: Their Role in Protein Digestibility." Conference on the Nutritional Improvement of Sorghum. West Lafayette, IN. February 26 - March 1.

Networking Activities

Workshops

Worked with the ARC/INTSORMIL Sudan Workshop Committee to plan the workshop technical program. Also participated in the Sudan Workshop held in Wad Medani, Sudan, October 29 - November 2, 1989.

Worked with the Nutritional Improvement of Sorghum Conference Committee to plan the conference technical program. Also participated in the conference held in West Lafayette, IN, February 26 - March 1, 1990.

Research Investigator Exchange

Dr. Laila Monawar, ARC/Food Research Center, Nutritionist, Khartoum North, Sudan, visited my laboratory in September 1989 to review our cooperative work on sorghum food quality. In addition, a number of traditional Sudanese sorghum foods were prepared during her stay for protein digestibility determinations.

Dr. Abdel-Mageed Abass Mohamed from the Department of Food Science and Technology, University of Gazira, Wad Medani, Sudan worked in my laboratory as a visiting professor in 1989/90. Dr. Mohamed worked on methods for evaluating fermented sorghum batters to determine their kisra making quality.

Assistance Provided

Laboratory supplies were provided to the Food Research Centre, ARC, Khartoum North, Sudan in 1989.

Tannins and Other Phenols: Effects on Sorghum Production and Utilization

Project PRF-104B

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Summary

We have developed a simple laboratory assay which can be used to screen progeny of susceptible X resistant sorghum crosses for resistance to *Striga*. This screening technique makes it possible to effectively breed sorghum for resistance to *Striga* even in locations such as the U.S. where *Striga* does not occur and its introduction is prohibited.

We have shown that sorghum roots produce a complex mixture of compounds which influence the germination of *Striga* seed. These include stimulants, inhibitors, and possibly other components which prevent decomposition of these materials. The relative amounts of these root exudate materials is strongly dependent upon genotype and environmental conditions. In order to reach a germinate/not germinate decision, *Striga* seeds apparently integrate the information borne by these conflicting signals. Our laboratory assay measures the integrated effect of these signals.

Sorghum genotypes which are bird resistant but do not contain tannin have been identified. At least one of these appears to have excellent nutritional value, much superior to previously available bird resistant sorghums. These genotypes are valuable sources of this characteristic.

As a byproduct of our sorghum tissue culture project, we produced thousands of plants regenerated from culture. Many of these are variants of the original genotype. These regenerants have been screened for variants with respect to several characteristics. Several variants have been found which appear to have superior resistance to acid soils.

The level of tannins in high tannin sorghums is sufficiently high to cause significant antinutritional effects, especially if the diet is inadequate in protein. We have found that the betel quid widely chewed in India and the Far East has tannin levels several times higher than those of high tannin sorghum. The betel quid was already known to contribute to the incidence of oral and esophageal cancer; it now also seems to constitute a potentially serious nutritional problem.

Objectives, Production and Utilization Constraints

Objectives

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

To elucidate the biochemical basis for the resistance to predatory birds, grain molding, and *Striga* which are provided by sorghum tannins and other phenols.

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

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

To train and/or support LDC collaborators to jointly pursue the above objectives.

Constraints

Production Constraints

Striga hermonthica (witchweed): The incidence of *Striga* seems to be increasing, at least partially due to more intensive cropping because of increasing population pressure on food production. This parasitic weed may now be the most significant biological constraint on cereal production in Africa. There are no effective means of control in the African context.

Grain molding/weathering: This is perhaps as much a utilization constraint as it is a production constraint because

not only is the yield diminished, the quality of the grain is strongly diminished by weathering. This is a particularly severe problem with introduced early maturing high yielding sorghums.

Bird depredation: Improved food quality sorghums low in tannin are often badly damaged by birds in many areas of Africa. *Quelea quelea*, which migrates across Africa in flocks numbering in the millions, is a particularly severe problem. In some areas of East Africa, all sorghums grown are high in tannin, and therefore of relatively low nutritional quality; these are used exclusively as human food. Similarly in Southern Africa, most of the sorghum is high in tannin and is used for producing beer. Better quality sorghums are needed for producing composite flour, but the suitable low tannin sorghums are difficult to produce because of bird damage.

Utilization Constraints

Tannins and other polyphenols in sorghum grain are responsible for diminished nutritional quality, digestibility and/or palatability. Traditional processing techniques developed for these high-tannin cultivars tend to at least partially detoxify the tannin and minimize this problem. These techniques tend to intensify the dark color of the grain and diminish its acceptability by potential consumers.

Research Approach and Project Output

Research Methods

Striga

Despite the pernicious and persistent characteristic of this parasitic weed, it is uniquely vulnerable to chemical control. *Striga* is not an efficient parasite. Far less than 1% of the seeds it produces actually result in damage to its host. *Striga's* early stages of development, seed germination and formation of the haustorium by which it attaches to the host root, do not proceed until separate chemical signals are received from the host. This ensures that the tiny *Striga* seeds do not commit their meager resources to germination and growth unless an appropriate host root is available. Few if any other plants depend upon developmental signals from a different plant. This dependency offers the potential for controlling *Striga* by intercepting the signals, or by providing spurious signals. We have previously characterized and identified a series of alkyl-substituted hydroquinones (the sorgoleones), the first *Striga* germination stimulants identified from a host root exudate. We developed an assay for sorgoleone and screened representative sorghum genotypes for their capacity to produce it.

We have developed a simpler laboratory bioassay which measures the host root's net capacity, stimulation minus inhibition, to cause *Striga* seeds to germinate. Conditioned *Striga* seeds are randomly dispersed in agar in which a germinating sorghum seed is placed. As the host roots develop and produce stimulant, *Striga* seeds germinate at varying distances from the root depending upon how much stimulant is produced. Within 72 hours the results are available. The method is nondestructive; the same seed can be recovered and planted. It requires little equipment, so it can be carried out in modestly equipped laboratories. This assay is being used to survey for germination stimulant production by sorghum cultivars and selections from resistant x susceptible crosses. These same materials are being evaluated for resistance to *Striga asiatica* in uniformly infested plots in North Carolina.

We are characterizing other chemicals in sorghum root exudate which influence *Striga* germination. Just as with sorgoleone, this involves concentration, purification, and analysis by mass spectrometry and NMR. We are also attempting to characterize the germination stimulant receptor site on *Striga* seeds by developing antibodies to it (these will make it possible to eventually isolate the *Striga* genes which regulate germination) and by determining the structural characteristics of molecules which bind to it and block germination.

We are also using our *in vitro* tissue culture methodology in an attempt to produce new sources of resistance to *Striga*. We challenge our rapidly growing suspension cultures of selected sorghum genotypes with an extract of *Striga* plants. This extract apparently contains a *Striga* toxin; it can reproduce most of the symptoms of *Striga* infestation when applied to the roots of sorghum seedlings. Sorghum cells which survive this challenge are rescued and grown out. From these clones of survivors we hope to regenerate plants with enhanced resistance to the *Striga* toxin.

Grain Molding/Weathering

Our approach has been to compare resistant and susceptible cultivars with respect to a wide variety of biochemical parameters. In this way we and our collaborators identified flavan-4-ols and showed that they correlate well with resistance to weathering. With Dr. Ejeta, we are now determining whether the 3-deoxyanthocyanidins, metabolic products of flavan-4-ols which have been reported to be fungitoxic, give better correlation with weathering resistance than do flavan-4-ols themselves. For the second year, we are doing comprehensive analyses throughout grain development not only for flavan-4-ols and 3-deoxyanthocyanidins but also for fungal population size and identity.

Bird Resistance

We are extending our field evaluations of relative bird resistance and are seeking to correlate the results with comprehensive polyphenol assays throughout grain development. Included in this study for the first time are two newly identified sorghums which are bird resistant but free of tannin. We are determining whether these tannin-free bird-

resistant sorghums have good nutritional value comparable to low tannin bird-susceptible sorghums.

Antinutritional Effects

We have reported that the major reason for depressed weight gains and feed conversion efficiencies of rats fed tannins from sorghum and other sources is inhibition of the conversion of digested and absorbed nutrients, largely protein, to new biomass, rather than inhibition of protein digestion. We have also found that these antinutritional effects would be much more severe if it were not for unique proline-rich salivary proteins which bind the tannin strongly. By feeding ^{15}N-labelled proteins we are finding that these proteins tend to remain complexed to tannin throughout the digestive tract and account for the observed increase in fecal protein and proline. We have produced and fed ^{14}C-labelled tannins and related materials to determine their metabolic fate but the tannins did not have sufficiently high levels of radioactivity to give unequivocal results. We have initiated a new approach for obtaining the ^{14}C-labelled materials.

Tissue Culture and Biotechnology

We have changed the focus of our *in vitro* tissue culture program to emphasize suspension cultures and their utilization for selection in culture for characteristics contributing to enhanced resistance to *Striga* and possibly to pathogens such as grain mold fungi. The cultures are also being used by our collaborators for transformation with exogenous DNA using a particle gun. In work not carried out in this laboratory but supported by a Rockefeller Foundation grant to this PI, an RFLP map of sorghum is being developed, with anticipation of mapping the gene(s) controlling production of water soluble *Striga* germination stimulant and eventually other genes.

Research Findings

Striga

We have demonstrated this year that sorghum roots exude a complex mixture of stimulants, stabilizers and inhibitors of *Striga* seed germination. The composition of the root exudate mixture is strongly dependent upon both sorghum genotype and environmental conditions including temperature. *Striga* seeds apparently integrate the information borne by the various amounts of conflicting signals in reaching a germinate/don't germinate decision. These materials are being purified and characterized, but their chemical structures have not yet been determined. The chemical signals are so highly active at such low concentrations (dilutions of crude exudate up to 100,000 fold) that we have had to devise new methods for producing them in relatively large amounts with a minimum of extraneous contaminants.

Sorgoleone, the *Striga* germination stimulant we previously identified from sorghum root exudate obtained under relatively dry conditions, is a hydroquinone insoluble in water and chemically unstable so that it rapidly loses its stimulant activity. We now find that all sorghum cultivars tested produce about the same amount of sorgoleone under optimal laboratory conditions regardless of whether they are susceptible or resistant to *Striga*, so sorgoleone does not appear to play a key role in *Striga* germination.

Using our new agar gel assay and new methods for producing germination stimulant hydroponically, we have found that in moist conditions sorghum not only does not produce sorgoleone, it does produce a germination stimulant with properties quite distinct from sorgoleone. Most importantly, sorghum genotypes differ greatly in production of this new stimulant, with some of the resistant genotypes producing almost none of it, and all susceptible genotypes producing large amounts of it. Some resistant genotypes also produce large amounts of this stimulant; their resistance must be due to another mechanism. This as yet unidentified stimulant is much more stable than sorgoleone and in some genotypes is produced along with other compounds which have the opposite effect, inhibition of *Striga* seed germination. At high concentrations of root exudate, inhibitors diminish germination despite high concentrations of stimulant. We have separated the water-soluble germination stimulant from its accompanying inhibitor(s), and have found that germination assays run in the absence of inhibitor are much simpler to interpret.

We have concentrated and purified this water-soluble germination stimulant until it must be diluted at least 150,000 fold to get its stimulant activity down to measurable levels. It is so active that it apparently occurs at extremely low molar concentrations, too low for us to detect by available chemical or physical methods even when greatly concentrated. Its identification will be a major challenge in the next year. We hope also to identify the germination inhibitor(s) and compounds which stabilize the stimulant, which are also present in sorghum root exudate.

Using the new agar gel assay, individual sorghum seeds can be readily (three days, hundreds at a time), and nondestructively screened for production of the highly active water soluble germination stimulant. The assay, which we adapted from Dr. J. Riopel of the University of Virginia, involves the developing root of a germinating sorghum seed growing through an agar gel in which conditioned *Striga* seeds are randomly dispersed. The furthermost distance from the sorghum root at which *Striga* seeds germinate is a measure of the sorghum seedling's capacity to stimulate *Striga* seed germination. There is no need to count germinated seeds and calculate % germination. Using this assay, sorghum genotypes differ by at least two orders of magnitude in the amount of stimulant produced, with SRN39, previously identified as the most broadly resistant genotype, producing virtually no germinated *Striga* seeds in the assay.

In field trials done in N. Carolina (to be reported by Dr. Ejeta), an extremely high correlation was observed between the incidence of *Striga* and the amount of stimulant observed in the rapid laboratory assay for *Striga* seed germination. The implications are that the water soluble stimulant is the one which is most significant in controlling *Striga* germination in the genotypes tested, and that the convenient assay we use for quantitating this stimulant can be used to effectively and rapidly screen breeding material for *Striga* resistance in the laboratory.

Grain Molding/Weathering

We are finding that the major fungi isolated from developing sorghum grain are *Alternaria* spp., *Epicoccum* spp., *Cladosporium* spp., *Fusarium* spp. (especially *F. moniliforme*), *Nigrospora* spp., and *Penicillium* spp. Early in the season (early milk stage) the number and kinds of fungi on the seed in all cultivars tested is very low. Most of the isolates at this stage are either *Cladosporium* spp. or *Penicillium* spp. As the season progresses the proportion of seeds infected with fungi and the kinds of fungi isolated from the seeds increase. By mid dough stage it is possible to isolate the whole range of fungi from the seeds.

Cultivars with relatively high levels of flavan-4-ols, proanthocyanidins (condensed tannins), and 3-deoxyanthocyanidins showed very low proportions of seeds infested with fungi. As the season progresses even these cultivars show increased levels of infestation. Cultivars previously identified as mold-resistant are at least a week later in flowering than the susceptible cultivars, and are generally higher in flavan-4-ols, proanthocyanidins and 3-deoxyanthocyanidins. Despite recent findings that 3-deoxyanthocyanidins are fungitoxic, we find that the level of flavan-4-ols in the seed is more highly correlated with mold resistance than the level of 3-deoxyanthocyanidins or, as we reported earlier, than the level of tannins.

Bird Resistance

The newly acquired genotypes (Ark 1097 and a Brazilian hybrid) reputed to be both resistant to birds and to be free of tannin were included in our comprehensive investigation of bird resistant sorghums. Both were assayed throughout seed development and found to contain absolutely no tannin. Both showed good bird resistance in our local trials. In Puerto Rico, where bird pressure is greater, both were found to be damaged in one of the two replications. They appear to be slightly less bird resistant than standard high tannin sorghums known to be strongly resistant. The level of resistance exhibited by these sorghums can be quite useful in areas where bird damage to susceptible genotypes is likely to be severe. In the single rat feeding trial we were able to carry out with the available grain, Ark 1097 produced rat weight gains and feed utilization efficiencies significantly better than both the high tannin bird resistant control and even than the low tannin bird susceptible control. There were no apparent nutritional problems associated with consumption of the bird-resistant tannin-free grain. We are initiating attempts to identify the grain components responsible for bird resistance in both these tannin-free genotypes.

Antinutritional Effects

Our major study completed this year was that the betel quid widely chewed in India and the Far East contains condensed tannins at levels several times higher than the level of tannin in high tannin sorghums. Based on our observations of the antinutritional effects of high tannin sorghums and the enhanced severity of these effects in low protein diets which may be common in India, betel quid appears to constitute a major health problem. With Dr. Pushpamma, we are publishing a manuscript which compares the betel quid to high tannin sorghum, and calls attention to this problem.

Tissue Culture

Approximately 500 clones of our regenerated sorghum plants of the high tannin genotype IS8260 were tested for possible somaclonal variants for disease resistance by Dr. R. Frederiksen and for acid soil tolerance by Dr. R. Duncan. Dr. Duncan found about 10 plants which appeared to have unusually high tolerance to acid soils, and will characterize these variants. Dr. Frederiksen did not observe any variants with enhanced disease resistance, possibly due to our failure to provide seeds soon enough for inclusion in the south Texas nursery.

We have essentially completed our screening of thousands of our regenerants from high tannin genotypes for loss of their capacity to synthesize tannin. All that we have tested produced approximately the same amount of tannin as the parent, an unexpected finding in light of the fact that many sorghums already available produce no tannin at all. In contrast, many variants were found which had completely lost their capacity to synthesize chlorophyll. It is not yet apparent why sorghums in culture readily produce variants which cannot synthesize an essential compound such as chlorophyll yet under the same conditions do not produce variants incapable of synthesizing nonessential compounds such as tannins.

We have extended the number and range of genotypes which we have regenerated from callus culture. These now include several *Striga*-resistant sorghums and other elite low tannin genotypes. We have independently produced again the unique developmental somaclonal variant we originally named *Hydra* because it produces up to 10 panicles on a single stem.

We have now shifted the emphasis of our tissue culture program to the establishment of rapidly growing regenerable suspension cultures. We have several genotypes in

suspension culture, some quite promising because of their rapid growth in small clusters of cells amenable to manipulation. As yet we have been able to regenerate only newly established suspension cultures. Cultures highly selected for optimum growth in suspension have thus far proved difficult to regenerate. We have supplied cells to colleagues for transformation with exogenous DNA using particle guns. Transient expression of the GUS gene has been observed.

Publications and Presentations

Publications

Journal Articles and Book Chapters

Butler, L.G. New Perspectives on the Antinutritional Effect of Tannins, in J. E. Kinsella and W. G. Soucie (eds): Food Proteins, American Oil Chemists Society, Champaign, IL (1989), p. 402-409.

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Abstracts

Hess, D.E., R. K. Vogler, G. Ejeta and L. G. Butler, Phenolic Compounds in *Striga*-resistant and *Striga*-susceptible Sorghums, Agronomy Abstracts, p. 85 (1989).

Mole, S., J. C. Rogler and L. G. Butler, Use of ^{15}N-Labelled Protein to Determine the Effect of Dietary Tannin on the Relative Abundance of Endogenous and Dietary Protein in Feces, Groupe Polyphenols, XVth International Conference, Strasbourg, July, 1990.

Other Presentations

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

"Recent Advances in *Striga* Research", Sudan Sorghum and Millet Workshop, ARC, Wad Medani, Sudan, Oct. 29 - Nov. 2, 1989.

"Use of ^{15}N-Labelled Protein to Determine the Mechanism of the Antinutritional Effects of Dietary Tannin", Nestle Research Headquarters, Vevey, Switzerland, July 17, 1990.

Networking

Research Investigator Exchange

Tishu Cai, Beijing Agricultural University, People's Republic of China.

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.

Cooperators

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Food and Nutritional Quality of Sorghum and Millet

Project TAM-126
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Summary

The goal of this project is to improve the utilization of sorghum and millet by developing new or modified processing methods to produce new food products and through cooperation with breeding programs to develop sorghum and millets with built-in improved quality.

The process for parboiled sorghum (sori) and millet (milri) was modified to save energy and reduce processing costs. The new 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 most suitable for preparation of foods from sori.

Fourteen sorghum cultivars representing commercial hybrids and lines with varying kernel properties were parboiled. Brown sorghums could be decorticated efficiently after parboiling. Most of the tannins were removed or eliminated. Soft, floury, high lysine sorghum could be decorticated. In general, the tan plant color sorghum gave the lightest appearing parboiled products. Forty percent of the starch granules lost birefringence during parboiling.

A blend of 70% millet and 30% cowpea flour was cooked, press dried on a hot plate and the flakes were ground

into a precooked weaning food. Sorghum malt was added to the flour to produce beverages with high nutrient density. The weaning food can be produced in villages with indigenous materials and equipment.

Sorghum varieties IS9530 and BTx378 had high diastatic activity and produced hybrids with consistently the highest diastatic activity and relatively low dry matter losses. In Africa, the malting of sorghum is widely used for traditional opaque beers and for lager beer in some countries i.e., Nigeria.

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 very hard grain with resistance to head bugs and molds.

Objectives, Production and Utilization Constraints

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 through development of agroprocessing entrepreneurs.

Objectives

Develop new food products from sorghum and millet using appropriate technology for use in less developed areas.

Develop simple, practical laboratory methods for use in breeding programs to assess important grain quality characteristics.

Determine physical, chemical and structural factors that affect the food and nutritional quality of sorghum and seek ways of modifying the properties or improving methods of processing.

Determine the factors that affect resistance to grain molds and field deterioration in sorghum and devise laboratory procedures to detect genotypes with resistance.

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 product evaluations. Some of these findings are summarized.

Parboiling of Sorghum and Millet

Additional research on parboiling methods and the effect of different varieties of sorghum and millet on sori and milri quality was completed in Mali and at Texas A&M. In Mali, a consumer study indicated that parboiled sorghum had excellent potential consumer demand as a prepared food that could be purchased and cooked similar to rice; but the price has to be lower than that of rice. Moreover, the consumers indicated a preference for smaller pieces of endosperm instead of the larger grits originally produced. The consumers suggested that sori could be used effectively as a substitute for fonio couscous which is a relatively expensive product. The medium to fine grits could be used as couscous and as riz au gras which is generally used to refer to rice fried in oil and then cooked in a stew with vegetables and meat or fish. These products were generally accepted by consumers including housewives and commercial restaurants in the Bamako area. Major concerns were the energy required to parboil the sorghum, the extra time required to cook the parboiled sorghum and the harder texture of stored cooked sori compared to rice stored similarly. A positive trait was that sori had a large increase in volume after cooking so the yield of food was enhanced. The study provided useful information for subsequent improvements in the parboiling procedure.

A modified parboiling procedure was developed by the Food Technology Lab in Mali which consisted of soaking the grain overnight followed by bringing the grain to boil, washing the grain and drying the grain at ambient temperature outside in the shade. This process gave acceptable products with a good distribution of fine to coarse particles of endosperm which was desired by consumers. The process was implemented in village trials near Cinzana. This method reduces cooking time during parboiling.

Evaluation of Sorghum Varieties

Fourteen varieties and hybrids of sorghum were parboiled using a boil, soak, and boil method. The sorghum varieties were selected based on their commercial availability. The parboiled grain was decorticated, cooked into a rice-like product and the cooking time, color, cooked grain texture and decorticated grain yields were determined. Data on a few selected hybrids are presented in Table 1. The soft floury endosperm high lysine cultivar P721 cannot be decorticated because the grain is too soft. Parboiled P721 had very high yields of decorticated grain. Thus, parboiling is a way of using the higher quality protein of P721.

Table 1. The properties of parboiled sorghum varieties with different kernel characteristics.

Variety		Density (g/cc)	Decortication yield (%)	Cook time (min)	Toughness (KPa)	Decorticated color index[1]	Cook grain[1]
A155xSC1207-2 (White)	Control	1.36	75.4	32.0±1.5	112±8.8	69.1	66.1
	BSB	1.43	87.0	32.5±1.3	134±4.0	51.3	61.8
Sureño (White)	Control	1.37	78.9	34.0±2.0	114±17.0	68.2	67.7
	BSB	1.42	86.2	36.3±2.9	175±9.8	51.1	65.3
ATX623xSC103-2 (Brown)	Control	1.35	63.7	34.0±1.0	199±7.4	60.8	45.6
	BSB	1.38	85.0	35.4±1.3	186±30.3	37.4	41.9
A378xTX430 (Red)	Control	1.35	72.1	34.0±0.0	176±15.3	64.7	57.5
	BSB	1.41	86.9	31.0±1.0	221±29.0	43.1	50.6
Dorado (White)	Control	1.35	77.2	37.0±2.0	135±10.3	69.5	67.7
	BSB	1.42	89.7	35.6±1.5	180±2.5	47.3	63.2
P721 (Floury, High Lysine)	Control	1.26	44.1	31.0±0.5	122±4.7	72.7	61.1
	BSB	1.42	87.7	31.0±1.0	210±9.5	42.5	54.9

[1]Color index of cooked grain

The brown bird resistant sorghum could be milled after parboiling to eliminate most of the tannins. The cooked parboiled brown sori was much lighter in color than the cooked nonparboiled brown grits. The vanillin-HCl method gave a negative test for tannins. Rat feeding trials also suggested that the tannins no longer negatively affected the nutritional value. This confirms previous data on the milling properties of brown parboiled sorghums.

Parboiling of 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.

Changes in Composition and Structure of Sorghum During Parboiling

The structure of parboiled sorghum was examined with scanning and light microscopy. The parboiled kernels of P721 were completely translucent and vitreous after parboiling. During parboiling, nearly 40% of the starch granules lost their birefringence in both P721 and Dorado. The starch granules apparently swell and may exude amylose during cooking which moves into the voids between the starch granules which upon drying solidifies and hardens the endosperm. The starch granules in the corneous endosperm do not swell as much and only partially lose their birefringence because they are surrounded by the protein matrix which restricts swelling and leaching of starch granules. The matrix proteins do not change appreciably in appearance. The pericarp was compressed and distorted in places but was generally unaffected. Fluoresence microscopy indicated that the cell walls lost their fluoresence during parboiling.

In general, parboiling caused some gelatinization and reorientation of starch molecules which decreased starch solubility and crystallinity. The softer endosperm sorghums after parboiling contained less dispersible and soluble starch than the intermediate texture sorghum varieties. The solubility increases resulted from gelatinization while the decreases were produced by retrogradation and recrystallization of the starch molecules during drying of the cooked grain. The change in starch affects the texture of the cooked parboiled products. For example, the stickyness of cooked milled sorghum is probably due to amylose and soluble amylopectins which retrograde during drying of wet parboiled grain. Therefore, the stickyness is gone and the cooked grain has a firmer texture because of the retrograded starch molecules.

Tortilla Quality

Thirty-eight improved maicillos criollos sorghum samples at Choluteca, Honduras grown 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 materials had excellent tortilla processing properties; but many of them 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. One of the experimental hybrids performed well in farmers' fields and had excellent tortilla quality in our cooking trials in 1988 and 1989.

Weaning Food Preparation

A simple method of processing millet and cowpea blends into precooked infant foods was developed by cooking millet flour in water and pressing the slurry on the surface of a hot plate to produce dried flakes. The flakes were ground into flour and mixed with press dried cowpea flour produced in the same way. Malted sorghum was used in some procedures to produce weaning foods with high nutrient density that could be consumed in sufficient quantities by children to meet their needs for most nutrients. The ingredients and methods necessary to produce these foods are available in villages in most developing countries. The weaning food does not contain milk or vitamin and mineral mixes or lysine which would be too expensive and unavailable in third world areas unless some outside agency subsidized the program. This procedure is time consuming, tedious and requires some energy; but it is considerably more practical than using extruders and other commercial equipment that is not available and is too expensive to operate. Using this procedure, a village mother can produce nutritionally improved weaning foods without much extra expense.

The weaning foods contained 70% dehulled millet flour and 30% cowpea flour. Composite flours had cold viscosities similar to commercial baby foods. The composites had 17% protein and 72 and 110%, respectively, of the lysine and threonine requirement recommended by WHO for a two year old child. Addition of 5% sorghum malt to the slurry for 5 min. produced a beverage that could be fed in a bottle. The composite flour is suitable for preparation of cold baby food pastes or beverages with improved protein quality.

The weaning food blend does not need to be press dried. It can be produced daily and fed to children. Food scientists in Mali have demonstrated in village trials that blends of cowpea and cereal flours are effective, practical weaning foods. The press drying allows storage of a prepared baby food that can be used without much preparation. This type of product might be prepared and sold in urban areas.

Malting of Sorghum

The malting characteristics of eight sorghum parents and their hybrids grown at Halfway and College Station Texas in 1988 and 1989 were determined. The samples were malted using a standardized malting procedure where 150 g of grain was steeped, germinated and dried. The malt was evaluated for enzymatic activity using a reducing sugar method. Dry matter losses and enzymatic activity, the most important properties of malt varied significantly among parents and among hybrids. The highest diastatic activity (>24 SDU) was observed in malts prepared from IS9530, ATx378*IS9530, ATx378*BTx430, ATx378*BTx432 and SA3067. Eight other cultivars produced malts with greater than 20 SDU. Hybrids utilizing BTx378 and IS9530 gave malts with consistently highest diastatic activity and lower malting losses than other parents. Malt quality appears to be the result of additive genetic traits. The sorghums with the highest diastatic activity had red pericarps and intermediate texture. However, pericarp color is not related to malting quality because information from Nigeria indicates that yellow endosperm and white pericarp sorghums gave the best overall malting quality. In fact, an intermediate texture, yellow endosperm sorghum variety is currently the most widely used sorghum for commercial malting in Nigeria.

Correlations between diastatic activity and kernel characteristics such as thousand kernel weight, density, hardness and pericarp thickness were nonsignificant. Germination was significantly correlated with malt diastatic activity. Grain with low germination had poor malting properties with greatly increased dry matter losses due to respiration of molds. Mold and weathered sorghum has very poor malting properties.

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 optimum 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.

The Potential Value of Dietary Fiber from Sorghum and Pearl Millet

Bran was obtained by decortication of a white, tan plant sorghum (Malisor 84-7), a brown, bird resistant, high tannin sorghum (ATx623*SC103) and blue pearl millet grain. The millet was a composite of different varieties from the Kansas State University nursery with mostly blue or purple kernels. The bran contained a large amount of insoluble fiber with

very small quantities of soluble fiber. There were no essential differences in dietary fiber content between the two sorghum brans.

The effects of sorghum and millet bran on blood and liver cholesterol levels and colonic physiology was determined by feeding the bran to rats for 21 days. The sorghum and millet bran was compared to cellulose, pectin, wheat bran, oat bran, and an American blend of fiber composed of mainly cellulose, corn fiber and lignin. The cecael surface of rats fed wheat bran, cellulose, sorghum bran and millet bran was similar and significantly higher than those of rats fed oat bran and pectin. The liver cholesterol values for oat bran and pectin fed rats were significantly lower than the other treatments. Thus, sorghum and millet brans were equivalent to wheat bran in terms of being a good bulking agent to reduce the possibility of colon cancer. However, sorghum and millet bran did not have any effect on cholesterol levels. Thus, sorghum and millets will not provide an alternative to oat fiber.

Digestibility of Sorghum

Several sorghums varying in texture and a waxy endosperm type were wet milled into free starch, decorticated into grits, ground into whole grain flour and the *in vitro* starch digestibility determined using rumen fluid. There were relatively little differences in starch digestibility among the free isolated starches although waxy sorghum starch was highest, being equal to corn starch. However, when grits or ground sorghums were compared, the soft floury endosperm sorghum had the highest digestibility while the hard, vitreous endosperm was the lowest. The protein matrix surrounding the starch significantly decreases starch digestibility. This information helps to explain why sorghum must be processed more thoroughly than other cereals for feeding and for food preparation. The traditional methods of processing usually involve thorough grinding and cooking with stirring, fermentation, malting, soaking and steeping which partially destroys the protein matrix and cell walls and frees many starch granules from the endosperm proteins. The prospect of increasing starch digestibility through breeding is not very encouraging because the soft floury sorghums are susceptible to mold damage and to damage during harvesting and handling, which means they are impractical for production. The key to improved digestibility in sorghum is to modify the protein matrix; however, the grain produced will likely be extremely susceptible to grain molds and weathering. Progress to develop a hard endosperm corn is being made. Similar progress can be made in sorghum.

Effect of Head Bugs and Molds on Quality

Trials were conducted in Mali to determine the effect of head bugs on the kernel properties, milling, cooking and other characteristics of sorghum lines grown under natural infection, protected by application of insecticides, protected by a cage, and protected by treated bags. The trials conducted in 1989 showed clearly that attack by head bugs caused serious damage to all of the sorghum lines evaluated in the trials. Details of the entomological data can be found in the report by Teetes (TAM-125) and in the Mali country report. The Malisor 84-7 cultivar had the most consistent tolerance to head bug attack of all the advanced improved sorghum varieties and lines (Figures 1 & 2). The color of the grain and food products was very dark, especially for the nontan plant colored sorghums (Figure 1).

Kernel weight, density, bulk density, germination, and hardness were significantly reduced by head bugs. The grain could not be dehulled efficiently by hand pounding or by mechanical milling. The pericarp could not be removed from the endosperm because the endosperm structure was partially destroyed (Figures 1-3) and the kernel disintegrates when subjected to the forces of milling. Malisor 84-7, a very hard, corneous variety bred in Mali, is attacked; but it was not completely destroyed like the other improved varieties (Figure 1C vs Figure 2C).

The local varieties are photosensitive, mature later and escape head bugs and grain molds most years because they mature during dry weather. In addition, they have a hard endosperm which does not deteriorate as quickly as softer kernels. However, in 1989, conditions were so severe in some locations that grain of the local cultivars was damaged compared to grain protected from head bugs. In a 25 entry advanced trial in Mali, the only sorghums that could be processed by hand pounding were the local checks and Malisor 84-7. The other lines were so badly damaged the grain was useless for food. We have found that parboiling soft damaged grain can make the grain usable; but the color is undesirable. Progress is being made to understand the factors affecting head bug damage. The development of harder kernels with tan plant color is a part of the solution. Crosses with Malisor 84-7 have produced selections with tolerance to the head bug; so progress is possible. The concepts of breeding for a hard endosperm that led to Malisor 84-7 are still valid for Mali and West Africa.

Phenolic Compounds and Mold Resistance

Sorghum cultivars were inoculated with *Fusarium moniliforme* at boot stage of growth in control and misted (daily) nurseries. Free phenolic compounds in spikelet tissues were analyzed 48 hours after inoculation using the Folin-Ciocalteu assay. Fungi colonized spikelet tissues of susceptible cultivars within 48 hrs; but colonization was absent in spikelets of most moderately resistant cultivars.

Free phenolic compounds were the same or were more abundant in moderately resistant cultivars in both control and misted environments (Table 2). Also, the % increases in phenolic compounds after inoculation were greater in moderately resistant cultivars. Cultivars with red pericarp color (vs white) contained more free phenolic compounds.

Table 2. Effect of misting and inoculation with Fusarium moniliforme on the free phenolic compounds in sorghum glumes at anthesis.

Molding resistance	Pericarp color	Number of cultivars	Free phenolic compounds (not inoculated)		% Increase (with inoculation)	
			Control	Misted	Control	Misted
Mod. resist.	Red	7	10	14	17	20
Mod. resist.	White	2	8	5	13	70
Mod. suscept.	White	4	7	6	10	14

This suggests that phenolic compounds contribute to the grain molding defense mechanisms of sorghum spikelet tissues in the boot/anthesis stage of maturity. Previous results suggested that phenolic compounds contribute "grain molding" defense mechanisms during the first 10 days after anthesis. Resistant cultivars usually have more phenols initially and their concentration increases more rapidly after inoculation with *F. moniliforme* than in susceptible cultivars.

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 has released several parents that produce white tan plant sorghum hybrids which have excellent food and feed processing quality. However, these sorghums 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 twice to develop work plans, Amendment #7 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, was present in January to initiate her E.E.C. funded project on post harvest technology that will be conducted by the laboratory. A joint plan between INTSORMIL, IRAT, and IER for purchasing the equipment for the laboratory was developed. Dr. John Scheuring, Ciba-Geigy, Ms. Haidara (IER) and L. W. Rooney designed a simple poster in French and Bambara to summarize use of the cowpea-millet composite weaning food.

Mr. A.B. Bello, Nigerian graduate student, Texas A&M University, completed analyses on sorghum and pearl millet samples to determine factors affecting tô quality.

Mexico and Central America

L.W. Rooney participated in the CLAIS Workshop on white sorghum for foods held at CIMMYT and jointly sponsored by ICRISAT-INTSORMIL. L.W. Rooney participated in the 4th Mexican National Sorghum Improvement Conference held in Guadalajara, Mexico. Work in Honduras on sorghum quality relates strongly with work in Mexico. Dr. F. Martinez-Bustos returned to the INIFAP quality laboratory. Plans have been made for exchange visits to develop long term collaboration with his laboratory. He will visit in October of 1990. We are trying to find funding to expedite collaboration with the University of Sonora. Poster papers of joint research were presented at the IFT meeting in California.

Dr. Benjamin Ramirez completed his Ph.D. on techniques for masa and tortilla quality evaluation in the spring of 1989, returned to the University of Sonora and is initiating his research program which will involve sorghum improvement for human foods, especially tortillas. The two students from Mexico are currently working on Ph.D. degrees on the INTSORMIL projects.

North America

Traveled to University of Nebraska and Kansas State University at Ft. Hays to review the INTSORMIL pearl millet breeding nurseries and to plan for expanded utilization and quality research of pearl millet. White endosperm millets afford an opportunity to improve the color of millet products dramatically. Project personnel participated in the workshop on nutritional quality of sorghum held at Purdue and the CLAIS workshop on grain quality held at CIMMYT in Mexico. L. W. Rooney participated in the 4th biennial conference of Mexican Sorghum Workers held at Guadalajara. Several papers were presented at the annual American Association of Cereal Chemists conference in Washington, D.C. and at the Institute of Food Technologists food exposition in Anaheim, California. The P.I. participated in the grain sorghum producers annual conferences 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 two trips to Mali and a meeting in February 1990 with Dr. Traore, IER Mali coordinator in Texas.

Figure 1. The effect of head bugs on Malisor 84-7 grain. (A) Protected; bar = .8mm (B) Protected; bar = 2.0mm (C) No protection; arrow indicates discoloration; bar = .8mm and, (D) No protection; arrow indicates external discoloration; bar = 2.0mm.

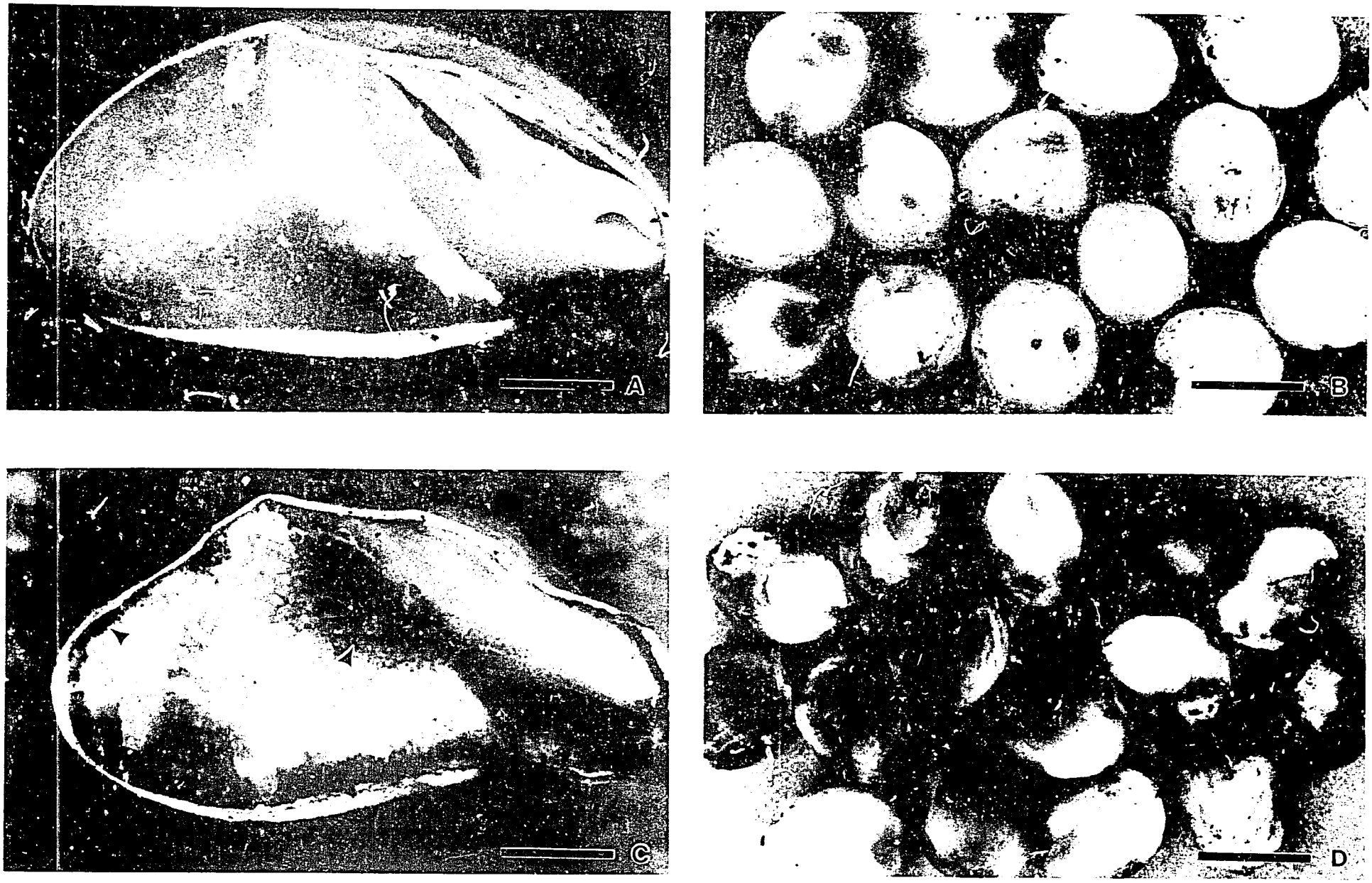


Figure 2. The effect of head bugs on ICSV 16-5. (A) Protected; bar = .8 mm (B) Protected; bar = 2.0 mm (C) No protection; arrow indicates discoloration; note floury texture when compared to Figure 2A; bar = .5 mm and, (D) No protection; excessive discoloration is evident; kernels are somewhat smaller; bar = 2.0 mm.

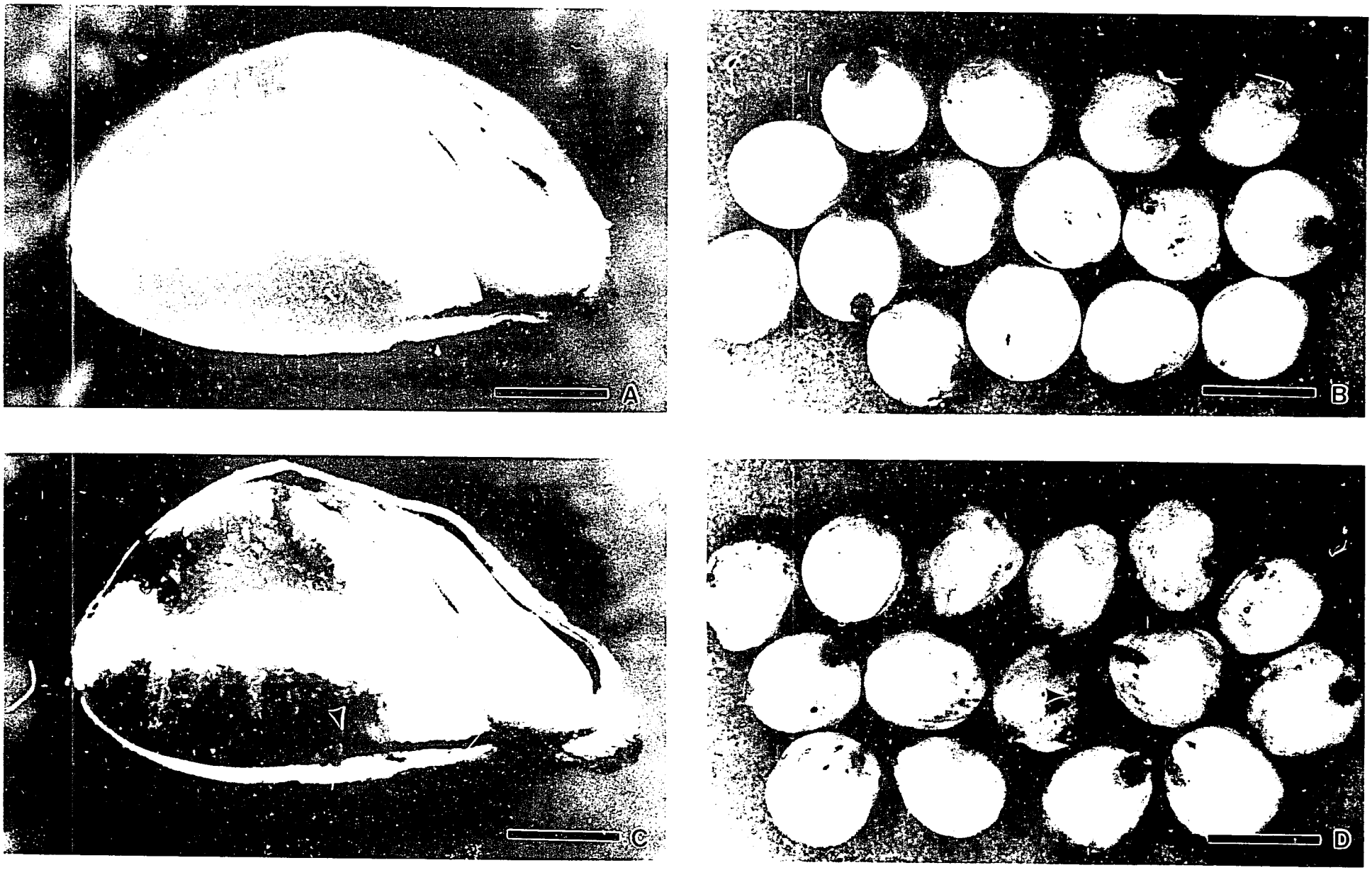
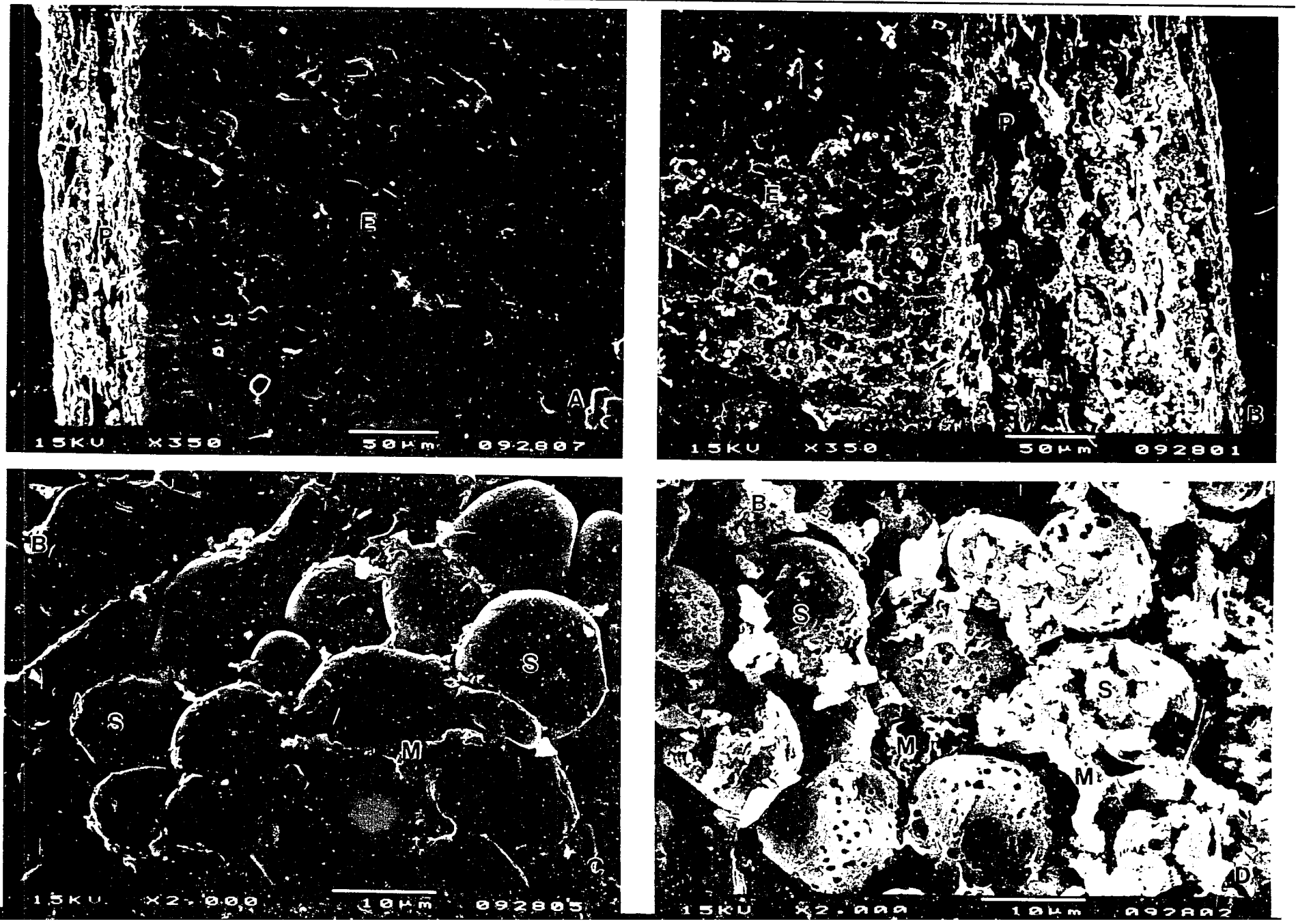


Figure 3. Endosperm structure of Malisor 84-7. (A) Protected; pericarp and endosperm areas have a normal appearance; P-pericarp, E-endosperm (B) No protection; pericarp is thicker and contains more starch; endosperm texture is more floury; P-pericarp, E-endosperm (C) Protected; corneous endosperm; protein matrix covers starch granules in a semicontinuous manner; S-starch granule, M-matrix protein, B-protein bodies, and (D) No protection; corneous endosperm; starch granules show evidence of enzyme attack; protein matrix is thicker in some areas; more protein bodies are present; S-starch granule, M-matrix protein, B-protein bodies.



Pathology

Identification and Quantification of Nematodes in Interactions with Bacterial and Fungal Incitants in Stalk Root Complexes of Sorghum and Millet

Project KSU-108
L. E. Claflin and J. F. Leslie
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Collaborating Scientists

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Dr. Sam Mukuru, Nairobi, Kenya
Mr. Clement Kamau (Sorghum Breeder-Katumani)
Mr. Wilson Songa (Pathologist-Katumani)
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Dr. Paul E. Nelson, Fusarium Research Center, Pennsylvania State University
Dr. Richard E. Frederiksen, Department of Plant Pathology, Texas A&M University, College Station, TX 77843
Drs. C.Y. Sullivan, D.J. Andrews, and M.B. Dickman, Department of Agronomy, University of Nebraska, Lincoln, NE 68583
Dr. D.T. Rosenow, Texas A&M Agriculture and Research Center, Lubbock, TX

Summary

Xanthomonas campestris pv. *vasculorum* is the causal agent of gumming disease or gummosis of sugarcane and is common in Eastern and Southern Africa. Thirty strains of *X. campestris* pv. *vasculorum* from diverse areas were tested for pathogenicity on maize, sorghum, and sugarcane. All of the strains were pathogenic to sorghum but not to pearl millet under greenhouse conditions. It is unknown if sorghum plants are susceptible under natural field conditions.

X. campestris pv. *zeae* has only been recorded in the Republic of South Africa as a pathogen of maize. Eight strains of this bacterial causal agent were tested for pathogenicity on maize, sorghum, sugarcane, and pearl millet. Only maize was found to be susceptible.

Nineteen strains of *Xanthomonas campestris* pv. *holcicola*, the causal agent of bacterial leaf streak of sorghum, were characterized by polyacrylamide gel electrophoresis (PAGE) of membrane proteins, restriction endonuclease analysis (REA), and restriction fragment length polymorphism (RFLP) analysis of genomic DNA. Three proteins of approximately 49,000, 32,000, and 21,000 daltons were common to all strains and, yet, were distinct from other pathovars of *X. campestris*. RFLP analysis of DNA from *X. campestris* pv. *holcicola* revealed two distinct bands; one band at 12 Kb and another band at 4.8 Kb. *X. campestris* pv. *holcicola* was distinctly different from patterns of other pathovars of *X. campestris*.

Over 1200 isolates of *Fusarium* from sorghum, maize and rice were collected in Thailand in October 1989. The majority of these isolates have been purified through a single uninucleate microconidium via micromanipulation and preserved for long-term storage at -80°C. These isolates will be used to measure genetic diversity within this population for comparison with populations from Africa and the Americas. Sexual testers for the known mating populations within *Fusarium* section *Liseola* have been constructed and are being made available to other investigators worldwide. Development of probes for RAPD and RFLP markers for strain

identification has begun for use in identifying strains that cannot be typed using the sexual crossing procedures.

Objectives, Production and Utilization Constraints

Objectives

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

To determine the relative importance of seedborne vs. soilborne strains of *F. moniliforme* as causes of stalk rot.

To ascertain the prevalence and importance of *Pseudomonas avenae* and *Xanthomonas campestris* pv. *pennamericanum* in pearl millet production areas in West Africa and their potential role as seedborne pathogens.

To continue investigating the epidemiological parameters of bacterial diseases and development of an antisera bank for LDC scientists for the purpose of diagnosing bacterial diseases of pearl millet and sorghum.

Constraints

1. Bacterial diseases of pearl millet and grain sorghum are often ignored due to poorly equipped laboratories and/or personnel with limited training in bacteriology. Bacterial diseases are reported to have limited or no effect on yields, however, these reports are based on anecdotal observations rather than on acceptable scientific experimental protocols. Bacterial pathogens most likely colonize the vascular tissue of grain sorghum and pearl millet which may contribute to development of stalk rots. This aspect has not been researched and a need exists for such research. Finally, a number of countries require a phytosanitary certificate which states that the seed or feed grain is free of bacterial stripe and/or bacterial streak.

We have developed serological techniques for diagnosing the causal agents of bacterial diseases of sorghum and pearl millet, e.g., the dot-immunobinding assay. However, this test is not reliable when minimal numbers of bacteria and/or when similar or closely related bacterial species in the genus *Pseudomonas* are present in the sample. Monoclonal antibodies would resolve most of the problems, but they are expensive to develop and insufficient funds are presently available for this work. If monoclonal antibodies were developed, then antisera would be readily available to scientists in developing countries for diagnostic purposes.

2. Stalk rots of sorghum and millet are a continuous problem wherever these crops are grown and losses usually range from 5-10% annually. The identity of fungal strains within the genus *Fusarium* that can cause this disease is uncertain. We have been developing techniques based on sexual and vegetative compatibility that provide fine levels of genetic discrimination using simple techniques that require little more than petri dishes, microbiological media, and incubator space.

Research Approach and Project Output

Research Methods

1. Seedborne bacteria may be found in infested plant debris, may reside on the surface of the testa or hilum, or colonize the embryo or other internal tissue. Methods to recover bacteria from seed usually involve soaking seeds in liquid media or washing the seeds briefly in a liquid medium. Seeds can be surface disinfested or left untreated and then plated on selective media. After isolating suspected colonies, the bacteria can be confirmed with pathogenicity tests, immunology tests or with more sophisticated procedures such as the polyacrylamide gel electrophoresis test which will compare membrane protein profiles of the bacteria.

2. *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.

Research Findings

1. *Xanthomonas campestris* pv. *vasculorum* is the causal agent of gumming disease or gummosis of sugar cane. This disease is common in Eastern and Southern Africa. Thirty strains of *X. campestris* pv. *vasculorum* from diverse areas were tested for pathogenicity on maize, sorghum, and sugar cane. All of the strains were pathogenic to sorghum under greenhouse conditions. It is unknown if sorghum plants are susceptible under natural field conditions. To our knowledge, this report is the first that *X. campestris* pv. *vasculorum* is a potential pathogen of sorghum. This phytobacterial organism was not pathogenic to pearl millet.

X. campestris pv. *zeae* has only been recorded in the Republic of South Africa as a pathogen of maize. Eight strains of this bacterial causal agent were tested for pathogenicity on maize, sorghum, sugar cane, and pearl millet. Only maize was found to be susceptible.

Nineteen strains of *Xanthomonas campestris* pv. *holcicola*, the causal agent of bacterial leaf streak of sorghum, were characterized by polyacrylamide gel electrophoresis (PAGE) of membrane proteins, restriction endonuclease analysis (REA), and restriction fragment length polymorphism (RFLP) analysis of genomic DNA. A common membrane protein was observed for all strains of *X. campestris*

pv. *holcicola* from Australia, Lesotho, Mexico, New Zealand, Republic of South Africa, United States, and Zimbabwe. Three proteins of approximately 49,000, 32,000, and 21,000 daltons were common to all strains and, yet, were distinct from other pathovars of *X. campestris*.

RFLP analysis of DNA from *X. campestris* pv. *holcicola* revealed two distinct bands; one band at 12 Kb and another band at 4.8 Kb. This pattern was observed after the *X. campestris* pv. *holcicola* DNA was digested with *Eco*RI and then hybridized with pJEL101 (a pUC18 derivative containing a 2.4 Kb repetitive DNA element from *X. campestris* pv. *oryzae*). *X. campestris* pv. *holcicola* was distinctly different from patterns of other pathovars of *X. campestris*.

PAGE, REA, and RFLP are relatively new developments for use in genetic engineering research. We have found these techniques to be useful in identifying *X. campestris* pv. *holcicola*; characterization of the strains of this pathogen from other sorghum production areas in the world, and separating the *holcicola* pathovar from other pathovars of *X. campestris* which is a difficult task.

2. An extensive collection of over 1200 isolates of *Fusarium* from sorghum, maize, and rice was made in Thailand during October 1989. The diversity observed in this population will be used to determine if the same pathogen can be recovered from rice, 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. The majority 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.

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 a working set of standards that have been made available on request to researchers doing these types of identifications. 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 he has recovered from his field populations.

We have begun to develop RFLP and RAPD markers for use in studying genetic diversity within *Fusarium* populations as well. These markers would provide evidence on genetic variability that is independent of either our sexual or vegetative compatibility markers. Using mitochondrial markers we hope to determine whether extensive migration or extensive sexual recombination is the explanation for the high levels of diversity observed within some populations with respect to VCG. The RAPD markers may eventually be applicable to less developed countries since the technology on which they are based is much less sophisticated than that usually associated with recombinant DNA biotechnology.

Publications and Presentations

Publications

Bramel-Cox, P. J., and L.E. Claflin. 1989. Selection for resistance to *Macrophomina phaseolina* and *Fusarium moniliforme* in sorghum. Crop Science 29:1468-1472.

Claflin, L. E., B.A. Ramundo, J.E. Leach and I.D. Erinle. 1989. *Pseudomonas avenae*, causal agent of bacterial leaf stripe of pearl millet. Plant Disease 73:1010-1014.

Klittich, C. J. R. & J. F. Leslie. 1989. Chlorate-resistant, nitrate-utilizing mutants of *Fusarium moniliforme* (*Gibberella fujikuroi*). Journal of General Microbiology. 135:721-727.

Correll, J. C., C. J. R. Klittich, & J. F. Leslie. 1989. Heterokaryon self-incompatibility in *Gibberella fujikuroi* (*Fusarium moniliforme*). Mycological Research 93:21-27.

Chaisrisook, C. & J. F. Leslie. 1989. Inheritance of perithecial pigmentation in *Gibberella fujikuroi* (*Fusarium moniliforme*) (Abstr.). Phytopathology 79:1003.

Dickman, M. B. & J. F. Leslie. 1989. Regulation of nitrogen metabolism in *Fusarium* by a homologous *Neurospora* gene (Abstr.). Phytopathology 79:1172.

Leslie, J. F. & M. B. Dickman. 1989. Heritability of hygromycin resistance in transformed strains of *Fusarium moniliforme* (Abstr.). Phytopathology 79:1186.

Presentations

Dr. Leslie made invited presentations or seminars as follows during 1989:

16th Fungal Genetics Information Conference, Asilomar, California.

International Conference on Fusarial Wilt of Banana, Miami, Florida.

Natl. Center Genetic. Engineering & Biotechnology, Kamphaengsaen, Thailand.

Dept. of Pest Management., Prince of Songkhla Univ., Hat Yai, Thailand.

Dept. of Microbiology, Kasetsart University, Bangkhen, Bangkok, Thailand.

School of Biol. Sci., Universiti Sains Malaysia, Penang, Malaysia.

Networking Activities

Workshops

Dr. Claflin attended the ARC/INTSORMIL Sudan Sorghum and Millet workshop in Wad Medani, Sudan from October 28 through November 2, 1989. Dr. El Hilu Omer and Dr. Claflin surveyed for sorghum diseases in the Sennar area and also planned collaborative research projects involv-

ing covered kernel smut of sorghum and bacterial diseases of sorghum and pearl millet.

Dr. Leslie attended an International Conference on *Fusarium* wilt in Banana in Florida and presented data on *Fusarium* from maize and sorghum populations as a model for the genetic analysis of populations from banana. He also described the sexual and vegetative compatibility techniques that have been developed in his laboratory and explained how they could be applied to the study of *Fusarium* populations recovered from banana.

Research Investigator Exchanges

Mr. Demba M'Baye, Plant Pathologist, ISRA/CNRA, Bambey, Senegal spent April 15-30, 1990 in Dr. Claflin's laboratory. Mr. M'Baye learned various techniques for diagnosing bacterial diseases of grain sorghum and pearl millet. These included immunofluorescent staining, preparation of selective media, dot-immunobinding assay and SDS-polyacrylamide gel electrophoresis.

Dr. Waheeb Saleem Suliman from Giza, Sudan worked as a visiting professor in Dr. Claflin's laboratory from August 1, 1989 to March 31, 1990. Dr. Suliman's sponsor was the International Atomic Energy Agency, Vienna, Austria. Dr. Suliman worked primarily with two grain sorghum and sugar cane bacterial pathogens: *Pseudomonas rubrilineans* and *P. rubrisubalbicans*. The research involved extraction, purification, and quantification of the chromosomal DNA from different strains of the two bacterial species and the plasmid DNA from *Escherichia coli*. This was used as a probe in the restriction fragment length polymorphism (RFLP) analysis.

Several sorghum leaf samples which exhibited symptoms of a bacterial disease were diagnosed for Dr. W. A. deMilliano, SADCC/ICRISAT, Bulawayo, Zimbabwe. The disease was identified as bacterial leaf streak which is caused by *Xanthomonas campestris* pv. *holcicola*.

Antisera from our collection at Kansas State University were provided to the Plant Quarantine Unit at the ICRISAT Center in Hyderabad, India. They utilized the antisera in a dot-immunobinding assay for detecting *X. campestris* pv. *holcicola* in a seed shipment from Yemen. Their results were published in: Indian Phytopathology 42 (1989):281-282. One of the investigators, Dr. J. Raghawa Reddy, Phytobacteriologist, Plant Quarantine Unit, ICRISAT, arrived in September, 1990 to spend a one year study leave in Dr. Claflin's laboratory to learn additional diagnostic techniques.

Collaborative projects were implemented with KARI/MIAC/ICRISAT/ INTSORMIL in Kenya. The sorghum and pearl millet producing areas near Kakamega and Katumani were surveyed for diseases in 1989 and 1990. Principal collaborators include Mr. Wilson Songa (pathologist), Mr. Newton Ochanda (breeder), Mr. Lawrence M'Ragwa (breeder) and Mr. Clement Kamau (breeder) from the KARI staff. Drs. Vartan Guiragossian and Sam Mukuru represent the ICRISAT staff. Numerous scientific reprints and Sorghum Disease Compendiums were distributed to the Kenyan scientists.

Dr. Leslie spent six weeks in Thailand and Malaysia as part of a USDA/OICD-sponsored scientific exchange. During this time he and Dr. Wiwut Daengsubha made extensive collections of *Fusarium* from throughout Thailand and planned further collaborative research. Dr. Leslie also taught a short course in Fungal Genetics during his stay at Kasetsart University.

Dr. Baharuddin Salleh, Deputy Dean of the School of Biological Sciences, Universiti Sains Malaysia in Penang spent six weeks in Dr. Leslie's laboratory learning techniques for doing sexual and vegetative compatibility analyses of *Fusarium* spp.

Sorghum and Millet Disease Control

Project TAM-124

R. A. Frederiksen and R. W. Toler
Texas A&M University

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Mengistu Hulluka, Agricultural Research Center, P.O. Box 32, Debre Zeit, Ethiopia
Issafou Kollo, INRAN, Niamey, Niger
Dan Meckenstock, Dep. de Ciencias de Suelos y Cultivos Escuela Agricola Panamericana, Apdo. Postal 93, Tegucigalpa, Honduras
Ronnie Duncan, Department of Agronomy, Georgia Agricultural Experiment Station, Experiment, GA
Paul Hepperly, USDA-ARS, South Atlantic Area, Tropical Agriculture Research Station, Box 70, Mayaguez, P.R. 00709
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Bhola Nath Verma, Sorghum and Millet Coordinator/Sorghum Breeder, Mt. Makulu Central Research Station, Private Bag 7, Chilanga, Zambia

Summary

Anthracnose caused major disease losses in Mali. Malisor 7, an elite sorghum developed in Mali, was damaged by this disease. Differences among cultivars for reaction to isolates of *Colletotrichum graminicola* exist in Mali as well as within other regions of Africa. Plant hormones are important in regulating the balance between a diseased and healthy state of infected plants. Current work has demonstrated that both the host and pathogen produce gibberelins which change during colonization of the host. Specific host pericarp genes affect grain mold development. Genes previously thought to play a major role have been found to be ineffective.

The international sorghum antiserum bank supplied antiserum on request to four cooperators in LDC's and six in the U.S. The international sorghum was grown in three countries in 1990. The final study on rate of loss of infectivity of maize dwarf mosaic virus by schizaphis graminum after different acquisition times was completed. The concentration of MDMV-A in varying sorghum cultivars was

determined. Both high and low concentrations were observed and correlated with susceptibility and resistance. A pathogenic interaction was observed between sorghum yellow banding virus and maize dwarf mosaic virus. A maize dwarf mosaic virus resistant germplasm was registered and released in 1990 as RTX 2858 by Toler and Miller.

Objectives, Production and Utilization Constraints

Objectives

Sudan

Charcoal Rot
- Continue to characterize plant traits useful in breeding for resistance.
- Identify sources of resistance.
- Evaluate effects of growth regulators on reaction of sorghum to charcoal rot.

Long Smut
- Identify sources of resistance.
- Identify plant traits leading to disease escape.
- Study survival of the pathogen.
- Assess economic importance of disease in rain fed production areas.

Honduras

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

Brazil

- In 1990, we will continue our collaboration 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 is being written for submission to USAID for collaborative work on long smut and ergot.
- Collaborate with Dr. T. B. Garud on virus problems in India.

Malawi

- Identify sorghum virus observed in Malawi in 1988.

Mali

- Mr. M. Diourti will begin work on long smut, grain mold, and sooty stripe in Mali.

Niger

- Evaluate methods of inoculating sorghum with the long smut pathogen *Tolyposporium ehrenbergii* in Niger.
- Characterize sorghum resistance and reaction following natural and controlled inoculation with *T. ehrenbergii*.
- Based on known host reaction and level of infection, develop a disease rating scale for use in the breeding program in Niger.

Venezuela

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

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.

Ethiopia

- No work planned for 1988-89.

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

Production Constraints

Pathogens cause damaging diseases to both sorghum and millet. Generally in areas with traditional or subsistence agriculture, systems have been developed to minimize losses and maximize stability but usually at primitive production levels. Efforts to increase production nearly always introduce production hazards. These problems have included the increased levels of disease because of genetic uniformity, changes in plant architecture, deployment of susceptible cultivars as well as changes in cropping sequences or cultural methods. Our work is directed toward identifying the best possible genotypes for each particular environment and the development of techniques that permit evaluation of candidate cultivars. Host plant resistance along with disease escape represents the most effective means of control in farmers' fields. Our approach is to utilize local environments with emphasis on disease resistance screening in national sorghum and millet programs wherever possible. Grain mold, downy mildew, long smut, charcoal rot, anthracnose, and several virus diseases are problems that need direct attention. Because all pathogens are variable and because host resistance is specific to selected pathotypes, part of the work is directed toward reducing the impact of this variability by utilizing broadly based "horizontal" resistance. Selected studies on the biology and population of pathogens assists in devising appropriate levels of disease control or management.

Funds to support purification and antiserum production are the main constraint to maintaining the antiserum bank. Also these funds are needed to fill all the requests for antiserum throughout the world.

Research Approach and Project Output

Long Smut

At the Sudan Conference in October 1989, Dr. El Hilu and I presented two papers on sorghum diseases in Sudan and collaboration on research progress. Dr. El Hilu also reviewed the long smut research reported previously (Annual report 1988-89) at the regional meeting of East African sorghum workers in June, 1990. In Sudan, advanced breeding lines were evaluated for reaction to long smut using the inoculation techniques developed by Dr. El Hilu and colleagues.

In Niger, selections were made within segregating populations for high and low reactions to long smut. Nurseries at Kollo were lost because of flooding caused by the Niger River.

Downy Mildew

Lindolfo Fernandez worked with Mr. Collins and Dr. Craig to develop techniques for improving downy mildew evaluations in Honduras. Pathotype 5 of *Peronosclerospora sorghi* has only been observed in Honduras, but the level of disease has been low over the past few years. At College Station, *Peronosclerospora sorghi*, *P. sorghi* Thailand isolate, *P. maydis*, *P. philippinensis*, *P. sacchari*, and two *Peronosclerospora* sp. isolates from China were readily differentiated by the Pvul RFLP patterns produced when one radioactively labeled probe PCLY83 was hybridized to southern blot containing DNA from the respective fungi. On the basis of RFLP patterns, these fungi can be divided into four groups:*P. sorghi*, *P. sorghi* Thailand isolate, *P. maydis*, and *P. philippinensis-sacchari*. The two isolates of *Peronosclerospora* sp. from China belong to *P. philippinensis-sacchari* group (Fig. 1). The patterns were the same whether DNA was extracted directly from the fungus or from the infected leaves. The probe was selected from a *P. maydis* DNA library in pUC19. Sorghum downy mildew and Java downy mildew inoculum in sorghum seeds and maize seeds collected from plants infected with *P. sorghi* and *P. maydis* respectively, were detected by probe PMLY12 which selected from a *P. sorghi* pathotype 3 DNA library in pUC19. This probe did not hybridize to DNA extracted from 10 of the common fungi of sorghum and maize, or to DNA isolated from plant tissue infected with other downy mildews, *Sclerospora graminicola* or *Sclerophthora macrospora*. These DNA probes provide a sensitive, accurate and reliable new tool for the identification and detection of this group of biotrophic fungi. It is important to know that live exotic downy mildew pathogens were not used, only their DNA is necessary. This work demonstrates both the application of new technologies for identifying species of downy mildew and enhanced abilities to detect the presence of seed or plant tissue borne pathogens.

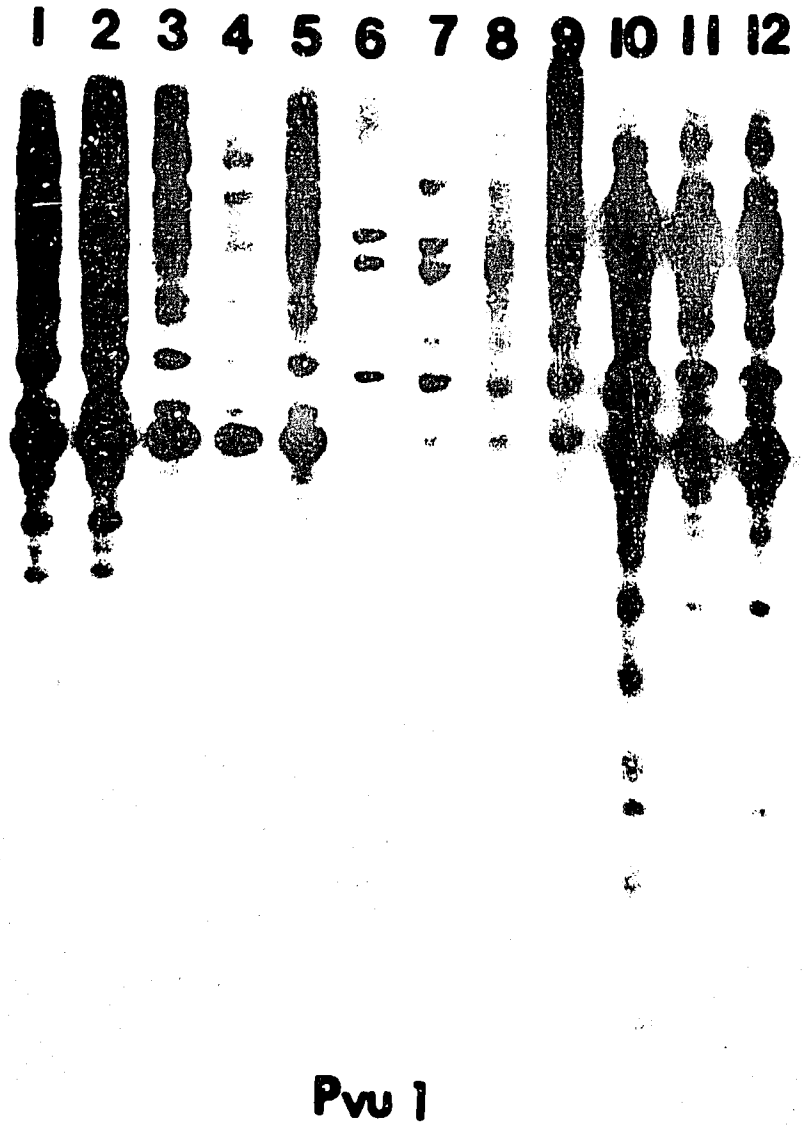
Biocontrol of sorghum downy mildew has been studied by Ms. I. Kunene. Her studies have demonstrated that at least one species of Gaertneriomyces significantly reduced the incidence of sorghum downy mildew when it was incorporated in microplot trials in the field.

Table 1. Effect of dosage of Gaertneriomyces incorporation in field soil on incidence of sorghum downy mildew.

Level of chytoid applied (Propagule/gr)	Disease incidence (%) Irrigated	Nonirrigated
100	37 A	61 A
50	45 A	71 AB
25	47 A	77 B
None (control)	79 B	87 C
Mean	53 (A)	77 (B)

These data demonstrate the importance of both the environment (irrigation) and dosage (propagules) in reducing the incidence of sorghum downy mildew with this biocontrol agent. Other work has shown the method of colonization (see TAM-128 Odvody et al.) by the mycoparasite.

Figure 1. Southern blot autoradiograph of Pvu I digested DNA extracted from: 1) P. sorghi pathotype 1, 2) P. sorghi pathotype 3) sorghum leaves infected with P. sorghi pathotype 1, 4) sorghum leaves infected with P sorghi pathotype 3, 5) sorghum leaves infected with P. sorghi Botswana isolate, 6) sugarcane leaves infected with P. sacchari, 7) sugarcane leaves infected with P. philippinensis, 8) maize leaves infected with Peronosclerospora sp. Yunnan isolate, 9) maize leaves infected with Peronosclerospora sp. Guangxi isolate, 10) P. maydis, 11) P. sorghi Thailand isolate 1, and 12) P. sorghi Thailand isolate 2, hybridized to POLY 83.



Anthracnose

Anthracnose continues as one of the most important diseases of sorghum worldwide. Our work deals principally with characterizing host resistance and pathogen variability. Recently however, we have found microsclerotia in stalk debris. Sorghum stalks bearing the *microsclerotia* of *Colletotrichum graminicola* were collected from susceptible cultivars at the end of the season, cut into small pieces, returned to the field and buried into different depths in the soil: 0-5 cm, 10 cm, and 20 cm, in three separate plots. Samples were taken every two months from each plot for a period of 16 months (September, 1988 to January, 1990). Sclerotia were recovered and evaluated for germination. A faster decrease in germination was observed from sclerotia placed at 20 and 10 cm depth as compared with those in the first 5 cm (Table 2). The period of survival of these structures in sorghum residues indicates that they are important survival structures as well as a source of inoculum.

Table 2. Germination of microsclerotia of Colletotrichum graminicola isolated from sorghum residues at different depths in the soil.

Month of collection	% germination		
	0-5 cm	10 cm	20 cm
September, 1988	80.11	80.24	80.15
November	72.40	46.60	25.13
January, 1989	70.48	33.70	33.80
March	65.20	18.37	14.65
May	45.20	15.25	14.70
July	55.23	16.23	17.42
September	38.30	10.50	8.70
November	38.75	0.04	0.03
January, 1990	28.30	0.00	0.00

Mr. Guthrie, working on TAM-128 as well as TAM-124, is developing a method for rapid, accurate identification of the races of *Colletotrichum graminicola*. Such a tool promises to become a reality with the advent of a technique based on a random-priming polymerase chain reaction (PCR) derivative known as random amplified polymorphic DNA (RAPD). Traditional PCR relies upon having sequence information for the bases flanding the fragment to be amplified, in order to synthesize the corresponding primers; RAPD, however, requires no such information. The technique uses random-sequence oligo dNTPs as primers, which, because of their low size (c. 10 bases), have a high probability of proximity to each other. In the correct orientation, the fragment between them will be amplified by PCR. Since this is likely to happen in several places along the genome, several fragments will be amplified, and in such high copy numbers that each of the fragments will be visible as a band on an ethidium bromide stained agarose gel, enabling any polymorphisms between isolates to be readily seen.

Current research is involved in testing ten different primers against a fixed number of *Colletotrichum graminicola* isolates, to determine optimum conditions for annealing temperature, extension time and other PCR parameters which have an impact on data quality. When the optimum primer(s) and PCR parameters have been selected the large worldwide collection of *C. graminicola* isolates in our possession will be screened by RAPD, and the resulting banding patterns converted to numerical data (corresponding to the molecular weight values of the bands). The same isolates will be tested against a standard set of differential hosts in order to classify them into races, and the race data will be compared with the banding data to see if any correlations can be obtained, enabling a given RAPD signature (or class of signatures) to be usable as a race indicator. The ultimate aim is to be able to bypass the use of differentials entirely, assigning isolates to races directly by the use of RAPD.

Grain Mold

Grain mold remains as one of the most significant disease/quality factors in grain sorghum production. Mr. Anaclet Mansuetus determined the relationship between glume physical characteristics and grain mold (GM) for a number of sorghum cultivars (Table 3). Cultivars differ significantly ($P = 0.05$) in their glume length. Glume cover ranged from 30-75%. GM tended to be negatively correlated with glume cover, glume length and glume area when the cultivars were not inoculated. These characteristics were negatively correlated with GM when the cultivars were inoculated (Table 4).

Table 3. Plant and glume characteristics and grain mold rating of various sorghum cultivars grown at College Station, summer 1988.

Cultivar	Pericarp[w] color	Glume[w] color	Glume length (mm)	Glume[x] cover (%)	Grain mold[y] rating (1-5)
SC279-14	R	R	6.7a[z]	65	1.8
SC630-11E	R	R	4.9bc	40	2.5
84BH5629,31	R	dT	4.5c	45	2.5
BTX626	R	dP	5.6bc	30	2.5
6BH6077	R	dP	4.1cd	30	2.3
80B2892	R	B	3.6d	30	2.0
IS9530	R	rP	4.9bc	40	2.3
SC719-11E	R (PT)	R	5.2b	35	1.5
Sureño	W	dT	4.3c	40	2.0
84BH5734	W	T	4.2cd	30	2.3
CS3541	W	T	4.4c	35	3.0
Malisor 7	W	dT	4.5c	50	3.0
SC170-6-17	W	R	4.1cd	35	3.5
TX2536	W	RrP	4.2cd	35	3.8
CSM63	W (PT)	R	6.2a	75	2.3

[w] Colors: R=red, W=white, PT=pigmented testa, T=tan, P=purple, dP=dark purple, dT=dark tan, PrP=faded red purple, B=black.

[x] Rating based on a 0-100 scale where 0=caryopses completely exposed, 100=caryopses completely covered by glumes.

[y] Rating based on a scale of 1-5 where 1=free from mold, viable caryopses and 5=molded, nonviable caryopses.

[z] Means followed by the same letter are not significantly different by Duncan's multiple range test (α=0.05).

Table 4. Correlation coefficients among various glume characteristics and grain mold on various sorghum cultivars grown at College Station, summer 1988.

Rain mold (control)	Grain mold (inoculated)	Glume cover	Glume lenght
Grain mold (inoculated) 0.72*	----		
Glume cover -0.30	-0.56*	----	
Glume length - 0.31	-0.64*	0.81*	----
Glume area -0.29	-0.62*	0.86*	0.94*

* Significant at a = 0.05 level of probability

Studies involving colonization of glumes by *Fusarium moniliforme* revealed that glumes of resistant cultivars were not as readily colonized as glumes of susceptible cultivars. Evidence from these studies and others which we have reported earlier (INTSORMIL Annual Report, 1989) suggests that glumes of resistant cultivars delay the pathogen access to the developing caryopses. They physically and chemically protect the caryopses against GM caused by *Fusarium moniliforme*. Therefore, glume characteristics are important for improving resistance to GM.

Little information is available on the genetics of grain mold resistance in sorghum. The problem is so complex that the resistance is thought to be a result of additive effects of many genes. These include genes for pericarp color (R-Y-), pericarp thickness (ZZ), presence or absence of a pigmented testa (B1-B2-); and the modifier genes, intensifier (II) and spreader (SS). The R and Y genes affect pericarp color. The pericarp can be red (R-Y-); colorless or white (R-yy, rryy); or lemon yellow (rrY-). The intensity of pericarp color is determined by the intensifier gene when R-Y- are in their dominant condition. The effect of the intensifier gene is readily expressed when the pericarp color is red. When present in its dominant form (II), the seeds appear brighter in color, while in the recessive form (ii), the seeds have a dull color. The color refers to the presence of particular pigments in the pericarp, which consist of phenolic compounds, primarily flavonoids. Presence of flavonoid compounds is associated with grain mold resistance.

B1 and B2 genes are complementary. When both are homozygous dominant, a pigmented testa is present in the caryopsis. When either locus B1 and/or B2 is homozygous recessive, there is no pigmented testa. The spreader gene determines if the pigments contained in the testa will be expressed in the outer layers of the pericarp (epicarp). If the spreader locus is dominant (SS), the brownish color of the testa will appear in the epicarp. If it is recessive, the testa pigments will not appear in the epicarp. This phenomenon has been described as the S gene allowing the brown pigments that originate in the testa to "spread" to the epicarp. Grains with a pigmented testa contain condensed tannins. Condensed tannins appear to improve grain mold resistance.

The Z gene controls the thickness of the pericarp. The pericarp is thin when the Z locus is dominant (ZZ) and is thick when the locus is recessive (zz). Pericarp thickness refers to the presence of starch granules in the mesocarp. A thin mesocarp has fewer starch granules, while a thick mesocarp has more starch granules. Mesocarp thickness appears to be an important component of grain mold resistance. Sorghums with a thin mesocarp are more resistant.

A study has been initiated to examine the effects of these genes, their inheritance pattern, and the subsequent reaction to grain mold in sorghum. Knowledge of the effects of these genes on grain mold reaction will be useful in the development of cultivars resistant to grain mold. Determining the dominance and number of genes involved in the resistance would indicate the relative ease of transferring the resistance. This study is being conducted at both Texas A&M University and at Serere Research Station in Uganda by J. Peter Esele.

Parents with distinct characters and gene markers and known mold reaction are being used in this study (Table 5). During the winter of 1988/1989, and summer of 1989, hand emasculations and the approach method of pollination were utilized in the greenhouse and field to make F1 seed. The crosses consisted of a complete diallel with their reciprocals. Selected F1 plants were self- pollinated to obtain F2 seed.

Table 5. The cultivars used to determine response to grain mold and explanation of known genotypes affecting the caryopsis.Head Smut

Cultivar	Mold reaction	Pericarp color	Intensifier	Spreader	Testa	Mesocarp	Phenotypic description
RTx2536	susc.	RRyy	ii	SS	$b_1b_1b_2b_2$	ZZ	white pearly grain, (yellow endosperm) no testa
SC103-12E	resist.	RRYY	II	SS	$B_1B_1B_2B_2$	ZZ	dark brown chalky grain, testa present
Sureño	resist.	RRyy	II	ss	$b_1b_1B_2B_2$	zz	white pearly grain, no testa
BTx3197	moder. susc.	RRyy	ii	SS	$b_1b_1B_2B_2$	zz	white chalky grain, no testa
BTx378	resist.	RRYY	II	SS	$b_1b_1B_2B_2$	zz	red chalky grain, no testa

At the same time, some F1 plants were backcrossed to their parents to obtain backcross one seed. In Uganda, these same parents were crossed with the Uganda developed elite cultivars with similar genotypes.

In the summer of 1990, all the populations: parents, F1, F2, and backcross one, were planted in the field in College Station, Texas, for grain mold evaluation and study of gene behavior. The experimental design consisted of a completely randomized design with two replications. A mixture of *Fusarium moniliforme* and *Curvularia lunata* spores were inoculated to the heads at 50% anthesis. Plant color, seed color and midrib color of the parental lines were noted to ensure that the lines were true breeding. The same data were taken on F1 plants to determine if they were actual crosses or if they were parental self-pollinations. The identification of loci R, Y, B1, B2, I and S as dominant or recessive was determined by phenotypic classification of parental lines, F1, backcross and F2 populations. Every individual panicle in the F2 and backcross populations was rated for grain mold reaction. A rating scale of 1-5 was used with 1 = no mold and 5 = severe mold. These same materials will be evaluated in Uganda in 1991. At the same time the crosses that were made with the Ugandan cultivars will also be evaluated.

Chi-square analysis will be used to determine the goodness-of-fit of the observed to the expected number of phenotypes within each of the F2 and backcross populations. Grain harvested from each of the F2 and backcross progeny will be visually classified for their genotypic combinations in an attempt to verify the gene inheritance and their correlation with grain mold reaction.

Head Smut

A genomic library has been created using the phage vector EMBL3 and it is being screened for low copy fragments that may be used as probes to detect RFLP's. *Sperisorium reilianum* reduces plant height principally by reducing elongation of internodes nearest the panicle. Detailed studies on gibberellin (GA) production in diseased plants, healthy plants and from the fungus provides evidence the GA production in the plant is shifted as a result of plant infection. These shifts suggest that GA's produced by the pathogen either compete with or substitute for host GA's during colonization by the pathogen.

Virus Diseases

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

Reaction of sorghum inbreds and F2 hybrids to maize dwarf mosaic virus strain A was tested. Four inbreds and 3972 hybrids were evaluated for disease severity and incidence. Twenty-one were resistant, 16 moderately resistant, and 6 susceptible. Resistant lines based on yield were derived from the cross B 599-6 X QL-3 India. A strong correlation (r=0.78609) between the proportion of plants infected and virus concentration was obtained based on this relationship. ELISA values can be used to screen sorghum accessions for reaction to MDMV.

A pathogen interaction between sorghum yellow banding virus and maize dwarf mosaic virus strain A was found to exist. Plants infected with SYBV alone were less severely affected than plants doubly infected with SYBV and MDMV-A doubly infected plants were shorter in height. All plants with multiple infections were dead at 17 days after inoculation.

Using ultra structure of SYBV infected plants, the virus was found throughout the infected leaves in all cell types of sorghum. The highest concentrations of virus were observed in the epidermal and parenchyma cells. The virus was packed into large vesicles which had expended into the vascular space and cytoplasmic areas adjacent to the chloroplast and nuclei. A large reduction in starch accumulation was noted in the chloroplast of infested cells. Mitochondria appeared swollen and contained reduced and irregular cristae. SYBV was associated with and seen in the endoplasmic reticulum. No viral particles were detected in the nuclei.

The relative importance of transient virus resident aphids in the spread of MDMV in sorghum was investigated. Two types of sorghum, one susceptible to infection by MDMV-A via aphid vectoring (Pioneer 8199) and one relatively resistant to infection by MDMV-A (Tx2786) were planted in pure stands as well as mixed stands of approximately 25:75 and 60:40%, respectively. Half of the plots were treated with systemic insecticide (Aldicarb). Disease incidence was recorded 10 weeks after emergence. Regression analyses showed the relationship between plant mixture proportions and the infection levels to be highly linear, indicating no dilution of the rate of virus spread among the susceptible plants. This suggests that the mode of any secondary spread typically spanned, and possibly included, several plants at a time since intervening resistant plants did not affect the virus spread. The insecticide treatment resulted in a 3% average increase in disease. These results are consistent with virus spread mainly due to the series probing activities of transient aphids whose activity may be aggravated by insecticides, rather than by aphids colonizing infected plants and then spreading the virus.

Virus concentrations were found to vary in sorghums with differing resistance to MDMV-A. Significant differences were observed within and among cultivars (CVS) in the amount of MDMV-A which accumulated over time. Differences among cultivar means were not uniform over time. Thus, area under the curve (virus accumulation over time) was used as a parameter for identifying cultivar resis-

tance. In the 36 CVS assessed, virus accumulation increased for 32 days after inoculation (DAI) and decreased thereafter except for 4 CVS with intermediate or long maturity. In these CVS, the virus titer remained high up to 64 DAI. The older the plant at inoculation, the lower the virus accumulation in the new, fully expanded leaf. Subliminal infections of MDMV-A were detected in both symptomless seedlings and older leaves of mature plants. The lowest virus accumulation was detected in the cultivar RTx430.

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Networking Activities

R. Frederiksen met with Issafou Kollo in Niger and with M. Diourte in Mali in September/October. Collaboration and research goals were discussed. Dr. Frederiksen and Dr. El Hilu Omer of Sudan outlined collaboration on the All African Long Smut Collaboration as well as participation in the Sudan workshop October 1989. Mr. C. Casela collected anthracnose data from cooperative nurseries with EMBRAPA in Brazil and Mr. D. Collins worked with Lindolfo Fernandez in Honduras to obtain information on pathotype 5 of *Peronosclerospora sorghi*. Frederiksen also met with Dr. Claire Shepherd and staff at Reading University to review their programs on pathogens of sorghum in Africa. Mr. Kollo from Niger also attended and reviewed pending work plans.

Germplasm Exchange

We distributed anthracnose virulence nurseries to eight cooperating countries; downy mildew virulence nursery to Honduras and Zimbabwe. The ADIN and IDIN's were widely distributed in Africa, South America, and Mexico. Antiserum from the International Sorghum Virus Antiserum Bank was supplied and viruses were identified in Malawi, Zimbabwe, and Zambia.

Germplasm Conservation and Exchange

The international sorghum virus nursery was sent to Venezuela, Zambia, and Zimbabwe. Sorghum antiserum was supplied to Brazil, Venezuela, Zambia, and India. Over 200 sorghum accessions from Africa, India, China, and Australia were introduced through our quarantine nurseries. These include sources of earliness, disease resistance, and genetic stocks.

Development of Control Programs for Millet and Sorghum Diseases in Semiarid Southern Africa

Project TAM-128

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Summary

Under high anthracnose pressure at Zimbabwe, Zambia, and Tanzania locations, sorghum nurseries from the Texas Agricultural Experiment Station and collaborative nurseries developed by SADCC/ICRISAT, SADCC national programs, and TAM-128 demonstrated that good anthracnose resistance was available in introduced and improved local germplasm. Anthracnose virulence appears to differ from that occurring in India and the U.S. and may even differ within the SADCC region. Acidified potato dextrose agar eliminated bacterial contamination sometimes encountered in mass production of conidia of *Ramulispora sorghi* in culture. Conidia of *R. sorghi* suspended in water and stored at 6 C rapidly lost viability within 48 hr indicating that conidial mucilage surrounding masses of conidia may have some function in longevity of conidia. SC326-6 and some cultivars derived from crosses with it had good adaptation and good resistance to many foliar diseases at several SADCC locations including the Henderson Station in Zimbabwe which generally has high leaf blight pressure. The chytrid, *Gaertneriomyces* spp., reduced incidence of sorghum downy mildew when incorporated into field microplots at two south Texas locations. Scanning electron micrographs demonstrated large holes of apparent chytrid attack on oospores of the sorghum downy mildew pathogen, *Peronosclerospora sorghi*, where *Gaertneriomyces* spp. inoculum was added but not in control treatments. In a study of *Fusarium* spp. associated with soil and sorghum, corn and cotton tissues, predominant fusaria were *Fusarium solani* and *F. equiseti* below ground, and *Fusarium* spp. Liseola above ground. Corn and sorghum tissues contained large numbers of *Fusarium* spp. section Liseola including *F. moniliforme* and a possible new species, *Gibberella thapsina* which occurred predominantly on sorghum. Cotton did not contain large numbers of any fusaria.

Objectives

Characterize of *Macrophomina phaseolina* from diverse hosts in Southern Africa (primarily Botswana).

Determine economic impact of leaf blight on sorghum.

Determine stability and sources of resistance to leaf blight through use of field nursery evaluations.

Determine stability and sources of resistance to sooty stripe of sorghum through use of field nursery evaluations.

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

Continue development and refinement of germplasm nurseries, deployment of nurseries, and germplasm screening for major diseases in the SADCC region.

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

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

Evaluate induced host plant resistance in sorghum to *Colletotrichum graminicola* (causal agent of anthracnose).

Research Approach and Project Output

Characterization of Macrophomina

Charcoal rot specimens (usually 50 per host) were collected from sorghum and millet at Lusitu, Zambia and from several gramineous and nongramineous hosts at Sebele, Botswana. These were sent to the U.S. for isolation of *Macrophomina phaseolina* and subsequent evaluation in culture to determine if host preferences exist in Southern African populations of *M. phaseolina* as in U.S. isolates.

Anthracnose

The International Anthracnose Virulence Nursery (IS-AVN), the All Disease and Insect Nursery (ADIN), and Anthracnose Resistant Germplasm Nursery (ARGN) from the Texas Agricultural Experiment Station and other nurseries including the SADCC Regional Anthracnose Resistance Nursery (RARSN) and the SADCC Regional Advanced Disease Resistance Screening Nursery (ADRSN) were grown at several locations in Zimbabwe, Zambia, and Tanzania. Several entries showed high resistance at all locations even under high anthracnose pressure at Mansa, Zambia. Some of the sorghums demonstrating good adaptation and agronomic type at Mansa, Zambia and high resistance to anthracnose at other test locations (if evaluated there) are shown in Tables 1-3. SC326-6 and some sorghums derived from crosses with it, had good adaptation across several environments in Zimbabwe and Zambia and maintained a high resistance to several foliar diseases including anthracnose and leaf blight.The virulence of *Colletotrichum graminicola* may vary within the SADCC region and apparently differs from U.S. and ICRISAT Center populations based on differences in cultivar susceptibility. Specific virulence differences have not yet been fully determined.

Mr. Phil Guthrie working on TAM-124 and TAM-128 is developing a method of rapid pathotype (race) identification of *C. graminicola*. The technique is based on a derivative of the polymerase chain reaction (PCR) technique called random amplified polymorphic DNA (RAPD). Details of the technique are included in the current TAM-124 report.

Sooty Stripe

At Golden Valley, Zambia in 1989 a collection of sorghums including several converted international sorghum lines were evaluated for sooty stripe resistance in a nursery that utilized natural inoculum augmented by introduction of sooty stripe lesion debris. The high incidence of leaf blight on some cultivars precluded accurate evaluation of sooty stripe and demonstrated the need for resistance to leaf blight and sooty stripe at this location. Those sorghums with good resistance to both leaf blight and sooty stripe and acceptable agronomic traits were grown at the Henderson station to determine adaptation to another SADCC environment and to determine their relative level of leaf blight resistance under the higher leaf blight pressure at this location. SC326-6 was a member of this group and continues to show excellent overall resistance to foliar diseases including *R. sorghi* and good adaptation to many SADCC regions. In 1990, incidence of sooty stripe at Golden Valley, Zambia was relatively low except in hybrid observation nurseries which are a few kilometers from the other breeding and disease nurseries. This contrast in sooty stripe disease intensity occurs yearly and may reflect the different types of nurseries and cultivars grown at the two locations but other reasons for the differential sooty stripe development are not known.

Additional cultural studies were conducted to maximize utility of conidial production techniques for *Ramulispora sorghi*. No advances were achieved in quantity of conidia produced but additional progress was made in avoiding two problems that might normally preclude use of this technique in laboratories with limited facilities or expertise in sterile technique. Because mass production of conidia requires a bacterial type of streaking across potato dextrose agar (PDA) plates, the introduction of bacteria can rapidly contaminate a large number of plates and pure culture reisolation of the slow growing *R. sorghi* is more difficult. The use of acidified PDA (pH 4.0) eliminated bacterial problems without any apparent decrease in conidial production but

controlled experiment comparisons have not yet been done. We previously reported that conidia of *R. sorghi* retained high viability for at least two months if the culture plates were stored at 6-10C soon after maximum spore production had been achieved. The conidial production matrix may be important in maintaining conidial viability since spores rapidly lost viability when suspended in distilled water. In our preliminary tests water-suspended conidia with an initial viability exceeding 85% were stored at 6 C to prevent germination but a significant percentage of conidia lost viability within 24 hr and most were nonviable by 48 hr. If the PDA-streaking colony techniques are used to mass produce conidia of *R. sorghi* the conidia should be maintained in situ (at the production temperature or at cool storage temperatures) until just prior to actual inoculations. Preparation of conidial suspensions and storing at nongerminable temperatures overnight could dramatically reduce the efficacy of inoculum.

Table 1. Anthracnose resistant sorghums with good adaptation and agronomic type (agronomic rating) at Mansa, Zambia, April 9, 1990[1]

Entry	Foliar anthracnose (Mean % severity)
(ADIN)	
82BDM499	1
86EON361	12
86EON362	0
88BD1749	15
B8610	0
B8618	0
86C28011	5
86C2803	0
87EON125	0
87EON109	2
84C9408	0
BTX631	0
(RADRSN)	
Framida	0
R6956	0
IS18688	0
DC75	2
(RARSN)	
A3139	0
TX84EON100	5
87L3450	5
87L3452	1
1228MS 88/89	0
3004MS 88/89	0
3012MS 88/89	0
3044MS 88/89	0
3062MS 88/89	0
3071MS 88/89	0
3093MS 88/89	0
3118MS 88/89	0
3174MS 88/89	0
3209MS 88/89	0
3273MS 88/89	2

[1]Included entries had foliar anthracnose at a mean percent severity of 15% or less in two replications and an agronomic rating of 3.0 or less (1.0=best, 5.0=worst). ADIN=All Disease and Insect Nursery, TAES; RADRSN=Regional Advanced Disease Resistance Screening Nursery, SADCC; RARSN=Regional Anthracnose Resistance Screening Nursery, SADCC. Although included here only once, some resistant entries occurred in all these nurseries and had similar anthracnose and agronomic ratings.

Table 2. Mean percent foliar anthracnose in International Sorghum Anthracnose Virulence Nursery (ISAVN) at Mansa, Zambia, April 9, 1990.[1]

Entry[2]	Foliar anthracnose (Mean % severity)
SC414-12E*	0
SC12065	65
BTX378*	0
Wiley	0
SC972	-
Honey	75
SC328C	80
RTX2536	60
QL3 India*	3
IS9569	0
SC283	0
SC748-5*	0
SC326-6*	0
SC167-14*	0
SC224	0
IS2057	90
B35-6	5
BTX398	0
RTAM428*	45
RTX434*	0

[1]Mean percent seventy of anthracnose from two replications. Several resistant entries were included in other replicated nurseries at Mansa where they had similar anthracnose and agronomic ratings.

[2]Asterisk indicates a mean agronomic rating (adaptation and agronomic type) of 3.0 or less (1.0=best, 5.0=worst.

Table 3. Sorghum entries of the Anthracnose Resistant Germplasm Nursery (ARGN) having a high anthracnose resistance and good agronomic rating at Mansas, Zambia, April 9, 1990.[1]

International sorghum number	Sorghum conversion number	Foliar anthracnose (Mean % severity)
IS2395C	SC647	2
IS2456C	SC623	0
IS2508C	SC414	0
IS2569C	SC60	0
IS3462C	SC701	1
IS3509C	SC562	5
IS3552C	SC748	1
IS3553C	SC575	5
IS7093C	SC726	0
IS7254C	SC566	3
IS12219C	SC991	0
IS12526C	SC6	0
IS12557C	SC37	0
IS12562C	SC43	0
IS12626C	SC135	1
IS12627C	SC136	0
IS12628C	SC137	0
IS12637C	SC146	0
IS12657C	SC166	0
IS12658C	SC167	0
IS12667C	SC176	0
IS3552deriv.	SC748-5	0
IS3758deriv.	SC326-6	0

[1]Foliar anthracnose value is mean percent severity of two replications. All entries had a mean agronomic rating (adaptation and agronomic type) from two replications of 3.0 or less (1.0=best, 5.0=worst).

Leaf Blight

Continued evaluation of sorghum cultivars at various locations established the consistency of leaf blight resistance reactions in cultivars previously identified as possessing resistance, especially under heavy leaf blight pressure at the Henderson Station in Zimbabwe. In the SADCC regional leaf blight resistance nursery at Henderson SC6, SC147, SC322, SC326-6, SC574, TX430, TX435, BTX3197, and TX86EON362 had leaf blight severities below 5% and leaf blight susceptible Framida had severities of 90% or above. Many cultivars with SC326-6 in the genetic background had good adaptation and leaf blight resistance.

In 1990 E. Mtisi identified fungicides that could be used at the Henderson station in Zimbabwe to reduce incidence and severity of leaf blight on susceptible genotypes in studies designed to measure economic impact of leaf blight; however, rainfall patterns interfered with efficient fungicide application times and efficacy, especially the contact fungicides. E. Mtisi began graduate work towards a Ph.D. in plant pathology at Texas A&M in September 1990; she will investigate several ecological factors affecting the biology and survival of *Exserohilum turcicum*, sources of initial inoculum, pathogen variability, and economic impact of leaf blight. Her preliminary research will be in the U.S. but most aspects of her field research will be conducted in Zimbabwe.

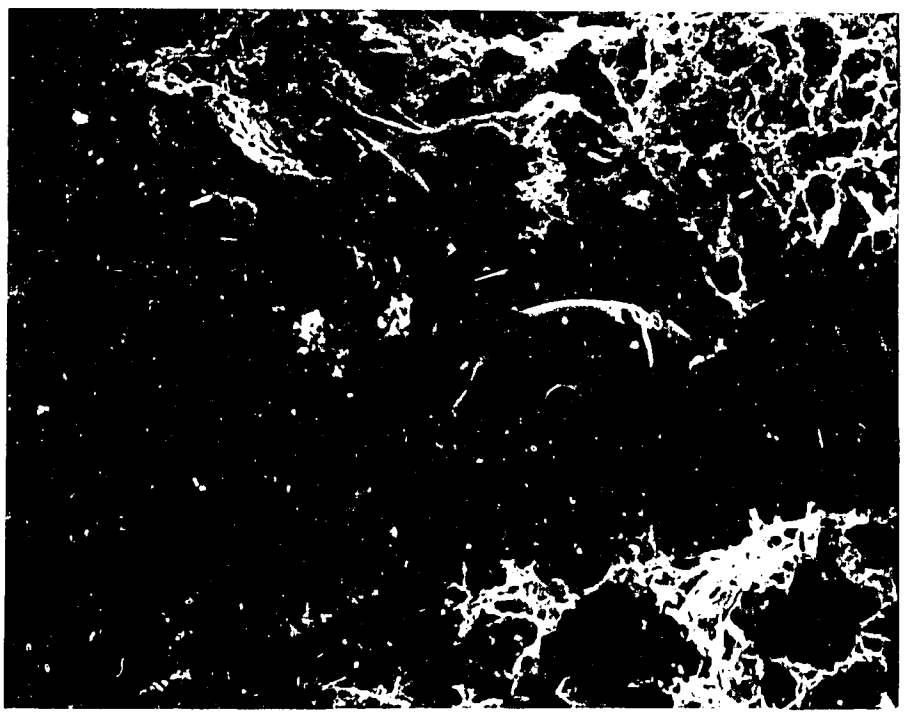
Sorghum Downy Mildew

S. Kunene continued her dissertation research on biocontrol of sorghum downy mildew (SDM) using the oospore parasite *Gaertneriomyces* spp. In a second year of field microplot experiments at two locations in Texas she was able to demonstrate a reduction in incidence of SDM compared to the control when inoculum of the chytrid was incorporated into the soil. The greatest reduction occurred in irrigated soil with the largest dosage of propagules (see current TAM-124 report). The method of oospore (*Peronosclerospora sorghi*) colonization and exit through the oospore wall was very apparent in parasitized oospores viewed with a scanning electron microscope (Figure 1). These attacked oospores were commonly seen only in oospore treatments where chytrid inoculum had been added.

Grain Mold and Fusarium

Grain specimens of pearl millet and sorghum were collected in 1989 from several Zambia, Zimbabwe, and Botswana locations and sent to Dr. P. Nelson at Penn State

Figure 1. Oospores of Peronosclerospora sorghi parasitized by the chytrid, Gaertneriomyces spp. (X2000); Note the raised circular holes caused by parasite attack on the oospore walls. No holes were present in control treatments.



University for isolation and identification of predominant fusaria associated with the seed. Most specimens had no significantly observable incidence of grain mold or weathering. Only two samples have been completed from Zimbabwe and the most frequently isolated fusaria were *Fusarium moniliforme* and *F. equiseti* from sorghum and *F. moniliforme*, *F. equiseti*, and *F. subglutinans* from pearl millet.

In domestic research conducted by A. Ring, the numbers and species of *Fusarium* from corn, cotton, and sorghum leaves, roots, inflorescence, stems, and rhizosphere soil were determined during crop development in the different rotation and tillage treatments of a farming systems experiment. Mean numbers of fusaria were, from highest to lowest, on corn tassels; corn and sorghum leaves, roots, and soil; sorghum seed; and cotton tissues and soil. Numbers of fusaria increased with crop maturation on corn and sorghum, decreased in soil, and remained low on cotton tissues. Predominant fusaria were *F. solani* and *F. equiseti* below ground, and *Fusarium* spp. section Liseola above ground. Corn and sorghum tissues contained large numbers of *Fusarium* spp. section Liseola which includes *F. moniliforme* and a possible new species, *Gibberella thapsina* (see 1989 annual report of KSU-108) that occurred predominantly on sorghum. Cotton did not contain large numbers of any fusaria. Overall relative percentages of *Fusarium* species did not change during maturation.

Ergot

A SADCC/ICRISAT ergot and seedset test of A&R sorghum lines was developed by W. deMilliano and T. Obilana of SADCC/ICRISAT and carried out in collaboration with national scientists in Botswana, Zambia, and Zimbabwe. High ergot severities occurred in A-lines at all locations except the early sown crop at Matopos, Zimbabwe (low incidence), Pandamatenga, Botswana (very low incidence) and Muzarabani, Zimbabwe (no incidence of ergot). Muzarabani and Pandamatenga may be excellent locations for production of hybrid sorghum seed without interference of ergot on A-lines.

Deployment of Nurseries

Through the collaborative efforts of TAM-122, TAM-124, and TAM-128, W. deMilliano of SADCC/ICRISAT, and national scientists, several nurseries have been assembled and utilized in strategic nursery locations in the SADCC region. New or existing nurseries were introduced or developed for anthracnose evaluation in 1989-90, especially for initial use in Zambia, Zimbabwe, and Tanzania. These nurseries included the International Sorghum Anthracnose Virulence Nursery (ISAVN), TAES; Anthracnose Resistant Germplasm Nursery (ARGN), TAES; and the Regional Anthracnose Resistance Screening Nursery (RARSN), SADCC/ICRISAT. Other disease screening nurseries grown at major disease screening locations were the All Disease and Insect Nursery (ADIN), TAES; Sorghum Downy Mildew Virulence Nursery (SDMVN), TAES; Regional Advanced Disease Resistance Screening Nursery (RADRSN), SADCC/ICRISAT; and the Regional Preliminary Disease Resistance Screening Nursery (RPDRSN), SADCC/ICRISAT.

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Mansuetus, S.B. 1990. The effect of glume and caryopses characteristics of [*Sorghum bicolor* (L.) Moench] on infection by *Fusarium moniliforme* Sheldon. M.S. Thesis. Texas A&M University, College Station. 109 pp.

Networking

The principal investigator traveled to Zimbabwe, Zambia, and Botswana on April 1-25, 1990 to evaluate disease nurseries with W. deMilliano, B.N. Verma, G. Kaula, E. Mtisi, and B. Motalaote. Traveling with W. deMilliano, nurseries were evaluated for diseases at Henderson, Panmure, and Matopos, Zimbabwe; Lusitu, Mansa, Golden Valley, and Mt Makulu, Zambia; and Sebele and Pandamatenga, Botswana.

On May 1, 1990, at Corpus Christi, Texas, the principal investigator met with Mr. Demba Mbaye of the Institut Senegalais De Recherches Agricoles (Senegal) to discuss the Texas A&M sorghum program with emphasis on plant pathology and potential future collaboration. Sorghum nurseries were toured at Corpus Christi and Beeville, Texas and Mr. Mbaye also viewed area agriculture and discussed research with other station scientists.

Socioeconomics

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

Project PRF-105
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Summary

The introduction of new sorghum cultivars and associated technologies is progressing well in both the main irrigated scheme (Gezira) of the Sudan and on the hillsides of southern Honduras.

In the Gezira, farmers utilize fertilizer, closer spacing, and improved land preparation with Hageen Dura I and achieve yields up to 2.8 times those of local sorghums without fertilization. For 1990-91 H-D I will be on an estimated 7% of the Gezira sorghum area, according to seed sales. Diffusion is now expected to accelerate, assuming that adequate supplies of H-D I seed and chemical fertilizer can be made available to Gezira farmers. The other irrigated projects are expected to follow the Gezira scheme. The Rahad project has recommenced H-D I seed production in 1990 for its farmers. Over one-fourth of the sorghum produced by farmers with H-D I in the Gezira is now sold as opposed to the previously observed sorghum purchases by farmers to supplement the production of local cultivars. With these surpluses, the irrigated regions can provide more food security for Sudan, especially for adverse rainfall years in the rainfed regions.

In southern Honduras, once farmers have constructed soil-conservation devices (SCTs) to keep their farms from washing down into the valley, they show more interest in yield-increasing technologies. In a sample of small farmers in southern Honduras, 43% of the farmers sampled had adopted both the SCTs and the new sorghum cultivars, Sureño and Catracho. The introduction of both technologies increases farm incomes by 15%, according to model results. If policies were introduced to eliminate the sorghum price collapse in good rainfall years, then the farm-income increase from the combination of new technologies and this policy change would be 58%.

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

New technologies are still not profitable in the extensive agriculture of the vertisols, according to model results. The combination of irregular water availability and low soil fertility appear to be the principal constraints. In contrast, the diffusion of Hageen Dura I is now proceeding rapidly in the irrigated area. Consumer tastes and miller complaints about hard seeds apparently are no longer constraints to the introduction of Hageen Dura I in the Gezira scheme. Rather, with the present very high prices for sorghum, availability of certified seed and chemical fertilizer are principal constraints there.

Honduras

On the hillsides, the most important technology requirement is to keep the farm from washing down into the valley. Once soil-conservation technologies are introduced, farmers in both the modeling results and field observations introduce the new sorghum cultivars and associated technologies. One important constraint is the tendency for sorghum price collapse in good weather years. More attention needs to be focused on demand factors to prevent the sharp price decline. Increased utilization of sorghum in feeds or mixing with wheat flour for bread are domestic options.

Niger

A critical constraint is soil-fertility improvement and maintenance now that the long fallow system is breaking down. Specific adapted fertilization technologies and even longer season cultivars to take advantage of normal and good rainfall years are expected to be necessary to increase the profitability of fertilization.

Burkina Faso

In regions such as the southwest of Burkina Faso where technological change has been rapid, there have been criticisms about the income distribution consequences within the household. Some have argued that new technologies could make women in the household worse off. Modeling is utilized to describe the expected within-household bargaining process and to estimate the land-use patterns and incomes to women as technological change is introduced.

Research Approach and Output

Five theses on the four priority countries -- Sudan, Honduras, Niger, and Burkina Faso -- were essentially completed in Year 11 (see Publications). All five were defended in the summer of 1990. Many of the preliminary results were previously reported in the INTSORMIL Annual Report for 1989. Here some final results of these theses and continuing fieldwork in the Sudan and Honduras on new cultivar introduction are reported.

Sudan

M. Habash (1990) and M. Ahmed (1990) indicated the economic and technical problems from introducing yield-increasing technologies into the extensive cropping system of the vertisols. In this large-farmer system, land and machinery prices are reduced by government subsidies. Farmers are thereby encouraged to expand land area rather than to increase yields. There are some indications of a long-run sorghum yield decline from this monoculture system. Farmers in this region purchase hired labor and seeds but do not invest in fertilizers or other chemicals. Technologies and policies need to be developed to enable land productivity increases, thereby making possible a more sustainable agriculture.

In modeling new technologies, including a new cultivar (Hageen Dura I), fertilizer, and an improved rotation, the impact of these policy factors distorting relative prices of land and labor, was less important than the technical and economic limitations of the new technologies. Farmers in the vertisols anticipate a price discount for the new cultivar. In the irrigated region, this price discount has now disappeared and almost all farmers interviewed prefer or are equally satisfied with the "kisra" (unleavened bread product from sorghum) of the new cultivar. Unfortunately, H-D I does not perform as well without the controlled conditions of fertilization and adequate water availability practiced in the irrigated region (see Table 1 and Habash, 1990).

In the irrigated region, the price collapse of sorghum with the large output response in 1985-86 after the drought year and the price differential in this year abruptly checked the diffusion process. Now as farmers are utilizing more fertilizer, the yield advantages to H-D I introduction are dramatic (Table 1). According to farmers' recall over five crop seasons, there was no yield advantage to Hageen Dura I without fertilizer. When H-D I was combined with moderate fertilization in the irrigated region, the yield advantage over the unfertilized local cultivars increased 2.8 times (Table 1).

The introduction of H-D I is associated not only with an increased farmer demand for fertilizer and other improved agronomic practices but also with an increased marketed surplus. With traditional sorghum cultivars, home and hired worker consumption was the principal manner of disposing of the low sorghum output levels. From 1984 to 1990, those farmers producing the local cultivars purchased substantial quantities of sorghum, 12% to 26% of their production in three of the years. In the last two years they produced enough for their own use but not for sales. In contrast, farmers producing H-D I sold 25% to 33% of their production during the last five years.

Table 1. Average sorghum yields for new (Hageen Dura I) and traditional cultivars from farmer interviews in the Gezira project, 1985-1989.

Cultivar	Fertilizer level (per ha)	Mean yields (m.t./ha)
Hageen Dura I	190 kg Urea and 95 kg Simple Superphosphate	3.28
Hageen Dura I	95 kg Urea and 95 kg Simple Superphosphate	3.07
Hageen Dura I	190 kg Urea	2.84
Hageen Dura I	95 kg Urea and 95 kg Simple Superphosphate	2.35
Hageen Dura I	47.5[a] kg Urea	2.05
Hageen Dura I	No fertilizer	1.17
Traditional cultivar	47.5[a] kg Urea	1.45
Traditional cultivar	No fertilizer	1.13

[a] Above zero and less than 95 kg/ha. Mean values utilized.
Source: These data were from interviews in 1990 of 56 farmers in four different regions of the Gezira project.

With H-D I, there are larger quantities of sorghum available so farmers are marketing more sorghum. This will increasingly make the irrigated regions a safety valve of available cereals in poor rainfall years when harvests are down in the rainfed vertisols. Moreover, Gezira farmers are selling their surpluses over the entire crop year. This should stabilize the annual sorghum price variation. So there are numerous potential benefits to the introduction of H-D I in the irrigated regions, including increased utilization of fertilizer, higher marketed surplus, reduced price variation within the season, as well as higher yields.

From certified seed sales, 17,343 ha, or 7% of the estimated sorghum area in the Gezira scheme, has been planted in H-D I in the 1990-91 crop year. In the field interviews in 1990, farmers complained of the inadequate supply available of both H-D I and chemical fertilizers. An accelerated diffusion process of H-D I is possible in the irrigated region once these supply bottlenecks are overcome.

In the long run, more profitable alternatives than sorghum, such as vegetables and fruits, will be found for the irrigated region. In the short run, there is substantial potential and a high public return to increasing sorghum production in these irrigated areas. The substantial between-year price fluctuations of sorghum will remain until alternative uses are further developed. Except for a special agreement with Saudi Arabia, now terminated, Sudan has had difficulty increasing its sorghum exports in good rainfall years when there is a surplus and a consequent price collapse. There are several potential methods for increasing domestic demand for sorghum. The demand for feeds for livestock production is expected to steadily increase as urban incomes grow, especially after the civil war ends. The government is beginning a program to require a minimum percentage of sorghum (probably 20%) to be combined with wheat for composite flour production for both bread and "kisra". This project to stimulate sorghum demand includes investment in several large-scale, new flour mills in different regions.

The theses of Habash and Ahmed indicate the economic potential of new technologies to improve agronomic conditions, i.e., water availability and soil fertility, in the rainfed region. A gradual shift to more intensive technologies could include increased chemical fertilizers, improved rotations including higher sesame yields and a grain legume, and a water-retention technique such as tied ridges. Once the improved agronomy is in place, the introduction of new sorghum cultivars in the rainfed regions will be facilitated.

Honduras

Fifty-one percent of the sorghum produced in Honduras from 1983-1988 came from the south and 95% of the sorghum from the south was produced by small farmers, principally those on the hillsides. The average small farmer family income in southern Honduras is $792 (U.S. dollars). Of this income 39% comes from the sale and the value of home consumption of the cereals, 37% from off-farm labor, and 15% from the sale of farm animals. These farmers often have to sell their cereals at harvest time after the seasonal price collapse and rebuy grain later at a higher price. Twenty-nine percent of their cash expenses are for cereals. With either on-farm storage or more fattening of animals with grain, these small farmers could avoid the forced sales of the cereals at harvest.

Given the slopes of these hillsides, the first technology requirement is a soil-conservation technique (SCT). Stone walls are constructed and supplemented with trees or bushes. The labor is paid with governmental food-for-work programs. Although these systems are extremely labor intensive and the income effect is small (7%), they stabilize the agricultural system, making an itinerant agriculture into a permanent one. With the food aid, the internal rate of return (financial) of the SCTs to the farmer over a 10-year lifetime is 39%. Besides the soil conservation the SCTs increase water retention, thus reducing the risk of fertilization not being profitable. In southern Honduras 2,400 hectares have been put into these terraces. The adopting farmers (52% of the sample) put on the average 0.4 ha into these stone walls. Ditches (31%) and permanent legume tree barriers (25%) are also utilized on average areas of 0.3 ha (Lopez-Pereira, 1990, p. 49).

Once permanent crop production is attained with these conservation devices, the farmer introduces Sureño or Catracho with fertilizer (Urea) on 25% of his crop area in the

first season and all of it in the second season (Lopez-Pereira, 1990, p. 97). The new cultivars will substantially outyield traditional varieties; however, they require more purchased inputs and better management. The combination of these SCTs with the new sorghum technologies increases farm income by 15%, according to model results (Lopez-Pereira, 1990, p. 93). In the sample taken in 1988, 28% of the farmers had planted Sureño and 15% Catracho. These cultivars were released in 1985 and 1984, respectively, by the Honduran Ministry of Natural Resources (MNR). Farmers in the sample introduced the new cultivars only when they had already adopted the soil-conservation technologies. Forty-three percent of the farmers sampled had adopted both the SCTs and the new cultivar technologies (Lopez-Pereira, 1990, p. 48).

An estimated 5% of the crop area of the small farmers of southern Honduras is planted to these new cultivars (Lopez-Pereira, 1990, p. 102). Given the substantial yield advantage of this new cultivar technology, why is profitability low and diffusion still limited? One principal problem in cereal production is the price collapse in good rainfall years, especially at harvest. With increased storage, animal fattening, or price supports, this price collapse could be avoided. If one or more of the above changes reduce the cereal price decline in good rainfall years, then the expected farm income from the combination of SCTs, new sorghum cultivars, and associated technologies increases by 58%. Expected farm income from sorghum production increases from $263, without new technologies and with the price collapse, to $415 with both the new technologies and the avoidance of the price collapse, according to model results. The increase in farmer income, adoption, and production from eliminating the sorghum price collapse in good rainfall years indicates the importance of further policy initiatives in this area. This level of minimum prices is already officially maintained by the Honduran marketing agency (IHMA) but small farmers are not presently able to take advantage of this program (Lopez-Pereira, 1990, p. 121).

The combination of technologies and policies then can substantially raise small-farmer incomes. These combined activities increase cereal production by almost 100% on these small farms and reduce the riskiness of the agricultural system, according to model results. The SCTs stabilize the agricultural system and allow more intensive agriculture. Sureño and Catracho are then introduced on these farms. These are short-season cultivars maturing in approximately 100 days; hence, they can fit into either the first or second season of this bimodal rainfall regime. Their introduction often implies a shift to monoculture. As in developed countries, Honduran small farmers need to be protected from price collapses when the weather conditions are favorable.

Niger

In the Niger farm modeling of the potential impact of new technologies, two farming systems were evaluated. One system had a small irrigated area of 0.4 ha in addition to the dryland area. This system had slightly higher annual rainfall of 570 mm as compared with 430 mm in the dryland system without irrigation. In the latter system, the rainfed land supply is more elastic and livestock is a more important economic activity. In neither dryland system are purchased inputs utilized, except for hired labor for various crops and fertilizer on the irrigated rice. In both systems, early cowpea and millet cultivars would be introduced, raising farm incomes by 13% and 20%, according to model results (Tables 2 and 3).

With the breakdown of the extended fallow system, soil mining takes place in the absence of fertilization. Hence, a sustainable system will require fertilizer. In both systems various policies and other innovations to make fertilization more profitable were then evaluated. On the river, with partial irrigation and higher rainfall, a fertilizer subsidy and different methods of fertilization (with P alone and with post-planting P application), both resulted in fertilizer being introduced and in further income gains. The fertilizer subsidy could easily result in the diversion of the fertilizer to the irrigated rice, where it is more profitable. Increased credit had no effect on fertilizer utilization as farmers had more profitable activities, such as small ruminants, for the increased capital available. Hence, rather than policy changes, further technical innovations such as different types and application times for fertilizer were necessary to create a sustainable system. Similarly, the introduction of a longer-cycle millet cultivar, which could take advantage of normal and good rainfall years, also would result in higher fertilizer utilization. These model results indicate the principal constraints to be further area-specific, adaptive research to help overcome technical constraints rather than just manipulating the policy variables of credit and input subsidies.

In the drier area without partial irrigation, none of the policy measures had any impact on fertilization. With almost any reasonable policy or technical innovation, it still was not possible to obtain the utilization of fertilization and hence create a sustainable system in this lower rainfall system (Table 3). The difficulty of finding a profitable, sustainable cropping system suggests that it may be more appropriate to withdraw from cropping here and to encourage livestock and forestry development in this dryland system. Initial resource endowment and the potential of successfully developing new crop technologies need to be important factors in research planning.

Burkina Faso

In the literature on women in development, it has been observed that with the introduction of technical change on the farm, the women often reduce time spent and area cultivated of their private plots. Some critics therefore have either opposed the introduction of technological change or

Table 2. Effect of various policy instruments on the adoption of the fertilizer technology, river system, Niger, 1988.

Policy or Program	Fertilizer Total use (ha)	Millet/ Cowpea income (FCFA)	Livestock income (FCFA)	Total income (FCFA)	Change Crop income (%)	Change Total income (%)	C.V. Total income
1. Current practices	N/A	132,984 (446)	34,520 (116)	242,008 (812)	--	--	.40
2. Improved cultivars	0	172,139 (578)	27,799 (93)	274,343 (921)	+30	+13	.39
3. Input subsidy (10%)	1.2	179,273 (602)	21,078 (71)	274,752 (922)	+35	+14	.41
4. Credit program (10,000 FCFA at 0% interest)	0	171,718 (576)	34,520 (116)	280,644 (942)	+29	+16	.39
5. Phosphorus fertilizer alone	2.1	187,117 (628)	21,078 (71)	282,595 (948)	+41	+17	.44
6. Post-planting P application (high soil fertility)	0.6[a]	172,800 (580)	30,078 (101)	277,283 (930)	+30	+15	.39
7. Long-cycle millet variety	1.5	185,877 (624)	21,078 (71)	281,078 (944)	+40	+16	.42

U.S. $ values for incomes are in parentheses. The exchange rate is 298/FCFA/U.S. $
[a] This 0.6 ha allocated to the post-planting fertilizer technology only in normal years.
Source: Shapiro, 1990.

Table 3. Effect of various policy instruments on the adoption of the fertilizer technology, dryland system, Niger, 1988.

Policy or program	Fertilizer Total use (ha)	Millet/ Cowpea income (FCFA)	Livestock income (FCFA)	Total income (FCFA)	Change Crop income (%)	Change Total income (%)	C.V. Total income
1. Current practices	N/A	89,605 (301)	55.279 (186)	149,790 (503)	--	--	.63
2. New technologies	0	121,979 (409)	52,879 (177)	179,188 (601)	+36	+20	.50
3. Price support (50 FCFA)	0	128,030 (430)	52,879 (177)	185,240 (622)	+43	+24	.57
4. Input subsidy (50%)	0	121,193 (409)	68,651 (230)	194,657 (653)	+36	+30	.54
5. Credit program (10,000 FCFA at 0% interest)	0	121,872 409	58,686 (197)	184,954 (621)	+36	+23	.50

U.S. $ values for incomes are in parentheses. The exchange rate is 298 FCFA/U.S.$.
Source: Shapiro, 1990.

suggested that technology be designed specifically for the women's plots to avoid this alleged increased dependency or decreased welfare levels of the women.

From field data and modeling, Ramaswamy (1990) suggested an alternative bargaining process to explain the observed shifts in female working patterns. The household head is expected to pay higher wages to his adult workers of both sexes as technological change is introduced. The new technologies include new cotton cultivars and improved agronomy plus fertilization of cotton, maize, sorghum, and peanuts. The combined technologies along with animal traction increase farm income from $573 to $1,426/farm.

As farm income increases substantially with technological change, so do the labor requirements on the collectively farmed area. The household head can either hire outside labor or bid away his own family adults from their private plots. There are advantages for the household head and the other adult household members when the household head utilizes family labor on the collective fields. With or without off-farm employment, the income of the one wife characterized in the model is increased with the introduction of new technology and she reduces her participation in her private plot (Table 4). The reduction in private-plot activity is associated here with higher incomes for women (and other adult family members). There are field data to support the consistency of these model results (Ramaswamy, 1990). Some other commonly suggested policies, such as concen-

trating technologies on the private fields, lead to lower income increases for the household and the woman.

Table 4. Income for the farm and to one woman from new technology introduction in the Burkina Faso cotton region (Solenzo), 1989.

Incomes	Traditional Technology[a]	Improved technology[b]	Improved technology[c]
Net farm income	$573	$1,426	$1,426
Representative individual wife compensation:			
Income from private plots	33 (0.75 ha)[d]	13 (0.3 ha)[d]	--[d]
Compensation from working on collective fields	--	65	115
Income from working off-farm	--	--	65

[a] In the traditional system with no new technologies, no compensation is paid out by the household head to mobilize family labor in the base model run.

[b] Use of fertilizer on maize, sorghum, and cotton; donkey and oxen power utilized. No off-farm employment available.

[c] Use of fertilizer on maize, sorghum, and cotton; donkey and oxen power utilized. Off-farm employment available at 50 CFA/hour ($0.17/hour). The exchange rate is 298 CFA/U.S.$.

[d] Parenthetic terms denote acreage cultivated by an adult female in her private-plot area. As work on collective fields becomes more profitable, less time is spent on the private fields, resulting in less income from produce sold. When off-farm employment opportunities are profitable, participation on private plots drops to zero.

Source: Ramaswamy, 1990

Publications

Journal Articles

Adesina, A.A., and J.H. Sanders, 1991. "Small Farmer Behavior and Cereal Technology Adoption: A Stochastic Programming Approach in Niger," Agricultural Economics 5(1): forthcoming.

Deuson, Robert R., and John H. Sanders, 1990. "Cereal Technology Development in the Sahel: Burkina Faso and Niger," (Viewpoint) Land Use Policy 7(3):195-197.

Nagy, Joseph G. and John H. Sanders, 1990. "Agricultural Technology Development and Dissemination Within a Farming Systems Perspective," Agricultural Systems 32(4):305-320.

Sanders, J.H., J. Nagy, and S. Ramaswamy, 1990. "Developing New Agricultural Technology for the Sahelian Countries: The Burkina Faso Case." Economic Development and Cultural Change, 39(1):1-22.

Southgate, D., J.H. Sanders, and S. Ehui, 1990. "Resource Degradation in Africa and Latin America: Population Pressure, Policies, and Property Arrangements," American Journal of Agricultural Economics 72(5) (Dec), forthcoming.

Dissertations, Staff Papers, and Nonrefereed Articles

Habash, Mohamed K., 1990. "Potential Returns and Constraints to the Adoption of New Technologies in the Mechanized Rainfed Region (Eastern Vertisols) of the Sudan," unpublished Ph.D. dissertation, Dept. of Agricultural Economics, Purdue University, West Lafayette, IN 47907.

M. Ahmed, Mohamed, 1990. "Economic Evaluation of New Sorghum Production Technologies and Policy Implications for Northern Gedaref Region of Eastern Sudan," unpublished Master's thesis, Dept. of Agricultural Economics, Purdue University, West Lafayette, IN 47907.

Gomez, Francisco, Miguel Lopez-Pereira, and Daniel H. Meckenstock, 1990. "Toward Sustainable Agriculture in Honduras," STAR Science & Technology Reporter 2(3):3-4.

Lopez-Pereira, Miguel A., 1990. "Economics of Sorghum and Soil Erosion Control Technologies for Small Hillside Farmers in Southern Honduras," unpublished Ph.D. dissertation, Dept. of Agricultural Economics, Purdue University, West Lafayette, IN 47907.

Ramaswamy, Sunder, 1990. "Technological Change, Land-Use Patterns, and Household-Income Distribution in the Sahel: The Burkina Faso Case," unpublished Ph.D. thesis, Dept. of Economics, Purdue University, West Lafayette, IN 47907. (In progress)

Sanders, John H., 1989. "Myths About the Sahel," in V.W. Ruttan (ed.), Biological and Technical Constraints on Crop and Animal Productivity: Report on a Dialogue, Dept. of Agricultural and Applied Economics, University of Minnesota, Staff Paper P89-45, Dec. 1989, pp. 67-69.

Shapiro, Barry I., 1990. "Potential Constraints, Policy, and New Technologies in the Niamey Region of Niger." Unpublished Ph.D. thesis, Dept. of Agricultural Economics, Purdue University, West Lafayette, In 47907. (In progress.)

Networking Activities

Workshops

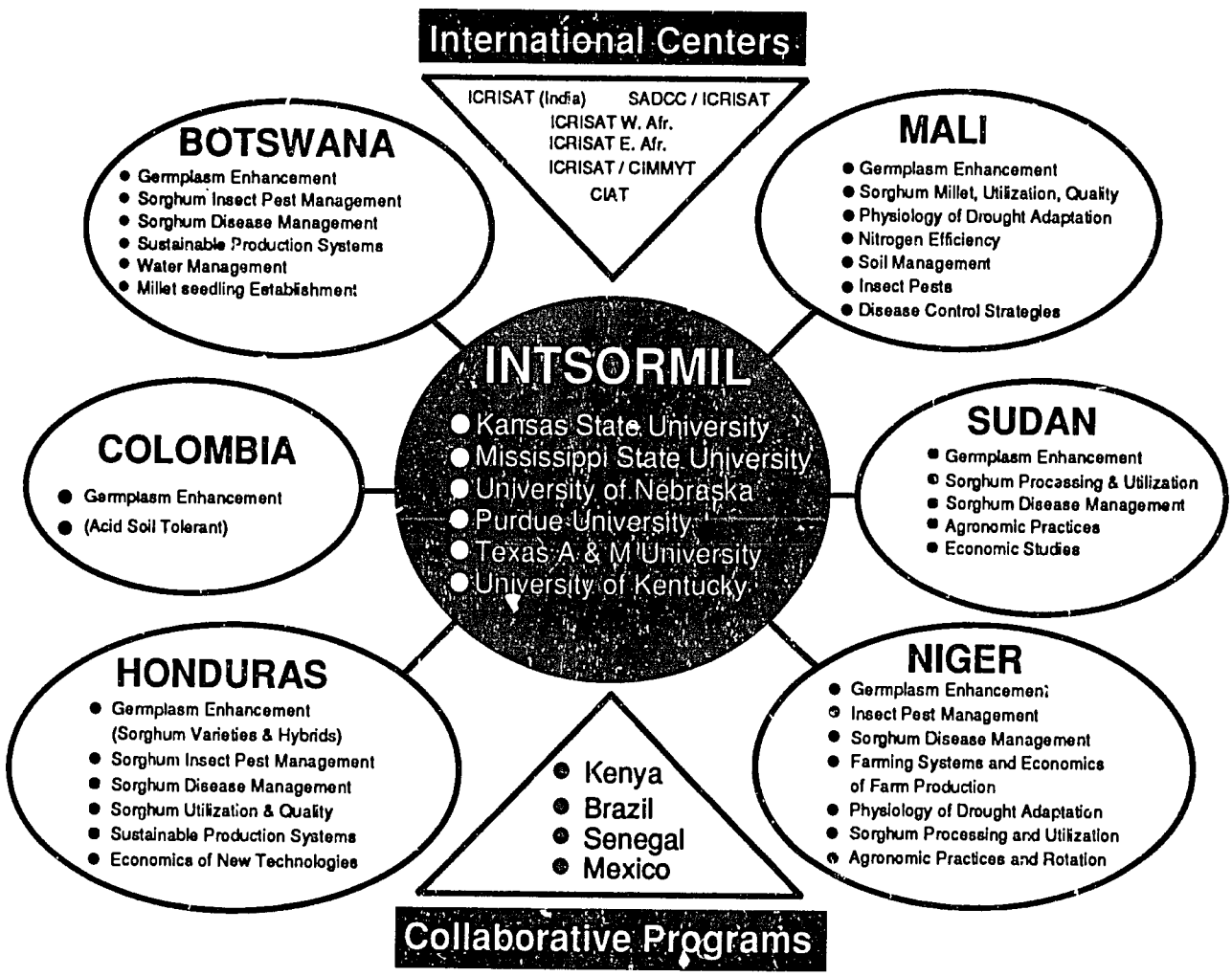
In July 1989, Sanders participated in a workshop at the University of Minnesota, supported by the Rockefeller Foundation. This workshop included agricultural scientists and economists. Its objective was to anticipate future constraints to increasing agricultural productivity in developing countries. Sanders presented a Sahelian perspective on future agricultural technology development (see Publications). With two other economists, an invited paper was presented at the national meetings of the American Agricultural Economics Associaton in Vancouver. The invited-paper session was on sustainability in the developing countries (see Southgate et al. in Publications).

Research Investigation Exchanges

Collaboration continued with Kimsey Savadogo of the University of Ouagadougou on income-distribution effects and income sustainability of new technologies in the former river-blindness regions of Burkina Faso. Two mimeos on technology-development activities were completed in Year 11 from this collaborative work.

1990 Country Reports

INTSORMIL Collaborative Sites



Botswana

M.D. Clegg
University of Nebraska

Coordinators

Dr. R.L. Vanderlip, Department of Agronomy, Kansas State University, Manhattan, KS 66506 (U.S. Coordinator, on sabbatical leave, Australia)
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. Acting Coordinator)

Collaborative Program

The Botswana project operates by approval of the U.S. Government and the provisions in Grant A.I.D./DSAN/XII-G-0149 to the University of Nebraska, The Management Entity (ME). Funding of the project is provided by the Government of Botswana (GOB), University of Nebraska (KSU-107) and the Agricultural Technology Improvement Project (ATIP-USAID Project 633-0221). The Memorandum of Understanding (MOU) in which INTSORMIL operated was under the umbrella of ATIP. ATIP has been phased out with the ending of its contract. A MOU between the GOB, USAID/Botswana and the INTSORMIL ME for two more years was obtained to continue agronomy/soil research.

The Botswana program can be divided into two very much related components: INTSORMIL researchers 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 many other projects which will be referenced.

Financial Inputs

USAID/Botswana provides costs per USAID regulations for upkeep of in-country scientists, a vehicle and maintenance, assists with telex and FAX communications and $43,000 to INTSORMIL ME to support KSU-107 and funds for travel and per diem for an IBSNAT consultant to demonstrate DSSAT software. GOB through the Arable Lands Development Program provided equipment (three neutron probes, drying ovens, moisture cans, augers, deep rippers, cultivators, etc.) needed for the multilocational tillage trials. Temporary field assistants to monitor trials at each site and supervision through their regional program managers were provided. GOB through DAR provided office space, one B.S. level research officer, four technical assistants, office supplies, field equipment, labor, laboratory facilities, transportation, housing maintenance and travel to regional meetings and workshops.

These resources allowed the INTSORMIL Botswana program to undertake its comprehensive, extensive, relevant, collaborative research on dryland sorghum/millet production. The value of support is estimated at over $200,000.

Collaboration with Other Organizations

Collaboration is occurring with the ODA Land and Water Management Project on rainfall runoff, with IBSNAT on DSSAT software, Department of Meteorological Services on use of agroclimatic data and FAO sponsored Soil Survey and Mapping Services on site selection and characterization. Entomology, pathology, and plant breeding collaborate with ICRISAT in Bulawayo.

The Planning Process

Several multidisciplinary working groups meet to put forth research recommendations. Dr. Persuad serves as chairman and team leader of the tillage and fertilizer group. The planning of research by the in-country scientists is reviewed at the annual DAR planning meeting in September or October. Their work plans are circulated with the national scientists' plans for review and then presented at the meeting. With other collaborative research, scientists and/or administrators of DAR are involved in the planning process.

Sorghum/Millet Constraints Researched

Production Constraints

Sorghum and millet are important crops in Botswana. The grain is an important food source for the population and the stalks are used as feed for livestock. There is a strong motivation in Botswana for increasing traditional, smallholder farm yields and output because:

Seventy to eighty percent of the food produced, including 90-95% sorghum, comes from these subsistence-oriented dryland farms.

Annual cereal requirements in Botswana are estimated at 250,000 metric tons of which about one third is usually satisfied in years of moderate rainfall.

Ninety percent of rural households produce harvests which are insufficient for subsistence, taking the average of six people per household.

One half of all farms produce under 320 kg of cereals per year.

In Botswana the low, irregular, and low-efficiency rainfall pattern results in low variable yields, low harvested to planted area ratios, and high-risk, economically marginal farm enterprises. Sandveld and hardveld soils have a low capacity to retain moisture, low N and P content, broadly graded sand fractions, and unstable surface. The last two properties 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 improvements, residue incorporation, and weed control are urgently needed to improve soil structure, rainfall infiltration and availability for promoting crop establishment and improved grain and stover yields.

The National Development Plan (NPD 7) has specifically identified an urgent need for improved soil and water management as a factor in aiding national and household food security, promoting crop diversification and expansion, and conserving the soil resource base.

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

Naraine Persaud, INTSORMIL/Botswana, Gaborone, Doug Carter, INTSORMIL/Botswana, Gaborone and Richard Vanderlip, Kansas State University, Manhattan, KS

The research is directed towards increasing sorghum and millet crop production through improved systems for utilizing rain. This includes runoff, fertility and residue management. Research has also been directed towards stand establishment. Collaborative research supporting relevant national research efforts is in progress. For in depth information see Annual Report INTSORMIL KSU-107.

Several summary reports are published in The Bulletin of Agricultural Research Botswana 7 & 8. Also some reports have been published in Agrinews, Ministry of Agriculture, Botswana, a monthly edition.

Joan Youngquist, University of Nebraska, Lincoln, NE., D.C. Carter, INTSORMIL/Botswana, Gaborone (KSU-107) and Max D. Clegg, University of Nebraska, Lincoln, NE.

Research from studies in Botswana have been prepared for publishing. The following article summarizes research on the quality of sorghum and millet crop residues as fodder.

Youngquist, J.B., D.C. Carter, and M.D. Clegg. 1990. Grain and Forage Yield and Stover Quality of Sorghum and Millet in Low Rainfall Environments. Exper. Agric. 26: 279-286.

Entomology

George L. Teetes, Texas A&M University, College Station, TX and Chris Manthe, Department of Agriculture Research, Botswana

The collaborative entomological research program is a student training program, with the student's research being done in Botswana, with some of the research done in Zimbabwe. The student is a Department of Agriculture Research employee as an entomologist.

The research program is currently being funded by a SADCC/ICRISAT/INTSORMIL training grant.

Part of the research was conducted at the SADCC/ICRISAT research station at Matapos. A major part of the research was conducted at the Sebele experiment station.

Collaborative research plans of work were developed through the student's dissertation proposal, with annual review.

Accomplishments - Research in Botswana and Zimbabwe is a collaborative research project to screen selected sorghum lines for resistance to sugarcane aphid, *Melanaphis sacchari*, study resistance mechanisms, and determine mode of gene action. Four hundred and fifty-eight lines were screened including 431 TAES lines, 7 from Botswana, 7 from South Africa, and 13 ICRISAT lines. Among the selected lines, TAM428, SC170, SC109, SC173, SA1221, and SA1469 had high levels of resistance to the aphid.

There was variability in virulence within the Botswana and between the Botswana and Zimbabwe aphid populations towards TAM428, SC109, SC173 and SC110. TAM428 resistance was most stable. SC110, SC109 and SC173 resistance was moderately stable. These findings suggest different biotypes exist among populations of the sugarcane aphid.

Antixenosis and antibiosis were present in highly resistant lines. Screening progenies of TAM428 and SC170 crossed to susceptible parents indicated that sorghum resistance to sugarcane aphid is simply inherited and controlled by a single completely dominant gene.

Plant Pathology

Gary Odvody, Texas A&M University, Agricultural Research and Extension Center, Corpus Christi, TX.

Under high anthracnose pressure at Zimbabwe, Zambia, and Tanzania locations, sorghum nurseries from the Texas Agricultural Experiment Station and collaborative nurseries developed by SADCC/ICRISAT, SADCC national programs, and TAM-128 demonstrated that good anthracnose resistance was available in introduced and improved local germplasm. Anthracnose virulence appears to differ from that occurring in India and the U.S. and may even differ within the SADCC region. By maturity in April 1990, charcoal stalk rot incidence was variable to high in pearl millet and sorghum at Lusitu, Zambia with sorghum showing the greatest diversity in cultivar response. Charcoal rot occurred on both gramineous and nongramineous crops at Sebele, Botswana with medium to low incidence and severity in most crops. Charcoal rot specimens were collected from these crops at Lusitu and Sebele for isolation of *Macrophomina phaseolina* and isolate characterization in culture by TAM-128 to determine if host preference differences exist in Southern Africa populations of this organism as in the U.S. A SADCC/ICRISAT test of A&R sorghum lines had a high incidence of ergot in the A-lines at most test locations in Zimbabwe but were very low at Pandamatenga, Botswana and Muzarabani, Zimbabwe. These may be excellent locations for production of hybrid sorghum seed.

Sorghum/Pearl Millet Breeding

David Andrews, University of Nebraska, Lincoln, NE and Louis Mazhani, Department of Agriculture Research, Botswana

Mr. Louis Mazhani's dissertation research in Botswana comparing the stability of performance of 25 sorghum genotypes in six different groups across five diverse locations was completed. Among these six groups, hybrids (with a mean yield of 30.3 q/ha), and blends (one each of hybrids, topcrosses, and varieties) (29.2 q/ha) were superior in grain yield to topcrosses (25.5 q/ha) composites (24.0 q/ha), varieties (23.8 q/ha), and parental lines (22.7 q/ha). Site mean yields ranged from 14.0 to 37.7 q/ha.

Two methods of analysis were used to quantify genotype x environment interaction; both gave essentially similar results. The common local variety, Segaolane--known to be reliable--gave as expected as good a yield as any genotype in more stressful lower yielding locations, but responded poorly to improved conditions having a 'b' value of 0.91 and an average yield of 28.7 q/ha. Hybrid, blend, and composite groups responded better to improved conditions. Because of their high mean yields, the hybrids and blends, despite b values greater than unity were able to give yields equivalent to Segaolane in poor conditions, but were much superior in good conditions.

The best individual genotypes both in terms of yield and stability were hybrid NO. 11 (SPL23A x SV1, averaging 36.4 q/ha) and the blend of four hybrids (34.3 q/ha). The yield of the hybrid blend was higher than the average of the four component hybrids grown separately. This effect was also apparent though to a lesser extent when the topcross and variety blends were compared to their component averages. Stability was best among the blends, possibly due to genetic heterogeneity, but hybrid No. 11, a single cross hybrid, was equally as stable (other hybrids were poor in this regard) showing that it is also possible to find stability in homogenous but heterozygous genotypes. Further research is planned regarding the stability and yield attributes of blends, as well as the breeding and identification of individual genotypes with stability and high yield.

The process of developing adapted drought resistant seed parents from UNL-115 material continued as an integral part of the Department of Agricultural Research sorghum breeding program at Sebele. Eighty percent of the test crosses made on this material were male sterile. Lines being developed from other sources as varieties also gave good restorer reactions. The basis has therefore been developed to produce both male and female hybrid parents in the Botswana sorghum breeding program.

Mutual Research Benefits

Mutual benefits occur with interaction and information flow between U.S. and African scientists.

More specifically, there is germplasm resistance for anthracnose and virulence appears to differ by country. Research suggests the possible existence of different biotypes among populations of sugarcane aphid. Development of drought resistant parents and breeding techniques is continuing. Such information and techniques may have application for Botswana, Southern Africa and the U.S. if problems arise. Germplasm exchange in plant breeding programs is always mutually beneficial.

Agronomic studies under conditions in which water and soil fertility is minimal and soil structure poor will allow the determination of mechanisms resulting in improvement. This will have mutual benefit for sustainable agriculture in the U.S. and for production improvement in Botswana and Southern Africa.

Institution Building

There have been modest expenditures for equipment. In-country support is very good.

Dr. Louis Mazhani has returned after completing his Ph.D. in plant breeding at the University of Nebraska. Mr. Chris Manthe returned to Texas A&M to complete his Ph.D. dissertation. Dollina Malepa is at Nebraska working on a Ph.D. in soil fertility.

Networking

Because the INTSORMIL researchers are working directly with the Department of Agriculture researchers, there

is direct communication of research results. Research reports are shared with DAR. With close linkage with ATIP, much of the research is disseminated in the Francistown and Mahalaype areas. Information is also distributed in other Southern African areas through SACCAR and ICRISAT. Dr. Persaud participated in the SADCC/ICRISAT/SMIP as did Prof. David Andrews.

INTSORMIL (KSU-107), ATIP, and Projects (KSU-106, UNL-113) research has been 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.

Research Accomplishments

Dr. Douglas Carter and Mr. Wayne Youngquist arrived in Botswana in April 1984, Dr. Carter as an INTSORMIL agronomist in collaboration with ATIP and Mr. Youngquist as an agronomist to continue the sorghum-legume rotation research of Dr. Lucas Gakale (research scientist), who was on leave in the U.S. obtaining a Ph.D. degree. Dr. Lucas Gakale is presently Director of Agricultural Research. Dr. Carter recently completed his tour and is continuing to summarize and publish the research accomplished in this period.

Through collaboration with UNL-115, 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 were sent to Botswana for selection. Some 36 selections were made from 119 F_2 and F_3 populations in 1985. Dr. Louis Mazhani (who recently earned his Ph.D. at the University of Nebraska) was involved with this research. His dissertation research was on the evaluation of the stability performance of 25 sorghum genotypes in six different groups across diverse locations. Two methods of analysis were used to quantify genotype x environment interaction; both gave essentially similar results. Segaolane gave good yields under stress conditions but did poorly under improved conditions. The best individual genotypes in terms of yield and stability were hybrid No. 11 (SPL23A x SV1, averaging 3.64 Mg/ha) and the blend of four hybrids (3.43 Mg/ha). The yield of the blend was higher than the average of the four component hybrids grown separately. Further research is planned regarding stability and yield of blends. Also, the process of developing adapted drought resistant seed parents from UNL-115 material is continuing.

Progress was made in identifying 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 different biotypes exist among the populations.

Material from Texas A&M University collaborative nurseries demonstrated that good anthracnose resistance was available in introduced and improved local germplasm. Anthracnose virulence appears to differ from that occurring in India and the U.S. and may even differ within the SADCC region. Charcoal stalk rot and ergot were other diseases characterized.

During the time INTSORMIL has been involved with research in Botswana there has been a drought seven of eight years. This definitely demonstrates the lack of moisture constraint. This has led to efforts being devoted to moisture conservation. Dr. Carter (KSU-107) established several studies of soil management practices that influence the amount of water for crop growth. These involved crop residue and manure, kind and time of tillage and planting, the diversion of runoff to portions of fields and runoff reduction by crop row orientation and land shaping. Results are as expected. Any practice that results in more water in the soil will probably increase yield if other management practices are adequate. Dr. Carter has summarized this research and reports and manuscripts have been prepared and published or are in the process of being published (see Refs. KSU-107).

The soil physicist position was filled by Dr. Naraine Persaud. This position was added to complement the work being done by both the INTSORMIL and ATIP scientists. This builds on the soils report produced by the Soil Conservation Service, USDA/SMSS on data on 22 soils in Botswana. 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. Addition of P gave a tremendous yield increase. Mean over all tillage treatments showed yield of 651 kg/ha with no P and 2095 kg/ha with P (15 kg/ha).

Botswana students trained through SADCC/ICRISAT/INTSORMIL, INTSORMIL, A.I.D/BOTSWANA, ATIP educational/research programs are Lucas Gakale, Louis Mazhani, Chris Manthe, Dollina Malepa, Elijah Modiakgotla, Bodiakgotla Motalaote, and Boi Sebolai. These scientists provide a good core but 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. A four-year program at the University of Botswana leading to a Bachelor of Science in Agriculture should help increase the number of students with proper credentials for advanced graduate studies in agriculture.

Honduras

Darrell T. Rosenow
Texas A&M University

Coordinators

Dr. Darrell T. Rosenow, Texas A&M University, Lubbock, Texas (U.S. Coordinator)
Dr. Francisco Gomez, Sorghum Breeder, SRN, Choluteca, Honduras (Host Country Coordinator)
Dr. Dan H. Meckenstock, In Country Sorghum Breeder, INTSORMIL (Texas A&M) SRN, EAP, Zamarano, Honduras

Institutions Involved

Secretaria de Recursos Naturales (SRN), Honduras
Panamerican Agricultural School (EAP), Honduras
Texas A&M University
Mississippi State University
Purdue University

Collaborative Program

Memorandum of Understanding

The current 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 drafted to formalize the officing of Meckenstock at the school, collaborative activities with INTSORMIL graduate students, and EAP/USAID collaboration with INTSORMIL/SRN sorghum research activities.

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, Sorghum Improvement in Honduras and Central America. Dr. Franciso Gomez, Ph.D.-Texas A&M, is a full time sorghum breeder and Head of the SRN National Sorghum Program. He is located at Choluteca, the center of sorghum production in southern Honduras. 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 uniform trials, and coordinating networking activities with researchers in neighboring countries.

In addition to sorghum breeding, the Honduras program involves collaborative activities in entomology, pathology, cereal quality, and agricultural economics. 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; and agricultural economics-J.H. Sanders (PRF-105) Purdue. Max Clegg and Steve Mason (UNL-113) University of Nebraska are initiating a program in agronomy.

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 collaborative sorghum 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. These funds pay Gomez's salary and support research at the Choluteca, Comayagua, and Catacamus Research Station. 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 Rodriquez, Rosenow, EAP and USAID. Graduate student research plans are developed annually and submitted to SRN for approval. Budgets for A.I.D/H support are jointly developed each year by Gomez and Meckenstock, and submitted by SRN to A.I.D/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, 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 drought resistance. Entomological field work, on-farm trials, and agricultural economics research is 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 in nonphotoperiod sensitive material is done in the U.S., with advanced material then sent to Honduras for evaluation and use. Elite U.S. breeding lines serve as sources of desirable traits in the maicillo enhancement breeding program.

Research Results

Breeding

The improved maicillo breeding program progressed well. Through the IIMYT (International Improved Maicillo Yield Trial), the best enhanced maicillo varieties and five experimental hybrids were evaluated at several sites in Honduras as well as in Guatemala and El Salvador.

Three new enhanced maicillo lines were evaluated in on-farm trials in 1989. Yield data from 16 sites indicated that they yielded as well or slightly better than the traditional maicillo with traditional cultural practices, but with 30 to 50% higher yield when using insecticide seed treatment and fertilizer. Many farmers saved seed of the enhanced maicillo cultivars for planting in 1990, and some even sold seed to neighbors for planting.

The hybrid maicillo program in Honduras is the only photoperiod sensitive hybrid sorghum breeding program in the world. Excellent progress was achieved in the development of female and male maicillo derivative parental lines. Performance of maicillo hybrids in multilocation yield trials indicated excellent yield over the local varieties. The hybrid program demands extensive fine tuning with regard to genes controlling height, maturity, plant and grain color, as well as the proportion of maicillo germplasm.

Evaluation and characterization of the native maicillo criollo varieties of the region continued. This, plus the entire maicillo breeding program, is aimed at conserving and using the genetic diversity of the area. Additional details of the breeding research in Honduras can be found in the TAM-131 Annual Report.

The release of a sorghum-sudangrass F_1 hybrid (ATx623*Tx2784) to be called 'Ganadero' is anticipated in 1990. It contains resistance to pathotype 1 downy mildew. About 1700 lbs of seed was produced in 1989 for sale to farmers to test its acceptance.

Cereal Quality

Grain samples from the 1988 and 1989 IIMYT grown at La Lujosa were evaluated for quality in the Cereal Quality Laboratory at Texas A&M by Dr. L.W. Rooney, et al. Among traits evaluated were endosperm texture, grain discoloration, ease of pericarp removal, nixtamal color, and protein content. Several entries were as good or superior to the maicillo criollo checks. In general, the tan plant color lines gave excellent nixtamal color, while red or purple plant color lines often produced badly stained grain and off-colored nixtamal, indicating the importance of tan plant color, especially when some grain weathering occurs. One tan plant line, DMV 195 (SPV346xGigante Pavana)-1 F7, was judged as having superior overall tortilla quality and it will be tested on-farm.

Entomology

Research continued on developing a control strategy for the langosta, a lepidopterous larval complex of four pests which ravages young sorghum and maize seedlings in southern Honduras. The two-pronged attack is based on host

plant resistance and studies on the biology and population dynamics of the pests.

Hector Portillo (Honduran, M.S., MSU, Pitre) studied the ecology, population dynamics, crop life tables, and loss assessment of the pests in southern Honduras. The presence of noncrop vegetation was shown to be very important in the buildup of insect infestations prior to feeding on the crops.

Lorena Lastres (Peru, M.S., TAM, Gilstrap) studied predation by fire ants and earwigs on the fall armyworm, the major pest in the langosta complex. She found that predation by earwig can be important in FAW larvae mortality, especially when combined with a significant number of fire ants.

Julio Lopez (Honduran, M.S., MSU, Pitre) studied antibiosis to the fall armyworm in the native maicillo criollo varieties and their derivatives. He found several with significant levels of antibiosis (San Barnardo III, Lerdo-104, Hilate-179, and Pina-61), and the antibiosis was manifested through reduced fecundity, while that in AF28 was through increased mortality. Studies to combine these to types of antibiosis were initiated.

Pathology

Diseases and disease resistance are important components of the breeding program. Several converted lines were identified as resistant to rust (SC158, SC120, SC21, SC1007, SC982, SC972, SC494, SC425, SC418, and SC326-6) along with Tx432 and Tx2767. Pathotype 5 of downy mildew continues to be a problem at Comayagua, but a trial with ten differentials indicated only pathotype 1 at other sorghum locations in Honduras. Sorghums with resistance to pathotype 5 of *P. sorghi* at Comayagua in 1989 are presented in Table 1. The line, IS3443, should be very useful, as it combines downy mildew resistance with many other desirable traits.

Table 1.

Sorghum entries with resistance to pathotype 5 Peronosclerospora sorghi at Comayagua, Honduras, 1989.

IS numbers				
1032	3546	5665	12646	22229
1317	3547	4743	14332	22230
2132	4696	6094	14387	27042
2204	5616	6457	18757	
2473	5628	6918	22227	
3443	5651	6807	22228	

Economics

An extensive farm-level analysis of new technologies in southern Honduras was the dissertation research of Miguel Lopez (Honduran, Ph.D., Purdue, Sanders). It used intensive interviews with 119 farmers to develop a model to estimate the effects of adoption, income impact, and constraints to new technology introduction. Given the steep slope (one-half had slopes of 50% or greater), the first pressing problem is to prevent the farm from washing into the valley. The technologies evaluated were rock terraces for soil conservation and the improved sorghum cultivars, Sureño and Catracho, released from the SRN/INTSORMIL program. Most farmers that had adopted the terraces were then interested in new varieties and other improved technologies. According to the models, the combined use of terraces and new cultivars increased expected income by 15%. If the price collapse in good rainfall years is avoided, the increased income would be 58%. The potential exists to make the hillside agriculture of southern Honduras a permanent, sustainable system rather than itinerant hillside farming.

Agronomy

A growth analysis study of a native maicillo and an improved maicillo in pure stand and intercropped with maize was done by Patricio Gutierrez of EAP as his Ingeniero Agronomo thesis. The improved maicillo produced significantly more grain than the native maicillo, especially in pure stands. However, the native maicillo produced the most total biomass, apparently partly due to its greater photoperiod sensitivity. This indicates the potential for using photoperiod sensitive hybrids as a crop for fuel in the tropics.

Two potential graduate students for M.S. degrees, Mr. Evelyn Oviedo and Mr. Patricio Gutierrez, both from EAP have been identified to work in agronomy research with Drs. Max Clegg and Steve Mason at the University of Nebraska.

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.

Institution Building

Research Supplies and Support

The USAID/H Mission contributed in local currency the equivalent of $114,000 to SRN and $83,000 to EAP for calendar year 1989 for support of sorghum research. In 1990, 479,000 lempires (equal to $111,266) was contributed by USAID, with 430,000 ls through EAP and 49,000 ls to SRN. The dollar value in 1990 was reduced substantially due to the devaluation of the lempire.

From TAM-131, $7,000 was placed in a special fund for use by Francisco Gomez. A remote telephone was procured with TAM-131 funds for the La Lujosa Station near Choluteca, to facilitate communication with F. Gomez. A new pickup was provided by MSU-105 for use by INTSORMIL graduate students doing research in Honduras. MSU-105 also supplied a Pentax K1000 camera to collaborators in Honduras. A subscription to CAB Sorghum and Millets Abstracts was provided to the EAP library. Other small equipment and supplies were provided to the National Sorghum Program.

Training of Host Country Researchers

Dr. Francisco Gomez (Ph.D., Texas A&M, F. Miller), is currently a sorghum breeder and Head of the National Sorghum Program in SRN.

Carlos Trabanino (M.S., Mississippi State, H. Pitre) is an entomologist, with the USAID sponsored MIPH (integrated pest management) project at EAP.

Marco Castro (M.S. and Ph.D., Miss. State, H. Pitre) is employed as an entomologist with FIAH (A.I.D supported research institute) in Honduras.

Host and U.S. Scientist Visits

To Honduras

Darrell Rosenow (TAM-122), Fred Miller (TAM-121), and Gary Peterson (TAM-123) breeding; Delroy Collins (TAM-124) pathology; Max Clegg (UNL-113) agronomy; and Tim Schilling (ME); Nov. 29-Dec. 5, 1989.

John Sanders and Miguel Lopez (PRF-105) agricultural economics, Jan. 22-24, 1990.

Louis Mughogho (ICRISAT, India) pathology; Tunde Obilana (SADCC/ICRISAT, Zimbabwe) breeding; and Tom Hash and Rene Clara, breeding, and Compton Paul, agronomy, of ICRISAT/LASIP, CIMMYT, Mexico; Nov. 19-23, 1989.

Julio Lopez and Hector Portillo, M.S. degree candidates in entomology, MSU-105, in Honduras three months, May-Aug. 1989, and May-June 1990.

To U.S.

Alejandro Palma, EAP, to INTSORMIL Graduate Student Tour, College Station and Corpus Christi, TX, June, July 1989.

Lindolfo Fernandez, SRN, pathology-agronomy to Texas A&M, College Station, May 6-18, 1990 for training in pathology and tour sorghum nurseries.

Dan Meckenstock, Texas A&M, August 1989 and January 1990.

Other Travel in Area

Francisco Gomez, SRN, Alejandro Palma, EAP, and Dan Meckenstock to CLAIS meeting, April 24-27, 1990, CIMMYT, Mexico.

Darrell Rosenow and Lloyd Rooney to CLAIS meeting, April 24-27, 1990, CIMMYT, Mexico.

Dan Meckenstock to Guatemala, Dec. 14-19, 1989.

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 are used to help identify problems and research needs and assist in on-farm research. An SRN report of all research data is prepared annually. Technical assistance is provided to the seed production branch of the government on seed increase of newly released cultivars. Extension personnel are used to distribute seed of the new cultivars. Graduate student research conducted in Honduras is planned through visits of the U.S. PI with appropriate collaborators and institutions in Honduras.

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 and PCCMCA. 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 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 LaLujosa 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.

The parental lines and hybrid seed of the sorghum-sudangrass F_1 hybrid (ATx623xTx2784) for use as a forage for livestock were increased in anticipation of release in early 1990.

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 and 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.

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%.

Mali

Sustainable Systems for Production, Utilization, and Marketing of Sorghum and Millet

L. W. Rooney and M. Traore
Texas A&M University

Coordinators

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Dr. Moussa Traore, Plant Physiologist, SRCVO, DRA/IER, Bamako, Mali

Institutions Involved

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Dr. Y. Doumbia, Entomology, IER/DRA/SRCVO, Sotuba
Mr. K. Traore, Millet Breeding, IER, Sotuba
Mr. M. Bagayoko, Agronomy, IER, Sotuba

Collaborative Program

The program in Mali is a coordinated effort among INTSORMIL, TROPSOILS, ICRISAT-Mali, 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 PI's 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 1989-90 workplan and budget was developed and approved by IER in July of 1989. The seventh workplan and budget for 1990-91 was approved 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. Grain is consumed in a thick porridge (tô) or as couscous. 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 TROP-SOILS 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. Consistent progress is being made.

New Opportunities

Two students completed M.S. theses and returned home to begin work in millet breeding and agronomy. This has led to additional activities in the program. Dr. Mason has initiated work with his former student in intercropping and residue management. An integrated approach to control head bugs including entomology/pathology, breeding, and food quality is providing useful information.

Additional equipment and training of personnel for the Food Technology Laboratory is required. Expanded efforts to develop new foods from sorghum and millet are underway.

Research Progress

Germplasm Enhancement

Sorghum

Head bugs are a major constraint to the development and use of improved yielding sorghums in Mali and in many other areas of West Africa. The local guinea type sorghums possess good head bug resistance, but they are extremely difficult to utilize in a breeding program due to their low yield potential and weedy traits. Malisor 84-7 has been proven to possess a high level of resistance to head bugs. It possesses the necessary traits for head bug resistance, in an agronomically improved plant, head and grain type. Thus, it is an extremely important line to present and future sorghum improvement programs in West Africa.

Malisor 84-7 is now being used extensively in the breeding program in Mali, and was crossed to many agronomically improved lines in both Mali and Texas. Segregating F_2 populations were planted and selected in both Texas and Mali, with some excellent progeny obtained. These will be planted as F_3's and F_4's in 1990. Elite lines used in Malisor 84-7 crosses in Texas include Dorado, Sureño, VG153, M50009, 86E0361, 84C7730, and 87E0366. The best crosses in Mali involved elite lines such as S34, S35, ICSV401, E36-1, ICSV1063BF, M36243, ICSV1002BF and CE151 along with Malisor 84-7, 84-5 and 84-1. It appears that several of the lines developed by ICRISAT in Burkina Faso possess moderate levels of resistance to head bugs and can be useful in breeding crosses.

A study was initiated by Aboubacar Toure as part of his Ph.D. research in Texas to study the breeding potential of Malisor 84-7 in several crosses. Yield relationships as well as grain and glume traits will be studied. Studies also continue to determine the nature and inheritance of grain/glume traits in Malisor 84-7 which impart head bug resistance.

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.

The guinea sorghums are the most dominant race in the Savanna Sorghum belt of West Africa. They are well known for their excellent food grain quality, good weathering, storage qualities and very low but stable yield levels. Moreover, when guinea sorghums are crossed with other taxonomic groups, the progeny produced have low yield potential and undesirable characteristics which has been a major handicap limiting progress in yield improvement of sorghums in West Africa. Mr. Aboubacar Toure's Ph.D. thesis involves research to determine factors affecting the combining abilities of West African guinea sorghums. Eleven converted guinea sorghums from seven West African countries were crossed to five high yielding zerazera lines and four improved inbred lines. These yield trials have been evaluated in College Station and Halfway, Texas. This study will provide useful information on the combining ability of guinea sorghums which should aid in the development of yield improvement schemes for Mali and West Africa.

Pearl Millet

F_1 and F_2 seeds of crosses between Mali varieties and UNL-118 lines were prepared in Nebraska and planted in Mali in 1989. Backcross seeds of these crosses to Mali parents were also made in the winter greenhouse to support the Mali pearl millet breeding program.

Sorghum Pathology

During the last two 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 both 1988 and 1989, disease severity was evaluated in nine different trials at Sotuba, Samanko, Cinzana, and Bema locations. In addition, the ADIN and ISAVN trials were conducted in the pathology program. B35-6, which is resistant to *Colletotrichum graminicola* in Texas, did not show symptoms of the disease at Cinzana and Longorola in 1989. In 1988, however, B35-6 was susceptible to leaf anthracnose at Cinzana.

Grain mold continues to be a major sorghum disease problem in Mali (Table 1). Germination is highly correlated with attack by grain molds. 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.

Malisor 84-7 is an improved variety with some tolerance to the head bug and molds. Malisor 84-7 has much better germination than most other improved sorghum varieties, especially when its maturity is considered. The locals are photosensitive and have the least mold and highest germination.

Investigations on sorghum long smut continue. In 1989, we found that sorghum planted during the first week of August was less infected than plants in the first planting date (July) and the grain yield was acceptable. Date of planting time may be useful in avoiding long smut at Bema.

Pearl millet varieties have been screened for downy mildew resistance at CINZANA. Good sources of resistance have been documented.

Head Bugs of Sorghum

Population Dynamics of Eurystylus marginatus at Sotuba

The first adults of *E. marginatus* appeared on sorghum panicles around September 15, 1989. Adults and nymphs were most abundant at two times during the season, late September and the last 10 days of October. Nymphs were more abundant than adults. During November, nymphs and adults were limited in number on ratoon and off-season sorghum. Very early planted sorghum (7-4-89) was not severely damaged by bugs. First generation bugs appeared between 9-20-89 to 10-15-89 during the late milk and beginning maturity stages of kernel development for early planted sorghum. The second bug generation appeared between 10-20-89 to 11-19-89. For the later sorghum planting date, this generation coincided with earlier stages of kernel development. The later planted sorghum was consequently more severely damaged than early planted sorghum.

Screening Sorghums for Head Bug Resistance at Sotuba

One hundred sorghum varieties tested showed differences in head bug damage. There was a relationship between bug abundance and damage and sorghum maturity. Bug numbers ranged from six to 218 per five panicles. The variety 87-CZ-CC-P23-2 was most heavily infested. Sorghums with the least infested panicles were 85-F4-164, 85-F4-107, CS630 and B-VAR1. Very early varieties such as CS566, SC630, Segolone, and CS560 were not severely damaged. At maturity, grain mold severity was evaluated. The number of punctures was independent of the number of bugs present. Malisor 84-1, 87-SB-F4-232-3, 87-SB-F4-16-1, 87-SB-F-129-1, 87-SB-F4-16-4, IS13518, OH/84-7/26/1, IS27454, ICSV1143-BF, ICSV1002 and Tx2536 had more than 60% of their grain damaged due to head bugs. Sorghum lines with less than 10% kernel damage included IS16123, IS20740, IS-27477, A2821, and Bagoba. Protected panicles had the highest kernel weight (4.40g/200), and unprotected panicles had the lowest (3.5g/200). Sorghum lines BTx632, BTx631, 87ED, 366 and TP21RB02-181-1-1 were severely damaged by molds (50%+). Varieties 84-QGH-12, IS16357, IS17610, IS20740, IS21444, IS27063, IS27466, A2821, A7081 had the least mold damage (1-10%). Kernels from protected panicles had a mean germi-

Table 1. Relationship between grain mold and percent germination of sorghum varieties planted at Sotuba (1989) and CINZANA (1988).

	Grain mold severity*				% Germination			
	P		NP		P		NP	
	C	S	C	S	C	S	C	S
CSM219	3	2	3	2.5	79	87	82	84
CSM228	1	1	1	1	94	90	89	86
CSM388		1		1		73		90
Gadiaba	5	1.5	4	2	72	49	96	6
Malisor 84-1		2		3.5		53		26
Malisor 84-5	1	2	4	3	75	46	61	39
Malisor 84-7	3	2	3	3	89	78	63	32
CE-90	2	2	3	3	95	30	61	36
CE-151	3	2	3	4	78	33	46	14
E-35-1	2	-	3	2	87	49	80	30
Sureño	2	2	4	4	80	50	68	6
S34	1	2.5	3	4	70	11	27	1
ICSV401		2		3		27		14
ICSV1063		2		3		62		45
ICSV1079		2		3.5		48		20
Means	2.3	1.9	3.1	2.8	82	52.4	65	35.3

*Grain mold severity 1-5, 1 = no molded grain; 2 = up to 10% molded grain; 3= 11 to 25% molded grain; 4 = 26-50% molded grain; 5 = more than 50% molded grain.
P = bag protection on the panicles two weeks after flowering
NP = control (no protection)
C = Cinzana, Mali - 1988
S = Sotuba, Mali - 1989

nation percentage of 78, while kernels of unprotected panicles had 55%. Similarly, kernels of protected panicles had only 18.5% floating seed, while unprotected had 66%. Kernels from protected panicles had better vitrosity and decortication values than kernels from unprotected panicles. These results define the relative amount of damage bugs cause to sorghum kernels and illustrate the parameters that need to be measured to identify resistant cultivars.

Screening Selected Sorghum Lines for Resistance to Head Bugs at Sotuba

Thirteen sorghum lines were evaluated closely for resistance using protected and unprotected comparisons. Protecting panicles with cages was better than protecting panicles with insecticide. SC283 and SC34 were the sorghum lines with the greatest amount of kernel damage. Malisor 84-7 was the least damaged sorghum line based on visual rating.

Head Bug Incidence in Farm Areas

Surveys and collections made in farmers' fields on improved and traditional varieties showed that bug abundance was high in some localities and low in others. Also, traditional varieties were sometimes heavily infested and damaged.

Effect of Head Bugs on Food Quality

Damaged and undamaged panicles and grain were used to determine the relationship between head bugs, mold, and food quality. Based on preliminary results, an appropriate screening method is to use a visual rating scheme of head bug damage and mold to eliminate very susceptible sorghum entries. Where more objective evaluations are required, head bug damage and kernel deterioration can be based on flotation and decortication tests. Germination loss is directly related to the severity of head bug attack. Additional trials in 1990 will be conducted to confirm the first year's results.

Head bugs significantly reduced the grain quality of sorghum by decreasing 1,000 kernel weight, germination and the ability to decorticate the grain (Table 2). The endosperm is converted into a high proportion of soft, floury endosperm and the kernels are crushed during decortication, especially when pounded in a mortar and pestle. Most introduced sorghums are extremely susceptible to head bugs and molds. Malisor 84-7 had the most resistance to head bugs (Table 2) of the improved sorghums. CSM-288 is the local Malian photosensitive type.

The combination of head bugs and molds, especially under humid conditions, virtually destroys the grain. For example, of 25 entries in an advanced sorghum nursery grown at Samanko in 1989 only Malisor 84-7 and CSM388, a photosensitive local, had acceptable dehulling properties. In addition, the soft, shrunken kernels were badly discolored; tan plant grains had the least discoloration.

Table 2. Effect of head bugs on grain quality of some sorghum varieties grown at Sotuba, Mali in 1989.

	Vitrosity[1]		Yield of decorticated[2] grain %		Flotation[3] %		Germ[4] %	
	P	NI	P	NI	P	NI	P	NI
Malisor 84-7	2	3	73	63	18.5	29.1	81	19
CSM 388	2	3	84	67.3	3.3	3.4	77	76
Sureño	2	4	87	56.3	20.5	52.8	92	44
ICSV 16-5	2	4	77.7	54.3	9.9	82.9	92	57
ICSV 1063	4	5	80.7	58.7	11.1	8.3	94	37

[1]Subjective ratings 1 - corneous, 5 - floury
[2]Grain was decorticated with the TADD
[3]The percentage of grains floating in 1.27 g/cc $NaNO_2$
[4]The percentage of kernels germinating with a standard germination test
P = grain was protected from head bugs by a bag
NI = natural infestation of head bugs.

New Sorghum/Millet Food Products

Parboiling converts the soft endosperm into a hard endosperm that resists breakage during decortication. The decorticated kernels or particles can be used for many different products depending upon their particle size. This may be a way to produce dry couscous more efficiently than the traditional method. The heating process inactivates enzymes and kills insects which should give enhanced shelf life to the milled productions. The process is relatively simple and uses existing equipment and skills. Evaluation of potential usefulness of parboiling is underway with village trials and other activities in the Food Technology Laboratory in Mali.

Consumer Test of Sori in Bamako

With the help of USAID - Mali, 1.2 tonnes of sorghum were parboiled and evaluated in six communes in Bamako. The study included 262 housewives and consumers and 14 restaurants. The study was aided by the Bureau of Studies, Counseling and Intervention in the Sahel (BECIS).

The information obtained from the study has provided definitive guidelines for improvement of parboiled products. Generally, the information was favorable even though the processing of the sori was not carefully controlled and it was stored for three months prior to the consumer trials.

General findings were:

- Whole sori was not desirable. Medium and fine brokens were preferred by consumers.
- 71% of consumers were satisfied with parboiled sorghum products.
- 93% of consumers in the survey were ready to buy sori if the price was lower than rice.
- Sori had a firm desirable texture when hot. It was too firm when cold.
- The volume of sori increased significantly during cooking which enhanced yield of food. This is a significant advantage.
- Certain particle sizes could be used effectively for couscous. Some mentioned it could be a substitute for fonio couscous.
- The parboiling process requires too much fuel. Drying is time consuming.
- The decorticated sorghum requires more time to cook than rice.
- The color of sori is darker than rice.
- Some consumers observed a musty odor. Sand, glumes and other impurities were present in some samples. This can be avoided under more controlled processing procedures.
- Sori is not an acceptable name. Gnôwusu and gnômalo names were suggested.
- Some women would produce sori depending upon economics and markets. The restaurants were generally favorable to the use of sori depending upon the cost and availability.

A revised procedure for parboiling was developed using a soak and boil method (Fig 1). Then the decorticated kernels can be crushed with a stone mill and sifted into optimum size for numerous dishes (Fig 2). This method was applied in village trials in Cinzana with good results.

Preparation of Dishes

Several products were prepared using parboiled sorghum products:

Riz au gras: Grits are cooked in tomato sauce with meat, fish or chicken.

Figure 1. Revised procedure for parboiling sorghum.

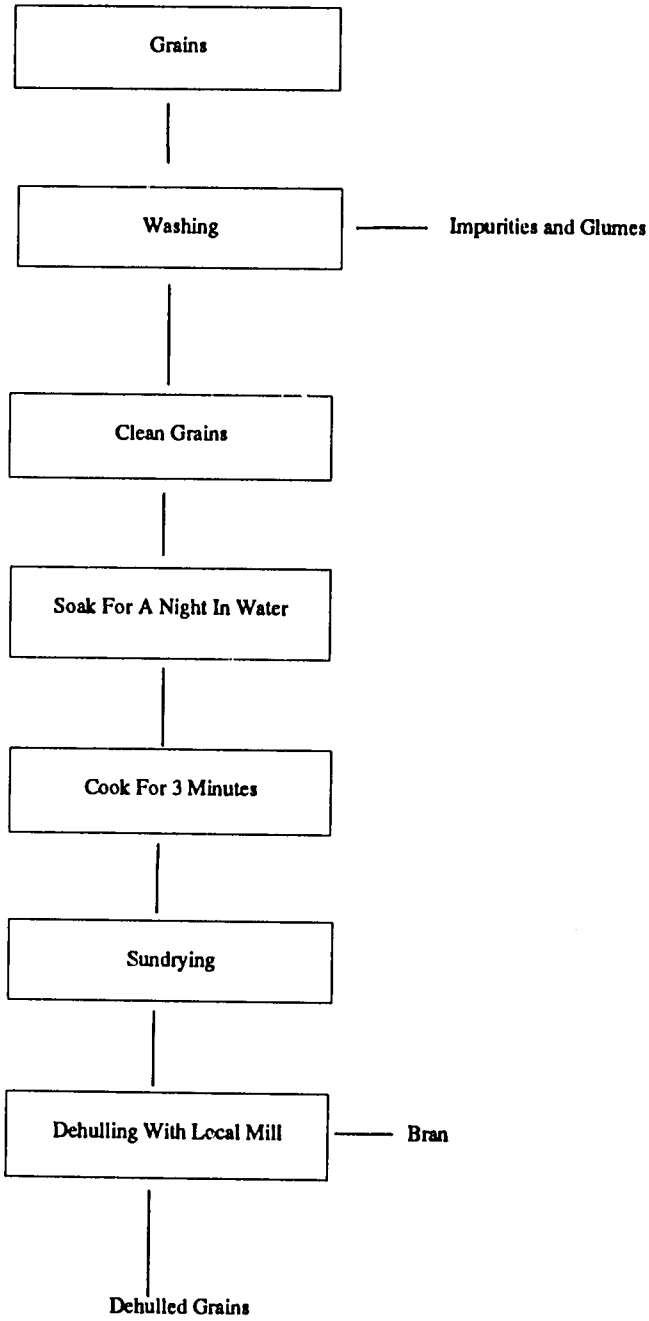
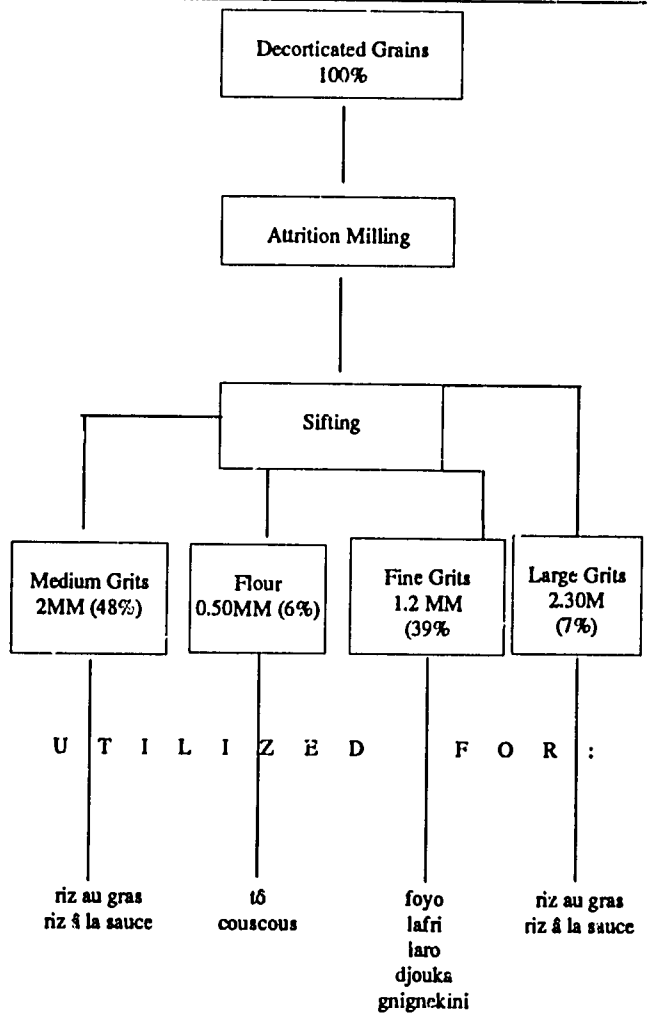


Figure 2. Utilization of parboiled grains to produce various Malian foods. The numbers in parenthesis refer to the yield of each product obtained from decorticated parboiled sorghum.



Riz â la sauce: Grits are cooked in water and eaten with tomato sauce or peanut

Tô: is a very thick porridge cooked with alkali (potasse) from wood ash leachates. The very fine particles could be used for tô.

Couscous and foyo: are steamed products that are eaten with sauce.

Lafri: is made like riz au gras but with smaller grits.

Gnignekini: is prepared like riz â la sauce but with smaller grits. It is eaten only with peanut sauce.

Djouka: is a steamed product with peanut powder and a little potasse. It is eaten without sauce.

Laro: is made from small grits prepared with peanut powder with fresh tomato solution.

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.

The tô quality of several food type sorghum introductions was evaluated. Many of the introduced grains had tô properties that were undesirable. However, upon closer evaluation of physical grain characteristics the intensity of damage due to head bugs/molding was high for many of the introduced materials. The variety Sureño released by INTSORMIL/Recursos Naturales in Honduras had excellent agronomic properties; but the tô was of questionable quality. The tô quality of Sureño grown elsewhere is acceptable. But attack by head bugs caused significantly lower tô quality. Head bug damage is significantly more severe in sorghums with tight grain panicles and especially those of early maturity because the humidity allows the molds to cause additional grain deterioration. Tan plant sorghums are not as severely discolored as red or purple plant sorghums.

Sustainable Production Systems

Experiments conducted in 1988 were repeated in 1989 relative to nitrogen (N) responsiveness of sorghum to application rate and timing of N. Varieties used were a local Malian type (CSM), S-34 (Nigerian origin, improved) and Malisor 84-7 (improved Malian type). Nitrogen rate experiments were conducted at N'Tarla location in 1988 and 1989 while N timing experiments were conducted at N'Tarla in 1988 and Samanko in 1989.

Results of these tests showed that the local sorghum responded to N application through at least 80 kg/ha urea in terms of increased grain yield, and the improved types responded linearly through 120 kg/ha applied N. Stover yields follow a similar pattern. The improved types yielded more grain than the local as expected at Samanko in 1989, but only S-34 outyielded the local in 1988. Nitrogen use efficiency (NUE) was only slightly higher for the improved types over the local in terms of biomass produced per unit N, but NUE was significantly higher in the improved types for grain produced per unit N.

Timing of N application was variable over genotype and year. Generally, the local favored an early application of N (tillering) for the bulk of urea in 1989 although no difference in timing was found in 1988 at the N'Tarla location. Malisor 84-7 favored a later application in terms of grain yield and S-34 favored early application in two years at different locations. A third location is included for some of the rate and timing experiments during the 1990 cropping season.

Nutrient Deficiency and Toxicity Studies

Studies were done in field plots and pots to define the nature of poor early sorghum (*Sorghum bicolor* [*L.*] *Moench*) 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.

The major soil of the field plot was classified as sandy, mixed, isohyperthermic Grossarenic Paleustalfs. A few research plots were classified as sandy, mixed, isohyperthermic Plinthic Paleustalfs.

Application of urea (100 mg N kg^{-1} of soil) neither inhibited plant symptoms of poor growth, nor resulted in significant dry matter production in the greenhouse. Liming followed by the above N rate had the same result. However, application of P alone or any treatment combination containing P resulted in good sorghum growth and yield. Dry matter yield correlated well with Bray-1 P ($r = 0.74^{**}$). Both exchangeable soil Al (34% Al saturation) and shoot Al concentration had a significant, negative impact on dry matter yield, but neither was strongly correlated with dry matter yield (r values of -0.42^{**} and -0.31^{**}, respectively).

A greenhouse experiment designed to establish a response curve to P indicated that a rate as low as 2.5 mg P kg^{-1} not only prevented symptoms of poor growth, but also produced a significant dry matter increase. An application rate of 15 mg P kg^{-1} of soil in the greenhouse appears to provide adequate P for optimum sorghum growth in Grossarenic and Plinthic Paleustalfs of the Cinzana Station.

In conclusion, P deficiency appears to be one of the major factors limiting sorghum growth and yield in acid, sandy soils of the Cinzana station. Exchangeable Al, due to its negative and significant impact on dry matter yield, seems to be a secondary cause of this soil problem.

Multidisciplinary research was conducted in Mali to study the adaptation of sorghum to diverse conditions of culture and utilization. Fifteen sorghum varieties were evaluated for morphological and physiological traits, development, and responses to biological and abiotic stresses. The varieties were planted at four locations: Cinzana (both sandy and heavy soils), Bema (two seeding dates), Samanko (two fertility levels), and Sotuba (insect and disease evaluations). At Bema, CSM 219 and Gadiaba exhibited good vigor in emergence and stand establishment. CSM 219 also exhibited good post-flowering drought resistance, as did

Gadiaba and improved variety Malisor-1. Variety CSM 388 produced a large amount of forage, but little grain. At Cinzana, CSM 219, Sureño and Malisor-7 had the highest grain yield on the heavy soils. At Sotuba, the effects of insects and diseases on seed germination was studied by panicle protection with solid bags or nylon-mesh bags which allowed free air exchange. Varieties CSM 219, CSM 228 and CSM 388, whether protected or not, germinated well. With the other varieties, panicle protection with the nylon bag generally gave the best quality seed, but not always. Germination of Malisor-7 seed was higher when protected with the solid bag, and about the same with nylon or solid bag with CSM 219 and CSM 228, whereas, CE 90 had much better germination when protected with a nylon bag, but about the same as unprotected when protected with a solid bag. These results show that there are interactions between environmental and biotic stresses in determining seed quality that differ among genotypes and that are not clearly understood.

Students studying physiology/agronomy at the University of Nebraska continued their research in developing a stress index linked to timing and severity of drought-temperature stress on different genotypes, and in defining some biochemical and phytohormone controlled responses to stress and growth/development, particularly as related to seedling survival and stand establishment.

Abscisic acid seed treatments have been shown to increase seedling emergence under drought stress significantly. Those genotypes strongly responding to ABA appear to be extremely susceptible to seedling drought. This information could be used for screening purposes and as a potential seed treatment to enhance early season drought tolerance.

The accumulation of proline during stress was further investigated. Large quantities of proline accumulated in sorghum pollen during maturation and differed markedly among genotypes. Also, when sorghum plants were inoculated with *Fusarium moniliforme* proline accumulation increased in the shoots and roots of some genotypes, but decreased in others. There appears to be some relationship between susceptibility to the infectious organism and proline accumulation, although the nature of this response has not been clearly defined.

Institution Building

Support to purchase supplies, equipment and a new vehicle enhanced the ability of IER to expedite the research program.

Five Malian students completed Master of Science degrees. Three returned to Mali while two are continuing on Ph.D. programs in agronomy and soils. Mr. A. Karim, M.S. in breeding, is working in the millet breeding program with Dr. O. Niangado. Mr. Bagayoko, M.S. agronomy, has initiated a research program with Dr. Mason, University of Nebraska, on residue management. Mr. M. Doumbia, soil fertility, returned to Mali to conduct Ph.D. thesis research on the soil toxicity problem at the Cinzana station. This work is funded jointly by TROPSOILS, INTSORMIL, and the ICRISAT/Mali project. Sorghum cultivars are being screened for response to soil toxicity.

Students are currently seeking advanced degrees in plant breeding, agronomy, economics, soil management and fertility at INTSORMIL universities.

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. IRAT has initiated 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 serves as chairman of the steering committee of the West and Central African sorghum research networks.

Progress to develop an effective network of sorghum and millet scientists in West Africa is occurring because of INTSORMIL, ICRISAT, and SAFGRAD mutually rewarding efforts to strengthen it. 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 of Bamako provides an opportunity for interaction with the regional program in West Africa. Current collaboration on insects, disease, and quality is well underway.

Training

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 (two times); Dr. D.T. Rosenow, Sor-

ghum Breeder, Dr. G. Teetes, Entomologist, and R.A. Frederiksen, Pathologist from Texas A&M University, Dr. C. Sullivan, Physiologist, J. Maranville, Agronomist, and S. Mason, Agronomist from the University of Nebraska. Dr. O. Tall, Director General and Dr. M. Traore, Physiologist, IER, traveled to the University of Nebraska and Texas A&M University.

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.

Seven 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. Equipment and short term consultants were supplied to establish and install sprinkler systems and 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 and milling yields and gave tô with unacceptable texture and keeping properties.

Parboiling can convert sorghum and millet into acceptable products.

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 appears to be the only improved sorghum with head bug resistance. As such, it will be used extensively in sorghum breeding in Mali, and all across West Africa where head bugs are a very serious constraint. These improved types in general have improved yields and good food quality properties. The Malisors are being used by some farmers under different names.

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. 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. The shift is still in progress to support INRAN collaborative research projects by returning newly trained INRAN staff similar to the model that INTSORMIL has developed in Sudan. The INRAN Director General and INRAN scientists are in agreement that more of the collaborative research support will go directly to INRAN scientists with collaborative ties to U.S. based INTSORMIL principal investigators.

Financial Inputs

Several proposals to negotiate buy-ins through the USAID Mission were developed in collaboration with INRAN. Currently, Management Entity is negotiating with USAID to implement these proposals.

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
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 Ousseini Sidibe as host country coordinators for this project.

Sorghum/Millet Constraints Researched

Drought, insect pests, long smut and *Striga* are the major constraints in Niger. Extremely high soil temperature leads to difficult problems in crop establishment. Sand blasting of young seedlings is also a complicating factor. Plant breeding for tolerance to these major constraints is one of the most feasible solutions. New cultivars must be acceptable for tô preparation. For example, the variety L-30 has been the highest yielding sorghum variety in the Sahelian trials for the past 10 years, but is not accepted by farmers because of poor food grain quality. A number of useful collaborative research activities have been developed in Niger between INTSORMIL principal investigators and INRAN scientists.

Research projects initiated in the past and currently underway include the following:

Agronomy Program - Grain Sorghum Emergence Studies

INRAN: Ibrahim Mohamadou, Maman Nouri, Chandra Reddy. INTSORMIL: Steve Mason, Minamba Bagayoko.

Niger, 1987. Twenty-two grain sorghum genotypes comprised of breeding lines from INTSORMIL Project PRF-107 and local Niger cultivars were planted in dune sand and valley soils on June 25 and July 9 in a split-split plot experiment. Emergence was collected every two days until eight days after planting. Survival data were collected weekly until eight weeks after planting. The survival ability index was determined by dividing the percent survival by percent emergence.

Multilocations, 1989. Grain sorghum emergence studies were conducted with 14 genotypes at N'Dounga, Niger, in 1989. A randomized complete design with six replications was used. Emergence counts were taken seven and 14 days after planting.

Grain sorghum emergence and survival in Niger, 1987. Analysis of variance indicated that planting date and soil type had no influence on emergence of grain sorghum genotypes. Genotype differences were present, with the best genotype having an emergence of 53% and the worst with

8% emergence. The local Niger genotype Bagoba had the greatest emergence, followed by P1055 and El Mota. Genotypes P1052, P1058, and P1006 had emergence less than 10%. Sixteen of the 22 genotypes had emergence less than 30%. The low percent emergence in this study was partially attributed to soil temperatures above 40°C several days at 1400 hours.

Survival variation was attributed to the soil type X planting date interaction, and to grain sorghum genotypes. The survival of grain sorghum genotypes was lower on the dune sand soil than on the valley soil. For the June 25 planting date, the survival was 7% lower on the dune sand soil, while for the July 9 planting date, it was 13% lower. Percent survival was much lower than emergence for all genotypes. To eliminate the confounding effect of genotypes with high percent emergence having more plants survive, a survival ability index was determined. This index indicated that the genotypes P8988012, P1006, and P954035 had a high ability to survive on the valley soil, but very low ability to survive on the dune sand soil. In contrast, the genotypes Bagoba and NGK had a lower ability to survive on the valley soil, but a much higher ability to survive on the dune sand soil. In fact, the ability to survive on the valley and dune sand soil was essentially the same.

Emergence in Niger, 1989. The highest mean emergence across locations was 63% for the genotype P1044, while the lowest was 37% for P1016. However, a significant genotype X location interaction occurred. The genotype P1044 had consistently high emergence across locations, being one of the top three emergers at all locations. The genotype P1056 did not emerge as well in Niger. The genotypes P1016 and P898012 had the lowest percent emergence in Niger, but had the highest soil temperatures.

Present study. Studies to evaluate kernel weight, mesocotyl, and coleoptile length, germination under varying temperature and osmotic potentials, and emergence through artificial crusts have been conducted. The data are now being analyzed in hopes of determining seed/seedling characteristics associated with the emergence differences among genotypes presented above.

Plans are to initiate a long-term study evaluating the cropping system (monoculture, intercrop, rotation) interaction effects with crop residue management.

Agronomy Program - On-Farm Variety Trials

INRAN: Issoufou Kapran, Moussa Adamou, John Clark. INTSORMIL: Gebisa Ejeta, John Axtell.

During the 1989-90 rainy season, on-farm trials of SRN 39, SEPON 82, and the hybrid ATX623xMR732 were conducted in two villages near Birni N'Konni, Niger. The trials were supervised by the INRAN Department of Rural Economics (DECOR) and the INRAN Sorghum Section, in collaboration with INTSORMIL. Thirteen farmers were involved initially, but only five farmers with fields on the irrigated perimeter at Konni were able to harvest grain. The heavier soil on the perimeter and the complementary irrigation in August allowed these fields to mature, while the trials in dryland sorghum fields on sandier soils dried up. The perimeter farmers tested only the SRN 39 because their fields are heavily infested with *Striga*. Because of the unusual rainfall pattern with most of the moisture early in the season, the dominant factor in determining yields was planting date. Some early planted fields yielded well, but in general, yields were low. The SRN 39 was planted at the normal planting time at the end of June and produced only a modest crop. Sorghum midge was the major problem due to earlier planting of nearby fields.

In spite of the production problems encountered, a post-harvest survey of participating farmers and a random sample of farmers who did not participate in the trials showed that they saw the potential of the SRN 39. Because the SEPON 82 and the hybrid did not reach maturity in their fields, they were not able to comment on them. Many farmers like the *Striga* resistance of SRN 39 and the fact that its leaves remain green after grain maturity, enhancing fodder quality. Of the farmers participating in the SRN 39 trials, 80% said that they would like to plant the variety again in 1991. In the sample of nonparticipating farmers, 40% said that they would like to plant the SRN 39 in 1991.

Breeding Program

INRAN: Moussa Adamou, John Clark. INTSORMIL: Lynn Gourley, John Axtell.

Soil acidity is considered a major growth-limiting factor for a number of crops, including sorghum, in many areas of the world. In Niger, the majority of sorghums used by farmers are local landrace varieties with low yields. Most soils used under cultivation 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 and other environmental stress conditions. There is a growing interest in Niger to consider an effective use of the sandy soils for some economically important cereal 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 open-pollinated varieties.

The main objective is to evaluate different hybrids, lines, and varieties of sorghum for tolerance to the acid soil conditions in Niger. In this work, new acid-soil-tolerant material would be developed and general and specific combining ability of selected sorghum germplasm evaluated.

All genotypes will be evaluated in a yield trial under the conditions of Niger at six locations (Kollo, Tarna, Bengou, Konni, Tillabery, and Diffa) on sandy as well as heavy soils, and in a laboratory experiment in nutrient solution at Tarna or Kollo station.

Sorghum lines, varieties, and hybrids, as well as selected pearl millet varieties, will be used. Pearl millet material will serve as Al-toxicity tolerant checks.

Crosses will be made among sorghum genotypes in the following ways: tolerant by tolerant, tolerant by susceptible, susceptible by tolerant, and susceptible by susceptible to produce F1 hybrids. The hybrids, their parents, some selected sorghum local varieties, and selected millet checks will be tested in a field, as well as in laboratory experiments.

For field experiment, soil samples from each experiment site will be taken at the moment of planting and analyzed for physical and chemical constitutions. The experimental design for the evaluation of the germplasm will be a randomized complete block with four replications per location. Notes will be taken for crop establishment, days to 50% bloom, plant height, grain weight per panicle, grain yield, stover yield, harvest index, and 100-grain weight.

For laboratory experiment, nutrient solutions to be used will be similar to those devised by Clark (1982). This laboratory experiment will evaluate sorghum seedlings in the nutrient solutions with at least three Al-concentrations at two pH levels. Seedlings for all genotypes will be grown in the solutions in a randomized complete block design with four replications for at least three weeks. At the end of the experiment, shoots and roots of the seedlings will be evaluated for their lengths and dry matter weight. For both experiments, the same germplasms should be used.

In Niger, both stover and grain sorghum are needed for the subsistence of people and animals. The sorghum genotypes tolerant to Al toxicity would yield more grain, more stover, and perhaps would be more drought-tolerant than those susceptible. These genotypes would be of great value in sorghum improvement programs for acid sandy soils. In the laboratory experiment, Al-tolerant genotypes would show little or no decrease in root and shoot length and dry-matter yield when grown at high Al-concentration, when compared to the lower one.

Economic Program

INRAN: Maliki Kadi, Mahaman Issa, O. Zarifa. INTSORMIL: Barry Shapiro, John Sanders.

In farm modeling of the potential impact of new technologies, two farming systems were evaluated. One system had a small irrigated area of 0.4 ha in addition to the dryland area. This system had slightly higher annual rainfall of 570 mm as compared with 430 mm in the dryland system without irrigation. In the latter system, the rainfed land supply is more elastic, and livestock is a more important economic activity. In neither dryland system are purchased inputs utilized, except for hired labor for various crops and fertilizer on the irrigated rice. In both systems, early cowpea and millet cultivars would be introduced, raising farm incomes by 13% and 20%, according to model results (Tables 1 and 2).

With the breakdown of the extended fallow system, soil mining takes place in the absence of fertilization. Hence, a sustainable system will require fertilizer. In both systems, various policies and other innovations to make fertilization more profitable were then evaluated. On the river, with partial irrigation and higher rainfall, a fertilizer subsidy and

Table 1. Effect of various policy instruments on the adoption of the fertilizer technology, river system, Niger, 1988.

Policy or program	Fertilizer Total Use (ha)	Millet/ Cowpea Income[1] (FCFA)	Livestock Income[1] (FCFA)	Total Income[1] (FCFA)	Change Crop Income(%)	Change Total Income(%)	C.V. Total Income
1. Current practices	N/A	132,984 (446)	34,520 (116)	242,008 (812)	-	-	.40
2. Improved cultivars	0	172,139 (578)	27,799 (93)	274,343 (921)	+30	+13	.39
3. Input subsidy (10%)	1.2	179,273 (602)	21,078 (071)	274,752 (922)	+35	+14	.41
4. Credit program (10,000 FCFA at 0% interest)	0	171,718 (576)	34,520 (116)	280,644 (942)	+29	+16	.39
5. Phosphorus fertilizer alone	2.1	187,117 (628)	21,078 (71)	282,595 (948)	+41	+17	.44
6. Postplanting P application (high soil fertility)	0.6[a]	172,800 (580)	30,078 (101)	277,382 (930)	+30	+15	.39
7. Long-cycle millet variety	1.5	185,877 (624)	21,078 (71)	281,078 (944)	+40	+16	.42

[1]All income given in FCFA. U.S. $ values for incomes are in parentheses. The exchange rate is 298 FCFA/$1 U.S.

[a]This 0.6 ha allocated to the postplanting fertilizer technology only in normal years.

Source: Shapiro, 1990

different methods of fertilization (with P alone and with post-planting P application), both resulted in fertilizer being introduced and in further income gains. The fertilizer subsidy could easily result in the diversion of the fertilizer to the irrigated rice, where it is more profitable. Increased credit had no effect on fertilizer utilization as farmers had more profitable activities, such as small ruminants, for the increased capital available. Hence, rather than policy changes, further technical innovations such as different types and application times for fertilizer were necessary to create a sustainable system. Similarly, the introduction of a longer-cycle millet cultivar, which could take advantage of normal and good rainfall years, also would result in higher fertilizer utilization. These model results indicate the principal constraints to be further area-specific, adaptive research to help overcome technical constraints rather than just manipulating the policy variables of credit and input subsidies.

In the drier area without partial irrigation, none of the policy measures had any impact on fertilization. With almost any reasonable policy or technical innovation, it still was not possible to obtain the use of fertilization and, hence, create a sustainable system in this lower rainfall system (Table 2). The difficulty of finding a profitable, sustainable cropping system suggests that it may be more appropriate to withdraw from cropping here and to encourage livestock and forestry development in this dryland system. Initial resource endowment and the potential of successfully developing new crop technologies need to be important factors in research planning.

Food Quality Program

A food quality trial was conducted with the three new cultivars and a local check at four villages from different regions in Niger. The trial consisted of decorticating the test varieties, reducing the decorticated grain to flour and the preparation of the local food product, tuwo, a rather firm gruel which is normally consumed with a tomato or peanut sauce. The decortication and grinding were done by local women using the traditional mortar and pestle. The final food product was submitted to sensorial analysis consisting of taste (with and without blindfold), texture, and color evaluations by 40 testers at each location. Average flour yield was comparable for SEPON 82, SRN 39 and the local check in a range of 50 to 55% of the whole grain. Flour yield from ATX623xMR732 F1 was in the neighborhood of 60%. The reverse was true for grain yield, as the same three cultivars produced approximately 20%, while bran yield of the hybrid was only 11%.

Food quality characteristics of the new cultivars were comparable to the local sorghum. Ratings by 160 testers for taste with and without blindfold and texture were well within a range of acceptability for all cultivars. There was a slight preference for the color of the tuwo food product made from the local check, a very vitreous, white, guineese sorghum.

Tuwo quality. Moussa Oumarou from INRAN's Cereal Quality Laboratory conducted consumer food quality trials on three improved sorghum cultivars developed by the Nigerien breeding program. These cultivars are being considered for release to farmers. The agronomic characteristics of the sorghums are given below:

SEPON 82 - a high-yielding variety suitable for either rainfed or irrigated production systems.

SRN-39 - a *Striga*-resistant variety for production in those areas where *Striga hermonthica*, a very serious parasitic weed pest of sorghums, is a constraint to sorghum production.

ATx632xMR732 F1 - a hybrid for rainfed and irrigated production systems with both stable and high yield characteristics.

Table 2. Effect of various policy instruments on the adoption of the fertilizer technology, dryland system, Niger, 1988.

Policy or program	Fertilizer Total Use (ha)	Millet/ Cowpea Income[1]	Livestock Income[1]	Total Income[1]	Change Crop Income(%)	Change Total Income(%)	C.V. Total Income
		(FCFA)	(FCFA)	(FCFA)			
1. Current practices	N/A	89,605 (301)	55,279 (186)	149,790 (503)	-	-	.63
2. New technologies	0	121,979 (409)	52,879 (177)	179,188 (601)	+36	+20	.50
3. Price support (50 FCFA)	0	128,030 (430)	52,879 (177)	185,240 (622)	+43	+24	.57
4. Input subsidy (50%)	0	121,193 (409)	68,651 (230)	194,657 (653)	+36	+30	.54
5. Credit program (10,000 FCFA at 0% interest)	0	121,872 (409)	58,686 (197)	184,954 (621)	+36	+23	.50

[1]U.S. $ values for incomes are in parentheses. The exchange rate is 298 FCFA/U.S. $.

Source: Shapiro, 1990

These three cultivars plus a local check were evaluated for food quality at four locations in Niger (Maradi, Konni, Tillabery, and Bengou). In brief, the food quality tests at each location were conducted on four successive days. Each day local women were hired to decorticate the sorghum, mill the decorticated grain into a fine flour, and prepare tuwo with the flour. During the preparation process, product yields, water absorption, and time required for each unit operation were recorded. Each day tuwo acceptability was evaluated by a 10-member, all-male consumer panel. Sensory data on taste, texture, and overall acceptability of the tuwos were collected. The sensory data were analyzed using the analysis of variance and LSD procedures at Purdue. As seen from the results shown in Table 3, the improved sorghum cultivars were, in general, given better color, texture, and overall acceptance ratings than the local checks. Thus, it appears that these improved sorghums should have acceptable food quality properties as judged by consumer tests.

Table 3. Tuwo sensory evaluation done at four locations in Niger.

	Means		
Cultivar	Color	Texture	Overall Acceptance
MARADI			
SEPON 82	0.71[a]	-0.08[bc]	-0.02[b]
SRN39	-0.09[c]	0.20[ab]	0.17[ab]
ATx623XMR732 F1	0.24[b]	0.31[a]	0.34[a]
Mota Maradi (local check)	-0.85[a]	-0.43[c]	-0.47[c]
KONNI			
SEPON 82	0.93[a]	0.41[a]	0.26[a]
ATx623xMR732 F1	0.14[b]	0.16[ab]	0.14[a]
SRN 39	-0.06[c]	-0.12[bc]	-0.13[ab]
Mota Ja (local check)	-1.01[d]	-0.45[c]	-0.27[b]
TILLABERY			
SEPON 82	0.42[a]	0.32[a]	0.23[a]
SRN 39	0.28[a]	0.06[ab]	0.02[ab]
ATx623XMR732 F1	-0.12[b]	-0.18[b]	0.09[ab]
Mota Ja (local check)	-0.60[c]	-0.20[b]	-0.17[b]
BENGOU			
SEPON 82	0.43[a]	0.06[b]	b
SRN 39	0.66[a]	-0.33[c]	b
ATx623xMR732 F1	-0.66[b]	0.53[a]	b
BKC (local check)	-0.43[b]	-0.25[bc]	b

[a]Means with the same letter are not significantly different at 0.05% level.

[b]No significant difference between cultivars.

Millet Program

INRAN: Ouendeba Botorou. INTSORMIL: Wayne Hanna, Gebisa Ejeta.

Characterization of African pearl millet landraces. Ten pearl millet landraces widely grown in some African countries (Niger, Nigeria, Senegal, Sudan, Togo, and Uganda) and two pearl millet hybrids were evaluated in two locations (Sadore and Bengou) in Niger during the 1989 rainy season. Downy mildew incidence, days to flowering, spike length, peduncle length, spike girth, flag leaf width, stem diameter, spike number per plant, noneffective tillers per plant, plant height, spike weight per plot, grain yield per plot, and 1000-grain weight were measured on the different cultivars.

The cultivars were all significantly different for all characters evaluated. 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 landraces, between Niger and Sudan pearl millets, and between Togo and Uganda pearl millets. 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.

These results could be useful in choosing potentially heterotic pearl millet populations for intercrossing in the development of improved varieties, synthetics, and hybrids for use in Africa.

Pathology Program

INRAN: Issoufou Kolo. INTSORMIL: Richard Frederiksen.

Long smut. In Niger, selections were made within segregating populations for high and low reactions to long smut. Nurseries at Kollo were lost because of flooding caused by the Niger River.

Physiology Program

INRAN: Cherif Ari, Goubé Gaoh. INTSORMIL: Jerry Maranville.

Objectives. (1) Identify sorghum and pearl millet genotypes which are superior in nutrient use efficiency (primarily nitrogen); (2) determine the physiological and morphological mechanisms which allow genotypes to be nutrient use efficient; (3) quantify the effects of environment on genetic response at different soil fertilities (primarily nitrogen); (4) determine optimum nitrogen and phosphorus management practices for arid and semiarid environments; (5) provide long- and short-term training experiences for students and scientists of collaborating institutions, as well as certain technical expertise for collaborative efforts related to overall INTSORMIL objectives.

Constraints to reaching objectives. Research in Niger could be potentially constrained by lack of trained personnel. There is also a need to put some priority on the UNL-114 collaborative research which appears lacking at this time. There is a definite need at Maradi for some research items

which INTSORMIL could provide to accommodate the collaboration. These items are difficult to get to the intended research locations and expensive.

Summary. Pearl millet studies in Niger showed that this crop responded favorably to moderate rates of nitrogen application. The most striking observation was that the crop gave a favorable grain yield increase due to nitrogen, even when rainfall was as low as 535 mm per season.

Experiments were conducted in pearl millet at the Maradi research station during the 1989 growing season by Mr. Cherif Oumarou to determine the response of three varieties to nitrogen rate. Varieties GP1, GRP1, and CIVT were planted in hills (1 m apart) on a grid July 6 in three replications and thinned to 2 or 3 plants per hill on July 18. Urea was applied July 24 (one-half dose) and August 11 at rates totaling 30, 45 and 60 kg/ha. Zero N served as a control. Plots were harvested on October 10. A total of 526.5 mm of rain was received during the season.

Table 4 shows the grain yield and grain:stover ratio data. All varieties responded significantly to N application, even though rainfall was not particularly high. Variety GP1 was the lowest grain yielder among the varieties and was the only one to respond linearly over the range of applied N. The higher yielding varieties GRP1 and CIVT reached a maximum yield with 45 kg/ha urea. Variety CIVT even had a 10% yield reduction with the higher 60 kg/ha rate.

Grain:stover ratios generally reflected the yield ranking among varieties and treatments. Nitrogen fertilizer obviously favored grain production over that of stover in all varieties. The best combination in this test was with variety GRP1 at the 45 kg/ha urea rate which produced nearly half as much grain as stover. The results of this test indicated that nitrogen application up to 45 kg/ha urea should significantly increase grain yields of certain millet varieties, even when rainfall is moderate to low.

Table 4. Grain yields and grain:stover ratio for pearl millet during the 1989 growing season at Maradi.

Genotypes	Urea rate (kg/ha)	Grain yield (kg/ha)	Increase from control (%)	Grain:stover ratio (kg/kg)
GP1	0	524		.27
	30	823	57	.32
	45	858	64	.35
	60	906	73	.32
	Mean	778		.32
GRP1	0	775		.39
	30	724	(7)	.36
	45	1195	54	.44
	60	1174	51	.43
	Mean	967		.41
CIVT	0	581		.27
	30	1017	75	.40
	45	1100	89	.40
	60	1003	42	.39
	Mean	925		.37

Mutual Research Benefits

Screening for drought stress is an easy and regular procedure in Niger. Some of the best new sources of drought tolerance in the U.S. have come from screening INTSORMIL germplasm in Sudan. It is anticipated that additional new sources of drought resistance will be identified from either local Nigerien varieties or from screening INTSORMIL sorghum germplasm in Niger. Research on mulching shows very positive effects on sorghum and millet agronomy.

Institution Building

Research Supplies

Laboratory supplies from INTSORMIL have been provided to the INRAN Cereal Quality Laboratory at Kollo.

Several boxes of scientific journals have been sent to the INRAN Library at Niamey.

Laboratory supplies and equipment for the pathology program were purchased and will be shipped to Niger.

Training of Host Country Researchers

Moussa Adamou, INRAN sorghum breeder, completed his Ph.D. studies at Mississippi State University and has since returned to Niger as Senior Scientist with INRAN. He conducted his thesis research in 1989 in Niger.

His major professor, Dr. Lynn Gourley, traveled to Niger to assist in his final data collection.

Ouendeba Botorou is expected to complete his Ph.D. training in millet breeding at Purdue in 1991.

Adam Aboubacar is presently working on his Master's thesis under the supervision of Dr. Allen Kirleis. Plans are for Adam to travel to Niger during Year 13 to collect data in collaboration with the INRAN Cereal Quality Laboratory.

Host Country and U.S. Visits by Scientists

Visits by Niger Scientists to the U.S.

Issoufou Kolo - to U.K. - May 23 - May 26, 1990

Visits by U.S. Scientists to Niger

Moussa Adamou, Sept. 29 - Oct. 7, 1989
Lynn Gourley, Sept. 27 - Oct. 6, 1989
Wayne Hanna, Sept. 3 - Sept. 10, 1989 - Coastal Plain Experiment Station, Tifton, Ga.

Allen Kirleis, April 18 - May 5, 1990
Jerry Maranville, Sept. 23 - Sept. 29, 1989

Networking

A workshop within the next two to three years is important and should be held in Niger with other CRSPs.

General Comments

Continual dialogue to establish solid working relationships between INTSORMIL and INRAN scientists must continue in the designated research areas. Joint research planning and joint nursery visits in both the host country and U.S. are essential. French language capability among INTSORMIL principal investigators continues to be a limiting factor and must be improved. The excellent support of the USAID Mission, including support by the Agricultural Development Officer and Mission Director.

Lack of a Niger Investigators' planning meeting in 1990 seriously interfered with research planning and budgeting for this year.

Three principal problems will face INTSORMIL during 1991 and they involve funding levels. When the INTSORMIL/Niger budget was first established, the exchange rate was 400 cfa/$1.00 and it has since declined to 248 cfa/$1 dollar. This has significantly reduced our purchasing power of those dollars spent in-country for such items as gasoline, research, labor costs and other expenses. The Purdue contract for Niger has been renewed for five years and INTSORMIL/NAAR cooperation will continue in 1991 as in the past. INRAN appointed Messrs. Jika Neino and Ousseini Sidibe to serve as host country coordinators which should significantly improve research coordination.

Major Accomplishments

Significant advances have been made in the breeding program at INRAN, primarily on sorghum, as a result of collaboration with INTSORMIL. A functional sorghum breeding program with an array of activities including varietal and hybrid development with carefully monitored screening and selection of genotypes, nursery management, and regional evaluation has been installed in place of a varietal testing routine that was practiced earlier. Intercrossing of adapted exotic germplasm with local Nigerien varieties has yielded useful selections that are currently under regional evaluation. One entry from a selection made by Dr. John Clark from the cross P967083 by SEPON 46 yielded 2,098 kg/ha in comparison with the check variety L-30 which yielded 802 kg/ha. Other entries selected by INRAN breeders from progeny of crosses between Tanzania rice type sorghums and SEPON selections also looked promising.

A hybrid sorghum breeding program initiated at INRAN in collaboration with INTSORMIL has also made useful contributions. A wide array of parental germplasm pool (which is essential in developing a functional breeding program) has been accumulated and made available to INRAN sorghum breeders. Two excellent M.S. thesis projects, supervised by INTSORMIL principal investigators, have just been completed on evaluating potential of sorghum hybrids in Niger. Issoufou Kapran, working with Gebisa Ejeta, evaluated 90 hybrids under contrasting environments over two seasons and identified five experimental sorghum hybrids with excellent adaptation and yield potential in Niger. Kapran found that sorghum hybrids yielded much higher than local varieties both under rainfed (149%) and irrigated (161%) locations in Niger; and that heterosis (the superiority of hybrids over parents) of experimental sorghum hybrids was higher under rainfed (166%) than under irrigated (145%) conditions.

A joint project between INRAN, INTSORMIL and ICRISAT on pearl millet breeding is going well. Mr. Botorou will undertake a pearl millet diallel using six agronomically superior millet populations. The project is collaborative between Dr. Kumar, Dr. Hanna and Dr. Ejeta.

Dr. Omer El Hilu (ARC/Sudan), working with Richard Frederiksen (Texas A&M), and John Clark (Purdue/INRAN NAAR Project) continues to explore an initiative to set up an All Africa Long Smut Disease Nursery (AALSN). Different research organizations in East and West Africa, for the last few seasons, have supported a disease screening program. Hence, it is essential at this stage to combine promising lines coming out of the different programs and INTSORMIL IDIN (International Disease and Insect Nursery) in one major nursery to be tested in various countries affected by the disease. The suggested nursery can be tested using artificial inoculation and, in those endemic areas, may also be left for natural infection. Results of this test will serve the objectives of: 1) detecting heterogeneity within the population of *T. ehrenbergii* in the African continent; and 2) selecting the most suited cultivars for the breeder.

Experiments are in progress by Dr. Paresh Verma and Dr. Jerry Eastin which will provide information needed to optimize water-use efficiency of the cereal/legume (millet/cowpea) intercropping systems. Studies are being conducted to determine seasonal and instantaneous water-use efficiencies of both millet and cowpea. 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

David J. Andrews
University of Nebraska

Country Coordinators

David J. Andrews, Department of Agronomy, University of Nebraska-Lincoln
Dr. Demba M'Baye, Plant Pathologist, ISRA, CNRA Bambey

Institutions Involved

Institut Senegalais de Recherches Agricoles (ISRA), Dakar, Senegal
USAID, Dakar, Senegal
University of Nebraska-Lincoln
Kansas State University, Hays
Texas A & M University, Lubbock and College Station
Michigan State University, East Lansing
ICRISAT Sahelian Centre, Sadore, Niger

Principal Collaborating Scientists

Mr. Adamu Fofana, Millet Breeder
Mr. Gilles Trouche, Sorghum Breeder, ISRA/IRAT
Dr. Jerry Eastin, Plant Physiologist
Mr. W. M. Stegmeier, Millet Breeder
Dr. Ismael Ouedraogo, Economist and Chief of Party, MSU, Senegal
Dr. Darrell Rosenow, Sorghum Breeder, TAMU
Dr. Fred Miller, Sorghum Breeder, TAMU
Dr. Anand Kumar, Millet Breeder, ICRISAT Sahelian Centre

Collaborative Program

Until late 1988 collaborative work in Senegal consisted of collaboration on millet food product research with the Institut Technologie Alimentaire in Dakar-Hann, and a limited amount of germplasm and information exchange. There was no separate country budget. One researcher, Mr. Amadu Fofana, was trained at UNL, obtaining an M.S. in millet breeding. Starting late in 1988, participation in the Senegal Agricultural Research Project II funded by USAID has permitted INTSORMIL to collaborate more significantly in Senegal, principally in pearl millet and sorghum breeding (as reported last year), with expansion planned in pathology and agronomy.

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, pests 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 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 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.

Varieties, hybrids, parental lines, and segregating populations of sorghum were provided to Senegal from Texas A & M (College Station, TAM-121 and Lubbock, TAM-122) and Nebraska UNL-114, -116 and -118. A number of these INTSORMIL introductions performed well and were retained both for the river valley and in the breeding program at Bambey.

Senegal River Valley

In the summer season in the Senegal river valley while several new lines were identified which require further evaluation, the existing food quality variety CE 151-262 was consistently outstanding, giving experimental yields ranging from 5200 to 7100 kg/ha. This confirmed results obtained prior to 1984, when experimentation on the river valley was deferred. It is clear that this variety, which has locally acceptable food quality, can now become the vehicle for other research that is urgently needed on agronomic factors such as soil preparation, fertilizer and irrigation requirements, and market evaluation. Variety CE 151-262 has another valuable attribute -- it is a good restorer and makes good hybrids, and probably better hybrids can be made with new introduced females. Agronomic parameters determined on the variety should therefore have some relevance to hybrids made with it.

In the dry season among advanced material, existing line 75-14 was again superior, giving yields (in experiments) of 3350 to 4250 kg/ha. As with CE 151-262, line 75-14 is also a restorer. Hybrid 610A x 75-14 is not always superior to the variety itself, and 75-14 needs to be tried on other females.

Pearl millet was tested only during the summer season. Variety evaluation could not be conducted during the hot dry season, the season in which millet may be the best adapted crop, because of station redevelopment. Yields were low in the summer season, probably because of the method of cultivation, flood irrigation in basins with heavy dry soil. Average yields in the tall varieties test was 1500 kg/ha (best entry ITMV 8304 at 1950 kg/ha) and 1800 kg/ha (best entry ICTP 8203 at 2140 kg/ha) in the dwarf varieties. These were in general earlier maturing (65 days to harvest) and may have yielded more if a higher plant density had been used. It is clear that alternative methods of land preparation (ridges or beds) and better control of soil moisture will be needed to grow pearl millet satisfactorily on these heavy river soils.

Bambey (Rain Fed)

Seven of 14 pearl millet topcross (local variety x INTSORMIL lines) F_1's were retained and selections made in 14 of 40 F_2's at Bambey. Further crosses were made between Senegalese varieties and UNL-118 inbreds. Backcrosses were planned between the best F_1's and adapted varieties. The objective of this work is to generate parents for new synthetic varieties, and new adapted inbreds which can potentially make topcross hybrids.

An extensive pearl millet disease nursery was being conducted where material was effectively screened for downy mildew and grain smut resistance. Some ergot screening was being done.

In sorghum one variety trial, one hybrid trial, two nurseries, several seed parents and segregative F_2 and F_3 families were supplied for evaluation at Bambey. Material was selected from each of these materials, and repeat seed of some F_2's was requested and sent. Some hybrid parents gave outstanding hybrids and seed of these was resupplied so other hybrid combinations could be made in the off season nursery. These parents were AVG1, Avar, ATX631, A155, N94A, N95A, N96A, and male parents 80C2241, RTX430, -2817, -8504 and -8505 and N91.

Travel

Mr. David J. Andrews traveled on a field trip to Senegal in October 1989 to collaborate in selection and formulate the next season's program. Dr. Demba M'Baye, in an initiative to increase the pathology input, traveled in March 1990 to Kansas State University to work with Dr. Larry Claflin on pearl millet pathology, especially laboratory techniques, and to Texas A & M to work with Dr. Gary Odvody on sorghum pathology, especially grain molds.

Future

In sorghum, selection and evaluation will continue at Bambey, and further segregating populations will be supplied. Variety and hybrid work will continue in both seasons in the Senegal river valley. Agronomy research will commence on ridges vs. flood basins, plant population and fertilizer levels. Some pre-extension tests will be conducted in the Bambey region.

Pearl millet variety tests will continue in the river valley and selection work at Bambey. The pathology program will be strengthened so that selection for resistance to downy mildew and grain smut become an integral part of the breeding process.

South America (Colombia/CIAT)

Guillermo Muñoz
Mississippi State University

Coordinators

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Dr. Manuel Torregroza, ICA, Director of Cereals, Apartado Aéreo 151123, Bogotá, Colombia (Host Country Coordinator).
Dr. Lynn Gourley, Department of Agronomy, Mississippi State University, Mississippi State, MS., U.S.A.

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

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.

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).

A large part of the research activity is 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.

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 and another for the drought project in the Atlantic Coast (Motilonia). 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, a lot of interinstitutional cooperation has had to be developed in Colombia, and will have to be developed in the future for Latin America.

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.

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.

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 in high-cost lands, making production of this crop a nonprofitable enterprise. An alternative to reducing production costs is incorporating marginal lands to 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 hectares 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 aluminun 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 fungous 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% A l
Level 2	36-60%	Class 1	36-45% Al
		Class 2	46-60% Al
Level 3	v 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.

Research Progress

Breeding/Germplasm Improvement. The main accomplishment of the INTSORMIL project in Colombia will be the coming release of two lines from the world collection. These lines have been under evaluation since 1983; according to INTSORMIL's reports, ICA finally agreed to release these genotypes for two levels of aluminum saturation: lines 156-P5-Serere-1 (Sorghica Real 40) and MN-4508 (Sorghica Real 60) will be released for soils with 40% and 60% aluminum saturation, respectively.

Year 11 includes several experiments trying to complete the agronomic package for these new lines, including planting densities, fertilization levels, and planting dates.

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. Some of these lines will be tested next year in 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.

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.

Both semesters A and B 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 fungous diseases.

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

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.

A great deal of effort has been placed on the increase of basic seed for line MN 4508 (Sorghica Real 60) for ICA. INTSORMIL assumed all the expenses related with the roughing of the 10-ha field and supplied the seed to be planted for increase.

Dr. Guillermo Muñoz (Ph.D. - MSU), a Colombian resident, 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. Yeser Ruíz (M.Sc. - MSU) is the principal sorghum breeder at ICA's main acid soil research station at La Libertad (Villavicencio, Colombia).

Agronomist Walter Rendón, a B.S. student trained by INTSORMIL, is working in sorghum research for the ICA/FENALCE Agreement and has strengthened ICA's sorghum program at La Libertad. He has been in charge of specific experiments and the semicommercial fields at La Libertad, Meta. He is currently coordinating all the students' research activities in that region.

Agronomist Alfonso González, another B.S. 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, 1988" was published; this is the first 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. George Teetes visited Colombia and informally reviewed the program at CIAT. He had the opportunity of being in contact with ICA entomologists and other re-

searchers in Colombia. After returning to the United States, he sent midge resistant germplasm to the program at CIAT.

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, the networking activities with other national programs in Latin America is very weak.

In January, 1991, an International Sorghum Meeting for Latin America is being organized by ICA, El Alcaraván, FENALCE, and INTSORMIL; this event seeks to strengthen the 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

Significant advances have been made in the breeding program at ICA as a result of 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.

Selections were made in the different ecosystems from 500 F_4 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_2 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 has been the release by ICA of two first-generation, aluminum-tolerant sorghum lines coming from the world collection. To backstop this accomplishment, the program has planted a 10-ha area for basic seed multiplication.

Sudan

Gebisa Ejeta
Purdue University

Country Coordinator

Gebisa Ejeta, Country Coordinator, Purdue University, West Lafayette, IN 47907
Katy G. Ibrahim, Administrative Assistant, Purdue University, West Lafayette, IN 47907
Omer El Hilu, Host Country Coordinator, Agricultural Research Corporation (ARC), Gezira Research Station, Wad Medani, Sudan

Collaborative Program

Organization

The INTSORMIL/U.S. principal investigators develop their scope of work jointly with ARC scientists. These workplans are reviewed and approved by 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 directly forwarded from 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 logistic 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 shortages 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 cen-

tral shoot fly. The major fungal diseases that affect sorghum 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

Pearl Millet Breeding

The major part of the current research program involves varietal screening and testing using both local and introduced varieties. A set of Standard (adapted), National, and Preliminary Variety Trials has been going on during the last four years. The severe drought and the large variation in rainfall distribution in the El Obeid area during the last few years have drastically affected the establishment and performance of the varieties planted from one year to another. In most of the seasons, the effective rainfall at El Obeid was below 250 mm, which is not enough to give appreciable grain yields from many of the varieties planted.

The results obtained from the National and Standard (Adapted) Variety Trials for the last two seasons (1987-88 and 1988-89) are as follows. Grain yields obtained at Kadugli were generally higher than those obtained at El Obeid. Bristled Population was the top-yielding variety at Kadugli during 1987-88, and also in the standard variety trial at El Obeid during the same season. However, it should be noted that the ranking of the varieties according to grain yield varied by season. Ugandi has been among the top-yielding three varieties in most of the trials. It is generally observed that it does better than other varieties in low-rainfall years and in marginal areas of North Kordofan, presumably due to its earlier maturity. In on-farm trials conducted through the Global 2000 program in North Kordofan, El Awad (1989) reported that Ugandi outyielded the local millet variety and the Bristled Population in five locations out of nine. Over all locations, Ugandi outyielded the local variety by 89 kg/ha, and Bristled Population by 59 kg/ha.

Bristled Population performed well during the severe drought season of 1984-85; it was able to produce grain yield when almost all other varieties failed. It has outyielded the local Kordofani variety in the majority of trials conducted recently. Mass selection is being used to improve this population for various desirable characters.

Since pearl millet production tends to occupy dryer marginal areas, and with the present increase in drought occurrence, the need will continue to be great for developing early maturing, drought-tolerant varieties that are adapted to such environments. However, a considerable part of the millet production area lies in the higher rainfall zone, especially in South Darfur and South Kordofan provinces. For such areas, the strategy should be to breed medium-maturing varieties that are able to fully utilize the longer season potential.

Because the millet production area extends over a number of environmental zones, the breeding program needs to have a number of experimental sites representing these environments. Such multilocational testing will result in achieving quicker results and, at the same time, will allow the stability of performance of the varieties to be tested. For traditional farmers, stability of performance is just as important as attaining higher yields. In order to implement such an effective improvement program, at least one more millet breeder, if not two, need to be trained.

Breeding for pest and disease resistance is an important component of most crop improvement programs. Breeding for resistance to Nafasha is top priority, since this pest is the most common on millet in western Sudan.

To release one variety such as Ugandi, thousands of entries must be repeatedly tested and handled. Effective exchange of genetic materials with other regional and international programs is an indispensable activity. This exchange activity has slowed down greatly since the termination of the ICRISAT/Sudan Cooperation Program. There is an urgent need for strengthening cooperation links with regional and international research bodies such as INTSORMIL.

To speed up the progress of the research program, off-season nurseries should be used to advance generations and

multiply promising genetic material. One of the most important constraints to the millet breeding program at El Obeid Station has been the loss of most of the genetic material due to the occurrence of consecutive years of drought. This would have been avoided if a source of supplementary irrigation were available to save this valuable genetic material in times of severe drought. Hence, it is very important to find a source of supplementary irrigation at El Obeid Station, which is the center of the millet breeding program.

Striga

Methods presently available for *Striga* control are generally too labor-intensive to carry out on a large scale (for example, hand-pulling) or too technologically intensive (for example, soil treatment with ethylene gas, application of specialized herbicides) for subsistence farmers.

Several recent studies have revealed new details of the unique relationship between *Striga* and its host plant. Host-produced chemical signals that control the early stages of *Striga* development have been identified. Sophisticated isotopic analyses of *Striga*-infested hosts have revealed a profound alteration of host physiology. New molecular approaches are proposed for characterizing relevant genes from *Striga* and from hosts. These studies are welcome, for they will greatly increase the level of understanding of these destructive, yet beautiful and fascinating, parasitic plants. They also may eventually point the way to development of specific and effective methods for controlling *Striga*.

At the present time, however, the most promising approach to overcoming the *Striga* problem is the development of *Striga*-resistant cultivars that are adapted to local conditions. The new biotechnological methods can play an important role in the breeding and screening effort required to develop these cultivars.

So far, the only *Striga* generation stimulant that has been identified in a host plant is sorgoleone, a group of hydrophobic hydrobenzoquinones exuded by sorghum root hairs. Sorgoleone is readily inactivated by oxidation to the quinone, and has little solubility in water. All sorghum genotypes tested so far, including those resistant and susceptible to *Striga*, produce equivalent amounts of sorgoleone when grown on moist paper. In contrast, when grown in agar in which conditioned *Striga* seeds are dispersed, a useful method developed by J. Riopel, these genotypes vary widely in their capacity to stimulate germination of *Striga* seeds. Some resistant genotypes stimulate virtually no germination; low stimulant production may contribute to their resistance. Under these conditions, it seems unlikely that sorgoleone is the stimulant responsible for *Striga* germination.

Several techniques are available for screening for low production of germination stimulants or haustorial inducers. We have found the use of preconditioned *Striga* seeds dispersed in the agar in which host roots are grown (an assay developed in Riopel's laboratory) to be quite useful. For instance, we showed that the reason some sorghum cultivars do not germinate *Striga* seeds was not because they produce a germination inhibitor, but because they do not produce a stimulant.

The results of the agar plate assay correlate well with field observations of resistance. The resistant cultivars SRN 39 and Framida stimulate almost no germination in this assay. Other cultivars known to be susceptible to *Striga* stimulate high levels of germination. The results suggest that screening for low stimulant production as a trait contributing to *Striga* resistance can readily be done in the laboratory, thus speeding selection in breeding programs.

Sorghum Diseases

The focus of research has been to develop techniques for sorghum resistance to major diseases and devise appropriate control measures for pathogens that are recognized as constraints to production.

The major diseases for which a basic and applied collaborative research program has been developed are charcoal rot, covered kernel smut, and long smut.

The causal organism of charcoal rot is a nonaggressive pathogen that only colonizes in plants stressed by drought and high temperatures. Water stress is the main factor that predisposes sorghum to charcoal rot.

Over the years, a large number of cultivars from the Sudanese sorghum collection, ICRISAT Center, and Texas A&M University have been tested. In each case, irrigation was withheld at the time of 50% flowering to induce the necessary stress. At harvest, the material was evaluated for stay-green character, disease progress, and yield parameters. Several sources of resistance to charcoal rot have been identified. The highly nonsenescent sorghums related to SC-599 have enhanced cytokinin physiology. Application of cytokinin to plant leaves sometimes delays their senescence. Thus, applying cytokinin to sorghum cultivars that are susceptible to charcoal rot may increase their level of tolerance. A study was carried out over two successive seasons. Tx623 was planted in the first season and Hageen Dura-1 was planted in the following season. Both cultivars are sensitive to water stress and susceptible to charcoal rot. The synthetic benzylaminopurine (BAP) was sprayed at a concentration of 10^{-4} M BAP + 0.05% tween 20 once every three days for 36 days. At the time of harvest, individual leaves were scored on a scale of 1 to 5, where 1 was a dry or completely senescent leaf. BAP showed marked delay of leaf senescence in stressed plants and greatly reduced the incidence of charcoal rot.

Long smut is prevalent in a number of African countries north of the equator. It is a major threat to sorghum in West Africa. In the Sudan, the disease occurs annually in North Gedaref, the Nuba Mountains, and occasionally in some areas in the Gezira. Unlike other sorghum smuts, long smut is nonsystemic, and infection occurs as a result of single floret infections. Infection occurs at the boot stage and before anthesis, and penetration of infection hyphae takes place through the stylar region. The main source of infection is from teliospores in the soil. During dry spells, the spore bolls are carried by the wind. If they are washed down the flag leaf, they find enough moisture to germinate and cause infection.

An ultimate goal of the collaborative research on long smut was to develop a reliable and meaningful inoculation technique for screening. Various methods were tried, but the most appropriate was to inject the sporidia or teliospores at the booting stage. Fresh teliospores were superior to sporidia and more practical for screening germplasm.

A wide number of local and introduced sorghum cultivars have been tested for resistance. Almost all known varieties in the Sudan are susceptible, with the exception of black seeded sorghum from the Nuba Mountains, which showed a good level of resistance. The many screening trials conducted in the past indicated that the following cultivars were resistant: SC-326-6, SC-630-11, QL3 India, and N.M. black. R-9188, Framida, and Cr.35.5 were only moderately resistant.

Sorghum Food Quality

The traditional processing of sorghum usually starts with harvesting and grain storage. In some regions of the Sudan, heads of whole grain are hung over a wood fire to be smoked. In other regions, the threshed grain is stored in matmura pits (underground pits), or placed in sacks and stored in a cottage. In some villages, the grain is mixed with wood ashes and stored in clay pits. All of these practices are used to reduce insect and rodent infestation. However, these practices may also lead to an alteration of the physical characteristics and chemical composition of the grain, as well as to a serious effect on the food quality of sorghum and millet.

The surveys showed that the prevailing traditional food-processing practices include hand pounding, malting, fermentation, pregelatinization (madida), baking, and boiling. Decortication reduces the ash, fiber, protein, and fat content of the grain, but starch is negatively correlated with decortication. Lysine also decreases, which might be due to the fact that the concentration of lysine protein is highest in the germ layer which is removed during decortication. Vitamins and minerals are also reduced during decortication due to the removal of the bran and germ.

Many workers reported that fermentation improved the quality of sorghum foods and it increases protein digestibility. The reduction of pH during fermentation enhances the native prolytic enzymes to work on the protein and helps digestion. Also, the utilization of carbohydrates as substrate in fermentation weakens the carbohydrate/protein linkages, and this makes protein more readily available for digestion.

Malted sorghum is used in many different products. It influences the quality of the product by reducing the viscosity and improves the nutritional value of the food. Malting increases the digestibility of sorghum protein by 7%. The indigenous enzymes liberated during malting effectively digest the corneous protein matrix better than enzymes found in the gastrointestinal tract of humans.

The addition of a pregelatinized batter to a fermented kisra batter at the cold stage facilitates spreadability by forming a matrix. The addition of madida also extended the shelf life of kisra.

Baking kisra on a hot plate for a short time at a high temperature (180°C to 200°C) helps to increase protein digestibility. These results were reported by several researchers. Also, an oil/brain mixture and an oil/marrow mixture rubbed on the hot plate to prevent the kisra from sticking to the baking plate increases the fat content of baked kisra.

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	$10,000
Millet breeding	3,500
Physiology/agronomy	5,000
Pathology	6,000
Striga/weed control	5,000
Entomology	3,000
Food quality	6,000
Economics	2,000
Library improvement	3,500

A photocopier, slide projector, and other agronomic and physiological equipment and supplies were purchased on behalf of the ARC.

Acquisitions for the ARC libraries continue to be based upon requests from Wad Medani and El Obeid scientists.

ARC Scientist Travel

Dr. Laila Manawar of the Food Research Centre/Khartoum traveled to West Lafayette and Lubbock to work with

Drs. Allen Kirleis and Lloyd Rooney, respectively, from September 20 to October 18, 1989. She worked in their laboratories on studies to develop weaning foods made from sorghum and millet and composite flour.

INTSORMIL Scientist Travel to Sudan

Mohamed Habash traveled to Sudan from May 15 to July 5, 1989. This travel was to complete his field research on economic analysis of potential for new sorghum technologies in the rainfed mechanized vertisols of eastern Sudan, in conjunction with his Ph.D thesis.

John Sanders, major professor of Mr. Habash, traveled to Sudan from May 15 to June 2 to assist in his fieldwork and become familiar with the economic environment for sorghum production in the Sudan.

Gebisa Ejeta, country coordinator for the INTSORMIL/Sudan program, traveled to Sudan from June 12 to June 23 to prepare the revised workplans for 1989-1990, to seek cosponsorship, and to finalize plans for the proposed INTSORMIL/ARC workshop.

In conjunction with the Sorghum and Millet Research Workshop held at Wad Medani, the following INTSORMIL Principal Investigators traveled to Sudan:

John Yohe, University of Nebraska
Larry Butler, Allen Kirleis and Gebisa Ejeta, Purdue University
Larry Claflin, Kansas State University
Henry Pitre, Mississippi State University
Richard Frederiksen and Darrell Rosenow, Texas A&M University
Milton Coughenour, University of Kentucky

Other participants who traveled from the U.S. to participate in the workshop were Dr. Hussein Idris, former director of the Agricultural Research Centre, Polly Ligon, technical editor from Winrock, and Katy Ibrahim, administrative assistant for the INTSORMIL/Sudan program at Purdue.

Networking

A successful Sorghum and Millet Research Workshop was held in Wad Medani, Sudan, October 29 - November 2, 1989, with sponsorship by INTSORMIL, USAID/Khartoum and the Sudan Agricultural Research Corporation (ARC). The Workshop was attended by ARC and INTSORMIL collaborators, key Government of Sudan representatives, USAID Mission staff, as well as farmers and managers of various production schemes in the Sudan. In addition, SAFGRAD/West Africa staff, SAFGRAD/East Africa staff and NARS members from eight Eastern Africa countries were in attendance, providing for a good networking opportunity.

Several technical and policy issues were addressed. The successful nature of the INTSORMIL/ARC collaborative research program was highlighted. Promising research in several areas was presented during the technical sessions. The field trips to the research plots, seed production facilities, and farmers' fields clearly demonstrated the importance of sorghum and millet in the Sudan. The plenary session served as a forum where local administrative, policy, and economic issues that impact technology generation and transfer were discussed. It was evident that several factors beyond the realm of agricultural research determine the success of agricultural growth and economic development. Yet it was the belief of the workshop participants that sustained commitment to agricultural research is a key component of agricultural development.

The ARC/INTSORMIL Sorghum and Millet Workshop was a significant milestone in agricultural development in the Sudan. The proceedings of this conference will be the first comprehensive review and documentation on sorghum and millet research in the country.

The ARC/INTSORMIL Collaborative Research Program has been in effect in Sudan since 1980. It is the oldest and most active collaborative program in INTSORMIL. The program has been interdisciplinary, covering relevant disciplines that impact technology generation in sorghum and millet production and utilization. The array of research efforts ranges from adaptive on-farm research to highly basic upstream research conducted at collaborating U.S. universities. Many of our programs have resulted in germplasm development as well as generation of technologies that have made significant differences in sorghum/millet research and production in Sudan.

TRAINING

INTSORMIL gives high priority to training host country scientists who will have major responsibilities for sorghum and millet research in their home countries. Training is also provided for young U.S. scientists who plan for careers in overseas development work.

The most frequently used mode of training is graduate study for advanced degrees, with the students' research forming an integral part of an INTSORMIL project. During the year covered by this report, 118 students from over 37 different countries were enrolled in an INTSORMIL advanced degree program. 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 Table 1 which shows that roughly 20% of all INTSORMIL graduate participants are women.

The number of students receiving 100% funding by INTSORMIL in 1990 totaled 20. An additional 19 students received partial funding from INTSORMIL. The remaining 60 students are funded from other sources but are working on INTSORMIL projects. A grand total of ninety-nine students were advised by INTSORMIL principal investigators in 1990.

Total student numbers remained constant with that of last year which has increased by 17% compared to 1988. 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. An even more significant factor is that budget flexibility for supporting training under INTSORMIL projects has been greatly diminished because of inflationary pressures. None of the INTSORMIL project budgets have been increased in the last five years.

In addition to graduate degree programs, short term training programs have been designed and implemented on a case by case basis to suit the needs of host country scientists. Several young Host Country scientists were trained in this fashion during 1990.

INTSORMIL also cooperates with ICRISAT on a ten year special training program aimed at the Southern African Development Coordinating Countries. 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.

The agreement for the second five year phase of the SADCC/ICRISAT/INTSORMIL program was signed in 1989 and will run through September 15, 1993. The second phase calls for a two fold increase in volume and activity. An additional 60 scientists from the SADCC region have been identified and will be processed for training in the next two years. Increased emphasis has been given for the disciplines of food technology, economics, forages, and agroclimatology. As of June 30, 1990 INTSORMIL has processed a total of 48 SADCC students encompassing nine SADCC countries.

The following table is a compilation of all INTSORMIL training activities for the period covered by this report, July 1, 1989 through June 30, 1990.

Year 11 INTSORMIL Training Participants

Name	Country	University	Discipline	Advisor	Degree	Gender	Funding*
Coulibaly, Adama	Mali	KSU	Agronomy	Vanderlip	MSC	M	I
Kabambe, Vemon	Malawi	KSU	Agronomy	Vanderlip	MSC	M	S
M'Khaitir, Yahya O.	Mauritania	KSU	Agronomy	Vanderlip	MSC	M	O
Maliro, Charles	Malawi	UNL	Agronomy	Clegg	PHD	M	S
Mohamed, Mirghani	Sudan	UNL	Agronomy	Clegg	PHD	M	I
Sebolai, Boingotla	Botswana	UNL	Agronomy	Clegg	MSC	F	S
Bagayoko, Minamba	Mali	UNL	Agronomy	Mason	MSC	M	P
Kasalu, Helen	Zambia	UNL	Agronomy	Mason	MSC	F	S
Sirifi, Seyni	Niger	UNL	Agronomy	Maranville	MSC	M	O
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
Muza, F. Ronald	Zimbabwe	MSU	Breeding	Gourley	MSC	M	S
Ortegon P., Jesus	Mexico	MSU	Breeding	Gourley	PHD	M	O
Saadan, Hamis	Tanzania	MSU	Breeding	Gourley	PHD	M	S
Zake, Vincent	Uganda	MSU	Breeding	Gourley	PHD	M	O
Mushonga, Joseph	Zimbabwe	PRF	Breeding	Axtell	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
Klingler, John	US	PRF	Breeding	Ejeta	MSC	M	I
Vogler, Renee	US	PRF	Breeding	Ejeta	MSC	F	I
Dahlberg, Jeffrey	US	TAM	Breeding	Miller	PHD	M	P
de Franca, Geraldo	Brazil	TAM	Breeding	Miller	PHD	M	P
Kanyenji, Ben M.	Kenya	TAM	Breeding	Miller	MSC	M	P
Khizzah, Bill W.	Uganda	TAM	Breeding	Miller	PHD	M	P
Nunes, Maria Eugenia	Mozambique	TAM	Breeding	Miller	MSC	F	S
Ombakho, Geroge	Kenya	TAM	Breeding	Miller	PHD	M	O
Tenkouano, Abdou	Burkina Faso	TAM	Breeding	Miller	MSC	M	P
Toure, Aboubacar	Mali	TAM	Breeding	Miller	PHD	M	P
Gilbert, Mike	US	TAM	Breeding	Rosenow	PHD	M	P
Gorman, Chris	US	TAM	Breeding	Rosenow	MSC	M	I
Isbell, Verne	US	TAM	Breeding	Rosenow	PHD	M	P
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	BSC	F	S
Mazhani, Louis	Botswana	UNL	Breeding	Andrews	PHD	M	S
Muuka, F.P.	Zambia	UNL	Breeding	Andrews	MSC	M	S
Traore, Karim	Mali	UNL	Breeding	Andrews	MSC	M	O
Ahmed, Mohamed	Sudan	PRF	Economics	Sanders	PHD	M	I
Coulibaly, Ousmane	Mali	PRF	Economics	Sanders	PHD	M	I
Habash, Mohamed	Syria	PRF	Economics	Sanders	PHD	M	I
Lopez-Pereira, Miguel	Honduras	PRF	Economics	Sanders	PHD	M	I
Nichola, Tennassie	Ethiopia	PRF	Economics	Sanders	PHD	M	I
Ramaswamy, Sunder	India	PRF	Economics	Sanders	PHD	M	I
Shapiro, Barry	US	PRF	Economics	Sanders	PHD	M	O
Lopez, Julio	Honduras	MSU	Entomology	Pitre	MSC	M	I
Portillo, Hector	Honduras	MSU	Entomology	Pitre	MSC	M	I
Bayoum, Imad	Lebanon	TAM	Entomology	Teetes	PHD	M	O
Jimenez, Nora	Colombia	TAM	Entomology	Teetes	MSC	F	O
Jost, Douglas	US	TAM	Entomology	Teetes	MS	M	O
Magallenes, Ricardo	Mexico	TAM	Entomology	Teetes	PHD	M	O
Manthe, Chris	Botswana	TAM	Entomology	Teetes	PHD	M	S
Musonda, Ephraim	Zambia	TAM	Entomology	Teetes	MSC	M	S
Pendleton, Bonnie	US	TAM	Entomology	Teetes	PHD	F	O
Rojas, Edgar	Costa Rica	TAM	Entomology	Teetes	MSC	M	O

Name	Country	University	Discipline	Advisor	Degree	Gender	Funding*
Roque, Javier	Mexico	TAM	Entomology	Teetes	PHD	M	O
Thindwa, Harriet	Malawi	TAM	Entomology	Teetes	PHD	F	S
Siame, Anthony Bupe	Zambia	PRF	Food Quality/Util	Butler	PHD	M	S
Weerasuriya, Yohan H.	Sri Lanka	PRF	Food Quality/Util	Butler	PHD	M	O
Aboubacar, Adam	US	PRF	Food Quality/Util	Kirleis	MS	M	O
Leonard, Dawn	US	PRF	Food Quality/Util	Kirleis	MSC	F	I
Mohammed, Selma	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
Bello, Tony	Nigeria	TAM	Food Quality/Util	Rooney	PHD	M	P
Clegg, Chally	US	TAM	Food Quality/Util	Rooney	MSC	M	I
Corujo, Juan	Spain	TAM	Food Quality/Util	Rooney	MSC	M	P
Gous, Franz	South Africa	TAM	Food Quality/Util	Rooney	PHD	M	O
Islas-Rubio, Alma	Mexico	TAM	Food Quality/Util	Rooney	MSC	F	P
Mrema, Greyson	Tanzania	TAM	Food Quality/Util	Rooney	MSC	M	S
Wright, Lee	US	TAM	Food Quality/Util	Rooney	MSC	M	P
Young, Robert	South Africa	TAM	Food Quality/Util	Rooney	PHD	M	O
Chaisrisook, Chulee	Thailand	KSU	Pathology	Claflin	PHD	F	O
Darnetty	Indonesia	KSU	Pathology	Claflin	MSC	F	O
Farrokhi-Nejad, Reza	Iran	KSU	Pathology	Claflin	PHD	M	O
Qhobela, Molapo	Lesotho	KSU	Pathology	Claflin	PHD	M	S
Xu, Jin-Rong	China	KSU	Pathology	Claflin	PHD	M	O
Zvoutete, Petros	Zimbabwe	KSU	Pathology	Claflin	MSC	M	S
Casela, Carlos	Brazil	TAM	Pathology	Frederiksen	PHD	M	O
Esele, Peter	Uganda	TAM	Pathology	Frederiksen	PHD	M	O
Mansuetus, Anaclet	Tanzania	TAM	Pathology	Frederiksen	MSC	M	S
Naidoo, Gnanambal	South Africa	TAM	Pathology	Frederiksen	PHD	F	O
Oh, B.J.	Korea	TAM	Pathology	Frederiksen	PHD	M	O
Guthrie, Phil	Great Britain	TAM	Pathology	Odvody	PHD	M	I
Kunene, Innocentia	Swaziland	TAM	Pathology	Odvody	PHD	F	S
Mtisi, Ester	Zimbabwe	TAM	Pathology	Odvody	PHD	F	S
Alexander, John	US	TAM	Pathology	Toler	PHD	M	O
Mahuku, George	Zimbabwe	TAM	Pathology	Toler	MSC	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	MSC	M	P
Kubik, Keith	US	UNL	Physiology	Eastin	PHD	M	P
Zavala-G., Francisco	Mexico	UNL	Physiology	Eastin	PHD	M	P
Coulibaly, Sidi Bekaye	Mali	UNL	Physiology	Sullivan	MSC	M	O
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 11 SADCC/ICRISAT Training Participants

Name	Country	University	Discipline	Advisor	Degree	Gender
Chitengue, Jone	Angola	Viscosa	Breeding	Vieira	MSC	M
Jose, Joao	Angola	Viscosa	Breeding	Cardosa	MSC	M
Mogorosi, Michael	Botswana	UNL	Agronomy	Mason	BSC	M
Sebolai, Boingotlo	Botswana	UNL	Biometrics	Clegg	MSC	F
Mazhani, Louis	Botswana	UNL	Breeding	Andrews	PHD	M
Manthe, Chris	Botswana	TAM	Entomology	Teetes	PHD	M
Malepa, Dollina	Botswana	UNL	Plant/Soil	Walters	PHD	F
Marake, Makoala	Lesotho	UNL	Agronomy	Walters	MSC	M
Mofolo, Moea	Lesotho	UNL	Agronomy	Sorensen	BSC	M
Mothokho, Neo	Lesotho	UNL	Agronomy	Lewis	BSC	M
Qhobela, Molapo	Lesotho	KSU	Pathology	Claflin	PHD	M
Moletsane, Nyakallo	Lesotho	PRF	Economics	Farris	MSC	F
Kabambe, Vernon	Malawi	KSU	Agronomy	Vanderlip	MSC	M
Msiska, Felix	Malawi	MSU	Agronomy	Hodges	MSC	M
Maliro, Charles	Malawi	UNL	Agronomy	Clegg	PHD	M
Chirwa, Rowland	Malawi	UNL	Breeding	Andrews	PHD	M
Thindwa, Harriet	Malawi	TAM	Entomology	Teetes	PHD	F
Theu, Matthew	Malawi	TAM	Pathology	Toler	PHD	M
Luhanga, Jeffrey	Malawi	MSU	Seed Tech	Andrews, C.H.	PHD	M
Pereira, Luiz	Mozambique	UNL	Agroclimatology	Weiss	MSC	M
Brito, Rui	Mozambique	CSU	Agronomy	Dumford	PHD	M
Nunes, Maria E.	Mozambique	TAM	Breeding	Miller	MSC	F
Nxumalo, Edgar	Swaziland	SHS	Agronomy	Lane	MSC	M
Kunene, Innocentia	Swaziland	TAM	Pathology	Odvody	PHD	F
Matowo, Peter	Tanzania	KSU	Agronomy	Pierzwnski	PHD	M
Mndolwa, Samuel	Tanzania	KSU	Agronomy	Moshier	BSC	M
Felix, Joel	Tanzania	PRF	Agronomy	Vorst	BSC	M
Mgema, William	Tanzania	UNL	Agronomy	Clark	MSC	M
Saadan, Hamis	Tanzania	MSU	Breeding	Gourley	PHD	M
Guutazi, Athman	Tanzania	KSU	Entomology	Reese	MSC	M
Mrema, Greyson	Tanzania	TAM	Food Science	Rooney	MSC	M
Mansuetus, Anaclet	Tanzanaia	TAM	Pathology	Fredriksen	MSC	M
Hikeezi, Doreen	Zambia	KSU	Agronomy	Kropf	BSC	F
Kasalu, Helen	Zambia	UNL	Agronomy	Mason	MSC	F
Chungu, Chibwe	Zambia	UNL	Breeding	Andrews	BSC	F
Muuka, Ferdinand	Zambia	UNL	Breeding	Andrews	MSC	M
Siame, Anthony	Zambia	PRF	Food Science	Butler	PHD	M
Muza, Figuhr	Zimbabwe	MSU	Breeding	Gourley	MSC	M
Mahuku, George	Zimbabwe	TAM	Pathology	Toler	MSC	M
Zvoutete, Petros	Zimbabwe	KSU	Pathology	Claflin	MSC	M

Acronyms

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
AID	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
BPI	Bureau of Plant Industry, Philippines
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
CENIAP-FONAIAP	Venezuela Agricultural Research Agency
CENTA	Centro de Technologia de Agricola, El Salvador
CESDA	Center for Agricultural Research, Dominican Republic
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
CIMMYT	International Maize and Wheat Improvement Center
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Développement
CLAIS	Consejo Latin Americana de Investigadores en Sorgho
CNPQ	Conselo Nacional de Desenvolvimento Cientifico e Tecnologico
CNRA	National Center for Agricultural Research, Senegal
CRSP	Collaborative Research Support Program
DAR	Department of Agricultural Research, Botswana
DR	Dominican Republic
EAP	Escuela Agricola Pan Americana, Zamorano, Honduras
EARSAM	East Africa Regional Sorghum and Millets

ECHO	Educational Concerns for Hunger Organization
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
ES	El Salvador
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
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
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
TARO	Tanzania Agricultural Research Organization
TC	Technical Committee
TROPSOILS	Tropical Soils Collaborative Research Program, CRSP
UK	University of Kentucky
UNILLANOS	Universidad Technologica de los Llanos
UNL	University of Nebraska - Lincoln
U.S.	United States
USAID.	United States Agency for International Development
USDA	United States Department of Agriculture
USM	University of Southern Mindanao, Philippines
WASAT	West African Semi-Arid Tropics
WASIP	West Africa Sorghum Improvement Program
WSARP	Western Sudan Agricultural Research Project