INTSORMIL

Annual Report 1989

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. Host country collaborator Mr. Henry Fuentes taking fertility notes in the maicillo sterilization nursery at the Escuela Agricola Panamericana (EAP), Honduras. Photo by Dr. Dan Meckenstock, Texas A&M University, EAP, El Zamorano, Honduras.

2. Host country collaborator Mr. Y. Doumbia, IER entomologist, IER entomology staff and Dr. George Teetes, Texas A&M University entomologist inspecting for sorghum panicle feeding bugs in Mali. Photo by Dr. Darrell Rosenow, Texas A&M University.

3. Left to right, Dr. J. Werder, ICRISAT Sahelian Center pathologist, Niamey, Niger, Dr. Issoufou Kolo, INRAN pathologist, INRAN pathology staff scientist, Niamey, Niger, and Dr. Omer Hilu, ARC, Wad Medani, Sudan, inspecting millet for disease. Photo by Dr. Richard A. Frederiksen, Texas A&M University.

4. 1989 millet harvest enroute to village storage. Photo by Dr. R.A. Frederiksen, Texas A&M University.

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

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INTRODUCTION

John M. Yohe
Management Entity

INTSORMIL, the working name used for the Sorghum/Millet Collaborative Research Support Program, was implemented in 1979. In an amendment to the International Development and Food Assistance Act of 1975, the Congress of the United States provided for "long-term collaborative university research on food production, distribution, storage, marketing, and consumption," in ways that "maximized the contributions to the development of agriculture in the United States and in agriculturally developing countries." One of the most innovative joint initiatives developed by A.I.D. and the Board for International Food and Agricultural Development (BIFAD) under Title XII is the Collaborative Research Support Programs (CRSP).

This report summarizes the program effort during the tenth year of implementation. Ten years of experience continues to reaffirm the need for this type of research program aimed at relieving the constraints to improved sustainable sorghum/millet production systems in developing countries.

This program has fulfilled the intent of the Title XII legislation where it authorized the President ...."to provide assistance on such terms and conditions as he shall determine.... to provide program support for long-term collaborative university research on food production and distribution, storage, marketing, and consumption."

Leadership for the INTSORMIL program has been provided by research and international research administrative faculty of Kansas State University, University of Kentucky, Mississippi State University, University of Nebraska, Purdue University and Texas A&M University and by the national agricultural research organizations of Botswana, Colombia, Honduras, Mali, Niger and Sudan. Core support for the program has come from A.I.D. Grant No. DAN-1254-G-SS-5065-00. Major support also has been provided by the participating U.S. universities, the collaborating host country institutions and buy-ins from U.S.A.I.D. Missions, ICRISAT/SADCC and some private sector companies/foundations. INTSORMIL has collaborated closely with ICRISAT, CIMMYT/ICRISAT, CIAT, ICRISAT Sahelian Center, SADCC/ICRISAT in Southern Africa and SAFGRAD/ICRISAT in East and West Africa.

The organizational framework of the program and the initiatives undertaken worldwide have resulted in an extensive effort involving 82 scientists from 25 collaborating institutions in 17 countries. There are six collaborative site programs with six of the countries representing the six major ecogeographic zones worldwide where sorghum and millet are grown.

Accomplishments

The executive summary at the beginning of each chapter presents some of the major program accomplishments for U.S. agriculture and collaborating host countries. INTSORMIL has trained 178 non-U.S. and 106 U.S. students from A.I.D. grant funds and 213 non-U.S. and 90 U.S. students on INTSORMIL projects who received training funds from other sources. Total students trained during the period 1979-1989 totaled 587. There were 257 Ph.D., 227 M.S., 26 B.S. degrees, 46 short term and 29 post doc/visiting Scientist recipients. There were 121 students from all funding sources under training during Year 10.

INTSORMIL has made tremendous progress in technology development for improved production and utilization of sorghum and millet in the developing world. In the process of implementing collaborative research with host country institutions, the human resource base for conducting research on these two priority crops has improved with each year of the program. As of June 30, 1989, three of the collaborative site LDC's, where INTSORMIL works, have the technical capability to implement a full multidisciplinary research program for the improvement of production and utilization of sorghum and millet. The INTSORMIL program has grown and developed to where U.S. and LDC collaborative research scientists work on a peer basis.

The program has made significant contributions to the participating U.S. institutions as well as the U.S. sorghum industry. Benefits to the U.S. institutions show up as increased involvement in international activities, and greater globalization and international awareness in courses offered which enhances the relevance of the training experience of all students, U.S. and international. Most significant of all is the emergence of INTSORMIL as an internationally recognized sorghum and millet research organization.

The most dramatic benefit to U.S. agriculture is the contribution to private sector breeding programs where parental lines of sorghum hybrids carrying specific traits beneficial to the U.S. sorghum industry are produced and marketed.

INTSORMIL believes that within a few years millet hybrids will be available for production in the U.S. Millet is a high quality grain which has great potential as a feed grain and food grain in the U.S. This would be a new crop adapted to the sandy, dryland areas of the Midwest. Millet also has great potential as a dryland crop following a winter crop in the Midwest.

Future Directions

Over the past 11 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 systems.
- Sustainable millet 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.

Sustainability

Building in disease and insect control, developing cropping systems which conserve and maximize efficient use of soil moisture, and developing highly adapted, drought resistant, disease and insect resistant and high food quality cultivars and hybrids of sorghum and millet will make significant contributions to the sustainability of these new production systems.

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.

Most notably, sustainability can be achieved when the host country resources are substituted for CRSP resources in operating the sorghum and millet research program in promoting improved production and utilization of these crops. This involves the setting of improved economic policies, new allocation of resources to establish sustainable agricultural production systems, and national will toward improved utilization and conservation of natural resources.

Host Countries

INTSORMIL has spent ten years in developing the linkages in key countries within six ecogeographic zones around the world which generate and contribute technology to the improved utilization and production of grain sorghum and pearl millet. This has been a slow process. Within the last few years the credibility of INTSORMIL has been recognized by U.S.A.I.D./Missions and the national programs. They now trust and recognize the benefits of the collaborative research program concept. More time is required to cement the current linkages into place so that the national programs can operate on a peer collaborative basis and not require the close collaborative interchange now taking place. This is all a matter of time and national budgetary support for the benefits of the collaborative research system to be institutionalized.

When local resources are assured, when adequate trained staff and backup people are in place, INTSORMIL can look forward to developing in-depth linkages with other national programs. This can also be a phasing process. INTSORMIL even today, provided funds are available, has the capacity and capability to begin the process of establishing linkages in new host country sites.

Because of the SADCC/ICRISAT training program, INTSORMIL scientists are already interacting with national programs throughout Southern Africa. INTSORMIL is collaborating with SADCC/ICRISAT in developing technologies for the whole Southern African region.

Networking

Established networking activities have continued with ICRISAT, SADCC/ICRISAT, ICRISAT Sahelian Center, ICRISAT West Africa Sorghum Program, East Africa Safgrad/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. One INTSORMIL PI is also a TROPSOILS investigator. His input has been a strong influence on addressing the interaction of soil fertility problems and sorghum and millet production.

Technology Dissemination

INTSORMIL participates in the technology diffusion process in several ways. Depending upon the organizational structure of research and extension within a country, the activities of A.I.D. bilateral assistance programs and the activities of other donor organizations, INTSORMIL interfaces in the technology diffusion process differently. The following are examples:

- Host country/INTSORMIL collaborative research results are reviewed and verified in farmers' fields and recommended to host country Agricultural Extension systems for dissemination. Most recently, this has occurred in Niger where an improved millet/cowpea cropping system was developed from INTSORMIL/INRAN research and was adopted by DECOR, the Nigerien Extension service. INTSORMIL has collaborated with the Botswana/U.S.A.I.D. Agricultural Technology Improvement Project (ATIP) in developing and extending water conservation technologies to small farmers.
- INTSORMIL and International Donor Technology Verification programs. In Sudan and in Ghana, the Global 2000 program has adopted INTSORMIL produced technologies and used them in wide testing programs through the respective countries. In Sudan, Global 2000 adopted the ARC/UNDP/ICRISAT/INTSORMIL Hageen Dura-1 hybrid and has tested it in western and eastern Sudan. The technology package used with the hybrid seed was from Sudan Agriculture Research Corporation collaborative research with INTSORMIL. The same is true for the UNDP/ICRISAT millet variety Ugandi and the INTSORMIL/ARC agronomic package.
- In Ghana, the Global 2000 program has tested the sorghum variety Sureño, which is a product of INTSORMIL/Honduras collaborative research.
- INTSORMIL collaboration with A.I.D. Mission bilateral programs. INTSORMIL has a memorandum of agreement with the Botswana/A.I.D. Mission Agricultural Technology Improvement Project. INTSORMIL has provided an agronomist and a soil scientist to this farming systems project which was designed to establish linkages with the Botswana Extension service and the Department of Research.
- In Honduras, INTSORMIL research has been testing improved varieties and hybrids on farmer fields in collaboration with the A.I.D. Mission Bilateral Steeplands project..
- INTSORMIL organizes and participates in technical workshops and conferences in host countries and in international settings. Plans have been made to hold the Sudan Sorghum and Millet Workshop on October 28 - November 2, 1989 in Wad Medani, Sudan. The forum of the workshop setting is an excellent opportunity to network regionally. Scientists from neighboring countries can attend and benefit from the collaborating host countries' relationship with the INTSORMIL program. In 1986 the Honduras workshop was held and six other Central American Countries were represented. In all cases proceedings are published and widely distributed.
- INTSORMIL has implemented what we call technical networking. Dr. Omer Hilu, ARC/Sudan in collaboration with Dr. R. Frederiksen, Texas A&M University has organized a regional nursery on the sorghum long smut disease. INTSORMIL has sponsored technical assistance for Dr. Hilu to visit Mali and Niger in West Africa to set this regional collaboration in place. This has been a very effective tool in bringing national programs into greater collaboration with one another.

All INTSORMIL scientists publish in refereed Journals. A list of these publications is included in the individual project reports.. This is an excellent forum for sharing research results with colleagues around the world. Most recently INTSORMIL scientists and host country scientists have been publishing jointly the results of their collaborative researcn.

Management Organization

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 -- Texas A&M, Purdue, Nebraska, Kansas State, Mississippi State and Kentucky -- 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 of the CRSP serves as the top management/policy board for the CRSP. The Technical Committee, Ecogeographic Zone Council, External Evaluation Panel 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 Board of Directors

The Board of Directors consists of one institutional representative from each of the six participating U. S. institutions. Board members are designated by the chief executive officers of their institutions to represent them on policy and administrative matters. The Board elects a chairperson and vice chairperson on an annual basis. The ME serves as the executive secretariat to the Board.

Technical Committee

The Technical Committee (TC) acts on most technical and operational matters and forwards its recommendations to the Board of Directors and the Management Entity. It reviews all project work plans and budgets and makes recommendations on overall program coordination. The TC consists of six members, representing each of the six disciplinary areas in the program. Principal investigators are nominated for membership on the TC by members of the discipline. All PI's vote for the candidates proposed by the discipline. The term of office is three years. Officers of the TC are the chair, vice chair and secretary.

Ecogeographic Zone Council

The Ecogeographic Zone Council's primary responsibilities are planning and implementation of identified host country and U. S. collaborative sorghum/millet activities as related to research, training and networking. Membership on the EZC consists of one principal investigator from each of the ecogeographic zones. In most cases the member is the country coordinator of the host country identified in the Global Plan as the prime site country, plus one at-large member. The at-large member is recommended to the Board of Directors by the ME. Membership of the Council is determined by the Board of Directors, with the composition of the Council to be reviewed annually. Officers of the EZC are the chair, vice chair, and secretary, all serving one year terms.

External Evaluation Panel

The External Evaluation Panel (EEP) consists of five members nominated by PIs, the TC and the Board of Directors. The Board then recommends the EEP membership to A.I.D./Washington and BIFAD, which give final approval. The EEP has a chair and a vice chair. Representatives from international institutions and countries other than the U. S. are included on the EEP. The EEP is charged with overall evaluation of the sorghum/millet CRSP program, which includes research collaboration with host countries. The overall evaluation includes a review of projects and programs of the CRSP and it provides a written evaluation and recommendation for addition, elimination, or modification of component projects and overall objectives to include retention, elimination, or addition of new activities.

Management Entity

The University of Nebraska Management Entity (ME) office is located in the Department of Agronomy, 241 Keim Hall, Institute of Agriculture and Natural Resources, University of Nebraska, Lincoln, NE 68583-0723. The ME office is responsible to A.I.D. for technical and administrative matters for the CRSP. As the prime grantee it is responsible to A.I.D. for all fiscal matters relating to the grant. Other responsibilities include coordinating all memoranda of agreement, coordinating and implementing all committee meetings, Board and EEP meetings, and all reporting and communications regarding CRSP activities. The ME office coordinates and obtains all travel clearances through A.I.D./Washington.

A.I.D. - Liaison is maintained on a weekly basis for advice in program direction and development, securing travel clearances, equipment purchase approvals and for coordination with Regional Bureaus and U.S.A.I.D. Missions.

BIFAD - The CRSP programs, as Title XII programs, were jointly developed by the BIFAD standing committee, JRC (now called the JCARD), and by A.I.D. Communication and coordination is maintained with the research division of the BIFAD staff office. BIFAD advises the agency on CRSP program evaluations and CRSP grant renewals.

Coordination with the International Centers

INTSORMIL has a history from the inception of the program of coordinating and collaborating with ICRISAT, the ICRISAT scientists located at CIMMYT for Latin America, with CIAT and with ICRISAT regional activities located in West Africa. ICRISAT management staff have attended INTSORMIL PI annual conferences and INTSORMIL ME staff have met with ICRISAT management staff to discuss coordination and collaboration in order to avoid duplication of activities.

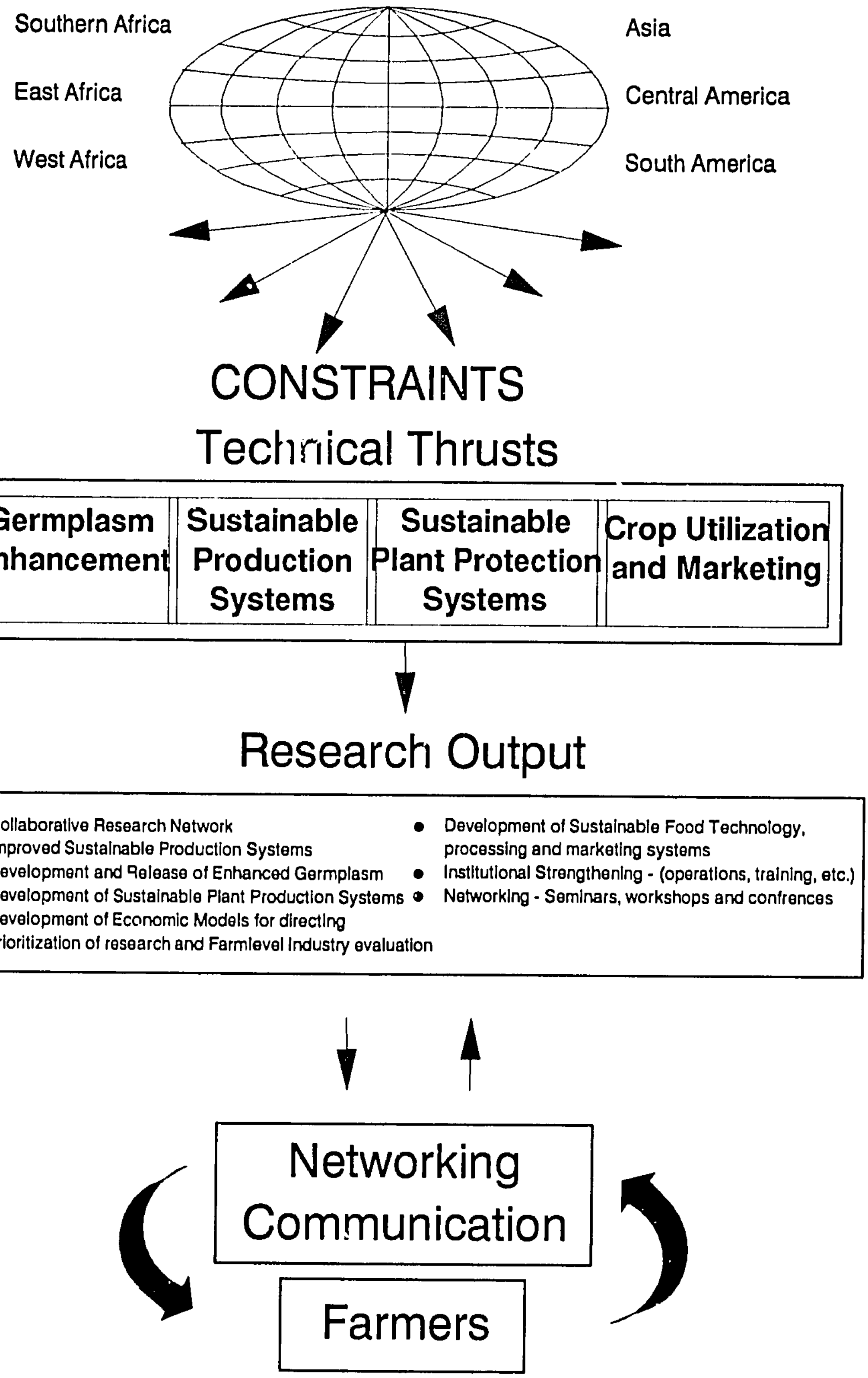
1989 Project Reports

The Sorghum/Millet CRSP has research linkages in three geographic regions as delineated by A.I.D. through the organization of the Regional Bureaus; the Africa Bureau, the Latin America and Caribbean Bureau, and the Asia/Near East Bureau. Depending upon the host country, the range of disciplines covered under collaborative activities, between INTSORMIL and the host country, varies from two to seven. The more multidisciplinary the country program is, the greater the potential for exchange of information on a regional or international basis.

This section of the report describes the collaborative research activity progress between individual U.S. scientists and their counterparts along disciplinary lines. Research progress has been significant. New varieties and hybrids have been identified which can make a contribution to the improvement of sorghum production in the developing world. A better understanding of insect pests and disease problems in the collaborating countries has been elucidated. Progress in food grain quality has been a major development. This is true for Latin America and Africa. The level of progress in the INTSORMIL program indicates the level of interest and commitment that the U.S. and host country collaborators have in the different areas of research. The collaborative mode of interaction has contributed significantly to the development process and has facilitated the administrative process for accomplishing the tasks undertaken by the program.

The annual progress reports were prepared by the U.S. principal investigators. Results presented are from research accomplished by both the U.S. and host country collaborators.

INTSORMIL GLOBAL PLAN



Agronomy/Physiology

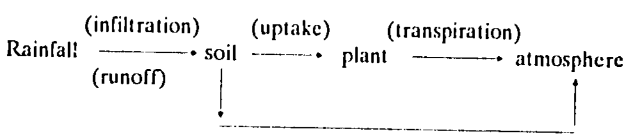
Executive Summary

Seed from two pearl millet hybrids, one a large seeded hybrid and the other a small seeded hybrid, were separated into size category and tested under a range of temperature and soil moisture conditions. Planting depths, soil moisture, and temperature had pronounced effects on emergence, establishment and seedling growth. In general, seed characteristics had no effect on any of the variables measured.

Comparisons between grain sorghum and pearl millet for responses to rate and date of planting show that there were no consistent differences between the two crops in response to date of planting. Because of its ability to compensate in terms of head numbers per plant and seed number, pearl millet showed very little response to plant population in comparison to grain sorghum. (KSU-106)

Food security continues to be a 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 crops and soil and crop management technology for dryland sorghum and millet production. U.S.A.I.D./Botswana and the Ministry of Agriculture are supporting these efforts both financially and logistically.

In developing their collaborative research program Botswana and INTSORMIL scientists recognized the primary need for practical and sustainable technologies to deal effectively with the twin primary constraints of soil-moisture and soil-fertility deficits. They considered practical ways and means to manipulate the soil and crop that would increase the water transpired in the final step of the following catenary pathway:



As a result, their collaborative research program became integrated and centered around long-term 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. The few years of 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.

With INTSORMIL help, a collaborative National Tillage Research Program was initiated. Under this program collaborative on-farm and on-station trials are being conducted on several promising soil-moisture conservation tillage/soil fertility improvement systems that can promote deeper moisture and root penetration, give better weed control, better crop establishment, and healthier crops. Results from multilocational trials clearly indicate that tillage and fertilizer management are key factors for increasing yields and rain use efficiency in Botswana and should be further 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. (KSU-107)

Studies in Botswana indicated that improved soil fertility (due to crop rotation or manure application) increased grain sorghum stover yield in 12 environments. However, grain yields increased only when biomass production (grain plus stover) exceeded 1.0 Mg ha^{-1}. At lower biomass yields, improved fertility did not improve grain yield.

Rotation studies were initiated in Sudan, and the groundwork was laid for cropping systems studies in Mali starting in 1990.

Pearl millet showed a quadratic yield response to nitrogen application in both 1987 and 1988. Intercropping systems with improved varieties and higher plant densities produced more grain than traditional systems. Pearl millet yields as influenced by cropping systems were not consistent across years. In 1988 pearl millet produced the greatest yield following a cowpea sole crop and the lowest yield following the traditional intercropping system.

The annual nitrogen removal by grain sorghum increased linearly from 59 kg ha^{-1} yr^{-1} for the zero N treatment to 143 kg ha^{-1} for 171 kg ha^{-1} applied N. Following a soybean previous crop 102 kg N ha^{-1} yr^{-1} was removed by the zero N treatment and N removal peaked at the 114 kg ha^{-1} applied N rate. Residual study of soybeans grown in rotation with grain sorghum indicated that soybeans present two years previous to grain sorghum contributed 18-24 kg ha^{-1} NO_3-N and increased grain sorghum yield by 1.4 mg ha^{-1}. (NU-113)

Experiments were conducted in Mali and Niger to determine nitrogen response of sorghums and pearl millets in several locations. Results from Niger are not available at this time.

Studies in Mali showed that the local variety of sorghum responded favorably to nitrogen application, and was able to outyield two improved types which were susceptible to grain molds. All of the varieties in the test performed best if the nitrogen application was split at tillering and preboot. The location with the highest rainfall was superior in terms of nitrogen responsiveness as might be expected.

Research on nitrogen response of pearl millet conducted in the U.S. by a Malian graduate student showed that varieties respond differently to timing of application and rate. The study was subject to high experimental variability and the arithmetic means in which large differences existed were not statistically significant for grain yield, nitrogen yield, and related parameters. The nitrogen use efficiency values, however, were significantly influenced by nitrogen rate, being highest at the lowest rates and vice versa. A late sidedress application of nitrogen resulted in higher nitrogen use efficiency values than if nitrogen was sidedressed earlier in the growing cycle. Soil moisture also influenced nitrogen response as in the previous experiment.

A separate experiment with five sorghum hybrids showed that some sorghums take up greater amounts of nitrogen during grain fill, but this does not necessarily result in higher grain yields. Higher nitrogen levels also resulted in greater green leaf area, but again, this did not result in greater grain yields. The results indicated that high nitrogen uptake by sorghum is not required to maintain grain yields. Genotype differences in response indicated the possibility of developing types which take up and utilize less nitrogen yet maintain profitable yield levels. (NU-114)

Germplasm improvement research to develop stress resistant and water responsive sorghum genotypes is in Year 10. Details of field screening technique and breeding methodology were reported in 1987 and 1988. Two early season stress resistant A/B pairs were released. Seventy-eight tan plant-light grain colored food grain type composite lines were distributed to several commercial and public breeders. A new stress resistant random mating sorghum population is being synthesized.

Cultural practice research to increase crop water-use efficiency (WUE) and reduce cool temperature stress injury in western Nebraska is continuing. Sorghum water-use efficiency and seed number was significantly higher in the no-till plots compared to either bare till or subtill plots in both 1986 and 1987. Yield of sorghum under no-till was significantly higher only in 1987. Grain yield, seed number, water use and WUE of 1987 wheat were significantly higher in the wheat-sorghum-fallow (WSF) system than in the wheat-fallow (WF) system. Averages of total grain production and water use were higher in the WSF system compared to the WF system. The WSF system produced 28% more grain than the WF system and used 19% more water.

Cooperative crop physiology/cropping systems research initiated in Niger two years ago is now being conducted by and in collaboration with Mr. A. Alou of INRAN. Crop residue amounts of 1, 2 and 3 t ha^{-1} left on the surface as a mulch increased millet grain yields by 306%, 458% and 545%, respectively, while total dry matter production increased by 253%, 347% and 382% in these respective treatments. Using artificial shades, it was determined that water-use efficiency and production of cowpea is maximum under full sunlight. An alternative to the currently recommended intensive millet/cowpea intercropping system which increased light availability to the cowpea canopy was tested. While millet yields were the same or slightly higher in this system, cowpea grain and total dry matter production increased by 15% and 24%, respectively, in the alternative system compared to the recommended system. Another alternative system increased millet grain and total dry matter yields by 24% and 42%, respectively, and cowpea total dry matter production by 53% compared to the traditional farmers' system under low-input (no fertilizer) situations. These alternative systems need to be further tested to determine their sustainability under reduced input conditions. (NU-116)

A major problem in West Africa, and other drought prone regions, is the effect of drought and high temperatures on crop stand, plant growth, and yields. 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. It is known that proline and other metabolites often accumulate in plant cells when they are exposed to drought and temperature extremes. Our basic research was aimed at determining how proline accumulation may contribute to the stress resistance of West African and other sorghums. It was shown that genotypes differ significantly in the quantity of proline accumulation, and that it is not necessarily positively related to the level of stress that the plants experience. In a study of 15 genotypes, converted Malian sorghums SC-90 and SC-283 did not accumulate large quantities of proline when mildly stressed, but in the same environment, sorghums selected from NP9BR accumulated much large quantities of proline. It was previously shown that the growth substance abscisic acid (ABA) when exogenously applied markedly influenced sorghum growth and stress resistance.

Progress was made in development of techniques and procedures for quantitative analysis of abscisic acid (ABA) in sorghum. A bioassay with wheat coleoptiles proved simple and easily performed with good results. An immunoassay with a commercially available monoclonal antibody was also developed. It is very specific for free ABA, and can detect small quantities. Experiments were initiated to determine whether there are inherent differences in quantities of ABA that may contribute to genetically different sorghums. Experiments were also initiated to determine whether proline accumulation is related to Fusarium infection in sorghum. Greater quantities of proline accumulated in leaves and roots of infected plants than in controls, and amounts accumulated differed significantly between two genotypes. Research in Mali showed that soil plowing and crust breaking improved emergence and decreased soil resistance to penetration. There were genotype differences in response to the treatments. (NU-123)

Seedling Vigor and Stand Establishment of Pearl Millet

Project KSU-106
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Summary

Seed from two pearl millet hybrids, one a large seeded hybrid and the other a small seeded hybrid, were separated into size category and tested under a range of temperature and soil moisture conditions. Planting depths, soil moisture, and temperature had pronounced effects on emergence establishment and seedling growth. In general, seed characteristics had no effect on any of the variables measured.

Comparisons between grain sorghum and pearl millet for responses to rate and date of planting show that there were no consistent differences between the two crops in response to date of planting. Because of its ability to compensate in terms of head numbers per plant and seed number, pearl millet showed very little response to plant population in comparison to grain sorghum.

Objectives, Production and Utilization Constraints

Objectives

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

Determine under controlled conditions the interactions of seed characteristics and environmental factors.

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

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 PET exceeds 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 which often does not enable establishment of an adequate stand.

Project Output

Current work at Kansas State University with millet stand establishment examines seed quality effects of sorghum and pearl millet in both field and controlled environment studies.

- Two studies were conducted to investigate establishment and seedling vigor response of two millet hybrids to varying environmental and management factors in a growth chamber and in the greenhouse.

Approach

Greenhouse study. This experiment was designed to quantify seed size and planting depth effects on the establishment and seedling vigor of two millet hybrids under near optimum greenhouse growing conditions. The design was a randomized complete block with three replications over time. 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, 8, and 12 cm. Four seed size classes were used as shown in Table. 1.

Table 1. Description of seed sources for the greenhouse and growth chamber establishment and seedling vigor studies.

Characteristic 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

Growth chamber study. This study examined temperature (30, 35, and 40 C), hybrid (as above), depth of soil moisture regime and planting depth (as above) effects on establishment and seedling vigor. A split-plot design was used. Temperatures were main plots and combinations of the remaining three factors were subplots. Only the medium size seed was used. The soil moisture regime (SMR) treatments consisted of a moist top soil with 0.5 cm sand layer on the surface used to reduce evaporation, and a dry top soil with a 2 cm sand layer.

Both studies were conducted in pots 20 cm in diameter and 20 cm deep, and were watered to field capacity at planting. No watering was needed up to 14 days when establishment was recorded. Daily emergence counts were taken for computation of emergence index at eight days. Seedling height (a vigor parameter) was the distance from the soil surface to the tip of the most fully extended leaf.

Results

Greenhouse study. Statistical analyses of results showed that there were no significant hybrid or seed size effects on establishment at 14 days, emergence index, or seedling height while planting depth significantly affected all of these factors (Table 2). The results suggest that under near optimum growing conditions there is no benefit in establishment arising from hybrid and seed size selection, and that increasing depth of planting from 4 cm is detrimental.

Table 2. Effect of hybrid and depth of planting on establishment and seedling vigor in the greenhouse study.

Factor	Variable		
Planting depth (cm)	Emergence index	Establishment 14 days	Seedling height
		%	cm
4	26.8	74	38.1
8	9.1	37	21.2
12	0.1	1	1.2
LSD (5%)	2.9	9	5.9

Growth chamber study. Figure 1 shows that increasing both temperature and depth delay emergence and reduce establishment and that at 40 C or 12 cm planting depth, both rate of emergence and establishment are drastically reduced for each level of the other factor. For seedling height, the effect was the same except that there was a greater response to 40 C temperature at 12 cm, unlike the other variables.

Figure 2 shows that a dry top soil delays emergence and reduces establishment at 4 cm planting depth and that increasing planting depth delays emergence at both SMR's. The establishment for dry top soil regime was the same at 4 cm and 8 cm planting depths. Figure 3 shows drastic reductions in seedling height with increasing temperature for both hybrids and that the large seeded hybrid had superior seedling vigor at 30 C.

These results suggest that the hybrids used were not resistant or tolerant to high temperatures (40 C and above) in terms of germination, seedling survival, and vigor. Results also agree with the greenhouse study in that deeper planting depths seem detrimental if growing conditions are favorable (moisture and temperature in this case). A combination of 4 cm planting depth, at 30 C in a moist soil appears optimal for emergence and establishment..

Figure 1. Chamber study of temperature and planting depth effects on emergence rate, percent establishment, and seedling height.

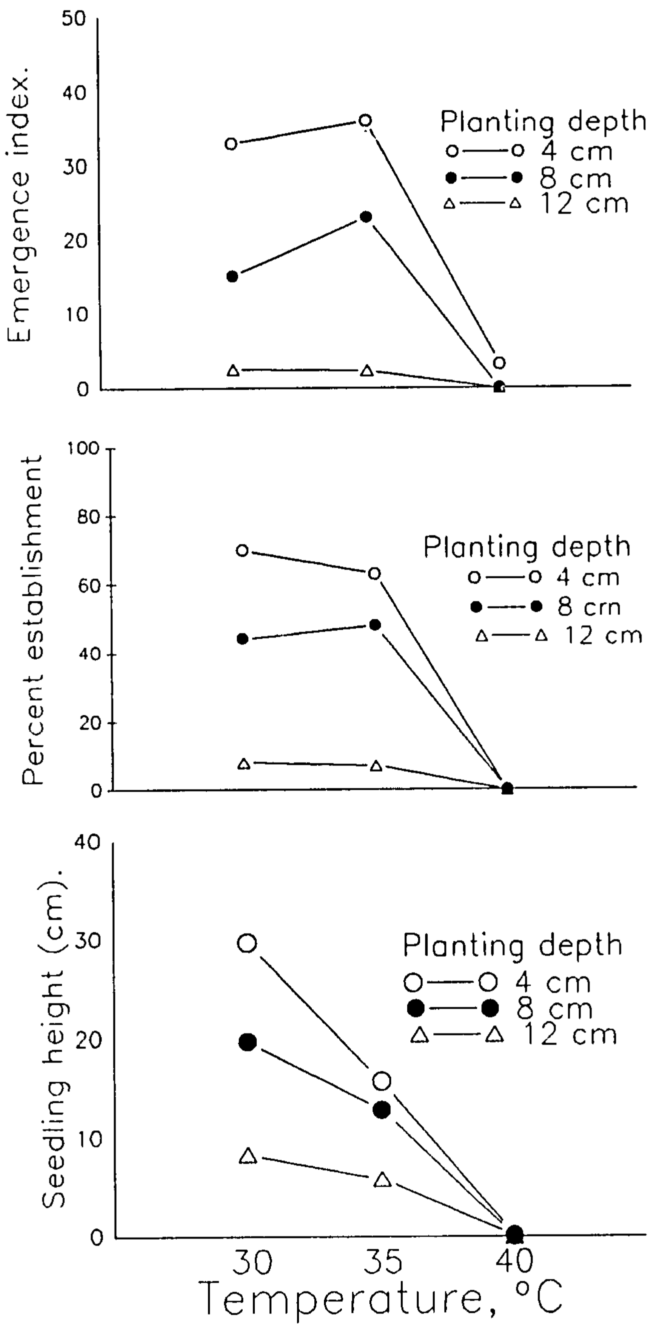


Figure 2. Soil moisture regime (SMR) and planting depth effects on emergence rate and per cent establishment.

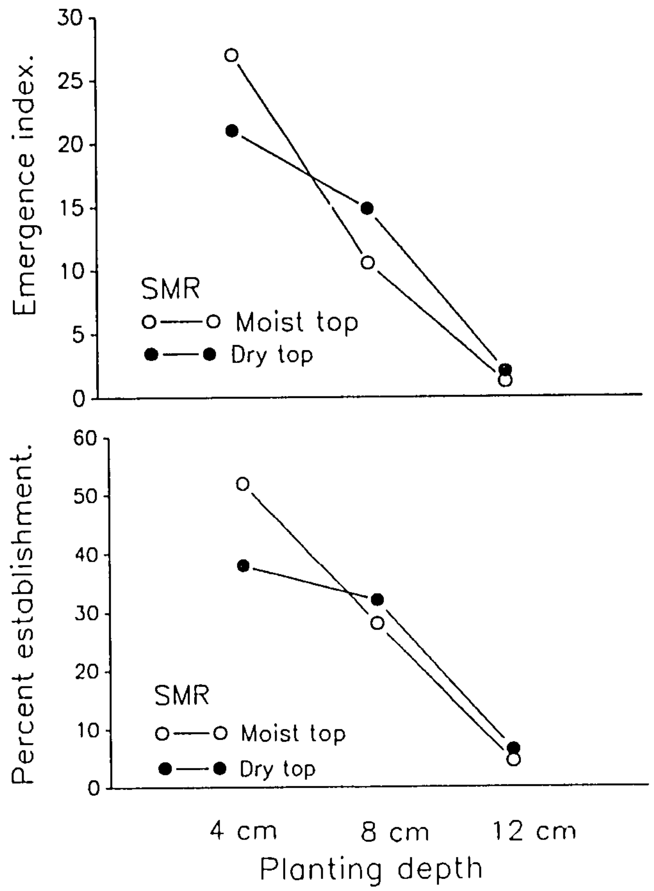


Figure 3. Temperature and hybrid effects on seedling height.

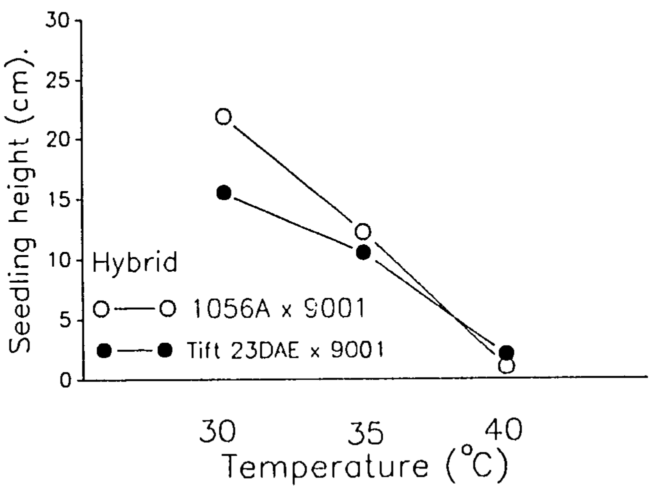


Figure 4. Yield response to rate and date of planting. St. John, 1988.

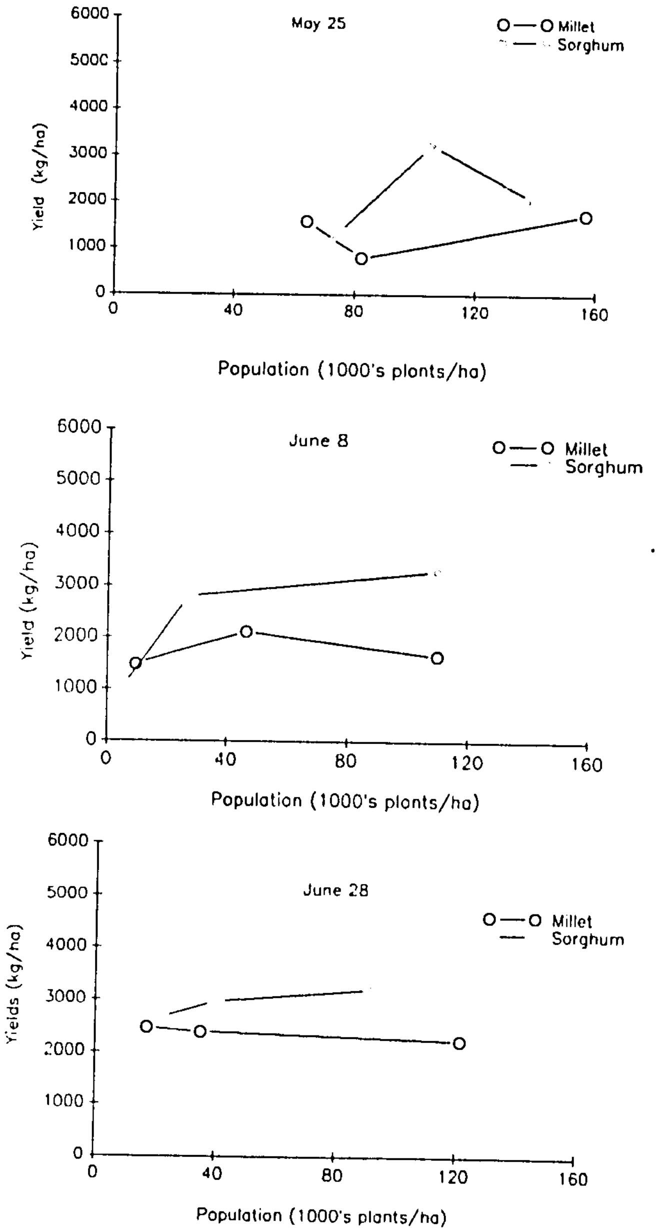
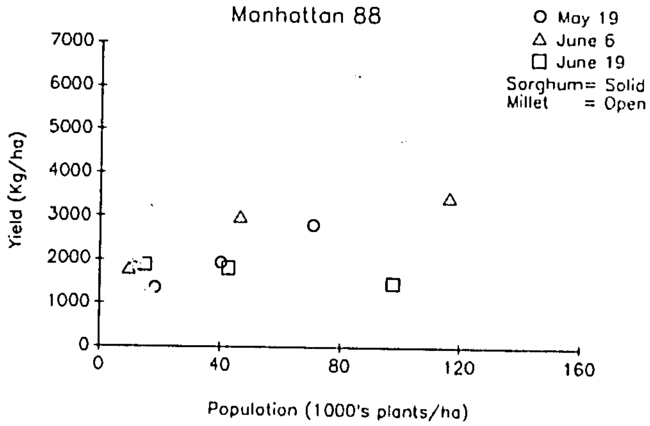


Figure 5. Sorghum and millet yield response to plant population



° 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.

Research Methods

A millet hybrid (81-1056 x 86-9001), a millet variety (Senegal Bulk), and a sorghum hybrid (DeKalb 39Y) were planted at 15,000, 45,000, and 135,000 plants/ha on three dates at Manhattan and St. John, Kansas. At Manhattan, the planting dates were 19 May, 6 June, and 27 June, and at St. John, 25 May, 8 June, and 28 June. The experiment was a split plot design with dates of planting as main plots and combinations of population and variety as subplots with three replications.

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/head were calculated based on yield, heads harvested, and seed weight.

Results

Senegal Bulk data were not used because of its poor stand establishment. At St. John there was no significant effect of population on millet yield and at Manhattan the effect was negligible. In contrast, sorghum yield increased with increasing population at both locations (Fig. 4 and 5).

Yield components of millet, particularly heads per plant, made up the differences among populations. The other yield components made a small contribution to offset the differences among populations. In sorghum, plant populations had no significant effect on yield com-

Figure 6. Effect of rate and date of planting on heads/plant, Manhattan, 1988.

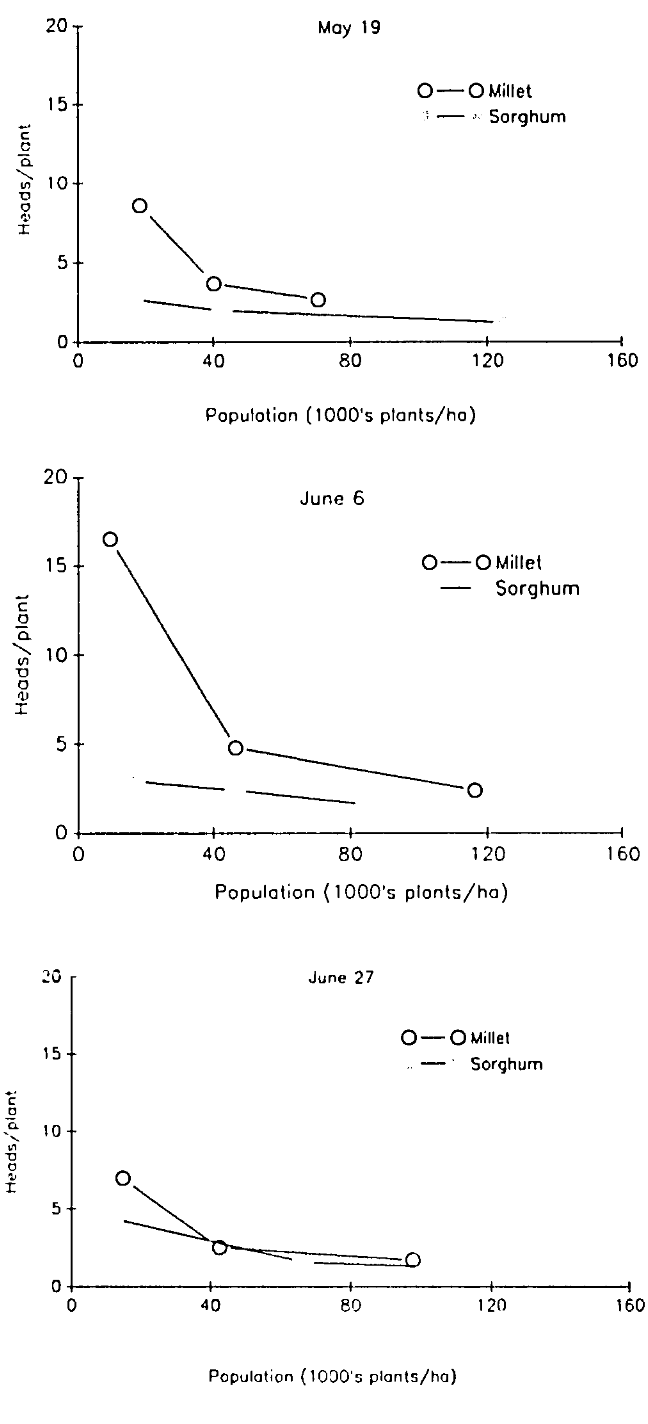
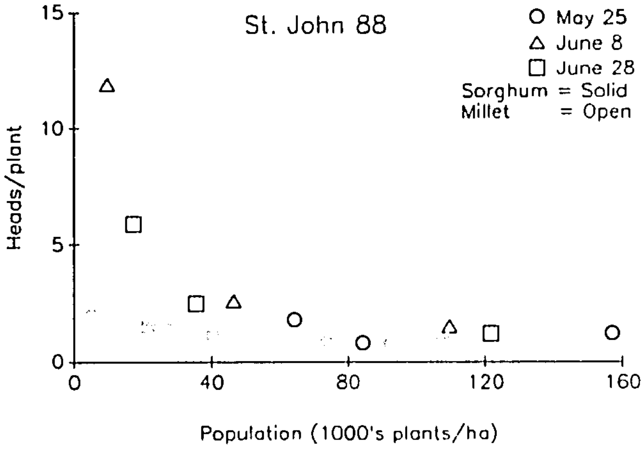


Figure 7. Sorghum and millet head number response to plant population.



ponents (Fig. 6 and 7). At St. John, there was a date effect on both crops. In sorghum, the second and third planting dates gave a higher yield than the first date at high populations, but there was no significant difference between the second and third dates. In millet, only the medium plant population showed a significant yield increase as planting date was delayed.

Publications

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 Research 20:41-49.

Gardner, J. C. and R. L. Vanderlip. 1989. Seed size and density effects on field performance of pearl millet. Trans. Kans. Acad. Sci. 92:49-59.

Mortlock, M. Y., and R. L. Vanderlip. 1989. Effect of seed quality on stand establishment of pearl millet: II. On-station millet experiments. Technical Report. 89-2.

Networking Activities

R. L. Vanderlip spent two weeks at the end of the 1987-88 growing season in Botswana working with the collaborating scientists in Botswana and investigating the possibility of a broader collaboration with the SADCC/ICRISAT program.

Botswana Agronomic Research

Project KSU-107
Richard Vanderlip
Kansas State University

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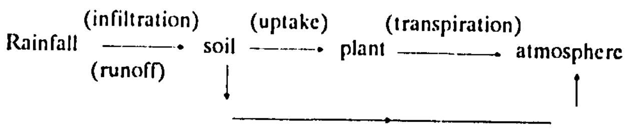
Summary

Food security continues to be a major goal for Botswana and other members of SADCC (the Southern African Development Coordination Conference). Since 1983 INTSORMIL, 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 crops and soil and crop management technology for dryland sorghum and millet production. USAID/Botswana and the Ministry of Agriculture are supporting these efforts both financially and logistically.

In developing their collaborative research program, Botswana and INTSORMIL scientists recognized the primary need for practical and sustainable technologies to deal effectively with the twin primary constraints of soil-moisture and soil-fertility deficits. They considered practical ways and means to manipulate the soil and crop that would increase the water transpired in the final step of the following catenary pathway:



As a result their collaborative research program became integrated and centered around long-term 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. The few years of 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.

With INTSORMIL help, a collaborative National Tillage Research Program was initiated. Under this program collaborative on-farm and on-station trials are being conducted on several promising soil-moisture conservation tillage/soil fertility improvement systems that can promote deeper moisture and root penetration, give better weed control, better crop establishment, and healthier crops. Results from multilocational trials clearly indicate that tillage and fertilizer management are key factors for increasing yields and rain use efficiency in Botswana and should be further 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 rainfed sorghum and millet crop yields by studies of sustainable systems for improving rain and soil-water use efficiency through manipulation of the crop/cropping system x cultural practice x soil interrelationships. Specifically: a) Evaluate on-farm rainfall runoff management systems. b) Evaluate crop response to improved tillage technology across various rainfall conditions and soil types. c) Evaluate the effects of manure and crop residue management on crop yields and stability over seasons and sites.

- Collaborate and support relevant national research efforts to improve and stabilize rainfed sorghum and millet crop yields, specifically, sorghum stand establishment, crop rotations, and climatic data analysis.

Constraints

The project seeks to develop sustainable agronomic production systems which stabilize sorghum and millet yields. Sorghum and millet production in Botswana is constrained principally by low rainfall and soil characteristics.

The low, irregular, and low-efficiency rainfall pattern contributes to a high risk of intraseasonal 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. The project addressed this issue through research on rainfall runoff management and tillage.

Sorghum is grown mostly 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. Primary tillage is necessary to improve structure and rainfall infiltration, to obtain good seedbed tilth, crop establishment and crop stands. These constraints were addressed in the research on residue management, and tillage.

Poor plant establishment is a problem related to soil properties, the condition of the seedbed, rainfall, and the quality of the seeds. Tillage, residue management, and rainfall runoff management all have an effect on stand establishment by improving the soil water status, fertility, and physical condition of the seedbed.

Research Approach and Project Output

Season Rainfall

The rainfall from 1 September to 30 May was 565 mm with distribution skewed toward the later part of the growing season. Rainfall which occurred between 9 January and early May made up approximately 68% of the total. Rainfall prior to this period was light and occurred in many low intensity and short duration storms.

Research Trials Summary

It is the philosophy of this project that sorghum grain yields must be stabilized at a significantly higher level than currently exists. Grain yield stability is the key factor if farmers are to make any meaningful resource investments in arable activities. Grain yields in the range of 1.0 to 2.0 Mg/ha in every year are possible through improved agronomic practices.

The research undertaken examined tillage practices, residue and manure management, crop establishment, and rainfall runoff management for crop production. These areas are the core of our efforts to stabilize grain yields and are detailed in the following sections.

Rainfall Runoff Management

Rainfall runoff management (RRM) is used to denote a range of rainfall runoff management schemes which seek to concentrate water for crop production. RRM trials were conducted in Francistown by G. Heinrich and S. Masikara (ATIP), in Mahalapye by J. Siebert and E. Modiakgotla (ATIP), and in Sebele by D. Carter and N. Persaud (INTSORMIL). Dr. S. Miller of the Land & Water Management Project collaborates with the project to measure the volume of runon. The research was categorized into two groups; 1) macrocatchment systems which collected rainfall runoff from off-farm sources, and 2) microcatchments which collected rainfall runoff from within the field immediately adjacent to the cropped area. More recently studies were initiated in collaboration with the Meteorological Services to derive parameters to aid in the design of such systems.

Macrocatchments-Research Methods

Runoff from a natural drainage channel was directed to a 0.5 ha portion of the field enclosed by a perimeter ridge 20-25 cm high. Shown in the aerial photograph in Fig. 1 are: A) the natural drainage channel, B) the diversion ridge across the channel, C) the delivery channel and, D) the area enclosed by the perimeter ridge.

The system, built in 1986/7 by INTSORMIL, is maintained by the farmer. Maintenance includes repairs of eroded areas along the ridges and the removal of sediment and debris from the channel.

The farmer plowed the runon area with a donkey-drawn, two-furrow plow during the winter and again four weeks prior to planting. A fertilizer experiment using 3-2-1, at a rate of 375 and 0 kg/ha was applied in a replicated (r=3) RCB design in the runon area. The same rates were applied to replicated (r=2) plots in the control area. Sorghum variety Segaolane was planted on 2 November. On 12 December Segaolane was planted between the rows of the 2 November planting. On 9 January the entire runon area and the control were plowed and replanted with Segaolane.

Runoff volume and duration were measured using an H-flume equipped with an electronic flow recorder. This was a collaborative effort between the Land and Water Management Project and INTSORMIL. All runoff events were measured except two in September before the H-flume was instrumented.

Rainfall amount and intensity was measured at the site using a tipping bucket raingauge. This was a collaborative effort between the L&WMP, Agricultural Meteorological Department and INTSORMIL.

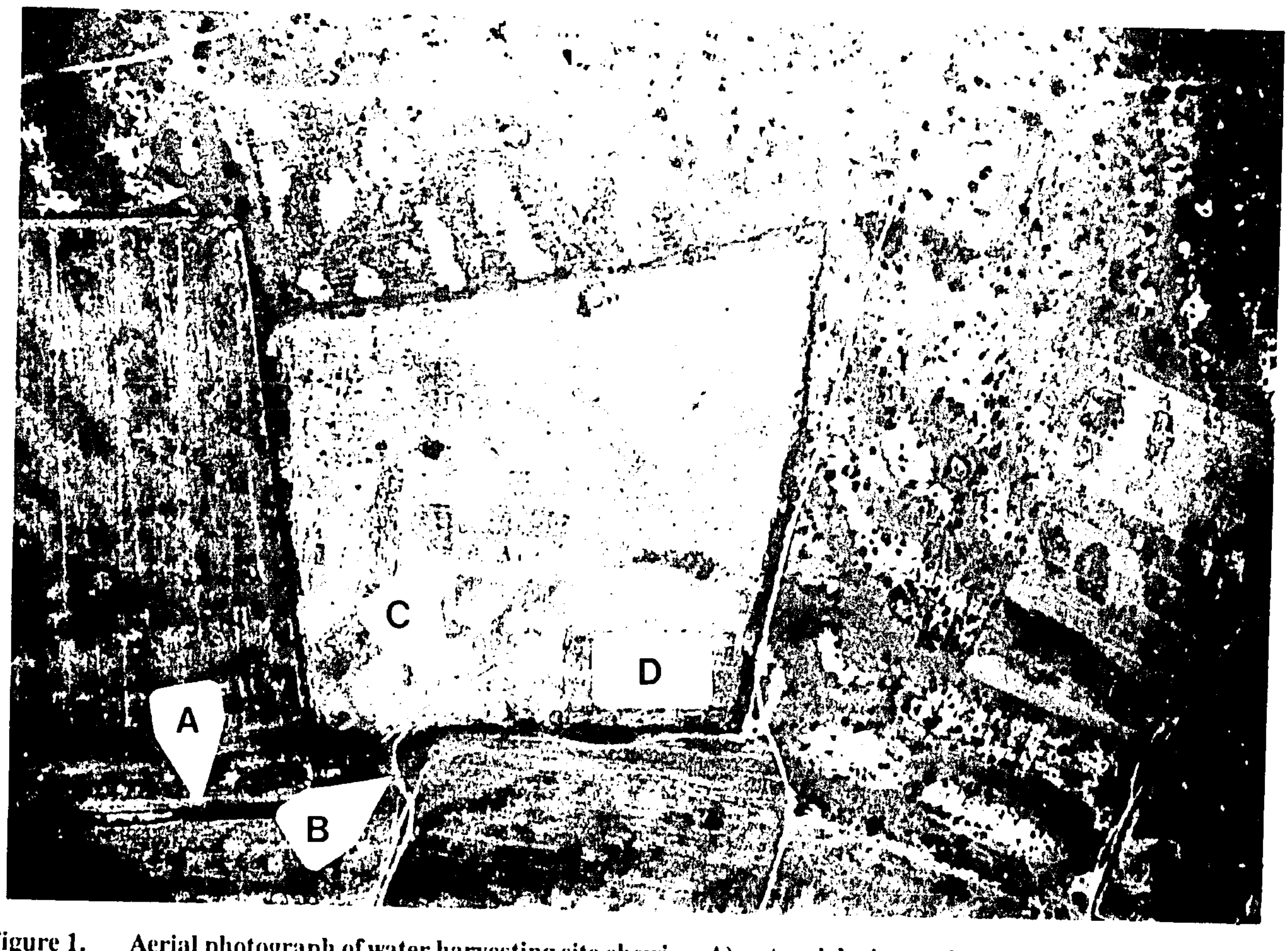


Figure 1. Aerial photograph of water harvesting site showing: A) natural drainage channel, B) the diversion ridge across channel, C) the delivery channel, and D) the area enclosed by the perimeter ridge.

Soil moisture was measured in the runon area and in various control plots using a neutron probe. Access tubes were placed across the microtopography at 'high', 'middle' and 'low' positions in the runon and control areas. Tubes were monitored weekly to a depth of 150 cm. in 20 cm. intervals.

Yield and components of yield were measured in the fertilizer plots within the runon area and in the control plots. Six plots 5 x 44 m were harvested in the runon area. The length of these plots spanned the runon area and included both high and low areas of microrelief. A .4 ha portion of the control area was systematically sampled by harvesting six rows spaced 10 rows apart. Because of the field shape, these six rows varied in length from 12 to 44 m. Total area sampled in the combined six rows was 210 m^2.

Macrocatchment-Research Findings

Stover and grain yields were similar between the control and the water harvesting plots (Table 1). Given the late planting date (9 January) and the above average rainfall conditions during the crops' growth, the similarity in yield is not unexpected. Plant populations were slightly lower than desired, 2.5 to 3.0 pl/m^2 was the target population, however, heads/m^2, a reflection of vigorous tillering, compensated for low population.

Table 1. Yield and yield components from the control and water harvesting areas.

Treatment	Plants/m^2	Heads/m^2	Grain	Stover
			---- (kg/ha) ----	
Control	2.0	5.0	1287	1221
Water harvt.	1.3	4.0	1240	1093

The amount of residual soil moisture from the previous season was slightly higher in the water harvesting area than the control. This difference probably reflects water harvested during runon events late in the 1987/88 season. In the control plot, microtopographic effects were apparent as the 'low' area had soil moisture contents similar to the water harvesting area, while moisture content decreased toward the relatively 'high' areas. In effect, the topography tended to create a natural water harvesting effect.

The effect of the water harvesting on soil moisture was shown in the comparison between soil moisture content before and after the 1 September runon event (Table 2). Soil moisture between 6 July and 4 October in the control plot decreased slightly from 1.22 to 1.77 mm/cm, probably reflecting moisture lost from tillage operations after the rain, while soil moisture content increased in the water harvesting area, 1.48 to 1.85 mm/cm. This enhanced early season soil moisture status improves the likelihood of early cultivation, because the soil is completely wetted, and thus broadens management options to address the major tillage/planting constraint in Botswana.

Table 2. Soil moisture status on 6 July and 4 October 1988 in the control and water harvesting areas.

	Position on Microrelief							
	Low		Middle		High		Average	
Treatment	6-Jul	4-Oct	6-Jul	4-Oct	6-Jul	4-Oct	6-Jul	4-Oct
	---------- (mm water/cm soil) ----------							
Control	1.53	1.54	0.99	0.95	0.99	0.81	1.22	1.17
Water harvt.	1.57	n.a.	1.36	1.89	1.47	2.26	1.48	1.85

The runoff event on 1 September realized one of the benefits of water harvesting. However, subsequent poor plant establishment coupled with a severe infestation of stalk borers necessitated that the crop be plowed down and replanted. The benefit, thus, was negated by suboptimal management. Two items are important from this experience; 1) the water harvesting system successfully captured runoff water which, without such an intervention, would not have been available to the crop, 2) the successful application of the water harvesting technology must be linked to the application of management practices which achieve appropriate plant populations and pest control. In short, the water harvesting system demonstrated a successful manipulation of soil water. However, the benefits of this enhanced soil water regime comes through the application of 'good' management practices.

Residue Management Study

Research Methods

This study consisted of two experiments which examined the use of manure and stover. The trials were established in 1984/5 and managed by D. Carter (INTSORMIL). Trial 1, the Residue Management trial (RM), had manure and stover incorporated into the soil at rates of 9 and 5 Mg/ha., respectively. The trial was conducted at the Goodhope substation and one on-farm site near Sebele (Mmamashia). Sorghum variety Segaolane has been grown every year in the RM trial. Trial 2, the Manure/Mulch (MM) trial, had manure (9 Mg/ha) incorporated into the soil and stover applied as a mulch at a rate of 5 Mg/ha. The 5 Mg/ha mulch produced a ground cover of 45-60%. It was conducted at Goodhope substation and two sites at Sebele Research Station, B33 and Block 8E. During the first two years the MM trial had 16 treatments, 8 varieties and 8 sorghum-based cropping system treatments. However, in the third year millet variety Serere 6A was grown. This year Segaolane was grown. Soil moisture was monitored in the MM trial. The objective of the trials was to determine the long-term effect of residue management on soil fertility as measured by grain and stover yield, and soil organic carbon and nitrogen.

Research Findings

In Trial 1, the incorporation of either manure or stover significantly improved sorghum grain and stover yields. Grain yield with and without manure was 1.1 and 3.2 Mg/ha, respectively, while stover yield was 1.6 and 3.4 Mg/ha, respectively. Soil-incorporated stover increased grain from 1.8 to 2.5 Mg/ha, while stover yield increased from 2.1 to 2.9 Mg/ha. In Trial 2, the incorporation of manure significantly improved sorghum grain (Table 3) and stover yield, but mulch had no effect on either.

Results from this year's experiments supported findings from previous years. As reported previously, the incorporation of organic fertilizers, either manure or stover, improved grain yield. Soil type, however, influenced the effect of manure, with greatest yield responses on the sandy soils, Goodhope and Sebele B8E, and little benefit on the heavier soil at Sebele B33. Mulch had no detectable effect on yield at any site. Analyses for organic carbon and N are in progress.

Table 3. Sorghum grain yield under different combinations of applied manure at each site.

Site	Applied manure, Mg/ha	
	0	5
Goodhope	1.6	2.9
Sebele B33	3.1	3.2
Sebele B8E	1.2	2.6

National Tillage Research Program
1988/89 National Tillage Trials

Research Methods

On semiarid dryland farms in Botswana, tillage practices can be used to increase the ratio of infiltration/precipitation, uptake/infiltration, and transpiration/evapotranspiration in the following catenary pathway:

$$\text{Rainfall} \xrightarrow[\text{(runoff)}]{\text{(infiltration)}} \text{soil} \xrightarrow{\text{(uptake)}} \text{plant} \xrightarrow{\text{(transpiration)}} \text{atmosphere}$$

Comprehensive data are needed on the interrelationships between tillage systems/soil physical properties/soil moisture availability and moisture use/soil fertility that can affect crop establishment and crop yields.

INTSORMIL, in close collaboration with scientists of the Department of Agricultural Research and the Dept. of Field Services in the Ministry of Agriculture, helped initiate, develop, and implement the National Tillage Research program to address this need. The overall objective of this program is to develop improved tillage technology for Botswana's farmers. The specific purpose of the 1988/89 tillage trails was to evaluate, for various soils and for different rainfall conditions, the effect of several moisture conservation tillage practices on sorghum production and on seedbed and rootbed conditions during the growing season.

Appropriate organization was considered a key to the successful implementation of this program. In August 1988 a National Tillage Research working group was established. As shown in Figure 2, this working group serves both planning and technical functions. The research results and other outputs of the program feed directly into the generation of improved tillage technology and practices for Botswana farmers. This information is also fed back into the planning activities of the working group in a continuous effort to keep the program relevant and responsive to the needs in this area of research.

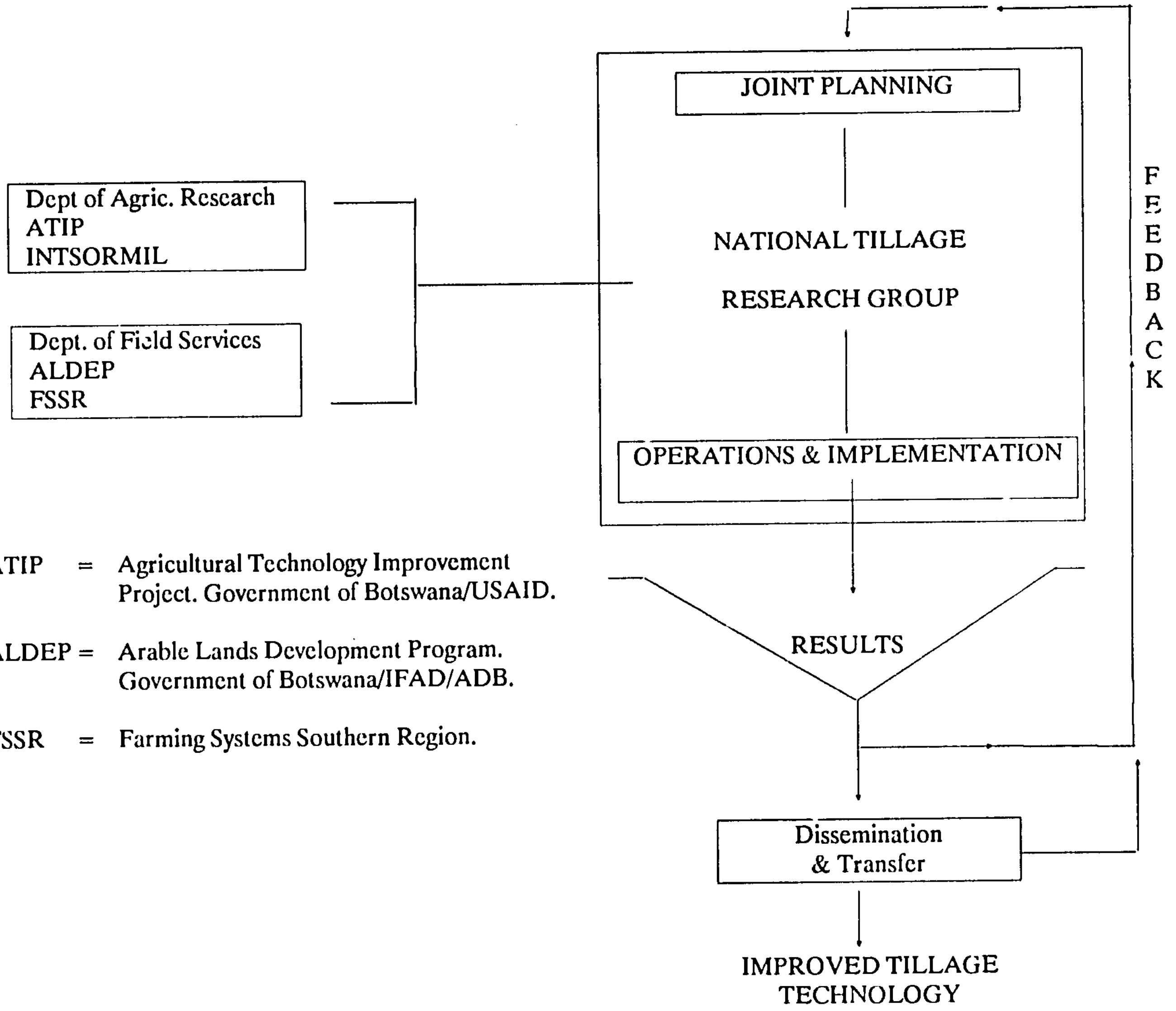
For the 1988/89 trials, nine sites were selected and coded as follows:

Site code	Location	Farmer
F1	Mathangwane	Zimundu
F2	Mathangwane	Mpatane
M1	Mahalapye	Moseki
M2	Mahalapye	Dipatane
M3	Mahalapye	Lekone
S1	Sebele	expt. station
P1	Tswidi	Ramaokane
P2	Tswidi	Katholelo
J1	Sese	Mabine

The following five core tillage treatments were evaluated using an RCB design at all sites except J1. At J1 the tillage treatments were combined with or without 15 kg P/ha as triple superphosphate in a split plot design.

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

T2 = Double ploughing: Early spring moldboard ploughing with first rains followed by second ploughing



ATIP = Agricultural Technology Improvement Project. Government of Botswana/USAID.

ALDEP = Arable Lands Development Program. Government of Botswana/IFAD/ADB.

FSSR = Farming Systems Southern Region.

Figure 2. Schematic of organization of National Tillage Research program in Botswana.

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%.

At several sites other treatments were added as appropriate to suit specific needs and objectives.

Research Findings

Table 4 shows the adjusted sorghum grain yields for the tillage treatments at the various sites except J1. Adjusted yields represent the yields from all mature heads harvested corrected for heads already harvested or grazed heads. Adjustments were required at few sites. The results in Table 4 indicate a beneficial effect, at some of the sites, of early ploughing. Table 5 shows the effect of the tillage treatments and fertilizer P at site J1. Application of 15 kg P/ha increased yields 2 to 3-fold for several treatments. The soil profile moisture was monitored gravimetrically at all sites. Table 6 shows the water use calculated from these observations for site S1.

Table 4. Effect of tillage treatments on sorghum grain yields at several sites in Botswana.

	Adjusted grain yields, kg/ha at 10% moisture						
	Site						
Treatment	F1	M1	M2	M3	S1	P1	P2
T1-Conv.	789	1255	1060	606	1836	1351	1470
T2-DP	1020	1334	1273	682	2430	2812	1365
T3-Deep rip	701	683	989	585	1667	1657	1196
T4-Plow + cult.	964	938	740	634	2504	3129	1821
T5-Conv. +WRS	484	1103	773	744	1363	1531	882
LSD.05	558	NS	NS	NS	509	512	NS

NOTE: Site F2 was planted but was destroyed by field mice.

Table 5. Effect of tillage treatments with or without 15 kg P/ha on sorghum grain yields at site J1.

	Adjusted grain yields, kg/ha of 10% moisture					
Fertilizer	T1 Conv.	T2 DP	T3 Deep rip	T4 Plow + cult.	T5 Conv. + WRS	Mean
- P	592	768	647	714	585	649
+ P	2802	2261	864	2144	2095	1769
Mean	1699	1515	756	1429	1340	

Note: 1. LSD.05 for comparing tillage means for each fertilizer level = 597.
2. LSD.05 between the two P treatments for each tillage treatment = 612.

Table 6. Rain use of various tillage treatments used in National Tillage trial at site S1, Sebele.

	Water storage and use in mm estimated for 1 meter of the profile for the following intervals of the growing period					
	05/12/88 to 08/02/89		08/02/89 to 09/03/89			
Treatment	S	P-S	S	P-S	P-S	Kg grain/ha P-S
T1-Conv.	24.3	116.7	3.8	150.9	267.6	6.861
T2-DP	15.7	125.3	-11.4	166.6	291.9	8.325
T3-Deep rip	-2.3	143.3	8.5	146.2	289.5	5.758
T4-Plow+cult.	-14.8	155.8	11.4	143.3	299.1	8.372
T5-Conv. + WRS	45.9	95.1	-2.6	157.3	252.4	5.400
Interval in days	65		29			
P values	141.0		154.7			
0.5 x Penman PET	166.4		58.0			

NOTE: Planting date = 1 December 1988.
S Values = Difference in soil water stored to 1m. at later - earlier date in each interval.
P Values = Difference in cumulative rainfall at later - earlier date for each interval.
denotes "the sum of".

The results indicate better soil water use efficiency for the early ploughing tillage systems. Similar results were obtained for the other sites.

This program has resulted in:

- A comprehensive tillage research program involving a close working relationship between the Department of Agricultural Research and the Department of Field Services.
- A model organizational structure for subject matter research and problem solving research. This model has been adopted for other research areas in the Department of Agricultural Research.
- A clear indication that tillage and fertilizer management can increase yields and should be further studied.
- Interest from IBSNAT - the International Benchmark Sites for Agrotechnology Transfer Project to discuss possible collaboration with this program.

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

Miscellaneous Research Support Studies

INTSORMIL has continued where relevant to support the activities and interests of the national researchers. Support was provided to:

- Meteorological Services researchers in a joint study to develop an appropriate set of parameters to calculate potential evapotranspiration with Penman's formulae. A computer program was developed and is currently being evaluated.
- Dr. L. Gakale's crop rotation program by evaluating the long-term effects of cereal-legume rotation on soil chemical properties and soil moisture status and balance.
- Mr. K. Molapong's greenhouse and field studies to develop soil test calibrations for P for 20 soils of Botswana.
- Ms. Malepa's Ph.D. dissertation research on critical levels of macro and micronutrients for 12 soils of Botswana.

Publications and Presentations

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Youngquist, J. B., D. C. Carter, W. C. Youngquist, and M. D. Clegg. 1989. Phenotypic and agronomic characteristics associated with yield and yield stability of grain sorghum in low rainfall environments. Submitted to Field Crops Research.

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Persaud, N., L. Gakale, M. Ouattara, and D. Carter. 1989. Improving and sustaining the productivity of the sorghum and millet producing soils of the subsaharan semi-arid tropics. Proceedings of the 1st All African Soil Science Society Congress, Kampala Uganda 5-10 Dec. 1988.

Gakale, L. and N. Persaud. 1989. An overview of the soil resource and its management in Botswana. Proceedings International Conference on Soil Quality in Semi-arid Agriculture, Saskatoon, Canada, 12-16 June 1989.

Contributions to the Department of Agriculture Research, Annual Report 1987/88. (a) Manure and residue management study (b) Report on an onfarm rainfall runoff management study (c) Deep ripping vs. moldboard ploughing.

Networking Activities

INTSORMIL researchers in Botswana participated in:

Land Use Planning Workshop by leading a discussion and field trip to the INTSORMIL water harvesting site near Gaborone.

ATIP Team Meetings.

Farmer field days held in Mahalapye and Francistown.

National Tillage Trial Field day Southern Region.

Field days for technical officers at Sebele.

Remote Sensing Workshop jointly sponsored by USAID and GOB.

Study by scientists from the Free University, Amsterdam, Netherlands and Goddard Space Center, Maryland, U.S. by collection of soil moisture data.

The 1st All African Soil Science Society Congress in Kampala, Uganda.

INTSORMIL is a standing member of:

The National Committee for Agricultural Meteorology.

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

The National Tillage Research Group which coordinates research on various tillage practices.

Agronomy and Cropping Systems

Project NU-113
Max D. Clegg and Stephen C. Mason
University of Nebraska

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Summary

Studies in Botswana indicated that improved soil fertility (due to crop rotation or manure application) increased grain sorghum stover yield in 12 environments. However, grain yields increased only when biomass production (grain plus stover) exceeded 1.0 Mg ha^{-1}. At lower biomass yields, improved fertility did not improve grain yield.

Rotation studies were initiated in Sudan, and the groundwork was laid for cropping systems studies in Mali starting in 1990.

Pearl millet showed a quadratic yield response to nitrogen application in both 1987 and 1988. Intercropping systems with improved varieties and higher plant densities produced more grain than traditional systems. Pearl millet yields as influenced by cropping systems were not consistent across years. In 1988 pearl millet produced the greatest yield following a cowpea sole crop and the lowest yield following the traditional intercropping system.

The annual nitrogen removal by grain sorghum increased linearly from 59 kg ha^{-1} yr^{-1} for the zero N treatment to 143 kg ha^{-1} for 171 kg ha^{-1} applied N. Following a soybean previous crop 102 kg N ha^{-1} yr^{-1} was removed by the zero N treatment, and N removal peaked at the 114 kg ha^{-1} applied N rate. Residual study of soybeans grown in rotation with grain sorghum indicated that soybean present two years previous to grain sorghum contributed 18-24 kg ha^{-1} NO_3-N and increased grain sorghum yield by 1.4 mg ha^{-1}.

Objectives, Production and Utilization Constraints

Objectives

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

Study the "rotational effect" in grain sorghum-soybeans and millet-soybean rotations by evaluating: (a) nitrogen contribution of legumes, (b) soil microbial populations, (c) soil physical and chemical properties, and (d) soil moisture relationships. At present isolines of non-nodulating and nodulating soybean have been incorporated into the study.

Evaluate the nitrogen contribution of intercropped cowpeas harvested for forage and grain to pearl millet.

Evaluate short season lines and hybrids of grain sorghum and maize for agronomic characters and use in cropping systems.

E. luate stand establishment properties of grain sorghum lines used in PRF-107 breeding programs for drought tolerance.

Determine the nitrogen and other nutrient dynamics (plant and soil) using improved pearl millet, grain sorghum, cowpea, and groundnut cultivars in common Malian intercropping systems under different crop residue and fertilizer management schemes and yield response of traditional and improved pearl millet and sorghums to different residue management schemes.

Determine the yield, bi-nitrogen availability and water use of grain sorghum and pearl millet grown in rotation with legumes in Sudan.

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 site, 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 NU-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

Improved fertility on grain sorghum [*Sorghum bicolor* (L.) Moench] fertility in low rainfall environments (Joan Youngquist)

Research Methods

When soil fertility is not adequate for plant growth, low crop yields occur even with ample water. Therefore, low fertility (particularly nitrogen) is often a major constraint for production of cereal crops. The objective of this research was to determine the effect of improved fertility on grain sorghum productivity in low rainfall environments. Grain sorghum was grown in Botswana in 1984/85 and 1985/86 in a total of 12 environments. The experiment was planted in a split plot completely randomized block design at three locations with low (no amendments) and high (9 t ha^{-1} manure plus 5 t ha^{-1} mulch) fertility on two dates and replicated four times. Sorghum productivity as influenced by soil fertility was compared using an environmental model to minimize the effect of environment (1). The bio-index is the mean total biomass (grain stover) yield for each environment and as its values increase the environment has greater productivity.

Research Findings

Sorghum grain and stover yields ranged from 0.15 to 3.10 and 0.70 to 3.6 Mg ha^{-1} respectively (Figs. 1 and 2). The model indicated a linear yield increase with improved environment and a greater yield increase with added fertility. Improved soil fertility was more effective in increasing yields of stover in all environments (Fig. 3). However, fertility was more effective in increasing yield of grain when the environments were capable of supporting total biomass (grain stover) yield of 1.0 Mg ha^{-1} or more (Fig. 4). At total biomass yield below this, improved fertility was ineffective or even detrimental for grain production. This last observation may indicate why fertility usually isn't considered limiting because many farmers' cereal grain yields are not above 1.0 Mg ha^{-1}.

Yield, bi-nitrogen availability and water use of grain sorghum and pearl millet grown in rotation with legumes in Sudan (Mirghani Mohamed).

Rotation experiments were established at Wad Elhari and Wad Medani last season (1988). Total soil characterization analyses were made. The soils were found to have a very high pH and may indicate iron deficiencies. Initial grain, straw and bio-yields and yield components were taken. *Striga* was a problem at Wad Medani.

Fig. 1. Grain Sorghum Yields
Botswana, 1984/86

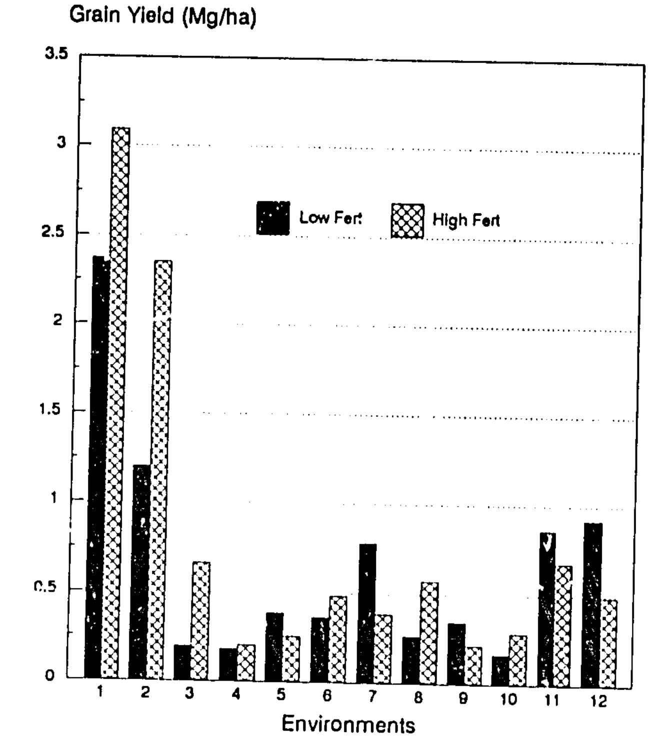


Fig. 2. Sorghum Stover Yields
Botswana, 1984/86

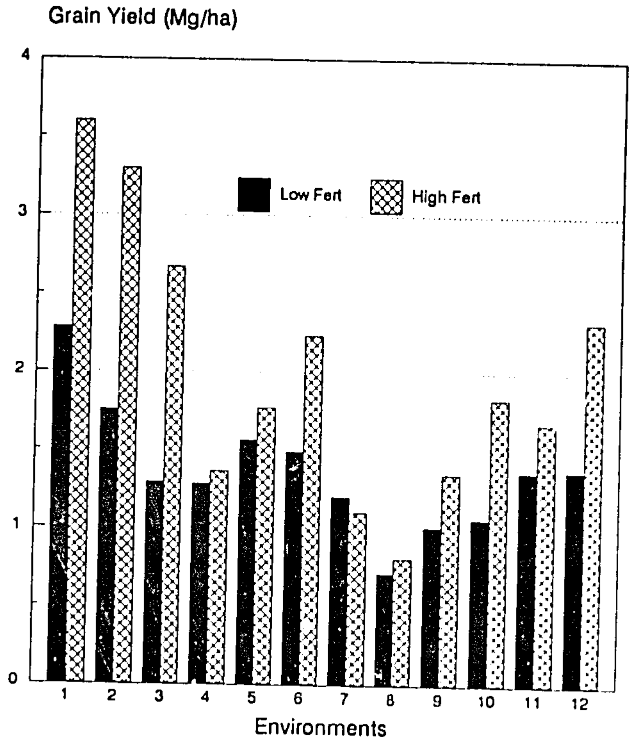


Fig. 3. Sorghum Stover Yields
Botswana, 1984-86

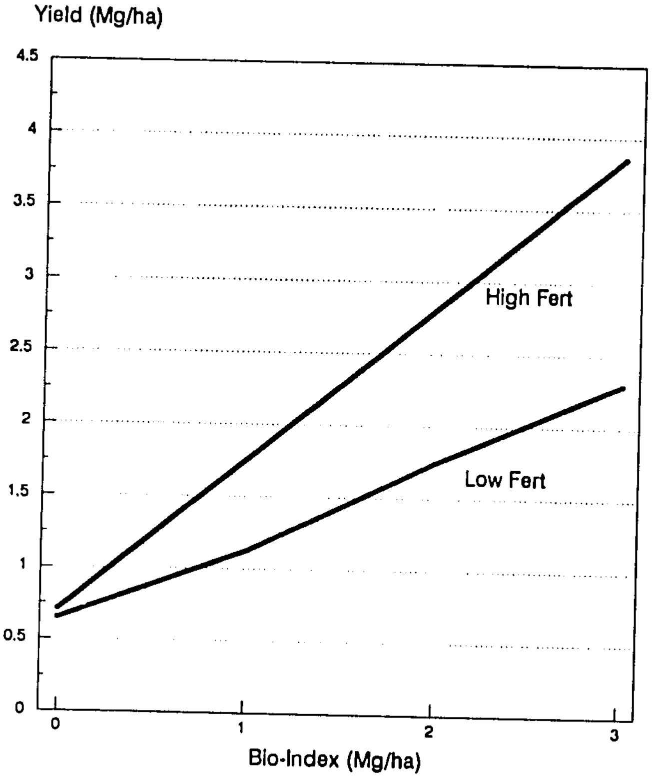
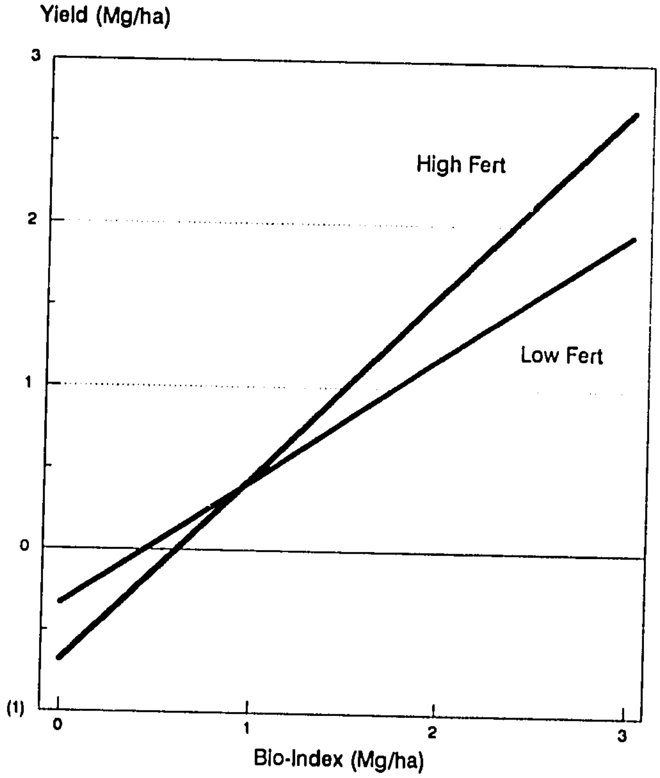


Fig. 4. Sorghum Grain Yields
Botswana, 1984-86



- Steve Mason - International

Nitrogen contribution of intercropped cowpea

Research Methods

A three year field study to evaluate the nitrogen contribution of intercropped cowpea harvested as forage and grain to pearl millet was initiated in 1987. This experiment includes three intercropping systems along with sole crops of both cowpea and pearl millet. Immediate nitrogen contribution was measured in 1987 and 1988, and residual nitrogen contribution in 1988 and 1989 by measuring yield and dry matter production, nitrogen removal, nitrogen concentration of critical plant parts, and nitrogen status of the soil.

Research Findings

Pearl Millet

In 1987 application of nitrogen from 0 to 150 kg ha^{-1} resulted in a quadratic yield increase from 780 to 1182 kg ha^{-1} (Fig. 5). A similar response occurred in 1988 except the maximum yield of 1195 kg ha^{-1} occurred at the 100 kg ha^{-1} rate. In 1988 both the intermediate (improved variety, higher plant density) and intensive intermediate plus nitrogen fertilizer intercropping systems produced 300 to 350 kg ha^{-1} more grain than the traditional intercropping system (Table 1). This trend was also present in 1987, but yield differences among cropping systems were smaller except for the intensive system with cowpea harvested for forage which had the greatest yield (1038 ha^{-1}). This was the only case when harvesting cowpea for forage (mid-pod fill) resulted in a pearl millet grain yield difference from systems where cowpea was harvested for grain.

Fig. 5. Pearl millet grain yield as influenced by nitrogen application rate in 1987 and 1988.

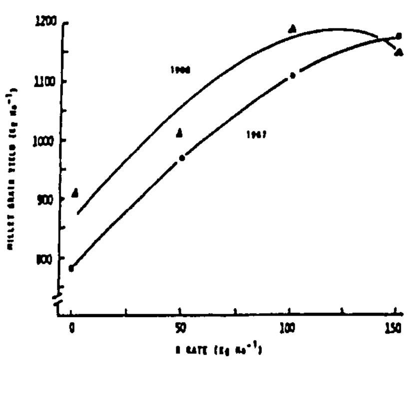


Table 1. Cropping system influence on pearl millet grain yield in 1987 and 1988.

Cropping system	Traditional	Improved variety Higher plant density	Plus N fertilizer
	....	kg ha^{-1}	....
		1987	
Intercrop-Cowpea Forage	609	654	1038
Intercrop-Cowpea Grain	596	706	813
Sole Crop		779	1110
LSD (0.10) = 221			
		1988	
Intercrop-Cowpea Forage	580	812	842
Intercrop-Cowpea Grain	600	947	943
Sole Crop		908	1194
LSD (0.10) = 1[illegible]3			

Pearl millet stover yields were not consistent across years. In 1987 the greatest stover yields occurred with the traditional cropping system, whereas in 1988 this system produced the lowest stover yields (Table 2). In the more intensive systems fertilizer application increased stover production in 1987, and for the sole crop system in 1988. Harvesting cowpea for forage (mid-pod fill) or for grain had no influence on pearl millet stover production.

Table 2. Cropping system influence on pearl millet stover yield in 1987 and 1988.

Cropping System	Traditional	Improved variety Higher plant density	Plus N fertilizer
	....	kg ha^{-1}	....
		1987	
Intercrop-Cowpea Forage	3456	2796	3000
Intercrop-Cowpea Grain	3669	2528	3493
Sole Crop		2795	3374
LSD (0.10) = 776			
		1988	
Intercrop-Cowpea Forage	1630	3354	2265
Intercrop-Cowpea Grain	1935	3600	2302
Sole Crop		2620	3295
LSD (0.10) = 873			

Cowpea

The intermediate and intensive intercropping systems resulted in 250 to 390 kg ha^{-1} increase in cowpea grain yield over the traditional system. However, the sole cropped cowpeas produced approximately 450 (1988) to 1000 (1987) kg ha^{-1} more grain than the best intercropping system. The traditional intercropping system and the sole crop produced approximately 350 kg ha^{-1} more cowpea stover than the intensive intercropping systems in 1987. The same trends were present in 1988, except a crop failure occurred for the traditional cowpea intercropping system.

Pearl Millet-Residual

In 1988 the residual effects of intercropping, cowpea, and nitrogen application were measured. Pearl millet produced the lowest yields following the traditional intercropping system with the highest yield of 1074 kg ha^{-1} occurring following the cowpea sole crop harvest for forage at mid-pod fill. Pearl millet yields following pearl millet previous crop which received 0 and 150 kg ha^{-1} were approximately 850 kg ha^{-1} while in plots receiving 50 or 100 kg ha^{-1} last year the yields were approximately 660 to 710 kg ha^{-1}. This unexpected result suggests that the greater grain yields at the 50 and 100 kg ha^{-1} rates in 1987 depleted the soil of nitrogen for the succeeding crop, while the zero and 150 kg ha^{-1} rates left some nitrogen in the soil.

- Max Clegg - Domestic

Grain sorghum/soybean rotation.

Research Methods

Sorghum and soybean are two crops that are grown in rotation, since both require similar climatic conditions. Measurement of nitrogen in the seeds allows for direct comparison of the crops. The objective was to determine the relationship of nitrogen removal in the seed of sorghum and soybean as affected by crop rotation and applied nitrogen. A randomized complete block design with four or five 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 plots. Data were taken from the two middle rows of six row plots. Annual nitrogen removed was determined from seed nitrogen and yield. Percent nitrogen recovery of applied nitrogen was calculated by:

$$\%N_{rg} = [(N_{gf} - N_{gc})/N_a] \times 100.$$

Where: $\%N_{rg}$ is nitrogen recovered in the grain, N_{gf} is nitrogen in grain from fertilized plots, N_{gc} is nitrogen from control (0 N applied) plots, and N_a is the amount of nitrogen applied to the plots.

Research Findings

The amount of nitrogen removed annually was nearly the same for continuous soybean or soybean after sorghum (all N levels), and ranged from 161-172 kg N ha^{-1} yr^{-1} (Table 3). For sorghum, the annual amount removed increased nearly linearly from 59 kg N ha^{-1} yr^{-1} for zero N treatment to 143 kg N ha^{-1} for 171 kg ha^{-1} applied nitrogen. Annual removal of nitrogen by sorghum after soybean was 102 kg N ha^{-1} for 0 N treatment and increased to 134 kg N ha^{-1} for 114 kg ha^{-1} applied nitrogen. An additional 57 kg ha^{-1} applied nitrogen resulted in no further change. Percent N recovery of applied N as grain averaged 27% for sorghum grown after soybean as compared to 57% for sorghum grown continuously (Table 4). The additional amount of available nitrogen contributing to yield following soybean reduces the efficiency of N use by sorghum.

Table 3. Average annual nitrogen removed in grain of sorghum and soybean (1978-1988) with different levels of nitrogen applied when in sorghum.

Applied[1] nitrogen	Sorghum after sorghum	Sorghum after soybean	Soybean after soybean	Soybean after sorghum
		Kg grain N ha^{-1} yr^{-1}		
0	46	100	161	171
57	92	114	...	167
114	122	134	...	162
171	143	137	...	172

[1]Nitrogen applied only when in sorghum

Table 4. Percent recovery of applied nitrogen in seed of sorghum.

Applied[1] nitrogen	Sorghum after sorghum	Sorghum after soybean
0	..	..
57	61	28
114	58	31
171	51	22
Average	57	27

[1]Nitrogen applied only when in sorghum

- Steve Mason - Domestic

Research Methods

A crop rotation experiment was initiated in 1980 on a Sharpsburg silty clay loam near Mead, NE with the objective of quantifying the effects of crop rotation on grain yield-soil moisture relationships, crop root development, microbial biomass levels and soil-plant nitrogen dynamics. The cropping sequences included continuous soybean [*Glycine max* (L.) Merr.], continuous grain sorghum [*Sorghum bicolor* (L.) Moench], and soybean-grain sorghum or grain sorghum-soybean rotations. Fertilizer treatments consisted of control (no fertilizer), nitrogen (45 kg ha^{-1} on soybean plots and 90 kg ha^{-1} on sorghum plots), and manure applied at 15.8 Mg dry matter ha^{-1} yr^{-1} (160-250 kg N ha^{-1}).

In 1988, half of the experiment was converted to a study of the residual effect of crop rotation on grain sorghum yield and soil mineral nitrogen present in 150 cm soil profile. In the other half of the experiment nodulating and non-nodulating varieties of soybeans have been incorporated. This will allow separation of nitrogen and other rotational effects in the future.

Research Findings

Treatments with soybeans as the previous crop produced 2.6 Mg ha^{-1} more sorghum grain than continuous sorghum, while rotation treatments with soybeans present two years produced 1.4 Mg ha^{-1} more grain. Soil NO_3^--N levels were influenced more than NH_4^+-N and total mineral levels. Soybeans as the previous crop resulted in 41, 36 and 9 kg ha^{-1} more NO_3^--N in the 150 cm soil profile than did continuous sorghum in May, June and October, respectively. Rotation treatments with soybean present two years previously resulted in 24 and 18 kg ha^{-1} more NO_3^--N in May and June. This indicates that the beneficial effects of rotating sorghum with soybeans was still present two years after the last soybean crop.

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Networking Activities

Equipment Purchased

Plant tissue grinder, INRAN, Niger; computer, IER, Mali; calorimetric thermometer, Botswana; neutron probe, Sudan.

Mineral Uptake and Utilization in Sorghum and Pearl Millet

Project NU-114B
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Summary

Experiments were conducted in Mali and Niger to determine nitrogen response of sorghums and pearl millets in several locations. Results from Niger are not available at this time.

Studies in Mali showed that the local variety of sorghum responded favorably to nitrogen application, and was able to outyield two improved types which were susceptible to grain molds. All of the varieties in the test performed best if the nitrogen application was split at tillering and preboot. The location with the highest rainfall was superior in terms of nitrogen responsiveness as might be expected.

Research on nitrogen response of pearl millet conducted in the U.S. by a Malian graduate student showed that varieties respond differently to timing of application and rate. The study was subject to high experimental variability and the arithmetic means in which large differences existed were not statistically significant for grain yield, nitrogen yield, and related parameters. The nitrogen use efficiency values, however, were significantly influenced by nitrogen rate, being highest at the lowest rates and vice versa. A late sidedress application of nitrogen resulted in higher nitrogen use efficiency values than if nitrogen was sidedressed earlier in the growing cycle. Soil moisture also influenced nitrogen response as in the previous experiment.

A separate experiment with five sorghum hybrids showed that some sorghums take up greater amounts of nitrogen during grain fill, but this does not necessarily result in higher grain yields. Higher nitrogen levels also resulted in greater green leaf area, but again, this did not result in greater grain yields. The results indicated that high nitrogen uptake by sorghum is not required to maintain grain yields. Genotype differences in response indicated the possibility of developing types which take up and utilize less nitrogen yet maintain profitable yield levels.

Objectives, Production and Utililization Constraints

Objectives

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

Determine the physiological and morphological mechanisms which allow genotypes to be nutrient 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 NU-114B 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 NU-114B 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

Research Methods

• Mali

Project NU-114B is in the second year of collaboration in Mali. The results from the first year are now partially available and will be presented here.

A fertility trial was conducted using the sorghum varieties S-34 (Nigerian), Malisor 84-7 (improved Malian type), and a local type grown in two locations (Samanko and Ntarla) using six replications. Samanko is a low rainfall region and Ntarla is usually high. Nitrogen treatments were as follows:

Split application of 100 kg/ha urea (46%)

Tillering (30 DAP)	Preboot (50 DAP)
0	0
1/4	3/4
1/2	1/2
3/4	1/4

Results and Discussion

Varieties responded differently at each location in terms of grain yield. At the Samanko location (Table 1), S-34 outyielded the local which in turn outyielded Malisor 84-7 although the differences were not significant. At Ntarla (Table 2), the local type significantly outyielded the others by as much as 4000 kg/ha. The high productivity of the local variety, whose growing cycle is longer than the improved types, might have been a result of the favorable rainfall patterns during 1988. This pattern appeared to favor the longer season type against the others which are more susceptible to grain molds with conditions of high humidity after physiological maturity. Previous studies on yield evaluations have shown that S-34 usually outyields Malisor 84-7 which outyields the local.

Table 1. Grain yields of three sorghum varieties grown at the Samanko location in Mali using four nitrogen treatment combinations in 1988/89.

	Time of Nitrogen Application Tillering/preboot using 100 kg urea				
Variety	0/0	1/4 / 3/4	1/2 / 1/2	3/4 / 1/4	Ave
	kg/ha				
Local	1354	1781	1967	1634	1684
S-34	1614	1915	1816	1912	1814
Malisor 84-7	1082	1629	1506	1339	1389
Average	1350	1775	1763	1629	

Nitrogen application combinations were also different between locations as averaged over varietal response. At the low rainfall location (Table 1), the best combinations appeared to be where nitrogen was applied evenly at the two growth stages or where the bulk was applied preboot. At the higher rainfall region (Table 2), however, best results were obtained when applying a bulk of the nitrogen either early or late. Although the differences were not significant, the best arithmetic results appeared to support a late application for the bulk of nitrogen fertilizer as averaged over all varieties.

Table 2. Grain yields of three sorghum varieties grown at the Ntarla location in Mali using four nitrogen treatment combinations in 1988/89.

	Time of Nitrogen Application Tillering/preboot using 100 kg urea				
Variety	0/0	1/4 / 3/4	1/2 / 1/2	3/4 / 1/4	Ave
	kg/ha				
Local	7611	9678	10052	9818	9290
S-34	5608	7214	5837	6878	6383
Malisor84-7	4292	6114	5073	5107	5147
Average	5837	7669	6987	7268	

Varieties, however, did not respond the same to nitrogen treatments. The local variety responded best to an application of N which was evenly split at both stages whereas S-34 generally responded best to the bulk of nitrogen being applied either early or late. Malisor 84-7 had highest yields if the bulk of nitrogen was applied late.

• Niger

Research to study the response of pearl millet to a number of nitrogen and phosphorus combinations were initiated in 1988. Results of this study are not available at the present time.

• Domestic (Study 1)

A study was conducted in 1988 near Mead, Nebraska on pearl millet by Mr. Abdoul Toure from Mali who is working on a M.S. degree. The objective of this experiment was to determine the effect of different levels of nitrogen and the timing of its application to development and yield of two pearl millet genotypes. Four levels of nitrogen (0, 28, 56 and 112 kg/ha) were used. The 0 and 28 kg/ha treatments were applied only preplant while the higher rates were applied entirely preplant or one half at preplant and the other one half at either 25 or 50 days after emergence (DAE) (Table 3). Varieties IAP-8202, a tall unimproved Malian type, and 68A x MLS, a short improved type, were grown in four replications at a population of 20 plants m^{-2}. Measurements included grain yield, total biomass, total N uptake, nitrogen use efficiency (NE1) as biomass/unit plant N, and nitrogen use efficiency (NE2) as grain yield/unit plant N.

Results and Discussion

Table 4 shows yield component, means, plant nitrogen content, and nitrogen use eficiency values. Genotypes were not significantly influenced by nitrogen levels for most parameters measured. Genotype ICTP-8202 was significantly higher than 68A x MLS for most of the measured parameters. The difference between the two genotypes expressed in percentage of 68A x MLS, was about 40% in head number, 113% in grain weight, 280% in biomass weight, and 143% in total plant N content (Table 4). In nitrogen use efficiency, ICTP-8202 was better for NE_1 (30.61 vs 66.7 g dm/g N) while 68A x MLS was better for NE_2 (66.7 vs 39.55 g dm/g N) which is not uncommon when comparing local versus improved types.

Table 3. Combinations of rate and timing of nitrogen application to two varieties of pearl millet grown at the University of Nebraska Agricultural Research and Development Center near Mead.

Treatment	Preplant (PP)	Sidedress (SD)	DAE to SD
	kg/ha		
1	0	0	--
2	28	0	--
3	56	0	--
4	112	0	--
5	28	28	25
6	28	28	50
7	0	56	25
8	0	56	50
9	56	56	25
10	56	56	50
11	0	112	25
12	0	112	50

Nitrogen rate effect on several measured parameters was not obvious. Grain weight was not affected by N rate with an average of 69.93, 58.65, 70 and 54.60 g $plant^{-1}$ being produced at 112, 56, 28, and 0 kg/ha N respectively, nor was total biomass with 142.58, 112.14, 163.12 and 100.36 g $plant^{-1}$ being produced respectively, for the same levels. The high level of biomass per plant with 28 kg/ha was due to the poor stand which allowed individual plants to produce greater amounts of tissue. However, N rate affected head number with the greatest number heads (3.081 $plant^{-1}$) being produced at 112 kg/ha N (Table 4). Other treatments were not different statistically. Total plant nitrogen content was also affected by nitrogen rate. The highest result (1.15 g of N $plant^{-1}$) was found with 112 kg/ha N, while other treatments were not different. The highest NE_1 value was found at 28 kg/ha and the lowest at 112 kg/ha N. NE_1 is usually highest at the lower N rates and vice versa. NE_2 also showed highly significant differences among treatments with the highest value at 0 kg/ha and the lowest at 112 kg/ha. NE_2 usually follows the pattern of NE_1.

Timing of nitrogen application did not influence grain yield $plant^{-1}$ nor total biomass $plant^{-1}$ (Table 4). Head number was affected by late application of N, but only at the 112 kg/ha treatment. Application at SD50 was inferior to SD25 and PP which were similar. Total plant nitrogen content was also affected by timing of application. Application of 112 kg/ha at SD50 produced the poorest results (0.90 g N) while PP (1.47 g N) and SD25 (1.40 g N) were similar. At the 50 kg/ha treatment, PP, SD25 and SD50 were similar. Nitrogen use efficiency (NE_1) was affected by late N application. The highest value was found for SD50, followed by SD25 and for any N rate. For NE_2, the best result was obtained at either date of sidedress application and the poorest with PP for either 56 or 112 kg/ha N.

Conclusion

From this experiment, it can be concluded that:

Rate and timing of nitrogen application have an effect on head number, total nitrogen content and nitrogen use efficiency in some pearl millet varieties.

Soil nitrogen level and soil moisture status influenced fertility response.

Other parameters should be included in the analysis of yield and yield components such as green leaf area, height and numbers of kernels to help interpret the N response.

Some parameters such as grain weight, biomass weight, head number and others should be expressed in surface area.

• Domestic (Study 2)

A study was conducted on sorghum by Dr. Joan Youngquist, a post doctoral scientist, on the influence of genotype and nitrogen application on leaf area, N content and yield. Maintaining profitable yields with low N fertility is of marked importance where fertilizers are unavailable, costly, or of environmental concern. However, insufficient sources of soil N can result in depletion of N reserves from leaf and stem fractions of the plant during grain fill. This, in turn, could reduce green leaf area, photosynthetic activity and ultimately lower grain yields. Five grain sorghum hybrids were grown with low (0 kg ha^{-1}) and high (150 kg ha^{-1}) N fertilizer applications at two sites in eastern Nebraska. Site 1 had residual soil nitrate of 54 kg ha^{-1} and site 2 had 85 kg ha^{-1} prior to fertilizer treatment. At anthesis and maturity, three plants per plot were harvested. Data were collected on green leaf area, partitioned above ground biomass and partitioned N content.

Table 4. Components of yield of pearl millet affected by rate and timing of N application.

Timing of Application			Sidedress									
N rate kg/ha	Treat label	Preplant %	25 days %	50 days %	Head number $plant^{-1}$	Grain weight $plant^{-1}$	Stem weight $plant^{-1}$	Leaf weight $plant^{-1}$	Biomass weight $plant^{-1}$	Plant N content	NE1 g DM/g N	NE2 g DM/g N
					----------	----------	g	----------	----------			
112	4	100	0	0	3.63 ab	85.58 a	120.60 a	44.06 a	182.14 a	1.47 AB	66.76 CD	38.73 D
	9	50	50	0	3.16 abc	70.37 a	87.23 a	35.89 a	123.72 a	1.21 BC	62.79 D	40.12 CD
	10	50	0	50	2.51 bc	48.62 a	75.97 a	29.37 a	105.33 a	0.75 C	79.18 BC	44.32 BCD
	11	0	100	0	3.94 a	83.52 a	125.00 a	58.46 a	183.16 a	1.40 AB	68.91 CD	37.26 D
	12	0	0	100	2.16 c	61.90 a	88.28 a	30.29 a	118.57 a	0.90 BC	81.44 ABC	46.34 BC
Mean					3.08	70.00	99.42	39.55	142.58	1.15	71.82	41.35
56	3	50	0	0	2.26 bc	50.27 a	67.97 a	27.87 a	95.53 a	0.25 C	74.19 CD	43.14 BCD
	5	25	25	0	2.68 abc	70.88 a	92.68 a	35.43 a	128.11 a	0.29 C	80.15 BC	46.60 BC
	6	25	0	25	2.66 abc	57.02 a	84.33 a	28.78 a	113.11 a	0.26 C	82.43 ABC	48.80 B
	7	0	50	0	2.35 bc	64.13 a	87.92 a	31.05 a	118.97 a	0.27 C	81.53 ABC	47.15 BC
	8	0	0	50	2.40 bc	50.96 a	74.62 a	30.37 a	104.99 a	0.22 C	81.99 ABC	43.69 BCD
Mean					2.47	58.65	81.50	30.64	112.14	0.26	80.05	45.88
28	2	25	0	0	2.67 abc	70.06 a	120.28	42.83 a	163.12 a	0.32 BC	97.34 A	47.93 b
0	1	0	0	0	2.24 bc	54.53 a	74.64 a	25.71 a	100.36 a	0.19 C	93.05 A	45.45 A
Var 1: 68A x MLS					2.26 A	41.25 A	30.32 A	23.02 A	53.23 A	0.58 A	66.70 A	50.24 A
Var 2: ICTP-8202					3.17 B	87.93 B	154.77 B	47.24 B	202.01 B	1.41 B	90.67 B	39.55 B

Genotypic differences in biomass, N content and green leaf area were detected (Table 5). High N level resulted in more green leaf area and higher N content of stem, leaf and grain fractions, but had little influence on biomass production. Genotype x N-level interactions were non-significant for all traits measured. Leaf area, leaf biomass and N content of leaf and stem fractions decreased with maturity. A high leaf N content should provide reserves for mobilization and delay the onset of senescence. Green leaf area was correlated with leaf N content ($r = 0.75$ and 0.77 at anthesis and maturity respectively, $P < 0.05$). Differences in green leaf area were due to variations in both leaf size and green leaf number per plant.

Active uptake and relocation was found to have positive effects on maize grain yield at low N levels, while under high N conditions grain yield was related to the capacity to store N in the plant and seed (DiFonzo et al., 1982). Mobilized N from vegetative tissue contributed significantly to grain N in all five grain sorghum hybrids. Leaf and stem fractions lost from near half to two-thirds of accumulated N during grain fill period (Table 6), and contributed between 67 and 82% of grain N, depending upon genotype. N application had a strong influence on N mobilization. In the high N application only 67% of grain N was mobilized from stem and leaf fractions, compared to 83% for the low N treatment. Absolute quantities translocated were greater in the high N treatment reflecting high N reserves. These values assume N lost from vegetative plant parts is all translocated to the grain. The actual contribution is probably less given translocation to roots and metabolic losses of N. The results are consistent with Zweifel et al., (1987) who reported a smaller fraction of N partitioned to the grain under high N levels. These values are greater in magnitude and range than those reported by Onken et al., (1986). They found translocation of N to seed relatively constant at about 65% in four sorghum lines treated in high and low N soils.

The efficiency of nitrogen translocation has been described using the grain N/plant N ratio (NHI) (Alagarswamy and Seetharama, 1983; Zweifel et al., 1987). Where NHI is greater than the HI (grain weight/total plant weight), N transfer is considered effi-

Table 5. Partitioned biomass and N-content per plant for five grain sorghum hybrids and two N levels.

Plant part	Growth stage	Hybrid: RS626	RS671	DK41Y	DK46	P8333	LSD .05	N-level: Low	High	LSD .05
		g/plant								
Leaf	Anthesis	19.9	25.3	22.1	23.0	31.2	2.3	23.6	25.3	NS
	Maturity	15.9	22.2	19.2	21.8	25.6	2.1	20.8	21.1	NS
Stem	Anthesis	56.2	62.9	50.3	59.8	54.2	NS	53.6	59.0	NS
	Maturity	50.5	67.6	53.3	65.4	59.6	7.1	62.2	57.9	NS
Grain	Maturity	79.7	87.8	72.2	84.0	79.7	NS	79.1	85.4	NS
Total	Anthesis	76.2	88.1	72.5	82.8	85.0	10.0	77.3	84.3	5.6
	Maturity	141.8	172.9	140.7	166.7	160.6	19.9	157.9	159.8	NS
N-content										
Leaf	Anthesis	0.53	0.31	0.57	0.76	0.64	0.05	0.57	0.70	0.08
	Maturity	0.25	0.39	0.31	0.37	0.37	0.02	0.28	0.38	0.04
Stem	Anthesis	0.67	0.94	0.54	0.60	0.69	0.12	0.57	0.78	0.15
	Maturity	0.21	0.31	0.21	0.25	0.25	0.04	0.18	0.30	0.05
Grain	Maturity	0.96	1.18	0.88	1.11	0.87	0.05	0.82	1.19	0.12
Total	Anthesis	1.21	1.66	1.10	1.34	1.32	0.11	1.14	1.61	0.17
	Maturity	1.42	1.86	1.39	1.73	1.50	0.10	1.28	1.89	0.15
		cm^2/plant								
Leaf area	Anthesis	2600	3286	3349	3254	4166	164	3270	3456	110
	Maturity	1262	1501	2234	2133	2253	239	1759	1952	92

cient. In this study, the NHI ranged from 0.58 for P8333 to 0.68 for RS626 (Table 6), while HI values were near 0.50, indicating all five hybrids had efficient N transfer. The rate of N application did not greatly influence the NHI. The low N treatment had a NHI of 64 compared to 63 for the high N treatment. The NHI is not an indication of efficient mobilization. Grain N can come directly from soil N or be mobilized from N stored in vegetative tissue. Thus, plants which have high reserves of N and are able to mobilize vegetative N may have a relatively low NHI. P8333 had a high proportion of grain N from vegetative fractions yet had lower NHI values than the other hybrids. Testing more divergent genotypes would allow a better evaluation of this relationship.

Muruli and Paulsen (1981) found the key to high yield in maize was accumulation of N after silking. Grain yields among the five sorghum hybrids tested were significantly different at the 0.10 level, and hybrids with greater total N uptake did tend to have higher grain yields. Higher N uptake in the high N treatment did not significantly increase yield, however. Greater uptake of N during grain fill did not necessarily result in greater grain yields. The lower total uptake of N by DK41Y and RS626 was primarily a function of plant size. All genotypes had a N concentration between 9.3 and 10.7 mg N/g biomass. The greater uptake of N in the high N treatment was not a function of plant size. N concentration in the high N treatment was 11.8 mg N/g biomass, compared to 8.1 in the low fertility treatment. While higher soil N content also resulted in greater green leaf area and thus potential photosynthesis, these factors did not translate into greater grain yields. Even with lower N concentration in the plant tissue, adequate N was available for translocation to and maintenance of grain in the low N treatment. These results indicate that high N uptake by sorghum is not required to maintain productive grain yields. Genotypic differences even among these five hybrids indicate the possibility of developing varieties which take up and utilize less N yet maintain profitable yield levels.

References Relative to Study 2

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Networking Activities

NU-114B supplied Mali with a new analytical balance ($3000) and supported the collaborative research with operational money of $7000. The project provided $1500 to Niger for collaborative research initiation.

Table 6. Changes in N content during grain fill and N harvest index (NHI) for five grain sorghum hybrids and two N levels.

	Hybrid					N level	
Quantity	RS626	RS671	DK41Y	DK46	P8333	Low	High
Leaf N loss	53	45	46	49	58	51	46
Stem N loss	69	67	61	58	64	68	61
Grain N from vegetative fractions	77	81	67	67	82	83	67
NHI	68	63	63	64	58	64	63

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

Project NU-116
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Summary

Germplasm improvement research to develop stress resistant and water responsive sorghum genotypes is in Year 10. Details of field screening technique and breeding methodology were reported in 1987 and 1988. Two early season stress resistant A/B pairs were released. Seventy-eight tan plant-light grain colored food grain type composite lines were distributed to several commercial and public breeders. A new stress resistant random mating sorghum population is being synthesized.

Cultural practice research to increase crop water-use efficiency (WUE) and reduce cool temperature stress injury in western Nebraska is continuing. Sorghum water-use efficiency and seed number was significantly higher in the no-till plots compared to either bare till or subtill plots in both 1986 and 1987. Yield of sorghum under no- till was significantly higher only in 1987. Grain yield, seed number, water use and WUE of 1987 wheat were significantly higher in the wheat-sorghum-fallow (WSF) system than in the wheat-fallow (WF) system. Averages of total grain production and water use were higher in the WSF system compared to the WF system. The WSF system produced 28% more grain than the WF system and used 19% more water.

Cooperative crop physiology/cropping systems research initiated in Niger two years ago is now being conducted by and in collaboration with Mr. A. Alou of INRAN. Crop residue amounts of 1, 2 and 3 t ha^{-1} left on the surface as a mulch increased millet grain yields by 306%, 458% and 545%, respectively, while total dry matter production increased by 253%, 347% and 382% in these respective treatments. Using artificial shades, it was determined that water-use efficiency and production of cowpea is maximum under full sunlight. An alternative to the currently recommended intensive millet/cowpea

intercropping system which increased light availability to the cowpea canopy was tested. While millet yields were the same or slightly higher in this system, cowpea grain and total dry matter production increased by 15% and 24%, respectively, in the alternative system compared to the recommended system. Another alternative system increased millet grain and total dry matter yields by 24% and 42%, respectively, and cowpea total dry matter production by 53% compared to the traditional farmers' system under low-input (no fertilizer) situations. These alternative systems need to be further tested to determine their sustainability under reduced input conditions.

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 cool night temperature water-conserving cultural practice research in western Nebraska.

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

5. Develop canopy photosynthesis/transpiration/water use efficiency (WUE) measurement techniques.

6. 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, 2) Description of practical prebloom field stress screening is outlined in the 1988 INTSORMIL report.

3) Cultural practices consist of dark soil tillage, subtillage and chemical tillage imposed on continuous sorghum, sorghum-fallow-wheat and wheat-fallow. Water levels imposed are dryland (ave. of 350 mm of water), dryland plus 75 to 100 mm (to include normal rainfall swings) and full irrigation.

4) Millet/cowpea ratio treatments have been altered in intercropping to shade cowpea less and make it more competitive with millet. Suggested stand geometry alterations were based on cowpea canopy measurements of instantaneous WUE at different shade levels.

5) Plywood bases were constructed on which to place canopy chambers over legume or cereal crops to measure photosynthesis, respiration and transpiration. The bases eliminate CO_2 and water vapor flux from the soil in the canopy measurements.

6) Substantial levels of PL 480 funds are being administered through USDA/OICD for cooperative US/INDO research of mutual benefit to both nations. Broad problem analysis took place in 1987 and 1988. First year work plans were completed in November, 1989. They include 1) rabi sorghum stress screening and breeding, 2) sorghum stress physiology research emphasizing post anthesis stress to complement western Kansas preanthesis research, 3) crop residue influences on water use efficiency 4) water stress effects on nitrogen fixation and 5) sorghum based cropping system influences on both nutrient and water use efficiencies in low input agriculture. These systems involve sorghum, grain legumes, oil seed cops (mustard and castor) and Luceana (agroforestry). Others likely to be involved are INTSORMIL scientists R. Vanderlip and D. Andrews, plus P. Bramel-Cox from Kansas State University.

Research Findings

Stress Screening

Reporting in this area was intensive in 1988 and will be minimal until 1990 in deference to emphasizing cultural practice research. Two early season stress resistant A/B pairs, N125 and N126, were released. Also 78 composite lines from a short, early version of TP 24 were distributed to about a dozen commercial companies and numerous public agencies. The 78 composites are tan plant - light grain colored food grain types. Also a new stress based population was synthesized. About two years will be required to achieve sufficient random mating for release.

Development of stress resistant lines through traditional line breeding associated with populations is continuing.

There were no significant differences in 1986 sorghum yields as a result of tillage method, but no-till plots had significantly higher seed numbers and used more water than bare till and subtill plots. The 1987 no-till sorghum plots had significantly higher yields, seed numbers and WUE's than either bare till or subtill plots. No-till wheat plots had greater seed size than bare till or subtill plots in 1986, but in 1987 all dependent variables (yield, seed number, seed size, water use and WUE) were significantly lower in no-till plots. Plot management was not perfect.

Yield, seed number, water use and WUE for 1987 wheat were all significantly greater in the wheat-sorghum-fallow (WSF) system than in the WF system. Respective WF and WSF 1986 and 1987 two-year grain production averages were 1707 and 2191 kg/ha. The WF and WSF two-year water use averages were 17 and 20.2 cm, respectively. The WSF system averaged 28% more grain than the WF system and used 19% more water.

Quite possibly the more intensive WSF system is passing more transpirational water through the crops and losing a lower comparative level of water through soil evaporation. This needs to be checked out in both U.S. and overseas cropping systems. We are close to having the equipment developed to make such measurements possible. Fallow systems in general are inefficient water harvesting and storage systems.

Cultural Practice/Cropping System Research

Most of this research is being done currently in Niger and to a lesser degree in Sudan. Niger research will be presented first. The experiments were conducted at the N'Dounga and Ouallam sites of the Kolo Research Station of INRAN. Ouallam is 100 km north of Niamey and has an extremely marginal environment with about 250-300 mm annual rainfall (1988 was wet with 360 mm). N'Dounga, on the other hand, represents one of the better environments for millet production in Niger with an annual rainfall of around 500-600 mm (510 mm in 1987 and 605 mm in 1988) and is located 25 km southeast of Niamey.

The importance of crop residue in improving the soil environment in Niger cannot be overemphasized. Unfortunately, very few efforts are being made to develop a standard, practical and readily adaptable set of recommendations for residue management scheme(s). After harvesting the millet grain and cowpea forage, the farmers let their livestock graze on the millet stubble. Therefore the amount of residue on the farmers' fields varies from little to almost none depending on how good or how bad the preceding year has been. INRAN experimental fields are usually 'cleaned' every year before planting to remove whatever stubble is left from the preceding year. Consequently, soils with less than 0.5% organic matter are very typical at most of INRAN's stations. Bare soils also aggravate water erosion and contribute to sand blasting problems which make stand establishment difficult.

We attempted to quantify and demonstrate the beneficial effects of crop residue on millet production. Crop residue treatments of zero, one, two and three tons of residue per hectare were imposed in 1987 after the harvest. The residue was left on the surface as a mulch and protected from the animals during the dry season. A pure crop of millet was planted in 1988. Plots received 25 kg of N ha^{-1}.

Grain yields were 191, 775, 1065 and 1231 kg ha^{-1} (LSD at $P<0.05 = 239$) and total dry weight produced was 743, 2621, 3321 and 3581 kg ha^{-1} (LSD at $P<0.05 = 632$) in treatments with 0, 1, 2 and 3 t ha^{-1} of residue, respectively (Table 1). These yield increases are up to almost 550% for grain weight and 400% for total dry weight.

Table 1. Grain and total dry weights (kg ha^{-1}) of millet in response to different amounts of crop residue left on the surface as a mulch (Ouallam, Niger, 1988).

Residue applied t ha^{-1}	Grain weight	% increase in grain wt. over 0 t ha^{-1}	Total dry wt.	% increase in total dry wt. over 0 t ha^{-1}
0	191		743	
1	775	306	2621	253
2	1065	458	3321	347
3	1231	545	3581	382
$LSD_{.05}$	239		632	

Soil temperatures at 2, 15 and 30 cm depths were measured in 0 and 2 t ha^{-1} treatments and soil moisture up to a depth of 150 cm was measured. During the first five weeks after planting, daily mean soil temperature at 30 cm depth was consistently higher by 1-2 degrees C in 0 t ha^{-1} treatment compared to 2 t ha^{-1} treatment. Daily maximum and minimum temperatures were also higher by an average of 1.6 and 1.2 degrees C, respectively, in the 0 t ha^{-1} treatment compared to the 2 t ha^{-1} treatment. At 2 and 15 cm depths, the soil temperatures in the two treatments were not different. No attempt has been made to document the effects of higher temperatures on millet roots. However, sorghum research has shown about a 15% increase degree C^{-1} in respiration (and presumably general metabolic pace).

Up to the depth of 90 cm the 2 t ha^{-1} treatment had more moisture in the soil compared to 0 t ha^{-1} during the first five weeks after planting, but between 90 and 150 cm the soil moisture was more in the 0 t ha^{-1} treatment. Total soil moisture (0-150 cm) was more in the 2 t ha^{-1} treatment only during the fourth and fifth weeks after planting. Results appear to indicate that the benefit of the residues in this above average rainfall year (360) comes from nutrient and stand establishment enhancement more than from enhanced soil moisture. Data from additional years are needed.

Intercropping has traditionally been a common feature of small- holder farming. However, our comprehension of the intercropping systems, especially their physiological aspects, is very limited. Millet/cowpea intercropping is the most common cropping system in Niger.

Farmers traditionally plant millet after the first rain. Cowpea is planted five to six weeks after millet. Neither hill spacing nor plants hill^{-1} for either millet or cowpea is controlled. The average number of hills ha^{-1} in a farmer's field is approximately 5000 for millet and 3000 for cowpea. The intensive system being recommended has much higher population densities for both millet (8889 hills ha^{-1}; 3 plants hill^{-1}). It also requires the nitrogen and phosphorous fertilizer dosage recommended for the region. Cowpea growth is likely inhibited by the shade from the millet canopy in the intensive millet/cowpea intercropping system. Besides altering the photosynthetic rates, reduced light could also influence the energy balance of the leaves and thus the transpiration from the canopy. Research was initiated (1) to determine the light level required to maximize the water-use efficiency (WUE) and production of cowpea, (2) to identify an alternative millet/cowpea intercrop arrangement which could increase light availability to the cowpea canopy, and (3) to identify a millet/cowpea intercropping system which could sustain productivity under continued low input situations.

Water-use efficiency of pure cowpea crop was measured under different light levels in 1987 and 1988 to determine the light level required to maximize WUE and production of cowpea. Artificial shades using shade cloth were used to impose different light level treatments. Shades were erected three weeks after emergence to impose 100%, 57%, 37% and 27% sunlight treatments in 1987 and 100% and 57% sunlight treatments in 1988.

Water-use efficiency of the canopy was measured using a portable photosynthesis system (LI-Cor 6000 in 1987 and Li-Cor 6200 in 1988) in a closed chamber. Soil and canopy fluxes were separated by 3/4 inch thick closed cell foam. The canopy was enclosed in a Plexiglas chamber to make the measurements. Different sized chambers were used to measure WUE at different growth stages since the size of the canopy was different at every stage. An infrared thermometer (Everest Interscience model 210) was used to measure the canopy temperature. Photosynthesis, stomatal conductance and transpiration were measured. Water-use efficiency was computed as a ratio of photosynthesis to transpiration. Measurements were made at the vegetative, 50% flowering and three weeks after flowering stages in 1987, while in 1988 all measurements were squeezed around the flowering stage. All measurements were made on a diurnal basis over a 24-hour period.

Rate of photosynthesis was maximum throughout the day under full sunlight at 40 days after planting when the crop was still vegetative (Fig. 1 A). Differences in transpiration among the treatments were less pronounced (Fig. 1 B). At 65 days after planting or around 50% flowering, there were no distinct differences among the treatments for photosynthetic rate (Fig. 2 A) but transpiration was maximum under 57% sunlight (Fig. 2 B). At three weeks after flowering or 85 days after planting, net assimilation rate was highest under full sunlight (Fig. 3 A). Transpiration was again maximum in the 57% light treatment (Fig. 3 B) thus resulting in maximum WUE under 100% sunlight. Diurnal means of photosynthesis, transpiration and WUE of cowpea at different growth stages are given in Table 2. Water-use efficiency was maximum or near maximum under 100% sunlight at all three stages. Lower transpiration under 100% sunlight after flowering might be due to some kind of adaptation for stomatal regulation or internal resistance(s) developed by the crop over the years to conserve water beyond a certain level of increased atmospheric demand. This low transpiration coupled with high net photosynthesis rates usually resulted in the most favorable water-use efficiency in the 100% light treatment. Consequently, the crop grown under full sunlight produced more dry matter, higher grain yield and probably fixed more nitrogen compared to other (reduced) light levels.

In 1988 the experiment was repeated with just two treatments: 100% and 57% sunlight. Diurnal means of photosynthesis, stomatal conductance, transpiration and water-use efficiency of cowpea at 50, 60 and 75 days after planting are given in Table 3. The results confirmed the observations made during the preceding year. WUE was higher under full sunlight on all three days when measurements were made. Cowpea yields (grain and total dry weight) were significantly lower under 57% light as compared to full sunlight. Reduction in grain and total dry weight yields was 65% and 50%, respectively under 57% sunlight compared to 100% sunlight (Table 3).

The results show that water-use efficiency and production of cowpea is reduced by reduced light availability. While this may not be a cause of great concern in the traditional system which has very low plant densities (wider spacing), it might be fairly critical to cowpea production in the intensive millet/cowpea intercropping system. Cowpea production in the intensive millet/cowpea intercropping system could perhaps be improved by altering the microenvironment of the cowpea canopy. An alternative system that made more light available to cowpea was proposed and comparing it with the intensive system for yield and total dry matter production was in order. A few other intercrop arrangements involving different combinations of cowpea density and arrangement were also tested.

Table 2. Diurnal means of photosynthetically active radiation (PAR; mmol $m^{-2}s^{-1}$), photosynthesis (PH; ug CO_2 m^{-2} s^{-1}), transpiration (TR; mg H_2Om^{-2} s^{-1}), water-use efficiency (WUE; ug CO_2 mg^{-1} H_2O), grain yield (kg ha^{-1}) and total dry weight (kg ha^{-1}) of field grown cowpea under different light levels (N'Dounga, Niger, 1987).

Days after planting	Variable	100% sunlight	57% sunlight	37% sunlight	27% sunlight
40	PAR	1573	746	406	438
	PH	394	197	192	135
	TR	28.1	16.0	20.3	13.1
	WUE	18.8	15.6	9.3	14.1
65	PAR	1382	609	488	382
	PH	172	196	170	162
	TR	21.1	36.8	23.2	28.3
	WUE	8.5	6.5	8.6	7.2
85	PAR	1143	551	372	363
	PH	255	74	74	64
	TR	38.3	69.3	44.4	42.4
	WUE	6.5	0.5	1.7	2.5
	Grain wt.	381	203	284	372
	Tot. dry wt.	2953	2551	2089	1980

Table 3 Diurnal means of photosynthesis (umol CO_2 m^{-2} s^{-1}), stomatal conductance (mol m^{-2} s^{-1}), transpiration (mmol H_2O m^{-2} s^{-1}) and water-use efficiency (umol CO_2 $mmol^{-1}$ H_2O) of field grown cowpea under two light levels (N'-Dounga, Niger, 1988; numbers in parentheses represent percent reduction under 57% sunlight compared to 100% sunlight).

Days after planting	Variable	100 % sunlight	57 % sunlight
50	Photosynthesis	3.805	3.341
	Conductance	0.165	0.203
	Transpiration	0.544	0.803
	Water-use efficiency	7.215	4.297
60	Photosynthesis	2.094	1.923
	Conductance	0.143	0.069
	Transpiration	0.440	0.532
	Water-use efficiency	5.332	3.641
75	Photosynthesis	6.232	4.389
	Conductance	1.094	0.915
	Transpiration	2.415	2.867
	Water-use efficiency	3.013	1.722
	Grain weight	1280	454 (65)
	Total dry weight	4569	2301 (50)

Two alternative arrangements in this experiment turned out to be quite interesting. The first one (T3) had the same population densities and fertilizer inputs as the intensive system (T2) but a different spatial arrangement of cowpea (only one row of cowpea between two millet rows), and the second one (T8) which had the same fertilizer input (no nitrogen) as the traditional farmers' system (T1) but a different density and arrangement for both millet and cowpea (paired rows of millet alternating with one row of cowpea). Millet grain yield in T3 and T2 was 868 and 852 kg ha^{-1} (NS), respectively, and total dry weight was 3603 and 3205 kg ha^{-1} (NS), respectively, in the two systems (Table 4). Millet and cowpea grain yields were a little higher in T8 compared to T1 but were not significantly different (millet: 563 and 455 kg ha^{-1} and cowpea: 603 and 562 kg ha^{-1} in T8 and T1, respectively). Total weight yields were significantly ($P < 0.05$) higher in T8 compared to T1 for both millet (2514 and 1774 kg ha^{-1}, respectively) and cowpea (2497 and 1632 kg ha^{-1}, respectively).

Table 4. Grain and total dry weights (kg/ha) of millet and cowpea grown in different intercrop arrangements (N'Dounga, Niger, 1988). Values in parentheses represent % increase in T3 over T2 and in T8 over T1, respectively.

Treatment	Millet Grain	Millet Total dry wt.	Cowpea Grain	Cowpea Total dry wt.
with fertilizer:				
T2	852	3205	801	2332
T3	868 (2)	3603 (12)	917 (15)	2889 (24)
without fertilizer				
T1	455	1774	562	1632
T8	563 (24)	2514 (42)	603 (7)	2497 (53)
LSD .05	145	741	300	860

It must be noted that the T3 arrangement received recommended nitrogen dosage and was compared to the intensive system (T2) that required similar fertilizer amounts. However, chemical fertilizer, especially nitrogen fertilizer, is beyond the reach of most Nigerien farmers. A more practical alternative for most immediate gains on the farmer's field would be an improved system which does not require the additional fertilizer inputs and still outyields the traditional farmer's system. The T8 arrangement should, therefore, be further tested to verify if it can increase and sustain productivity over the years without requiring the application of nitrogen fertilizer.

Publications and Presentations

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Dhopte, A.M. and J.D. Eastin. Response of Sorghum to Elevated Night Temperature Imposed During Floret Differentiation Under Field Conditions. International Congress of Plant Physiology. Febr. 15-20, 1988. New Delhi, India.

Livera-Munoz, M. and J.D. Eastin. Some Physiological and Genetic Bases to Overcome Low Night Temperature Stress on Sorghum in the Mexican Highlands. International Congress of Plant Physiology. February 15-20, 1988. New Delhi, India.

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Eastin, J.D. and P.K. Verma (presenter). Stress Screening from a Physiology Point of View. ICRISAT Regional Workshop in Niamey, Niger. April, 1988.

Gandoul I. Gandoul, J.D. Eastin, M.D. Clegg, M. Mirghani. 1989. Factors influencing water use efficiency. ARC/INTSORMIL Sudan Sorghum and Millet Workshop. Wad Medani, Sudan. 1989.

Farah, Saeed and J.D. Eastin. 1989. Effect of plant population and fertility level on yields of sorghum varieties and hybrids grown under irrigated and rainfed conditions. ARC/INTSORMIL Sudan Sorghum and Millet Workshop. Wad Medani, Sudan. 1989.

Networking Activities

Workshops

Served as a U.S. advisor for the 1988 International Plant Physiology Stress Congress in February, 1988. Specific duties were convener of the sorghum, millet and corn sessions and getting an NSF grant to accommodate travel for 17 U.S., Canadian and Mexican scientists. We sponsored a U.S.-India Biotechnology Workshop at the close of the Physiology Congress.

Research Investigator Exchanges

Numerous scientists from LDC's visited research plots in 1989. Scientists from Sudan, Mali, Botswana and Mexico have requested germplasm.

Germplasm

Three R lines and three stress resistant A/B pairs were released in 1988 and distributed by request to 13 commercial companies and numerous public researchers. Two A/B pairs were released in 1989 in addition to 78 line composites derived from a food grain random mating population.

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

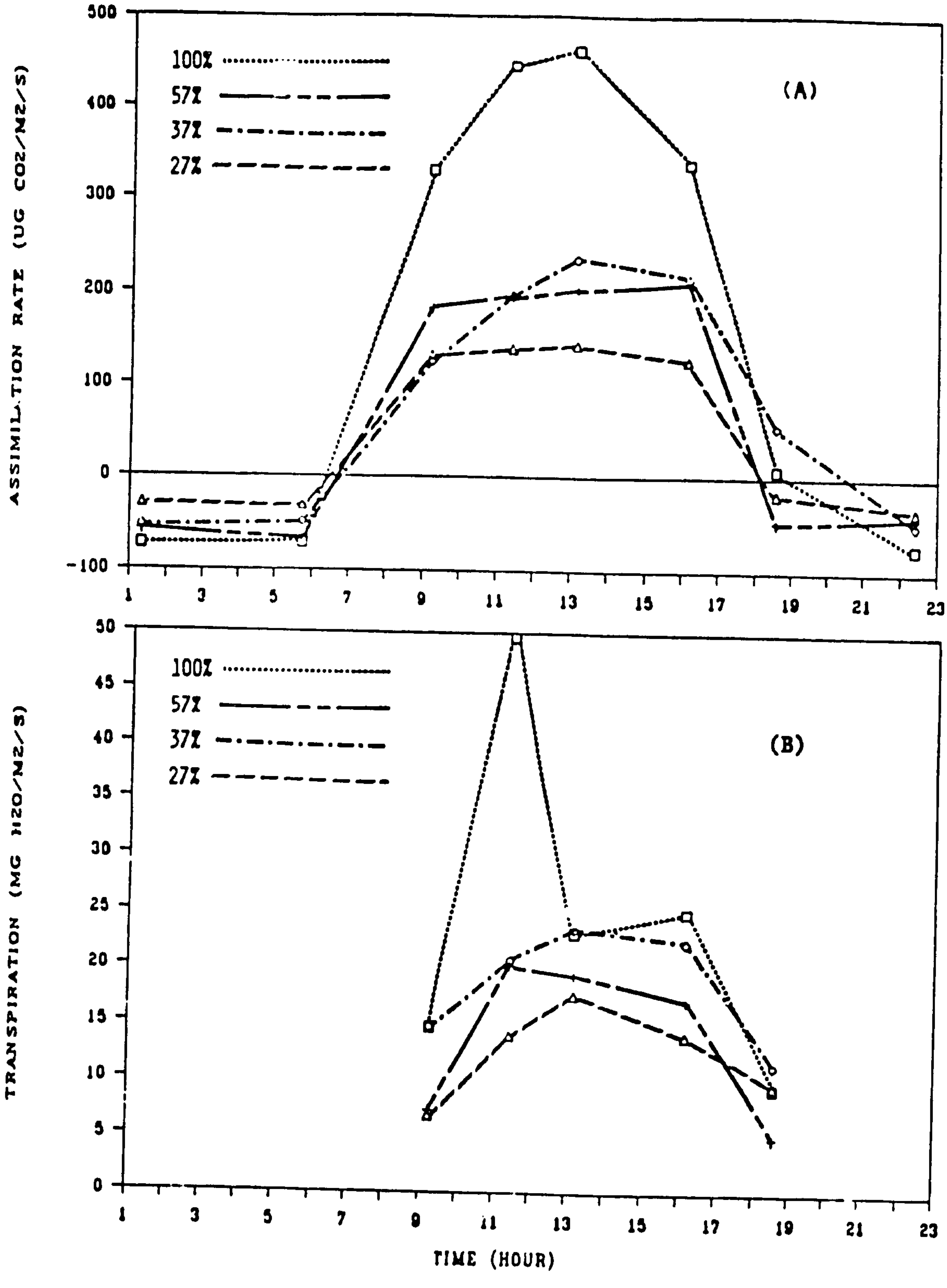

Figure 1. Assimilation rate (A) and transpiration (B) of cowpea under different light levels at 40 days after planting (Niger, 1987).

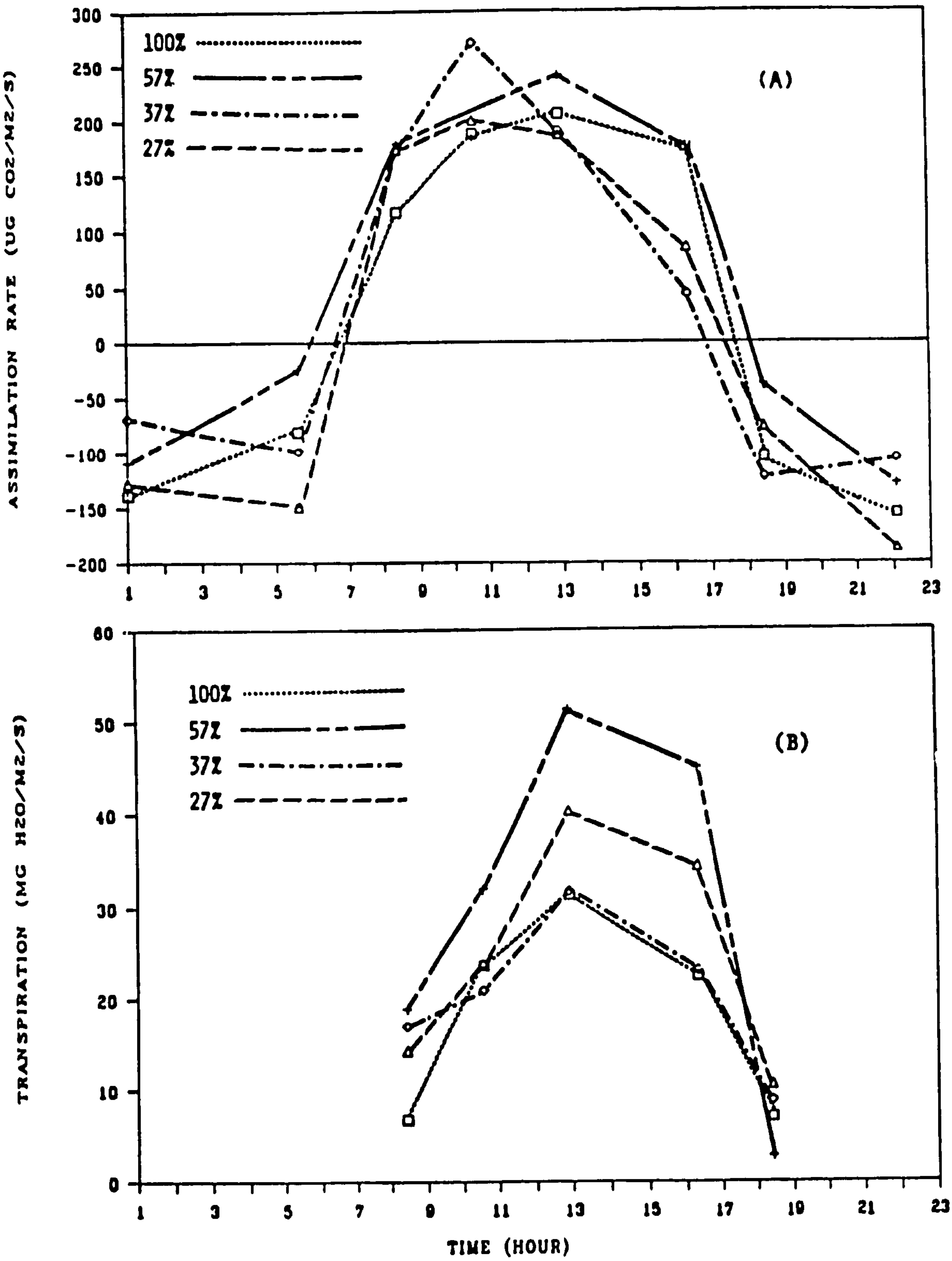

Figure 2. Assimilation rate (A) and transpiration (B) of cowpea under different light levels at 65 days after planting (Niger, 1987).

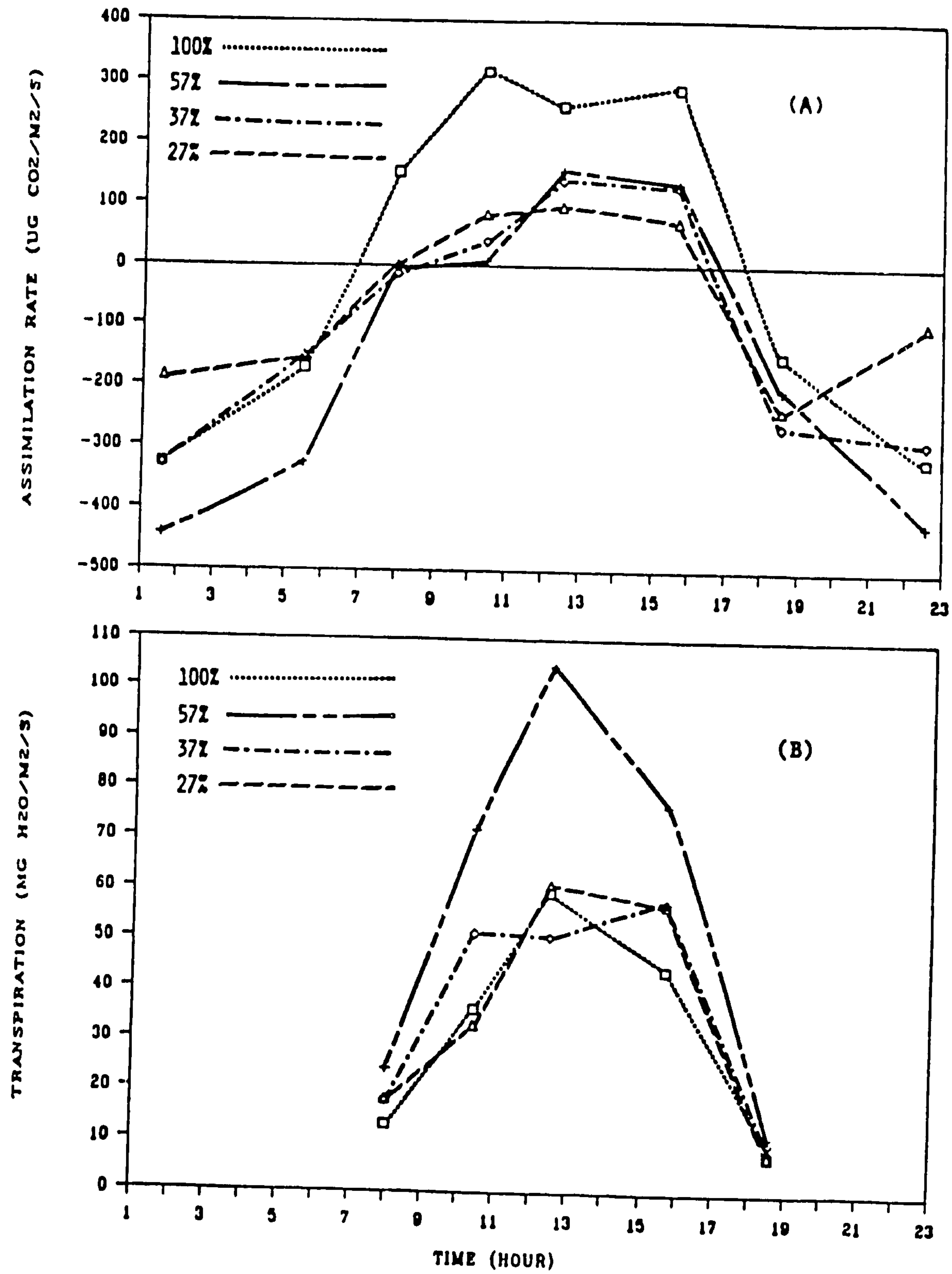

Figure 3. Assimilation rate (A) and transpiration (B) of cowpea under different light levels at 85 days after planting (Niger, 1987).

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

Project NU-123
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Dr. John Leslie, Department of Plant Pathology, Kansas State University, Manhattan.

Summary

A major problem in West Africa and other drought prone regions is the effect of drought and high temperatures on crop stand, plant growth, and yields. 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. It is known that proline and other metabolites often accumulate in plant cells when they are exposed to drought and temperature extremes. Our basic research was aimed at determining how proline accumulation may contribute to the stress resistance of West African and other sorghums. It was shown that genotypes differ significantly in the quantity of proline accumulation, and that it is not necessarily positively related to the level of stress that the plants experience. In a study of 15 genotypes, converted Malian sorghums SC-90 and SC-283 did not accumulate large quantities of proline when mildly stressed, but in the same environment, sorghums selected from NP9BR accumulated much larger quantities of proline. It was previously shown that the growth substance abscisic acid (ABA) when exogenously applied markedly influenced sorghum growth and stress resistance.

Progress was made in development of techniques and procedures for quantitative analysis of abscisic acid (ABA) in sorghum. A bioassay with wheat coleoptiles proved simple and easily performed with good results. An immunoassay with a commercially available monoclonal antibody was also developed. It is very specific for free ABA, and can detect small quantities. Experiments were initiated to determine whether there are inherent differences in quantities of ABA that may contribute to genetically different sorghums. Experiments were also initiated to determine whether proline accumulation is related to Fusarium infection in sorghum. Greater quantities of proline accumulated in leaves and roots of infected plants than in controls, and amounts accumulated differed significantly between two genotypes. Research in Mali showed that soil plowing and crust breaking improved emergence and decreased soil resistance to penetration. There were genotype differences in response to the treatments.

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 that of drought and high temperatures. Germination, seedling emergence and stand establishment may be a major problem in Mali and other drought prone countries, as well as effects of drought, often accompanied by high temperatures, at other stages of development throughout the growing season. 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

It has been shown that proline often increases in plants when they are drought stressed or exposed to temperature extremes. Further studies were conducted to investigate the accumulation of proline as it may relate to sorghum and millet performance.

Proline concentrations in leaf tissue were determined on plants grown under dryland field conditions. The second expanded leaf from the top was sampled and analyzed. The method of Bates *et al.* (Plant and Soil 39:205-207, 1973) was used.

Abscisic Acid

Both bioassay and monoclonal antibody techniques were developed for continued studies on the effects of abscisic acid (ABA) on stress resistance. Wheat varieties Redland, Siouxland and Centurk 78 were used for the bioassays. The monoclonal antibody was commercially obtained. The bioassay is inexpensive and can be conducted with minimal equipment. After seed germination, growth of cut segments of the coleoptile or the whole coleoptile were measured after treatment with ABA solutions ranging from 10^{-3} to 10^{-7} molar or with unknown solutions plus a control. Plant extraction of ABA generally followed the procedure described by Beardsell and Cohen (Plant Physiol. 56:207-212, 1975). The procedure for immunoassay of ABA was that of PHYTODETEK-ABA as described by IDEATEK, Inc., San Bruno, CA. The ABA project is part of a graduate student program.

Fusarium/Proline Relations

A study was initiated in cooperation with Dr. John Leslie, Kansas State University, on possible relations among sorghums susceptible to *Fusarium* sp. attack and proline accumulation. Since Dr. Leslie previously found that some Fusariums grow well on proline media, 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 inoculated at one week of age with *Fusarium moniliforme* by dipping a sterile toothpick in the culture and piercing the plant stem. Controls were treated similarly without the organism.

Pysiological Characteristics of Drought Resistant Sorghums

A graduate student project was initiated to study several physiological characteristics of Malian and other sorghums that may contribute to their differences in drought and high temperature resistance. The study includes field, greenhouse, and growth chamber studies. Parameters measured include leaf number and leaf area, internode length, plant height, photosynthesis rate, diffusive resistance, soil water depletion, depth of rooting, root mass, desiccation and heat tolerance, water use, and water use efficiency. Data collection and analysis is incomplete on this study.

Effects of Soil Crusting

Soil crusting is a major constraint to stand establishment in many areas of West Africa. A study was conducted in Mali with an objective of better understanding the differential genotype responses to soil crusting, and to use that information in breeding programs; also, to test techniques that could help alleviate this problem.

Five millet and five sorghum varieties were used in the study. The varieties were planted in a factorial design with two levels of plowing and crust breaking, using a simple implement developed by ICRISAT.

Crust development was induced with a strong irrigation after planting. The trial was conducted in the hot, dry season. Crust hardness was measured with a penetrometer, soil temperatures measured, and percent emergence recorded at 3, 5, and 7 days after planting for the millets and 4, 6, and 8 days after planting for the sorghums.

Research Findings

Proline

This study was a continuation of that reported in the 1988 Annual Report. Proline concentrations were measured in leaf tissue from 15 sorghum genotypes, sampled during a natural drought period.

Genotypes included seven selections from NP9BR, 7078, 9040, Martin B, Redlan, B35-6, 4104 (NP3), SC-283, and SC-90. Leaf proline concentrations ranged from 185.2 to 96.3 micrograms per gram dry weight, with significant differences among genotypes. The four selections 272, 121-LT435, 9-3, and 121LRS2 (all from NP9BR) had the highest accumulation of proline, while 9040 and 103-S-11 (NP9BR) were the lowest. Malian converted sorghums SC-283 and SC-90 were medium-low in proline accumulation in this study. While leaf water potentials were not taken at the time of sampling, visual notes were taken on leaf curl and general stress symptoms. There was no indication that the quantity of proline accumulated in the different genotypes was strongly correlated with major differences in abilities to avoid stress. For example, 121LT435, which was selected for deep rooting potential and good avoidance characteristics, appeared turgid, while sorghum 4104 - which is known for its cellular tolerance of stress - had visible symptoms of stress, although they both had equal quantities of proline accumulation. Neither of the two Malian genotypes exhibited strong symptoms of stress suffering nor had they accumulated high proline concentrations. At this time it appears that proline may accumulate in some genotypes even when they are mildly stressed, apparently as a protective mechanism. However, this is not true for all genotypes, as our study has shown.

Abscisic Acid

In the bioassay with wheat coleoptile growth, in the presence of ABA, generally the greatest stimulation of growth occurred at 10^{-7} molar ABA. The response, however, was found to differ somewhat with genotypes. A similar response was obtained with sorghum , without emerging coleoptiles, but the difference in growth among treatments was less and again genotype variability occurred. The study is progressing with free and conjugated ABA concentrations being determined for seeds, germinating seeds, roots, leaves and stems of sorghums under different stress and non-stressful conditions. However, the data are incomplete at this time.

Fusarium/Proline Relations

In the initial experiments of this study sorghums CK-60 and SC-283 were grown hydroponically in complete nutrient with five replications and two treatments - inoculated with fusarium and uninoculated controls. Plants, including roots, were harvested 14 and 30 days after inoculation. Leaves and roots were separated and analyzed for proline content. At 14 days after inoculation, proline concentrations were slightly higher in both roots and leaves of infected plants. At 30 days after inoculation the mean quantities of proline in micrograms per gram dry weight were as follows: Leaves (inoculated) - CK-60, 727.3; SC-283, 663.3. Leaves (not inoculated) - CK-60, 613.2; SC-283, 592.5. Roots (inoculated) - CK-60, 163.5; SC-283, 203.9. Roots (not inoculated) - CK-60, 331.5; SC-283, 261.3. In both genotypes proline accumulation was greater in leaves and roots when they were inoculated with fusarium. This may be in response to stress induced by the pathogen. However, the accumulation in the leaves of inoculated SC-283 was significantly less than in inoculated CK-60 leaves. It was not determined in these experiments whether there was any preferential growth of the fusarium when proline accumulation was higher. Several additional experiments are in progress in this area.

Effects of Soil Crusting on Millets and Sorghums

Results of this study conducted in Mali are shown in Tables 1-4. Table 1 shows that plowing improved the expression of millet seedling vigor, and the response was genotype dependent. Millet IBV8001 and Yoe had the most vigorous seedlings, and the vigor was enhanced when the plot was plowed.

Percent emergence showed a synergistic effect of plowing and crust breaking. Measurements with a penetrometer showed a significant effect of plowing on soil resistance to penetration (Table 2). Soil temperatures at 1 and 3 cm depth was reduced by about 2 to 4 degrees C due to the crust breaking treatment, and this effect could be very important to seed germination and emergence in such an environment. At the same time, the crust breaking als(reduced the resistance of the soil that the germinating seedling had to break through.

Correlation analysis for the millets showed that percent emergence 3 days after planting was negatively correlated with soil resistance to penetration. And, emergence percentages at 5 and 7 days after planting were negatively correlated with soil temperature.

The effects of plowing and crust breaking on emergence of sorghum seedlings are shown in Table 3. Contrary to the millets, the effects of crust breaking were apparent on the first emergence count, 4 days after planting. In general, the effects of plowing on emergence were not strong, but there was a noticeable effect of crust breaking, and there was a synergistic effect when the two types of cultural practices were simultaneous. The two locals responded distinctively different from the other sorghums. There were no significant effects of the treatments when evaluated at 4, 6, or 8 days after planting. By contrast, the improved varieties responded positively to the treatments in improved germination, seedling vigor and emergence. Malisor-1 and E 35-1 were the least vigorous, but were the most responsive to the soil treatments.

Table 4 confirms, as occurred in the millet experiment, that the soil temperature was reduced when the crust was

Table 1. Means of the effects of plowing or not plowing and crust breaking or not crust breaking on millet emergence at 3, 5, and 7 days after planting.

	Percent emergence											
	3 d.a.p.*				5 d.a.p.				7 d.a.p.			
Variety	p c	P c	p C	P C*	p c	P c	p C	P C	p c	P c	p C	P C
Yoe	0.5	1.8	0.8	3.3	9.8	10.0	13.5	20.0	10.8	13.8	15.0	20.3
M9D3	0.0	0.3	0.0	0.0	0.0	0.0	0.3	2.0	0.0	0.3	0.3	3.5
M2D2	0.8	2.3	0.0	1.3	8.8	14.0	13.0	20.5	9.5	14.8	14.5	20.5
Boboni	0.0	2.8	0.0	1.0	6.0	14.0	13.8	17.8	6.8	14.8	13.8	18.5
IBV8001	0.5	6.5	0.8	6.5	9.5	15.0	18.3	21.3	10.5	17.3	18.3	21.3

* d.a.p. = days after planting
p = not plowed; P = plowed
c = crust not broken; C = crust broken

Table 2. Means of the effects of crusting on soil temperatures and resistance to penetration.

	Soil temp. at 1 cm depth, °C				Soil temp. at 3 cm depth, °C				Soil resistance to penetration*			
Variety	p c	P c	p C	P C*	p c	P c	p C	P C	p c	P c	p C	P C
Yoe	39.2	40.6	35.7	36.2	36.2	37.5	33.5	33.1	1.76	1.27	1.75	1.18
M9D3	39.1	39.4	38.3	37.8	36.0	36.6	34.9	34.4	1.66	1.11	1.70	1.30
M2D2	39.3	40.7	37.6	36.4	36.5	37.2	34.6	34.0	1.68	1.19	1.58	1.25
Boboni	38.6	40.4	37.6	36.1	35.5	37.4	35.0	33.2	1.56	1.19	1.51	1.20
IBV8001	39.6	40.5	38.0	37.0	36.4	36.1	34.7	33.8	1.64	1.08	1.76	1.44

* Penetration in kg/cm²
p = not plowed; P = plowed
c = crust not broken; C = crust broken

Table 3. Means of the effects of plowing or not plowing and crust breaking or not crust breaking on sorghum emergence at 4, 5, and 8 days after planting.

	Percent emergence											
	4 d.a.p.*				6 d.a.p.				8 d.a.p.			
Variety	p c	P c	p C	P C*	p c	P c	p C	P C	p c	P c	p C	P C
CSM 219	9.0	12.3	17.5	15.3	18.5	19.5	20.0	19.8	19.3	21.0	20.3	20.3
CSM 228	7.5	12.0	15.0	18.3	17.0	16.5	20.3	21.0	18.0	17.3	20.3	21.5
Malis-1	2.5	3.3	4.5	13.5	7.8	13.0	13.3	20.0	10.3	14.5	13.5	18.8
Malis-7	2.0	4.0	15.8	16.8	10.8	14.0	19.8	21.0	11.5	14.5	19.5	21.3
E 35-1	6.3	5.8	12.8	14.8	10.3	10.0	17.3	19.3	12.3	10.3	17.0	18.3

* d.a.p. = days after planting
p = not plowed; P = plowed
c = crust not broken; C = crust broken

Table 4. Means of the effects of crusting on soil temperatures and resistance to penetration with sorghum genotypes.

	Soil temp. at 1 cm depth, °C				Soil temp. at 3 cm depth, °C				Soil resistance to penetration *			
Variety	p c	P c	p C	P C*	p c	P c	p C	P C	p c	P c	p C	P C
CSM 219	39.1	39.3	37.0	37.5	36.8	37.6	36.1	35.3	1.70	1.34	2.04	1.64
CSM 228	39.3	39.1	36.1	36.9	36.9	37.5	34.2	34.9	2.23	1.55	2.29	1.56
Malis-1	38.5	39.5	37.2	37.4	36.0	38.0	35.4	35.3	2.31	1.58	2.01	1.70
Malis-7	38.8	40.0	37.5	36.9	36.7	38.3	34.9	34.9	2.00	1.56	1.83	1.68
E 35-1	38.4	39.2	36.7	38.2	36.1	37.6	34.2	35.7	1.88	1.50	2.29	1.65

* Penetration resistance in kg/cm².
p = not plowed; P = plowed
c = crust not broken; C = crust broken

broken, and the effects of plowing on penetration resistance was equally apparent in this experiment. As with the millets, correlation analysis showed that soil temperature and emergence at all observation dates were highly negatively correlated. These experiments have shown that both plowing and crust breaking can be very important to stand establishment of some genotypes.

Publications and Presentations

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Networking Activities

Research Investigator Exchanges

The P.I. visited Mali, September 16-25, 1989. The purpose of the trip was to discuss the research in progress and planned, to visit the experimental plots at Somanko, Ntarla, and Cinzana Research Stations and take field notes, and to review with USAID and IER personnel the continuing collaborative research program in Mali. Physiological experiments were also planted at Koporo-Keniepe, and Bema Research Stations. Since Kopore was visited last year, plans were made to visit Bema on this trip, but were canceled due to difficulties with air travel.

Assistance Given

Several pieces of equipment, supplies, and books were purchased 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 and repair, maintenance, and recalibration of other equipment.

Plant Breeding

Executive Summary

Project KSU-101 continued to make progress in the identification and stabilization of inbred lines and population progenies possessing seed and seedling traits associated with improved stand establishment. Testing in the laboratory and screening in greenhouses and field plantings have identified selections possessing long mesocotyl length and rapid seedling elongation with the ability to emerge one-half to two days earlier than the line used as checks. Combining abilities of these characteristics are being determined by testing in hybrid combinations with elite tester lines.

Increased seed size has been an important consideration in selection for improved stand establishment. However, F_2 families with very large seeds (16-25 g/1000 seeds) derived from a Morocco line had reduced total emergence and emergence indices when planted in a marginally moist seedbed. Crosses have been made to transfer the large-seed character into an array of genetic backgrounds in an attempt to stabilize and enhance its expression and exploit its potential for improved stand establishment.

The exchange of materials with ICRISAT followed by crossing and selection at each location has been producing higher levels of improvement for each location. The latest imports, when crossed to elite lines, have produced hybrids with excellent agronomic characteristics and grain yield potential exceeding 4500 kg/ha.

More than 1900 lines were received from the Tissue Culture for Crops Project at Colorado State University. Results from a planting of 472 of these lines indicate tissue culturing for drought tolerance generates extensive variation within several agronomic characteristics. Large populations are required for screening because a very high proportion of the materials are inferior. Selections from fewer than 5% of these lines will be advanced in the program.

At least two hybrids using 2068A as the seed parent are being considered for release in northwest India by the national program. (KSU-101)

The primary collaborative research site of the germplasm enhancement conducted by MSU-104 is Colombia. Host country capabilities have been strengthened through trained staff, equipment, cold room seed storage facilities, sorghum and millet germplasm, literature, and travel for ICA staff for professional improvement. Through joint planning, INTSORMIL scientists have been able to provide input into ICA priorities in sorghum research. For tropical acid soil research, the facilities and research stations of CIAT, ICA, and El Alcaravan Foundation make Colombia a good research site. Also it represents the relevant ecogeographic zone of South America well. Technology developed at this site has been transferred to Brazil, Venezuela, Peru, Zambia, Niger and Kenya.

This year, the most significant aspect of the acid soil research has been the production and evaluation of F_1 hybrids from photoperiod insensitive, Al-tolerant A- and R-lines developed by this project. All world collection lines identified as Al tolerant were photoperiod sensitive which limited their usefulness to acid soil areas near the equator. Now, however, elite U.S. lines can be used as one parent with the new genetically dominant Al-tolerant lines to produce high yielding, acid soil tolerant hybrids for temperature as well as tropical regions of the world. This research now becomes more relevant to both U.S. and LDC farmers. (MSU-104)

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 El 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 14 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. (MSU-111)

Project NU-115 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 consumption. A collaborative breeding project has commenced in Botswana, where progeny of crosses with drought tolerant Segaolane (and other similar varieties) and U.S. B-lines have succeeded through 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 will be tested for drought/heat tolerance. Segments of this material will support breeding programs in collaborating countries, and will be released in the U.S.

The exotic introductions used in crosses were also selected and tested as varieties and hybrids and nurseries were provided to Niger, Senegal, and Sudan. 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. Three seed parents and 36 germplasms were released. The germplasm release was designed so that sorghum breeders could have early access to new project material with potential for breeding new seed parents. Germplasm was exchanged between countries and with U.S. scientists. (NU-115)

The principal objectives of Project NU-118 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 NU-118 has been the continued development of elite inbred lines which will be used in both custom crosses with host country varieties and to produce parental lines and varieties for the U.S.

Two thousand one hundred and ninety F_3-F_7 lines from tropical x early parent crosses were evaluated and selfed in 1988, and backcrossing continued on 250 male sterile testcrosses and backcrosses. Selection was continued for lodging resistance. Backcrossing, selfing and hybrid production was continued on 240 elite lines sent to the winter nursery. Custom crossing continued with project inbreds and leading Mali, Zambian, and Malawi introductions and backcrosses to Mali varieties 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 1988 confirmed that topcrossing these varieties to a seed parent increases yields by 20-30%. Such topcross hybrids have distinct advantages for LDC conditions and are easier to develop. (NU-118)

The major focus of Project PRF-103A 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. Relatively little is known about sorghum breeding and genetics in comparison to other major staple cereals. Genetic studies contribute to the development of improved breeding methodologies for sorghum improvement. New knowledge has been gained by this project about utilization of sorghum populations in breeding programs. Traits such as heritability of grain hardness and heritability of seedling cold tolerance are important for both the U.S. and developing countries. Selection methods for improving these important traits have been developed. (PRF-103A)

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. INTSORMIL Project PRF-107 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 in terms of both germplasm and information.

In Year 10 studies on performance and stability of *Striga* resistant cultivars, the genetics of *Striga* resistance, and integrated cultural control of *Striga* were completed. Six sorghum varieties previously reported as being tolerant to *Striga hermonthica* in other African countries were tested and found to be well adapted in Niger. However, two cultivars, SRN39 and IS9830 showed significantly better resistance as well as better stability and adaptation than the other four cultivars. The inheritance study showed that *Striga* resistance in SRN39 was heritable and its mode of inheritance was recessive. The effects of varietal resistance, application of nitrogenous fertilizers, and mode of tillage prior to sowing on infestation of *Striga hermonthica* was also studied. The results reaffirmed that application of urea at 100 kg N/ha significantly reduced infestation and when coupled with a resistant cultivar provided better protection against *Striga* infestation. The effects of tillage treatments varied according to location, rainfall, and type of sorghum cultivar used. (PRF-107)

Sustainable yield of an adequate magnitude and quality at an economic level is productivity. The principal objective of Project 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 adequate resistances to biotic and abiotic stresses.

The drought resistance breeding program and the genetic/physiologic explanation of resistance continues. The glossy trait found in sorghum contributes to drought resistance through morphological means. Greater root system development occurs throughout the plant's life cycle. Glossy isolines showed greater capability to survive severe drought, recover, and resume growth sooner than the normal lines. The ability to stay green under severe stress was determined to be genetically dominant in B35 and recessively inherited in R9188.

The ability for some sorghums to remain fertile under low temperatures (approx. 10°C) at flowering is controlled by one or two pairs of genes. The system appears economically useful in the development of sorghum hybrids which can be used in both high altitudes and intermediate elevations.

The taxonomic groups of sorghum zerazera, nigricans, nigricans/feterita, durra-nigricans and caudatum-kaura combined well to produce high yielding hybrids in both the A_1 and A_2 cytoplasmic-genetic male-sterility systems.

Resistance to damage caused by the head bug that attacks sorghum in parts of West Africa may be related to a water/carbohydrate concentration in the developing grain and be only indirectly related to rapidity of dry matter accumulation.

A MDMV-strain A resistant restorer line (RTx2858) was released for use in areas of the U.S. and LDC's where virus is a problem in productivity. Also, GTPP7R was jointly released by Texas and Georgia. This material has excellent disease resistance as well as white grain, tan plant color and grain mold resistance. It will contribute significantly to programs throughout the CRSP.

A large amount of new germplasm was added to the program through introductions from LDC's which has been crossed or otherwise incorporated into the project improvement program. A large amount of germplasm of all types was distributed to LDC, other international and domestic collaborators.

The food type sorghums evolving from this project are beginning to impact the U.S. The sorghum industry is recognizing the benefits of white grain, tan plant color and a grain that will process into a food as well as being a superior poultry or livestock feed. Food use and new product development underway with sorghum will continue and with a major shift in U.S. usage of these types of new sorghums, there will be economic improvement from sorghum in the U.S. as well as in those countries which already consume sorghum. (TAM-121)

The principal objectives of Project TAM-122 are to identify and develop disease resistant and drought resistant sorghum germplasm in diverse backgrounds for use by collaborating 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 with several breeding lines and parental lines ready for release, as well as some new converted lines. New cultivars were introduced into the U.S., evaluated, and used in crosses. A large amount of new germplasm containing a large number of desirable traits was generated by the new crosses. Large numbers of germplasm lines of all categories were distributed to LDC, other international, and domestic collaborators.

A white seeded, tan plant, food type, foliar disease resistant population, GTPP7R(H)C5, was cooperatively released by Georgia, Texas, and Puerto Rico. It carries high levels of resistance to anthracnose, rust, and other foliar diseases in a diverse genetic background, as well as possessing grain with desirable food properties.

The new female parental lines with high levels of post-flowering drought resistance, charcoal rot resistance, and lodging resistance are being released. The two lines, A35 and A1, to be released as ATx633 and ATx634, should be very useful as parental lines in hybrids in the U.S. as well as in LDC's as parental lines or germplasm sources.

The Malian developed improved line, Malisor 84-7, has excellent head bug resistance. Crosses of this line with elite, high yielding lines were made and showed excellent breeding potential in both Texas and Mali.

The ICRISAT/CIMMYT developed female parental line, A&B Var 1, was found to possess excellent post-flowering drought resistance and head smut resistance. It is a white seeded, tan plant, good food type line.

Several new converted lines and recently introduced exotics were identified as having excellent drought resistance. The outstanding new recently introduced exotics included: Segaolane, a Kafir line from Botswana; El Mota, a Caudatum from Niger; and two Sudanese Feterita varieties, Ajabsido and Koro Kollo. All four showed outstanding resistance to severe pre-flowering drought stress. Many of the new lines were crossed to U.S. elite lines to transfer the drought resistance into improved agronomic types.

New exotics were introduced from Northern Nigeria and Somalia, and should be useful as sources of drought resistance. (TAM-122)

Project TAM-123 reports that germplasm lines resistant to sorghum midge (21 lines) or biotype E greenbug (10 lines) have been developed and released. The lines represent a significant improvement in the diversity of elite germplasm available with resistance to either insect. In addition to superior resistance the lines are widely adapted, being suitable for use in most sorghum production areas, and possess excellent yield potential in either the presence or absence of the insect pest. The lines in hybrid combination should contribute to greater yield stability, reduce susceptibility to biotic stress, and contribute to less dependence on chemical control of the insect pests.

Results from a field study with two grain sorghum genotypes, three water levels and three nitrogen fertilizer rates indicate a genotype x water x N rate interaction on evapotranspirational water use efficiency and nitrogen use efficiency. Preliminary results indicate a significant effect of N level on transpiration water use efficiency under field conditions.

Preliminary evaluation of results from a lysimeter study conducted under a rainout shelter indicates significant effects of phosphorus level and sorghum genotype on transpirational water use efficiency. Nutrient uptake was related to biomass production and transpiration. Highest water use efficiencies were obtained at the lowest water level. (TAM-123)

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 in Honduras that produce sorghum through the conservation of biodiversity and enhancement of traditional sorghum varieties.

Near term goals emphasize the enhancement of improved varieties and hybrids which make up roughly 10% of the sorghum acreage in Honduras. These goals have been met with the introduction and joint release of sorghum cultivars Tortillero (1983), Catracho (1984), and Sureño (1985). Farm level studies indicate that Sureño and Catracho increase grain yield over traditional technologies by 68 and 113% respectively. This translates into an increase in family income from \$1.60 per day ha^{-1} to \$2.70 with Sureño and \$4.40 with Catracho.

Midterm goals focus on conservation and enhancement of tropical landrace sorghum called maicillo criollo. Maicillo is traditionally intercropped with maize on marginal land by resource poor farmers who use it as "drought crop insurance". Enhanced maicillo varieties will upgrade small farmer food production for self-sufficiency and sustain conservation of local germplasm and biodiversity associated with intercropping. The new maicillo will facilitate *in situ* conservation via an informal network of village level landrace custodians that will forge a rural landscape mosaic of modern, enhanced traditional, and traditional varieties and technologies. Enhanced maicillos have produced up to 58% more grain yield than their maicillo parent and are resistant to sorghum downy mildew.

Long term goals call for the extension of enhanced maicillo varieties to hybrids for the purpose of maximizing small farmer benefit and shifting subsistence agriculture towards production agriculture. Forty-three experimental half-sib maicillo hybrids outproduced their maicillo parents by 94% (3.1 vs 1.6 t/ha, respectively) over three locations in 1988. In another test at the same locations, an enhanced maicillo hybrid produced 4.6 t/ha. Male sterilization of enhanced maicillo lines is on schedule and the first lines will have completed five backcrosses by December 1989. (TAM-131)

Pearl Millet Breeding

Project KSU-101

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Summary

Progress continued in the identification and stabilization of inbred lines and population progenies possessing seed and seedling traits associated with improved stand establishment. Testing in the laboratory and screening in greenhouses and field plantings have identified selections possessing long mesocotyl length and rapid seedling elongation with the ability to emerge one-half to two days earlier than the line used as checks. Combining abilities of these characteristics are being determined by testing in hybrid combinations with elite tester lines.

Increased seed size has been an important consideration in selection for improved stand establishment. However, F_2 families with very large seeds (16-25 g/1000 seeds) derived from a Morocco line had reduced total emergence and emergence indices when planted in a marginally moist seedbed. Crosses have been made to transfer the large-seed character into an array of genetic backgrounds in an attempt to stabilize and enhance its expression and exploit its potential for improved stand establishment.

The exchange of materials with ICRISAT followed by crossing and selection at each location has been producing higher levels of improvement for each location. The latest imports, when crossed to elite lines, have produced hybrids with excellent agronomic characteristics and grain yield potential exceeding 4500 kg/ha.

More than 1900 lines were received from the Tissue Culture for Crops Project at Colorado State University. Results from a planting of 472 of these lines indicate tissue culturing for drought tolerance generates extensive variation within several agronomic characteristics. Large populations are required for screening because a very high proportion of the materials are inferior. Selections from fewer than 5% of these lines will be advanced in the program.

At least two hybrids using 2068A as the seed parent are being considered for release in northwest India by the national program.

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 case 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 Results

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_1 B_1 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 (RD), mesocotyl (MC), and coleoptile (CL) structures. Length measurements of these structures 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. Ten randomly selected seedlings from each germinated seed lot are measured. 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 in paired rows at two depths, 37, and 75 or 100 mm depths, to identify lines possessing superior emergence characteristics.

Research Findings

The drought severity index of the Fort Hays Experiment Station for the 22-month period covering this report period and immediately preceding it was as severe as reported for similar periods of time in the 1930's and 1890's. Soils on our testing sites that were fallowed throughout 1987 were able to accumulate about 250 mm of stored soil moisture in the upper 1.5 m of the soil profile. With the 240 mm (75% of normal) rainfall received during the 1988 June-to-October growing period, growth and development of performance tests and crossing blocks planted on these fields was near normal. All of the F_3 to F_5 segregating materials are planted on fields fallowed for a 10-month period which usually allows selection and advancement of materials to take place under moderate stress conditions. Drought stress on these fields was too severe and all of the medium-early to late maturing materials failed to complete anthesis and set seed.

Characteristics such as increased seed size, weight, and density, type of endosperm (floury vs. vitreous), increased seedling mesocotyl and radical lengths, rapid mesocotyl elongation, and rapid plant growth are traits that are associated with improved stand establishment. Selection for increased seed size and weight is a routine procedure within all of the project materials and in selection for improved stand establishment characteristics, emphasis is placed on increasing seedling length, rate of seedling elongation, and improved seedling emergence indices.

Increased seedling length and rate of elongation does not guarantee improved stand establishment, but screening in planting depths of 75 to 120 mm gives a reasonably good separation of genotypes with vigorous seedlings possessing the ability to emerge from normal planting depths one to two days earlier than non-selected genotypes. Quite often, under conditions when crusting occurs, the rapid emergence of the selected materials allows seedling emergence before the soil crust becomes too thick and hard to penetrate.

Numerous inbred lines and selections that had been classified for seedling mesocotyl length were grown and reselected in 1987 and 1988 to advance and stabilize the expression of desired seedling characteristics and to select for good agronomic plant type. A group of 154 hybrids grown in 1987 and 1988 were obtained from crosses of superior long mesocotyl selections and elite tester lines. These hybrids were evaluated for stand establishment characteristics and combining ability to identify superior lines. The best parental lines identified by these tests and superior lines selected on their ability to emerge to good stands from planting depths of 75 and 100 mm have been used in a total of 856 crosses within this group of materials and to other elite inbred lines. Ninety-one of these hybrids were planted in replicated trials in two environments in 1989 to evaluate performance characteristics. Segregating F_2 families are being extracted from the best F_1's of the remaining crosses.

The 1989 field plantings of stand establishment materials include the following:

432 F_2 families segregating for seed and seedling characteristics.

890 F_3 lines extracted from 716 F_2 families grown in 1988.

430 advanced inbred lines in crossing nurseries.

482 F_3 to F_6 inbred lines and S_4 population progenies undergoing screening for emergence capability from deep planting.

Preliminary studies comparing four seed size fractions extracted from seed lots of five genotypes planted at 37 and 75 mm depths were conducted in the greenhouse. Seed size separations were made by sieving to minimum seed diameters of 2.0, 2.4, 2.8, and 3.2 mm. The selection of the five genotypes was determined by the presence and quantity of varying seed sizes within each lot of seed. All of the genotypes produce medium-length seedlings ranging from 9 to 14 cm.

Chemical characterizations of the seed size fractions indicated only minor differences existed between seed size fractions of each genotype and between genotypes. Overall, the range in contents was: crude protein, 15.6 to 17.1; ash, 1.35 to 1.78; fat, 4.3 to 6.5; and fiber, 1.4 to 2.0. No significant correlations were found between any of these factors and the responses obtained from measurements of germination index, total germination, seedling height, and plant weight as affected by genotype, seed size, or planting depth.

As expected, depth of planting (D), genotype (G), and seed size (S) effects (Table 1) were significant or highly significant for all variables measured except the G effect on plant weight (harvested 14 days after planting). Second order interactions involving G * S effects on emergence index and total emergence were significant but seedling height and plant weight were not affected by this interaction. The lack of significant effects of the D * G interaction on all variables reflects the uniformity of response to planting depths by the genotypes tested. Nonsignificance of the D * S effects on emergence index was expected since the index is influenced by the period of time involved in emergence more than by numbers of seedlings emerged, whereas the significance of D * S effects on total emergence is influenced by the differences in numbers of seedlings produced by the different seed size fractions in shallow and deep plantings.

Table 1. Combined ANOVA for emergence index, total emergence, seedling height, and plant weight of five pearl millet genotypes, four seed sizes and two depths of planting under greenhouse conditions.

		Mean squares			
Source	df	Emergence index	Total emergence	Seedling height	Weight per plant
Replications (R)	2	2/8.8	23.2	33.4	0.001
Depth of planting (D)	1	20/884.0**	4071.7**	251.4*	0.023**
R * D	2	1068.1*	11.0	418.7**	0.010*
Genotype (G)	4	1427.7**	25.7*	159.3**	0.001
Seed size (S)	3	5040.2**	89.2**	1041.0**	0.025**
G * S	12	1056.6**	21.9**	50.5	0.003
D * G	4	314.5	9.7	79.2	0.002
D * S	3	588.7	36.4**	175.9**	0.008
D * G * S	12	433.6	9.2	15.0	0.003

**Significant at the 0.01 probability level.

Interchanges of breeding materials with ICRISAT personnel have been occurring since 1978. Crossing and reselecting of the materials in Kansas and at ICRISAT Center in each cycle of exchange have produced increasing levels of improvement. The 1987-88 importation of ICRISAT advanced B lines received by KSU-101 and NU-118 have been placed in approximately 175 hybrid combinations with elite Kansas B lines. Yield potential, plant type, seed size, tillering, and apparent food quality of these hybrids appear to be considerably better than for hybrids produced from previous importations. In both the 1988 and 1989 nurseries of these hybrids, estimated grain yields range from 4,500 to over 6,000 kg/ha. The 1989 planting of 190 F_2 families derived from the 1988 nursery is producing excellent segregates under moderate drought stress conditions. Test crosses of 20 of the best Kansas B x ICRISAT B hybrids to elite A lines has produced hybrids with excellent sterility and yield potential equaling our better A x R hybrids.

In our germplasm collection, we have three cultivars or landraces from Morocco that possess average seed size but one, Maurakeck, may have genetic factors enhancing seed size different from the genes present in our breeding populations. Our largest seeded lines have 1000 seed weights of 16 grams. Since 1985, several progenies derived from the Maurakeck line have had 1000 seed weights of 15 to 25 grams under conditions of above normal rainfall and mild air temperatures during the seed fill period in mid-August. This year, we imported seeds of millets produced in the Fez and Rabat areas of Morocco to search for additional seed size modifiers. Thirty-two hybrids between elite KSU lines and the Morocco germplasm were made during the quarantine period. Seed sizes produced by these hybrids in the 1989 field are not expected to exceed 16 grams per 1000 seeds, although nearly all of the hybrids do have above average seed size.

The 1988 F_2 nursery was planted with a loose-ground lister-type planter that placed the seeds in minimally moist soil below the dry surface soil. Nearly all of the 936 F_2 families in this nursery emerged to good stands. However, several of the large-seeded (16 to 25 g/1000 seeds) Maurakeck F_2's had low emergence indices and thin stands. With increasing drought stress during seed fill, F_3 seed weights ranged from 8 to 13 g/ 1000. These results indicate considerable effort will have to be expended to place these seed size modifying factors into genetic backgrounds that allow more stable expression and enhance their potential to improve stand establishment.

The Colorado State University Tissue Culture for Crops Project (TCCP) has been working with several KSU-101 millet lines and populations to develop stress resistant materials. Because of budgetary constraints and difficulties encountered in evaluation and seed production of millet, the TCCP has decided to terminate the work. A total of 1919 lines derived from tissue culture was sent to KSU-101 for evaluation and possible breeding use. These lines are the result of from 5 to 18 passages through culturing medium. A large proportion of the lines have received from 2 to 12 passages through varying concentrations of PEG, NaCl, and $AlCl_3$ stress- inducing media. Seeds of more than half of the lines were produced in the TCCP greenhouse resulting in very small sizes and quantities. A sizable proportion has received up to three regenerations with the last regeneration performed under field conditions either at one of three

Arizona locations, a low Ph site in Georgia, or at Fort Hays. Nearly all of these materials have acceptable seed sizes and quantities (10-100 g).

Prospects for successful field production of these materials were very poor at the beginning of the 1989 planting season because of severe drought and the absence of stored subsoil moisture. We planted 472 of the lines that had acceptable seed size and sufficient quantities to allow replanting in 1990. Rainfall in June and July was adequate for good plant development, and drought stress throughout August has produced good stress differentials. Preliminary results indicate fewer than 5% of the lines will be directly useful as sources of drought tolerance as the majority of the lines have failed to head. The results indicate that tissue culture generates extensive variation for agronomic traits such as plant height, maturity, head size, and tillering. However, screening will require large populations because of the tendency to generate a large proportion of inferior lines.

Publications and Presentations

Stegmeier, W.D., B. Khaleeq, R.L. Vanderlip, and D.J. Andrews. 1988. Pearl Millet a Potential Early Maturing Dryland Feed Grain Crop. Abstract of a poster paper presented at the First National Symposium, New Crops Research, Development, and Economics, Indianapolis, Indiana, October 23-26, 1988. Proceedings in press.

Khaleeq, B., W.D. Stegmeier, and R.L. Vanderlip. 1988. Stand Establishment in Relation to Seedling Mesocotyl and Coleoptile Length in Pearl Millet. Abstract of a poster paper presented at the First National Symposium, New Crops Research, Development, and Economics, Indianapolis, Indiana, October 23-26, 1988. Proceedings in press.

Mohamed, A., F.L. Barnet, 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

Workshop

October 23-26, 1988. First National Symposium, New Crops Research, Development and Economics. Indianapolis, Indiana. Two poster papers were presented describing progress in stand establishment improvement of pearl millet and the development of pearl millet as a potential grain crop for mechanized agriculture.

Research Investigator Exchange

August 17, 1988. F.R. Muza, graduate student, MSU-104. Discussed his genotype X environment MS thesis study and examined the FHBES unit of the study. The data collected at the FHBES were forwarded to him in November.

September 16, 1988. As part of the INTSORMIL External Evaluation Panel's review of the Kansas INTSORMIL program, the review team and participants in the review toured the pearl millet breeding program. Several breeders and agronomists spent additional time examining the breeding nursery.

October 4-5, 1988. Traveled to Lincoln and Mead, Nebraska, via Manhattan, to examine FHBES pearl millet lines and hybrids at each location and to tour the INTSORMIL/NU-118 millet and NU-115 sorghum breeding programs. Participants included five KSU and seven Nebraska graduate students.

October 15, 1988. The pearl millet breeding program was visited by Mr. Amadu Fofana, Millet Breeder, Senegal, and three INTSORMIL/ NU-118 graduate students from Malawi, Mali, and Zambia. Discussions centered on field layout and breeding program management, breeding goals and methods, and on types of materials needed in developing countries. Lists of FHBES materials were made to be sent to their respective countries upon their return.

October 17, 1988. The project was visited by Dr. Lloyd Rooney, INTSORMIL/TAM-126, to select millet materials for use by his project. Discussions included breeding objectives, methods, and goals to develop grain types needed for superior food products. Arrangements were made to supply his laboratory with grain for research.

Interest shown by U.S. commercial seed company personnel in grain-type pearl millet breeding has been very limited in past years although representatives of several foreign companies have visited the program. This year, breeders from two U.S. seed companies and a representative of a large food company toured the project. Follow-up included sending 10 kg samples of millet grain to poultry nutritionists of two companies.

Germplasm

Accessions Collected

Two accessions were acquired from Morocco to be used as possible sources of large seed size characteristics. Twenty- nine white-seeded lines were imported into the U.S. from ICRISAT/ Bulawayo but arrived too late for quarantine growout in 1988- 89.

Since the start of the INTSORMIL program, 746 pearl millet cultivars, landraces, inbred lines, and F_1 hybrids have been received from ICRISAT and LDC cooperators.

Two introductions, Malawi IP6774 and Zambia IP8868, and six inbred lines were sent to NU-118.

International Exchange

Shipments of KSU millet materials were reduced in number this year, reflecting the presence of several LDC millet breeders in graduate school training programs in the U.S. and Europe and the loss of much of the early generation inbred materials because of drought in 1988. Sixty-eight items sent to Senegal included seven populations, one landrace, 58 advanced inbred lines, and one A-B pair.

Impact

Previous reports have indicated the wide use of the A-B lines 2068 and 2221 in ICRISAT and Indian national breeding programs. A recent report indicates that two and possibly three F_1 hybrids using 2068A as the seed parent are being considered for release by the Indian program for production in the low rainfall areas of northwest India (Rajasthan).

Assistance Given

Seeds of six pearl millet hybrids, five parental inbred lines, and field space were provided to MSU-104 for a multilocation genotype X environment MS thesis study. Cooperating projects are NU-118, MSU-104, and PRF-103A.

Two shipments of millet grain totaling 1040 kg were sent to TAM-126 to be used in studies developing pearl millet-based food products with extended shelf life.

Three lots of millet grain with yellow, brown, and blue seed colors were provided to Dr. C. Klopfenstein, Department of Grain Science and Industry, KSU, to continue studies of the goitrogenic effects of flavinoid pigments in pearl millet.

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

Project MSU-104
Lynn M. Gourley
Mississippi State University

Principal Investigator

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Dr. Dale Bandy, North Carolina State University, Mission/INIPA and TROPSOILS, Lima, Peru.
Mr. Pedro Carrasco, Leader of INIIPA's Selva Program, INIIPA-Yurimaguas, Peru.
Dr. Antonio Pinchinat, Research Specialist, IICA-Lima, Peru.
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Mr. David Hopkinson, North-West Province Area Development Project, P.O. Box 110296, Solwezi, Zambia.
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Mr. Hamis Saadan, Tanzanian Sorghum Breeder, on study leave at Mississippi State University.
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Dr. Fred Miller, Sorghum Breeder, TAM-121 PI, Department of Soil and Crop Sciences, Texas A&M University, College Station, TX.
Dr. Pedro Sanchez, Soil Scientist and TROPSOILS Coordinator, Department of Soil Science, North Carolina State University, Raleigh, NC.

Summary

The primary collaborative research site of the germplasm enhancement conducted by MSU-104 is Colombia. Host country capabilities have been strengthened through trained staff, equipment, cold room seed storage facilities, sorghum and millet germplasm, literature, and travel for ICA staff for professional improvement. Through joint planning, INTSORMIL scientists have been able to have input into ICA priorities in sorghum research. For tropical acid soil research, the facilities and research stations of CIAT, ICA, and El Alcaravan Foundation make Colombia a good research site which represents the relevant ecogeographic zone of South America well. Technology developed at this site has been transferred to Brazil, Venezuela, Peru, Zambia, Niger and Kenya.

This year, the most significant aspect of the acid soil research has been the production and evaluation of F_1 hybrids from photoperiod insensitive, Al-tolerant A- and R-lines developed by this project. All world collection lines identified as Al tolerant were photoperiod sensitive which limited their usefulness to acid soil areas near the equator. Now, however, elite U.S. lines can be used as one parent with the new genetically dominant Al-tolerant lines to produce high yielding, acid soil tolerant hybrids for temperate as well as tropical regions of the world. This research now becomes more relevant to U.S. as well as LDC farmers.

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

Acid soil tolerance conveys a qualitative assessment of plant adaption to acid soil conditions including low fertilizer and lime inputs. The soil constraints must be characterized and crop response to these production-limiting factors evaluated. Less than optimum conditions for plant growth are implied in this type research. Low-input systems are considered to be transitional technology in both agronomic and economic terms. They provide low-cost alternatives for shifting cultivation in highly acid soil regions.

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 the acid soil complex; 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

Moussa Adamou, INRAN sorghum breeder, conducted a portion of his Ph.D. research in Niger. Soil samples from Bengou, Konni and Kolo were analyzed in the soil testing laboratories at CIAT and INRAN (Table 1). Some of the differences obtained by the two laboratories were due to analytical methods used. The topsoil (0-20 cm) at all three locations does not have toxic levels of Al. Soluble Al would not be expected in soils above pH 5.2. Samples of topsoil and subsoil were collected for analysis in 1989.

These soils have very low cation exchange capacity (CEC), however they do not appear to be below the critical level for essential mineral elements. The analyses show excess P and Mn at Bengou and Kolo and possibly B at Kolo. Low water holding capacity due to the high sand and low organic matter contents would be expected.

Data are not yet available from the genetic combining ability trials conducted in Niger. Several dune adapted sorghum cultivars from Niger along with the combining ability study will be evaluated in Al-supplemented nutrient solution studies at Mississippi State University.

Screening for Mn Tolerance

Using nutrient culture screening techniques, 12 previously screened sorghum lines were evaluated for tolerance to Mn toxicity at 18 (control), 3600, 5400, 7200 uM Mn L^{-1} in the laboratory at Mississippi State University prior to additional genetic studies. Significant differences ($P < 0.01$) among genotypes, Mn levels, and genotype by Mn interactions were found for dry matter (DM) yield of shoots, roots, and whole plants. Means of the DM yield variables are shown in Table 2. Toxic levels of Mn produced a nonlinear decrease in DM yields. For whole plant DM yield at 7200 uM Mn, genotypes TX 623, Wheatland, IS 8931, TX 430, and IS 6944 produced the highest amount and were not statistically different from each other. Least growth was shown by IS 7173C.

Table 1. Soil analysis results from CIAT and INRAN laboratories for three test locations in Niger.

Variables	Bengou CIAT	Bengou INRAN	Konni CIAT	Konni INRAN	Kolo CIAT	Kolo INRAN
Organic matter %	0.52	0.55	0.23	0.21	0.29	0.22**
pH	5.71	5.56	5.59	5.28	6.66	6.63
P (ppm)	19.59	14.10*	7.17	6.36	37.09	15.45**
Al ($cmol\ kg^{-1}$)	T	--	T	--	T	--
Ca ($cmol\ kg^{-1}$)	1.41	1.63*	0.53	0.52	0.62	1.19
Mg ($cmol\ kg^{-1}$)	0.40	0.43	0.16	0.16	0.17	0.50
K ($cmol\ kg^{-1}$)	0.16	0.16	0.16	0.08*	0.15	0.15
CEC ($cmol\ kg^{-1}$)	1.97	2.28**	0.85	0.87	0.94	1.91
B (ppm)	0.60	--	0.92	--	1.34	--
Zn (ppm)	0.85	--	0.31	--	0.92	--
Mn (ppm)	43.98	--	9.14	--	24.48	--
Cu (ppm)	0.24	--	0.36	--	0.29	--
Fe (ppm)	7.36	--	5.18	--	7.26	--
Clay (%)	13.82	--	12.51	--	12.54	--
Sand (%)	67.16	--	84.79	--	85.99	--
Silt (%)	18.86	--	2.78	--	1.47	--

*, ** Significantly different between CIAT and INRAN laboratories at the 0.05 and 0.01 levels of probability, respectively.

Only two of the highest yielding genotypes at 7200 uM Mn, IS 8931 and IS 6944, have been reported to be tolerant to high levels of Al in previous INTSORMIL Colombian acid soil field tests, while IS 7173C was highly tolerant to Al toxicity. It would appear that tolerance to Mn toxicity was, based on this study, independent from tolerance to Al toxicity.

Broadsense heritability estimates for DM yield of whole plants of 84, 46, 54 and 72% at control, 3600, 5400, and 7200 uM Mn, respectively, indicate that a portion of the phenotypic variability for Mn tolerance expressed by these 12 sorghum genotypes should be a trait under genetic control. Improvement in tolerance to Mn toxicity in sorghum should be possible.

Tolerance of Sorghum to Al and Fusarium moniliforme

Low pH has been reported to favor the growth of *F. moniliforme* in competition with other fungi and bacteria. However, reports of the presence of both bacteria and *Fusarium* in some acid soils indicate that the pH phenomenon is complex and that the effect of Fusarium could be due to the favorable nutrition of the fungus on susceptible plant hosts. *F. moniliforme* represents a potential production hazard to acid soil tolerant sorghum cultivars grown in the tropics.

To evaluate the susceptibility of selected sorghum genotypes to *F. moniliforme* and the interaction between this fungus and Al, a series of nutrient culture experiments were conducted at Mississippi State University. Using Al-supplemented nutrient solutions (pH 4.0), sor-

Table 2. Means of shoot, root, and whole plant dry matter yields for 28-day-old sorghum seedlings of 12 selected genotypes at four levels (μM) of Mn.

Genotypes	Shoot 18	Shoot 3600	Shoot 5400	Shoot 7200	Root 18	Root 3600	Root 5400	Root 7200	Whole plant 18	Whole plant 3600	Whole plant 5400	Whole plant 7200
	mg											
IS 9084	3056	626	278	215	1455	171	62	46	4512	799	340	262
IS 6944	2571	780	398	340	1177	248	98	83	3748	1028	496	423
IS 3071	2455	827	275	213	1085	238	65	50	3541	1066	341	263
IS 8931	2255	745	440	358	1002	189	108	80	3257	935	548	438
Wheatland	2055	460	383	342	994	154	120	98	3050	623	504	441
IS 8577	2127	932	457	180	883	270	117	41	3010	1203	574	221
TX 2219	1617	531	228	169	770	161	53	41	2387	692	282	211
B-Yel PI	1521	363	194	192	680	114	48	56	2202	477	242	249
TX 623	1466	1074	400	465	681	440	114	140	2147	1520	514	605
C. Sagrain	1268	342	281	241	638	90	76	54	1907	432	357	295
TX 430	1098	630	223	330	488	250	[illegible]	101	1586	880	293	431
IS 7173C	873	177	139	107	360	58	[illegible]	25	1234	235	167	132
Mean[1]	1863 a	624 b	308 c	262 d	851 a	189 b	80 c	68 d	2715 a	824 b	388 c	331 d
LSD (0.05)	684	543	202	157	401	218	59	49	1082	755	260	205

[1]Means in a row, within plant components, followed by the same letter are not significantly different at the 0.05 level of probability according to Duncan's multiple range test.

ghum seedlings were treated with 100 ml of 25 x 10^6 spores ml^{-1} *F. moniliforme* inoculum. Seedlings had initiated adventitious roots and had been growing in nutrient culture for 17 days prior to inoculation. The plants were allowed to grow for 10 days more before harvest. The study included two Al levels (77 and 222 uM L^{-1}); two inoculation treatments (uninoculated and inoculated); and 22 sorghum genotypes (B- and R-lines) with different degrees of tolerance to Al toxicity. Treatments were replicated four times.

The combined analyses of variance for total plant DM yield produced significant mean squares for the main effects Al level (Al), *Fusarium* (F), and genotypes (G); and for interactions Al by F, Al by G, and F by G. In separate analyses of treatments, significant differences among genotypes were found for total plant DM yield in all four environments. Means of DM yield for the 22 genotypes are shown in Table 3.

On the average, data indicated that DM yield reduction was slightly higher for Al toxicity (34%) than for *Fusarium* (27%) effect, whereas, accumulative reduction due to both effects was 49%. Genotype IS 8931 produced the highest numerical DM yield for the combined effects. Other high yielding genotypes were MN 4508, IS 3071, IS 6944, FG UNK, IS 9084 and IS 8577 for these combined effects. All of these genotypes are tolerant to acid soils and produce good grain yields in field trials in Colombia.

Breeding for Tropical and Temperate Zone Acid Soils

Hybrids produced by crossing some of the 442 experimental Al-tolerant IS 7173C derivative A-lines by elite U.S. R-lines were evaluated in Colombia and Niger. Additional F_1 hybrids produced from some of the 244 experimental Al-tolerant R-lines developed in Colombia which are photoperiod insensitive are being crossed to elite U.S. A-lines for evaluation in Colombia. These combining ability studies will identify the experimental lines with the highest potential for commercial grain sorghum production. Some of the Al-tolerant A-lines and R-lines produce hybrids with a brown testa (high tannin) and would be better for humid tropical areas in which birds are a problem. Hybrids with red, yellow, or white grain color will be retested in lower rainfall areas.

Efforts to restart the INTSORMIL program in Kenya were initiated in Year 10. A buy-in by USAID would assist INTSORMIL efforts to reestablish collaborative sorghum and millet research with KARI, the Kenyan national program. Most of the nearly 700 photoperiod sensitive R-lines developed in Colombia had as one of their parents varieties from Uganda or western Kenya. Some of these improved brown seeded lines should be adapted to western Kenya and Uganda because these areas of Africa share a common latitude with the INTSORMIL breeding site in Colombia.

Table 3. Means of total plant dry matter yields of the uninoculated and F. moniliforme inoculated 22 sorghum genotypes grown in nutrient culture at two Al levels.

	Uninoculated		Fusarium[1]	
	Al level (μM)		Al level (μM)	
Genotype	77	222	77	222
	mg			
TX 430	955	252	592	180
TX 623	985	275	780	220
TX 648	1102	505	850	410
TX 2219	907	450	710	445
B-Yellow Pl	1345	535	1052	352
Wheatland Der	1442	367	837	370
Wheatland	962	585	747	415
NB 9040	2680	835	1757	815
IS 7173C	1167	937	907	760
IS 12685C	912	857	780	720
IS 1309C	867	805	595	440
IS 2765	1732	1487	1122	862
IS 3071	2020	1722	1554	1535
IS 3522	1222	1055	910	692
MN 4508	2195	1755	1715	1572
IS 6944	2800	1927	1465	1402
IS 8577	1645	1502	1480	1330
IS 8931	2440	2042	1937	1830
FG UNK	3045	1632	2742	1345
IS 9084	2032	1640	1380	1355
SC 326-6	1980	1582	1082	777
SC 175-14	1837	1300	1530	965
Mean	1649	1093	1205	849
LSD (0.05)	400	310	322	219

[1]Inoculated with 100 ml of 25 x 10^6 spores ml-1 F. moniliforme inoculum.

From dissertation of Jesus Ortegon-Perez, Screening Sorghum Germplasm Against the Combined Effects of Fusarium moniliforme and Aluminum Toxicity. Mississippi State University.

A large quantity of sorghum germplasm from this project was sent to SADCC/ICRISAT for evaluation in the Southern Africa environments. Items sent included: 21 A and B-line pairs of tan plant color, yellow endosperm grain sorghum lines; 83 tan plant color, yellow endosperm food grain R-lines; 244 Al-tolerant, photoperiod insensitive R-lines; 13 A and B pairs of brown-midrib, low lignin grain sorghum lines; 30 brown-midrib, low lignin sudangrass lines; and 20 brown-midrib, low lignin dual purpose forage or food grain lines. Some of these lines are downy mildew resistant and some have potential for forage production in the SADCC countries.

Publications and Presentations

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Flores, C. I., R. B. Clark, and L. M. Gourley, 1988. Agronomic traits of pearl millet grown on infertile acid soil. p. 108. In Agronomy Abstracts, Am. Soc. Agron., Madison, WI (Abstract).

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Presentations

Flores, C. I., R. B. Clark, and L. M. Gourley. 1988. Agronomic traits of pearl millet grown on infertile acid soil. Presented by Clark at the Am. Soc. Agron. meetings, 27 Nov. - 2 Dec. 1988, Anaheim, CA.

Clark, R. B., C. I. Flores, and L. M. Gourley. 1988. Mineral element comparisons of pearl millet and sorghum grown on acid soil. Presented by Clark at the Am. Soc. Agron. meetings, 27 Nov. - 2 Dec. 1988, Anaheim, CA.

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Zummo, N., L. Gourley, and M. Adamou. 1989. A rapid method for evaluating sorghum varieties for resistance to seed mold. Presented by Adamou at the Sorghum Improv. Conf. of North Am., 20-22 Feb. 1989, Lubbock, TX.

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Gourley, L. M. 1989. INTSORMIL collaborative research around the world. Presented at the ICA-INTSORMIL planning conf., 7-9 Feb. 1989, Bogota, Colombia.

Networking Activities

Workshops

Served on the planning committee and participated in INTSORMIL CRSP Conference, 3-5 January 1989, at Scottsdale, AZ.

Participated in and presented a report at the ICA-INTSORMIL Planning Conference, 7-9 February 1989, at Bogota, Colombia.

Co-authored two papers which were presented at the Sorghum Improvement Conference of North America, 20-22 February 1989, at Lubbock, TX.

Research Investigator Exchanges

Organized and participated in the EEP Review of INTSORMIL Projects and student activities at Mississippi State University, 15-16 September 1988, for the EEP team of Dr. Glenn Johnson, Dr. N. G. P. Rao, and Dr. Tim Schilling.

Helped plan and coordinate the EEP Review of the Colombian Collaborative Site for 7-10 December 1988. The review was cancelled due to USAID travel restrictions.

Served on the INTSORMIL Grant Renewal Committee.

Coordinated and helped fund the participation of Dr. Dorance Munoz, Colombian Director of Annual Crops and INTSORMIL Colombian Coordinator; and Dr. Luis de Angulo, Director of the El Alcaravan Project, to the INTSORMIL CRSP Conference.

Brazil, 7-18 April 1989, review of INTSORMIL-EMBRAPA collaborative research.

Colombia, 19 April-4 May 1989, coordinated INTSORMIL collaborative research in Colombia.

Participated in the INTSORMIL AID Management Review, 4-5 May 1989, at College Station, TX.

Consulted with the MIAC/KARI National Agricultural Research Project in Kenya about a possible buy-in for INTSORMIL, 7-21 June 1989.

Niger, 23 June - 4 July 1989, coordinated acid soil research of graduate student Moussa Adamou, with INRAN.

Germplasm and Research Information Exchange

Distributed several copies of the book Sorghum for Acid Soils to collaborators and other scientists around the world.

Two hundred forty-four photoperiod insensitive, Al-tolerant R-lines were distributed to several locations in the SADCC region, three locations in Colombia, Brazil and Kenya.

Thirteen A and B pairs of brown-midrib grain sorghum lines were distributed to Argentina, Australia, Southern Africa, Egypt, Zimbabwe and to several locations in the U.S.

Twenty-one A and B pairs of yellow endosperm, tan plant color grain sorghum lines were sent to Zimbabwe.

Eighty-three yellow endosperm, tan plant color, food grain R-lines were sent to Zimbabwe.

Thirty brown-midrib sudan lines and 20 brown-midrib dual purpose forage or food grain lines were sent to Zimbabwe.

Other cultivars and lines were supplied to U.S. public breeders.

Adaptation of Sorghum and Pearl Millet to Highly Acid Tropical Acid Soils

Project MSU-111
Lynn M. Gourley and Guillermo Munoz
Mississippi State University

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Mr. Luis de Angulo, Arauca Project, Occidental de Colombia, Inc., Apartado Aereo 092171, Bogota, Colombia.
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Dr. Gilson Pitta, Soil Scientist, CNPMS/EMBRAPA, Caixa Postal 151 35.700 Sete Lagoas, M. G., Brazil.
Dr. Gabriel Alves Maciel, Breeder, EUP-PI, Serra Talhada, Brazil.
Mr. Hector Mena, Director of Cereal Research, CENIAP-FONAIAP, Via El Limon, Apartado Aereo 4653, Maracay (Aragua), Venezuela.
Dr. Dale Bandy, North Carolina State University, Mission/INIPA and TROPSOILS, Lima, Peru.
Mr. Pedro Carrasco, Leader of INIPA's Selva Program, INIPA-Yurimaguas, Peru.
Dr. Antonio Pinchinat, Research Specialist, IICA-Lima, Peru.
Dr. Henry Pitre, Entomologist, MSU-105 PI, Department of Entomology, Mississippi State University, Mississippi State, MS.
Dr. Jerry Maranville, Plant Nutritionist, NU-114 PI; Department of Agronomy, University of Nebraska, Lincoln, NE.
Mr. David Andrews, Sorghum and Pearl Millet Breeder, NU-118 PI, Department of Agronomy, University of Nebraska, Lincoln, NE.
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, Texas A&M University Agriculture and Research Center, Route 3, Lubbock, TX.
Dr. Pedro Sanchez, Soil Scientist and TROPSOILS Coordinator, Department of Soil Science, North Carolina State University, Raleigh, NC.

Summary

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 El 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 14 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 sustainable minimum-input technology strategies for the evaluation of sorghum and pearl millet germplasm for tolerance to aluminum (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 network for the development and exchange of sorghum and pearl millet germplasm with tolerance to tropical acid soils with phytotoxic levels of aluminum among national programs in Latin America.

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

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

Constraints

The most important constraint to the increase of sorghum and pearl millet areas of production in South America is soil acidity. South America has the largest acid soil areas in the world. These unproductive acid soils contain toxic levels of Al and sometimes Mn, enough to inhibit the growth of major cereal crops. In addition, they are characterized by low P content and availability due to high chemical fixation. They are also deficient in various other plant nutrients. The second most important constraint of 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 acid soil constraints, specific long-range research goals in Colombia now include pearl millet, drought tolerance, pathology and grain quality investigations.

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

Research Approach and Project Output

Breeding and Institution Building in Colombia

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.

The main breeding and evaluation research was accomplished at CIAT-Palmira, CIAT-Quilichao, ICA-La Libertad, and Arauca, Colombia and at Mississippi State University. 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. 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 Programs staff.

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 (NU-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 NU-114. Studies concerning sorghum in food products involve direct consultation between ICA and INTSORMIL food quality projects.

Breeding material was generated from crosses among Al-tolerant sources, agronomically elite lines, and new sources of tolerance. The material was screened in the field in Colombia for Al tolerance and agronomic type, and in the U.S. for agronomic type, maturity, plant height, and photoperiod sensitivity. Yield trials of the most agronomically acceptable Al-tolerant lines identified were conducted by ICA at several locations in the Piedmont areas of the Llanos. Several of these trials were on-farm trials as a doublecrop following rice. ICA continued to conduct economic analyses on these trials in preparation for release of Al-tolerant varieties. ICA agronomists also conducted fertilizer, plant population, and other agronomic trials at La Libertad. The most Al-tolerant selections have been distributed to regional collaborators as yield trials. Winter and seed increase nurseries are being conducted in cooperation with MSU-104.

The research conducted in Arauca in collaboration with El Alcaravan was totally funded by the El Alcaravan Foundation. This was a new research area in Colombia for INTSORMIL and both normal and acid soil sites were used for sorghum and millet evaluations. Selected advance material, as well as regional yield trials, was evaluated in this area.

Grain Sorghum Yield Trials in the Territory of Arauca

Regional grain sorghum trials were planted at four sites in the Territory of Arauca during the first semester of 1988 (1988A). Sites of the trials ranged from native savanna at La Antioquena to mixed soils at Raul Ruiz and the El Alcaravan farm and piedmont soils in the eastern Cordilleran foothills at San Lorenzo.

The site at La Antioquena had the highest level of Al saturation, 67%, and a clay pan which hindered drainage of surface water, and made soil preparation and establishment of the trial difficult. At Raul Ruiz, the microrelief of the area caused variability of the trial due to poor surface drainage; however, the soil was fertile. The trial conducted on the El Alcaravan farm was near the town of Arauquita in the floodplain of the Arauca river. The soil was acid, but relatively fertile with good surface and internal drainage. A farmer's field near San Lorenzo was chosen for the fourth trial. This farm was also in a river floodplain and the soil was only slightly acid.

Grain yields of 16 entries in these trials were affected by level of Al saturation, natural soil fertility, drainage, and texture of the soil along with other factors (Table 1). Aluminum toxicity and excess surface water limited grain yields to 2000 kg ha^{-1} at La Antioquena. Grain yields ranged from 1587 to 3216 kg ha^{-1} at Raul Ruiz and from 2512 to 4248 kg ha^{-1} at El Alcaravan. Highest grain yields were recorded at San Lorenzo (3396 to 4950 kg ha^{-1}). These photoperiod sensitive lines were taller and later at the higher latitudes of these sites compared to those at Quilichao and La Libertad. Planting in March also caused an increase in plant height and maturity.

Grain Yields at High Al Saturation Levels with Low Inputs

Dolomitic limestone was used in fertilizer amounts (500 kg ha^{-1}) as a source of calcium and magnesium, and to lower the Al saturation level from the 80 to 90% found in virgin soils. Six of the most Al-tolerant sorghum genotypes evaluated to date were grown at three locations in Colombia (Table 2). Quilichao is the main INTSORMIL acid soil screening site and La Libertad the main ICA acid soil breeding station. La Antioquena is a new experimental site in the Territory of Arauca. The Al saturation levels of these sites (67 to 77%) kill all sorghum genotypes not tolerant to Al toxicity. Maximum grain yields of these "best" Al-tolerant varieties generally do not exceed 2 1/2 tons ha^{-1} and this level of production is probably not sustainable in monoculture at these low quantities of inputs. Additional research is underway using these sorghum genotypes in rotations with rice and pastures.

Publications and Presentations

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Flores, C. I., R. B. Clark, and L. M. Gourley. 1988. Agronomic traits of pearl millet grown on infertile acid soil. p. 108. In Agronomy Abstracts, Am. Soc. Agron., Madison, WI (Abstract).

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Table 1. **Grain yield and agronomic traits of 16 grain sorghum lines grown at four locations in the territory of Arauca, Colombia - 1988A.**

	La Antioquena			Raul Ruiz			El Alcaravan			San Lorenzo			Mean
Genotype	Grain Yield	Plant height	Days to bloom	Grain yield	Plant height	Days to bloom	Grain yield	Plant height	Days to bloom	Grain yield	Plant height	Days to bloom	Grain yield
IS 3071	729	183	79	2540	237	71	4248	240	74	4880	249	71	3099
IS 9042	2074	159	81	3216	224	74	3295	250	74	3396	233	71	2995
MN 4508	834	172	82	3020	218	74	4208	234	72	3602	222	73	2916
IS 6944	1858	192	78	2432	243	78	3184	264	71	4118	225	73	2898
IS 2765	1024	161	83	1832	210	78	3397	256	72	4683	249	72	2784
IS 8959	430	173	78	1587	224	77	4165	256	72	4950	237	71	2783
IS 3522	1647	190	77	2614	208	71	2586	267	70	4061	228	66	2727
IS 8998	946	148	80	2167	204	75	3680	246	70	4012	220	70	2701
5 DX	1467	177	79	1838	227	76	3005	241	70	4317	250	71	2657
IS 8577	970	190	78	2656	218	74	2942	253	70	4012	201	70	2645
IS 9636	863	145	80	3001	197	73	2512	261	70	4179	237	70	2639
IS 7151	778	171	80	2464	216	74	2559	244	74	4559	255	71	2590
IS 9084	925	201	77	2192	223	72	2804	234	72	4418	236	72	2585
Serere 1	761	147	77	2000	169	74	3186	230	70	4089	200	70	2509
IS 8933	595	166	79	1644	220	72	2839	258	73	4937	243	71	2504
PPQ-2	1088	139	71	1965	162	71	2694	192	67	3818	159	68	2391

Table 2. **Grain yield of six sorghum lines grown in high aluminum saturated soils at three locations in Colombia.**

Genotype	Quilichao 77% Al sat.	La Libertad 72% Al sat.	La Antioquena 67% Al sat.	Mean grain yield
		kg ha		
IS 8931	2148	2267	1279	1897
IS 3522	1667	1741	1647	1685
IS 3071	2625	1563	729	1639
IS 6944	1167	----	1858	1512
IS 8577	1417	1643	970	1343
MN 4508	1208	1826	834	1289
Mean	1705	1808	1220	1561

Clark, R. B., C. I. Flores, and L. M. Gourley. 1988. Mineral element comparisons of pearl millet and sorghum grown on acid soil. Presented by Clark at the Am. Soc. Agron. meetings, 27 Nov. - 2 Dec. 1988, Anaheim, CA.

Gourley, L. M. 1989. CIAT/South America: Colombia. Presented at the INTSORMIL CRSP Conf., 3-5 Jan. 1989, Scottsdale, AZ.

Clark, R. B., C. I. Flores, and L. M. Gourley. 1989. Comparisons of mineral elements in sorghum and pearl millet grown on acid soil. Presented by Clark at the Sorghum Improv. Conf. of North Am., 20-22 Feb. 1989, Lubbock, TX.

Gourley, L. M. 1989. INTSORMIL collaborative research around the world. Presented at the ICA-INTSORMIL planning conf., 7-9 Feb. 1989, Bogota, Colombia.

Networking Activities

Workshops.

Participated in INTSORMIL CRSP Conference, 3-5 January 1989, at Scottsdale, AZ.

Coordinated, participated in, and presented a report at the ICA-INTSORMIL Planning Conference, 7-9 February 1989, at Bogota, Colombia.

Research Investigator Exchanges

Helped plan and coordinate the EEP Review of the Colombian Collaborative Site for 7-10 December 1988. The review was cancelled due to USAID travel restrictions.

Coordinated the participation of Dr. Dorance Munoz, Colombian Director of Annual Crops and INTSORMIL Colombian Coordinator; and Dr. Luis de Angulo, Director of the El Alcaravan Project, to the INTSORMIL CRSP Conference.

Germplasm and Research Information Exchange

Distributed several copies of the book *Sorghum for Acid Soils* to collaborators and other scientists in Latin America.

Two hundred forty-four photoperiod insensitive, Al-tolerant R-lines were distributed to several locations in the SADCC region and three locations in Colombia, Brazil and Kenya.

Breeding Sorghum for Developing Countries

Project NU-115
David J. Andrews
University of Nebraska

Principal Investigator

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Collaborating Scientists

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Dr. John Clark, sorghum breeder, INTSORMIL/INRAN, Niamey, Niger
Dr. C. Luce, sorghum breeder, CNRA, Bambey, Senegal
Dr. S.M. Mukuru, sorghum breeder, ICRISAT, Patancheru, PO AP 502325, India
Dr. D. W. Rosenow, sorghum breeder, TAM-122, Texas A&M University, Lubbock, TX
Dr. Paula Bramel-Cox, sorghum breeder, Kansas State University, Manhattan, KS
Dr. Ronnie Duncan, sorghum breeder, University of Georgia, Griffin, GA
Dr. J. D. Eastin, physiologist, NU-116, University of Nebraska, Lincoln, NE 68583
Dr. J. W. Maranville, physiologist, NU-114, University of Nebraska, Lincoln, NE 68583

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 consumption. A collaborative breeding project has commenced in Botswana, where progeny of crosses with drought tolerant Segaolane (and other similar varieties) and U.S. B-lines have succeeded through 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 will be tested for drought/heat tolerance. Segments of this material will support breeding programs in collaborating countries, and be released in the U.S.

The exotic introductions used in crosses were also selected and tested as varieties and hybrids and nurseries were provided to Niger, Senegal, and Sudan. 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. Three seed parents and 36 germplasms were released. The germplasm release was designed so that sorghum breeders could have early access to new project material with potential for breeding new seed parents. Germplasm was exchanged between countries and with U.S. scientists.

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, are 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 of crosses between appropriately adapted exotic lines are provided to LDC breeders to initiate collaborative selection programs. At F_4/F_5, selections with per se worth are tested for drought/heat stress resistance, in conjunction with NU-116, and for combining ability. Those which act as non-restorers will be considered for producing new seed parents. Well adapted partial inbreds/lines are released as germplasm stocks/parental lines for use in the U.S.

The introductions are also tested for per se performance and in hybrid combinations for possible dissemination in international nurseries. However, these nurseries will eventually contain hybrids made with lines derived from the exotic x U.S. crossing program.

The research program provides opportunities and material for postgraduate student thesis problems. Both selection and testing in the NU-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

Three seed parents (N122, N123 and N124) and 36 germplasms were released from NU-115. The germplasm release contained F_5 and F_6 bulks selected from crosses between tropical and U.S. parents and was designed so that sorghum breeders could have early access to project material with potential for producing new seed parents.

Over 3,000 F_3 to F_6 lines were evaluated and 175 A/B pairs backcrossed in the Mead, NE nursery. Three hundred and fifty-four of the F_6 lines were jointly evaluated for drought tolerance in conjunction with Kansas State University at Garden City, KS, and for leaf disease and acid soil tolerance with the University of Georgia at Griffin, GA.

Because of the number of potential A_1 seed parents being developed, research is being conducted as to how best to determine their combining ability. One of several testers being used is a restorer on the A_1 system but a maintainer on the A_2 system. Through these tests, lines that can be good seed parents in both systems can be identified.

The Garden City test, which contained environments with and without moisture stress prior to heading, enabled the separation of genotypes which have high yield potential and are relatively tolerant to stress as measured by an aggregate of factors (yield loss, height reduction, delay of bloom, and reduction in grain size). Average yield of all entries under non-stress was 5560 kg/ha (6860 for hybrid checks) and 3400 kg/ha (4780) under stress. As expected, the inbreds in general tended to be more sensitive to stress than hybrids.

A number of yield tests were conducted at Mead without fertilization but on land rotated with soybeans. Rainfall was about half (400 mm) normal in 1988.

1. In the final year of evaluation of introduced tropical dwarf varieties, 18 of 22 varieties gave yields exceeding 6000 kg grain/ha. The best variety, IRAT 204, slightly exceeded the hybrid check yield of 8200 kg/ha.

2. In the tropical food-quality hybrids trial, 16 of 31 hybrids gave yields higher than the check, at 7000 kg/ha. The two best were N95 x Dorado and ATX623 x LL34 at 9000 kg/ha (LL34 is an ICRISAT derived line obtained via the Dominican Republic).

These tests have identified varieties and hybrids that will be used in collaborative trials in developing countries.

3. In trials of Nebraska adapted material, the yield of hybrid N122 x RTX430 at 9300 kg/ha exceeded the yields of both commercial checks. Similar yields were obtained from hybrids with experimental seed parents from NU-115 with N91, a restorer line released from NU-116.

Collaborative sorghum research in Botswana continued to focus on the development of stress resistant adapted seed parents and lines. Sixty-two selections were retained in 1988, some of which had been testcrossed and found to be maintainers. These were further backcrossed in the winter nursery. On-farm tests with the late planting of early varieties (intended to simulate situations in areas where planting rains are greatly delayed) failed at one site (no rain) and gave inconclusive results at the other (Tatume). These will be repeated in 1989/90. Mr. Louis Mazhani successfully completed his Ph.D. thesis field work, a multilocation yield test in Botswana comparing sorghum lines, populations, hybrids, and hybrid mixtures.

Networking Activities

Member, Committee for Scientific and Technical Research, Institute Senegalais de la Recherche Agricoles (ISRA), December 1-8, 1988, Dakar and Bambey, Senegal.

INTSORMIL Biennial CRSP Conference, January 3-6, 1989, Scottsdale, AZ.

San Juan de Abejo, Mexico, winter nursery breeding, January 14-February 2, 1989.

Zimbabwe, SADCC/ICRISAT TAP Meeting, Matopos, March 13-19, 1989.

Botswana, collaborative breeding with Botswana, Sebele and Francistown, March 20-28, 1989.

INTSORMIL EZC meeting, Kansas City, April 6, 1989.

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

Germplasm and Research Information Exchange

Twenty germplasm accessions were acquired; 462 are in storage; 47 lines in germplasm amounts were supplied domestically.

A total of 87 lines in germplasm amounts were supplied to Senegal, Mexico, Niger, and Botswana. One hundred and thirty-five introductions were increased and deposited in the National Germplasm System sorghum collection at Griffin, GA.

Discussion with LDC scientists of 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 NU-118

David J. Andrews
University of Nebraska

Principal Investigator

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Collaborating Scientists

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Ms. A. T. N'Doye and Mr. Amadou Fofana, millet breeders, CNRA, Bambey (as above).
Drs. J. R. Witcombe and K. N. Rai, millet breeders, ICRISAT, Patancheru P.O. AP 503 325, India.
Dr. S. C. Gupta, millet breeder, SADCC/ICRISAT, Southern Africa Regional Sorghum and Millet Research Program, P. O. Box 776, Bulawayo, Zimbabwe.
Drs. J. D. Axtell and J. Clark, PRF-103, Department of Agronomy, Purdue University, West Lafayette, IN 47907.
Dr. R. R. Duncan, cereal breeder, Department of Agronomy, University of Georgia, Experiment, GA 30212.
Dr. L. Gourley, sorghum breeder, MSU-111, Department of Agronomy, Mississippi State University, MS 39762.
Dr. W. W. Hanna, geneticist, USDA/ARS, Tifton, GA 31793.
Mr. W. M. Stegmeier, millet breeder, KSU-101, Department of Agronomy, Kansas State University, Hays, KS 67601.
Dr. J. D. Eastin, cereal physiologist, NU-116, Department of Agronomy, University of Nebraska, Lincoln, NE 68583.
Dr. J. W. Maranville, cereal physiologist, UN-114/121, Dep. of Agronomy, University of Nebraska, Lincoln, NE 68583.

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 NU-118 has been the continued development of elite inbred lines which will be used both in custom crosses with host country varieties and to produce parental lines and varieties for the U.S.

Two thousand one hundred and ninety F_3- F_7 lines from tropical x early parent crosses were evaluated and selfed in 1988, and backcrossing continued on 250 male sterile testcrosses and backcrosses. Selection was continued for lodging resistance. Backcrossing, selfing and hybrid production was continued on 240 elite lines sent to the winter nursery. Custom crossing continued with project inbreds and leading Mali, Zambian, and Malawi introductions and backcrosses to Mali varieties 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 1988 confirmed that topcrossing these varieties to a seed parent increases yields by 20-30%. Such topcross hybrids have distinct advantages for LDC conditions and are easier to develop.

Postgraduate thesis research studies were continued on lodging resistance, effects of a recessive chlorophyll mutant on growth and yield, and on the relationship of the performance of a synthetic variety with a given set of parent lines by evaluating these per se and as hybrids. In collaboration with thesis research at Mississippi State, the performance of two types of hybrids, and their parents, were compared with sorghum checks at several locations in the U.S.

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 with stocks known to perform well in the region concerned, to selected high HI lines, is developed for selection in collaborative projects.

The selection criteria used in developing improved basic breeding stocks are numerous and involve morphological and physiological traits and estimates of genetic combining ability for performance. Principal morphological traits involve determinants of seed number/m^2 and seed size. Performance data under moisture stress and lower soil fertility are needed. Both specific and general combining ability estimates are needed. These are principally thought of in the context of hybrid parent development (for pollen and seed parents, respectively), but they are also of use in identifying parents for varieties (synthetics), and possibly for indicating parental worth, which will be important in generating collaborative material for selection.

Objectives

The objectives of the breeding program, with slight modifications, remain as in previous years:

To establish a diverse base of agronomically elite inbred and semi-inbred lines from crosses between U.S. parents and introduced tropically adapted stocks and from prior program material (for maintenance of non-inbred diversity see Research Methods). 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 NU-118 lines and collaborating country stocks will be selected in that country. It also permits hypotheses to be tested about the relative potential of various types of varieties and hybrids and parental breeding procedures and also enables the identification of parents to make hybrids adapted to the U.S.

A type of modified mass selection is being tested on the Nebraska dwarf millet population (NBDMP) generated from introductions from Senegal, India, Hays, KS, and Tifton, GA, prior to 1984. Further populations will be developed when appropriate parental stocks are identified. Besides information, improved lines and varieties will result from this process. Both the above approaches provide opportunities and material for postgraduate student theses.

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.

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

Inbreeding was continued on 2200 F_3 to F_8 lines generated from exotic x U.S. crosses with selection for seed set, per se performance and lodging resistance. About 400 of these were testcrossed and 200 with sterile reactions in A_1 cytoplasm were backcrossed.

Utilization of these inbreds has begun, as planned, in (i) crosses with Malian, Malawian, and Zambian varieties as the basis for collaborative breeding, (ii) the production of hybrids, with and without the use of cytoplasmic male sterility (cms) and (iii) in the formation of varieties and new breeding populations.

In (i) above, F_2 seed of crosses between nine Mali varieties and four NU-118 lines was produced and the F_1's backcrossed to complementary Mali varieties. Initial crosses were made between 10 further NU-118 lines and Mali, Malawi, and Zambian varieties. F_3's were also selected from crosses between KSU-101 x Sudan varieties for use in Sudan collaboration.

Partial diallel matings and crosses to a variety tester were used to evaluate three groups of inbreds for their potential both for hybrids and to form synthetic varieties. In all three groups, the average of the single crosses was not higher than those to the variety tester, averaging 3500-4300 kg/ha in unfertilized tests at Mead, NE. Yields in the same tests at Sidney, NE, where the rainfall is lower and the season shorter, averaged 2500-2800 kg/ha. The highest yielding individual hybrids tended to be from line x line single crosses at 6000 kg/ha rather than from the line x tester topcross hybrids. The degree of superiority of the hybrids over the parental lines ranged from 40 to 80%.

Projects NU-118 and KSU-101 supplied germplasm for the M.S. thesis of Mr. F. P. Muza at Mississippi State (advisor Dr. L. M. Gourley) which in 1988 tested two types of single cross pearl millet hybrids (line x line and line x variety) against their parents and sorghum checks. Test locations were Mississippi (2), Kansas, Nebraska (2), and Indiana. Location mean yields ranged from 2650 to 3800 kg/ha and entry means from 2400 to 3680 kg/ha (Table 1). At three locations a pearl millet hybrid outyielded the sorghum checks. The highest millet yields were given by line x line hybrids but these when compared on the same seed parent (68A = 2068) were not significantly different from line x variety hybrids (3370 vs. 3510 kg/ha). Line x variety hybrids averaged 26% more yield than their respective variety parents and showed a much better and more predicatable response to better environments (Table 2).

The third cycle of modified mass selection which uses spaced single plants was completed on the Nebraska Dwarf Pearl Millet Population. A three year test using 50 S_1 families was concluded to check the validity of selecting spaced plants for performance at normal (higher) planting densities. 1988 was a drought stress year and higher mean yields (1870 kg/ha) were obtained from the wider (34,000) than normal (79,000 plants/ha) spacing (1520 kg/ha). Genotype performance at the two spacings was significantly correlated (r = 0.64) which confirmed previous results. A selection system using spaced plants is obviously relevant to LDC conditions where the crop is grown at low plant densities, often in spaced hills, but these results show it may also apparently be used for row crop situations.

Publications and Presentations

Singh, P., K. N. Rai, J. R. Witcombe, and D. J. Andrews. 1988. Population breeding methods in pearl millet improvement. l'Agronomie Tropicale 43:185-193.

Andrews, D. J. 1989. Advances in INTSORMIL millet research. INTSORMIL International Sorghum/Millet CRSP Conference, Jan. 3-5, 1989, Scottsdale, AZ.

Andrews, D. J. 1988. Intercropping in low resource agriculture in Africa; Millet breeding for low resource agriculture in Africa. Technology papers for Enhancing Agriculture in Africa. Congress of the United States, Office of Technology Assessment OTA-F-356, Washington, D.C.

Networking Activities

Collaboration was continued with Botswana, Mali, Senegal, Sudan, and Zambia. In Botswana, strategies were planned and implemented on improving population Botswana Serere 6A by recurrent selection. Progeny for producing an improved variety were sent for off-season random-mating. 1988 tests failed in north Senegal, but Mr. Amadu Fofana, ISRA millet breeder, Bambey, visited Lincoln, selected material for crossing and planned further collaboration. Details of this were worked out in a follow-up visit to Senegal in December 1988. Crosses were made between NU-118 stocks and Senegal varieties in the winter nursery at Bambey.

Dr. Oumar Niangado, senior sorghum and pearl millet breeder, IER Mali, visited Lincoln in September 1988. He viewed and discussed the material being developed for the collaborative breeding program for Mali with the help of Mr. Karim Traore, M.S. in millet breeding at the University of Nebraska. Further crosses were made in the winter greenhouse for Mali, Malawi, and Zambia.

Forty F_3 lines were selected for Sudanese x U.S. crosses in 1988 and sent to El Obeid for evaluation. Plans made previously to begin a two-year rotation on pearl millet fields to create better environments for selection and testing were implemented at El Obeid.

Travel

Senegal, Committee for Scientific and Technical Research, Institute Senegalais de la Recherche Agricoles (ISRA), December 1-8, 1988, Dakar and St. Louis.

INTSORMIL Biennial CRSP Conference, January 3-6, 1989, Scottsdale, AZ.

Mexico, San Juan de Abejo, winter nursery breeding, January 14-February 2, 1989.

Table 1. Grain yield means (kg ha^{-1}) for 19 pearl millet and two sorghum check genotypes at six sites in 1988.

Genotype	MSU-1 MS	MSU-2 MS	Mead, NE	Sidney, NE	Ft. Hays, KS	West Lafayette, IN
68B	3062	2388	2583	1838	2613	2013
68A x NBDMP85	4598	2082	3460	2310	3785	3322
NBDMP CO86	3426	1848	3264	2873	2357	2823
68A x EDS	4211	3035	3402	2739	3386	3534
EDS	3086	2272	2803	2786	1977	2976
68A x MLS	4594	2613	3794	2514	3609	3669
MLS	2546	2023	2794	2286	2918	2925
68A x 80013	5353	2957	3365	2138	4031	+
80013	2514	1651	2035	1311	3040	1787
79-2069B	2980	1593	2592	1912	2493	2229
78-7088R	3780	2719	3081	2294	2765	2439
86-9001R	3510	2862	3230	2535	2788	2823
81-1164B	3285	1925	2791	2362	2689	2456
79-2068 x 78-7088	4457	3478	3954	2457	3041	3492
79-2068 x 86-9001	4843	2957	3388	2132	3279	4380
81-1163 x 78-7088	5278	2434	3937	2874	3489	4055
81-1163 x 86-9001	4525	3315	3711	2903	3485	3715
87-7170 x 86-9001	3406	3665	3700	2339	4639	+
87-7170 x 78-7088	4403	2973	3707	2384	3020	1921
F2233 Sorghum	3346	2499	5379	5339	4808	2439
39Y Sorghum	2882	1975	5845	5350	5558	1905
Mean	3814	2537	3468	2652	3323	2850
LSD (0.05)	932	802	665	423	891	+

+ No single LSD because of several missing plots.

Zimbabwe, SADCC/ICRISAT TAP Meeting, Matopos, March 13-19, 1989.

Botswana, collaborative breeding with Botswana, Sebele and Francistown, March 20-28, 1989.

INTSORMIL EZC meeting, Kansas City, April 6, 1989.

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

Germplasm and Research Information Exchange.

Germplasm Exchange

20 new accessions were acquired, 437 are in storage and 35 samples were exchanged domestically

62 germplasm lines/populations were sent to three countries--Senegal, Sudan, and Mexico

Breeding Strategies

Breeding strategies were planned for Botswana, Mali, Senegal, and Zambia with breeders in those countries.

Table 2. Estimates of grain yield stability parameters for 19 pearl millet genotypes over 60 locations in 1988 (see Table 1).

Genotype	n	Genotype grand mean (kg/ha)	b ± Sd	R^2
68B	6	2416	0.72 ± 0.20*	0.76
68A x NBDMP85	6	3247	1.66 ± 0.25**	0.91
NBDMP CO86	6	2766	0.68 ± 0.43	0.39
68A x EDS	6	3385	0.89 ± 0.13**	0.92
EDS	6	2637	0.28 ± 0.37	0.12
68A x MLS	6	3466	1.42 ± 0.17**	0.95
MLS	6	2582	0.32 ± 0.30	0.22
68A x 80013	5	3569	1.92 ± 0.36*	0.90
80013	6	2057	0.82 ± 0.41	0.50
79-2069B	6	2300	0.86 ± 0.16**	0.87
78-7088R	6	2847	0.90 ± 0.21*	0.83
86-9001R	6	2946	0.59 ± 0.15*	0.79
81-1164B	6	2585	0.77 ± 0.18*	0.83
79-2068 x 78-7088	6	3480	1.08 ± 0.35*	0.71
79-2068 x 86-9001	6	3484	1.51 ± 0.49*	0.71
81-1163 x 78-7088	6	3678	1.71 ± 0.36**	0.85
81-1163 x 86-9001	5	3609	0.96 ± 0.15*	0.91
87-7170 x 86-9001	6	3550	0.53 ± 0.73	0.15
87-7170 x 78-7088	6	3068	1.30 ± 0.52	0.52
Mean		3035		

*, **Significantly different from 0.0 at the .05 and .01 levels of probability, respectively.

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. Relatively little is known about sorghum breeding and genetics in comparison to other major staple cereals. Genetic studies contribute to the development of improved breeding methodologies for sorghum improvement. New knowledge has been gained by this project about utilization of sorghum populations in breeding programs. Traits such as heritability of grain hardness and heritability of seedling cold tolerance are important for both the U.S. and developing countries. Selection methods for improving these important traits have been developed.

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.

Develop improved B-lines for adaptation in Niger and Sudan. These can provide a genetic base for future hybrid production in these countries.

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 that of other cereals. This includes the tannin problem, the protein quality problem, the protein digestibility problem, and the local processing methods involved in elevating the nutritional value of 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 but are not available in 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 Gebisa Ejeta and the modified vitreous endosperm characteristics have been documented in 1988 in Lafayette, IN. 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 which should be an additional benefit if it can be confirmed in the QPS lines. The digestibility problem can also be approached at this time by a better understanding of traditional processing technologies. We believe the identification of a low fraction III (cross-linked kafirin fraction) sorghum variety in the World Collection has the potential to provide a genetic and breeding solution to the digestibility problem in sorghum which would be a significant achievement in utilization of sorghum as a food grain and also as a feed grain.

A major priority will be the development of a vitreous endosperm high lysine sorghum variety using germplasm developed from crosses with P-721 opaque. This will be a combined effort with Allen Kirleis, Gebisa Ejeta, and Larry Butler. The modified endosperm high lysine sorghum parental materials will be tested in Niger, Sudan, and West Lafayette to verify environmental stability of the vitreous endosperm and the lysine content. An extensive second cycle breeding program will be initiated to further improve the protein quality, vitreous endosperm, and protein digestibility of the new lines.

Another major focus will be to continue to ascertain the nutritional value of thin fermented porridges as used in East 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 the low adoption rate of improved varieties.

Joe Mushonga's research on developing rapid assays for diastatic power and studying inheritance of diastatic activity in sorghum cultivars will be continued. Second, Dr. Sam Mukuru has completed his study at Purdue on the digestibility of thin fermented sorghum porridges in Uganda and has found that there is no effect of the tannins on digestibility after the traditional wood ash and fermentation treatments.

Another focus of activity will be to pursue the development of cold tolerant sorghum lines with markedly improved seedling vigor for higher elevations in East 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.

Research Approach and Project Output

Research Methods

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

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

Training M.S. and Ph.D. LDC students will continue.

Research Findings

Genetic mapping and characterization of sorghum and related crops using maize DNA probes. Cloned maize DNA fragments from 14 characterized genes and 91 random fragments used for genetic mapping in maize were tested for their ability to hybridize and detect restriction fragment length polymorphisms (RFLPs) in sorghum and other related crop species. Most DNA fragments tested hybridized strongly to DNA from sorghum, foxtail millet, Johnsongrass and sugarcane. Hybridization was generally weaker to pearl millet and only a few probes hybridized to barley under the conditions used. Patterns of hybridization of low copy sequences to maize and sorghum indicated that the two genomes are very similar. Most probes detected two loci in maize; these usually detected two loci in sorghum. Probes that detected one locus in maize generally detected a single locus in sorghum. However, repetitive DNA sequences from maize present on some of the genomic clones did not hybridize to sorghum DNA. Most of the probes tested detected polymorphisms among a group of seven diverse sorghum lines tested; over one third of the probes detected polymorphism in a single F_2 population from two of these lines. Cosegregation analysis of 55 F_2 individuals enabled several linkage groups to be constructed and compared to the linkage relationships of the same loci in maize. The linkage relationships of the RFLP loci in the two species were usually conserved, but several rearrangements were detected.

Kernel characteristics and protein fraction changes during seed development of high-lysine and normal sorghums. Changes in seed characteristics and the proportions and electrophoretic mobilities of Landry-Moureaux (L-M) endosperm protein fractions of high-lysine opaque and normal sorghums were followed during kernel development. Seed weight and volume increased steadily through 45 days after half-bloom for normal but plateaued a week earlier for opaque. Percentage embryo of whole seed increased similarly for both lines from an average 2.1 to 8.1% during development. Normal endosperm protein declined 0.7% during seed maturation while that of opaque increased 1.2%. L-M fraction I (albumins and globulins) differed little among lines. Fraction II plus III (total kafirin) accumulation in opaque plateaued two weeks before normal, whereas fraction IV plus V (total glutelin) increased more rapidly in opaque than normal endosperms. Sodium dodecyl sulfate-polyacrylamide gel electrophoresis of endosperm protein fractions showed few or no differences in banding patterns. It is concluded that the opaque gene (O) manifests itself in a pleiotropic manner with respect to endosperm proteins through quantitative rather than qualitative shifts in major fractions. The enhanced lysine content of opaque results primarily from an increase in relatively lysine-rich glutelins and decrease in lysine-deficient kafirins.

Phenolic compounds and microbial degradation of sorghum stover. Both alkali-labile and non-alkali-labile phenolic compounds have been shown to inhibit plant cell wall digestion. Studies were conducted to determine the influence of alkali-labile phenolic monomers on digestion of diverse sorghum genotypes, including brown-midrib (bmr) and normal genotypes. Stover from each genotype was separated into leaf blade, leaf sheath, and stem. Alkali-labile phenolics varied among genotypes studied. The bmr mutant was higher in syringic acid, vanillin, and sinapic acid than the normal genotype. p-Coumaric acid (PCA) was lower in the brown-midrib genotype than the normal genotype. Alkali-labile p-coumaric acid and vanillin were lower in leaf blade than leaf sheath or stem, whereas caffeic acid was higher in leaf blade than leaf sheath or stem. Of the phenolic acid compounds investigated, PCA was observed in largest quantities (4.4, 8.7, and 15.5 g kg-1 for leaf blade, sheath, and stem, respectively). p-Coumaric acid to ferulic acid (FA) ratio was lowest in neutral detergent-extracted leaf blade (1.1), followed by leaf sheath (2.5) and stem (3.6). The bmr mutant had lowest PCA:FA ratios for all neutral detergent-extracted morphological components. Extracts of cellulase-digested neutral detergent fiber yielded two major peaks when separated by size exclusion chromatography (Sepharose CL-6B); peak 1 contained a much higher PCA:FA ratio (3.0) than did peak 2 (0.1 PCA:FA) in all three morphological components. Addition of extracts to rumen bacteria resulted in growth curves differing from controls, indicative of changes in bacterial profiles.

Combining ability of high lysine sorghum lines derived from P-721 opaque. The P-721 opaque (P-721Q) endosperm of sorghum [*Sorghum bicolor* (L.) Moench] has better protein quality (lysine/protein ratio) than normal sorghum endosperms. However, sorghum with opaque endosperm has not been readily accepted for wide cultivation due to its lower yield potential and some other problems associated with its soft endosperm.

The objective of this study was to determine whether hybrids between high yielding opaque lines resulted in heterotic response for grain yield and kernel weight without loss in protein quality. Each of 10 high lysine lines derived from P-721Q was mated with the same three cytoplasmic male-sterile lines, also derived from P-721Q by backcrossing to sterile cytoplasm. The F1 hybrids derived from these matings were field-evaluated for grain yield, 100-kernel weight, protein concentration, and lysine concentration in protein on a fine-silty, mixed, mesic Typic Haplaquoll. Significant differences among general combining ability effects were observed for all characters except grain yield, whereas significant differences among specific combining ability effects were observed for only grain yield. Correlation between grain yield and protein in the 30 hybrids was negative and significant ($r = -0.63$); correlation between grain yield and lysine concentration in protein was also negative but not significant. The best male parent, R-3 (P-850314), also produced hybrids with the highest lysine concentration. Among the female parents, A-3 (P-851063) gave hybrids with the highest protein quality. The best single-cross hybrid, A-3 x R-3, for agronomic and protein quality, had 35% more lysine than the normal cultivar P-721N and yielded as much as the NK-180 check. Thus, this hybrid has the potential of substituting for other expensive protein and lysine sources in the semiarid tropics.

Chromosomal interchange linkage studies with the high lysine gene (hl) in sorghum. The discovery of the high lysine gene (hl) offers opportunity for improved nutritional quality of sorghum. Although the hl gene is inherited as a simple recessive, the chromosomal linkage is unknown. Five hl lines were crossed with a set of 18 chromosomal reciprocal translocations stocks. Progenies of these crosses were grown in the F_2 generation. Plants are classified as semisterile or fertile based on pollen sterility and seed set percent. Presence of the hl gene was verified by the determination of protein and lysine concentration of the kernels. Independence X^2 and fixed ratio X^2 tests for linkage were conducted for the F_2 data. Maximum likelihood method in terms of x [x = (1-p)] was also used to estimate linkage and recombination frequency. Data analysis gave evidence of linkage between the hl gene and the translocations T28(BH) and T72(BE). The results suggested that the hl gene was linked with the break-point on chromosome B rather than on chromosomes E or H, and that it was segregating independently from the break-points on chromosomes A,C,D,F,G,I, and J.

Traditional food processing technologies in East Africa improve nutritive value of high tannin sorghums. High tannin sorghum [*Sorghum bicolor* (L.) Moench] is grown in many regions where birds and fungi causing grain mold are major production constraints. The objective of this study was to evaluate the effectiveness of two traditional sorghum processing methods in improving the digestibility of high tannin grain. Kabale, a Uganda variety of high tannin sorghum, was treated with wood-ash according to a Uganda village method. This removed over 97% of the tannin. *In vitro* pepsin digestibility of treated Kabale was as high as that of the low tannin control grain. Rats fed with wood-ash treated, high tannin BR64 grain showed significantly higher weight gains than those fed with untreated BR64. A non-alcoholic beverage, Obushara, and an alcoholic beverage, Omuramba, made from high tannin, ash-treated grain also had *in vitro* digestibility values equal to those found with low tannin sorghum. Mumbala, or local magadi, is a mineral soil found in abundance in Kilimanjaro, Tanzania. The potential for its use to detoxify sorghum tannins was tested. A water extract from magadi (pH 9.7) increased the *in vitro* pepsin digestibility of a high tannin sorghum variety IS 1291 by 15%, similar to that of a tannin-free variety P721N. No significant change was observed by treating the tannin-free variety. This implies a potential for use of magadi to improve the nutritive value of high tannin sorghums.

Publications

Hulbert, S.H., T. Richter, J.D. Axtell, and J.L. Bennetzen. 1989. Genetic mapping and characterization of sorghum and related crops using maize DNA probes. Proc. Natl. Acad. Sci. USA (accepted for publication).

Ejeta, G., J.D. Axtell, L.G. Butler and A.W. Kirleis. 1989. Breeding sorghum [Sorghum bicolor (L.) Moench] for improved nutritional, food, and feed quality parameters. In: Proc. Grain Sorghum Research and Utilization Conference. Lubbock, TX. pp. 187-207.

Cherney, D.J.R., J.A. Patterson, J.H. Cherney, T.C. Griggs and J.D. Axtell. 1989. Phenolic compounds and microbial degradation of sorghum stover. Agronomy Abstracts, p. 168.

D'Croz-Mason, N.E., J.D. Axtell and W.E. Nyquist. 1989. Chromosomal interchange linkage studies with the high lysine gene (hl) in sorghum. Agronomy Abstracts, p. 79.

Mukuru, S.Z., E. Monyo, G. Ejeta, M. Hassen, E.T. Mertz, and J.D. Axtell. 1988. Traditional Food Processing Technologies in East Africa Improve Nutritive Value of High Tannin Sorghums. 1988 ASA Annual Meetings, Anaheim, CA.

Networking Activities

Workshops

Attended the "First National Symposium on New Crops Research, Development and Economics". Indianapolis, Indiana. October 24-26, 1988.

Co-authored a poster paper on "Traditional Food Processing Technologies in East Africa Improve Nutritive Value of High Tannin Sorghum" at the 1988 American Society of Agronomy Annual Meetings. Anaheim, California. November 28 - December 2, 1988.

Presented a seminar entitled "The Use of Molecular Genetics to Increase Drought Tolerance in Cereals" at the Purdue International Programs in Agriculture Program Support Grant Seminar Series. February 27, 1989.

Participated in the Technical Advisory Panel Meetings of SADCC/ICRISAT/IIE Program. Harare, Zimbabwe. March 8-25, 1989.

Participated in "The Molecular Biology of Crop Improvement", Third Annual Plant Symposium, West Lafayette, Indiana. March 29-30, 1989.

Presented a discussion presentation entitled "The Mechanism of Drought Resistance in Crop Plants - An Interdisciplinary Approach" for the Purdue Research Foundation. March 31, 1989.

Participated and chaired numerous EZC INTSORMIL meetings and chaired the INTSORMIL External Evaluation Panel Review at Purdue, Sept. 1988.

Research Investigator Exchanges

Traveled to Nairobi, Kenya to collaborate with Dr. Sam Mukuru, ICRISAT, for screening cold tolerance sorghum germplasm in Kenya Highlands. May, 1989

Mr. Xiaokun Yang - Visiting Scholar from the People's Republic of China (May 1987 - January 1989)

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
Gebisa Ejeta
Purdue University

Principal Investigator

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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 10 studies on performance and stability of *Striga* resistant cultivars, the genetics of *Striga* resistance, and integrated cultural control of *Striga* were completed. Six sorghum varieties previously reported as being tolerant to *Striga hermonthica* in other African countries were tested and found to be well adapted in Niger. However, two cultivars, SRN39 and IS9830 showed significantly better resistance as well as better stability and adaptation than the other four cultivars. The inheritance study showed that *Striga* resistance in SRN39 was heritable and its mode of inheritance was recessive. The effects of varietal resistance, application of nitrogenous fertilizers, and mode of tillage prior to sowing on infestation of *Striga hermonthica* was also studied. The results reaffirmed that application of urea at 100 kg N/ha significantly reduced infestation and when coupled with a resistant cultivar provided for better protection against *Striga* infestation. The effects of tillage treatments varied according to location, rainfall, and type of sorghum cultivar used.

Objectives, Production and Utilization Constraints

Objectives

To strengthen sorghum research capabilities of collaborating scientists in less developed countries, thereby accelerating the rate at which the production and utilization of sorghum is enhanced. To achieve this objective, the technical resources of other 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 in Africa, primarily at the Gezira Research Station in Sudan and at INRAN, Niger.

Research objectives for Year 10 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 characterize traits associated with resistance to drought, *Striga*, and grain mold.

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 millet 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 grain mold causing fungi. Tall, late maturing, photoperiod sensitive local varieties completing their grain filling period after cessation of rains tend to escape grain deterioration problems in the field.

Research Approach and Project Output

Sorghum germplasm from various sources 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.

Research findings for PRF-107 in Year 10 focus on *Striga* resistance. A study on performance and stability of *Striga* resistant cultivars, inheritance of resistance, and integrated cultural control of *Striga* was just completed as part of a Ph.D. dissertation by Dale Hess. The following is a capsule summary of selected aspects of this study:

Performance and Stability of Striga Resistant Sorghum Cultivars

Varietal resistance is perhaps the most promising economic *Striga* control measure. Adapted, resistant cultivars can be grown without additional costly inputs on the part of the subsistence farmer. Sorghum cultivars with good levels of *Striga* resistance have been identified. However, many of these cultivars have not been evaluated for stability in yield and resistance to different strains of *Striga*. The purpose of this study was to evaluate the adaptation and resistance to *S. hermonthica* of ten sorghum cultivars. Six sorghum varieties previously reported as being resistant to *Striga* in other countries and four local cultivars were evaluated at seven locations in Niger during two (1986 and 1987) crop seasons.

The introduced sorghum cultivars had no survival disadvantages (Table 1) compared to the local cultivars resulting in equivalent plant stands for all cultivars studied. With the exception of SRN39 and IS9830, the introduced sorghums were rather late-flowering, suiting them better to the higher-rainfall regions of southern

Table 1. Means of developmental characters of ten sorghum cultivars grown in a Striga-infested field at Konni, Niger.

Cultivar	Stand est.	Vigor	Half bloom	Survival %	Plant no.	Plant ht. cm	Panicle no.
*Babadia Fara	58.3bc	36.3a	123.0a	75.5b	55,209b	132.5b	11,458c
*Bagoba	83.1a	37.5a	123.0a	58.0c	60,417ab	76.3c	0c
*Tcholori	60.0bc	31.3a	123.0a	84.0ab	62,500ab	166.3b	19,010c
*L30	58.3bc	42.5a	115.3a	92.4a	68,490ab	135.0b	23,958c
P967083	50.0bc	46.3a	101.0b	91.0a	57,292ab	167.5b	44,011b
Dobbs	66.9b	36.3a	123.0a	94.0a	78,906a	81.3c	13,281c
Framida	64.8b	43.8a	101.3b	88.1a	71,354ab	153.8b	50,521b
N13	65.4b	40.0a	108.0ab	95.4a	78,125a	210.0a	54,688b
IS9830	65.2b	46.3a	75.8c	96.1a	78,125a	221.3a	81,771a
SRN39	46.5c	48.8a	74.5c	97.5a	56,771ab	128.8b	56,250b

*Local varieties

Table 2. Striga infestation means for ten sorghum cultivars grown at Konni, Niger.

Cultivar [1,2]	Count 1 [3]	Count 2	Count 3	Count 4	STRWT	STRPLWT
Babadia Fara	5.1032a	5.9976abc	5.8952abc	5.9308abc	1237.7abc	1.1400a
Bagoba	5.2272a	6.2248a	6.1233ab	6.1546ab	1839.8ab	1.0650a
Tcholori	5.2346a	6.0758ab	6.0809ab	6.1060ab	2025.6a	1.2850a
L30	4.6569a	6.0707ab	6.2742a	6.3486a	1184.9abc	0.4475b
P967083	3.2823a	5.9662abc	6.2978a	6.4080a	1035.0abc	0.4050b
Dobbs	3.8826a	5.9615abc	6.2110ab	6.2651ab	1085.2abc	0.4850b
Framida	5.0590a	5.9974abc	6.1753ab	6.2434ab	947.32bc	0.4050b
N13	4.9264a	5.5342bc	5.6395bc	5.6729bc	749.0bc	1.3225a
IS9830	4.9867a	5.8872abc	6.0404ab	6.0930ab	916.6bc	0.5875b
SRN39	3.0014a	5.3851c	5.4805c	5.5047c	404.2c	0.5200b

Niger or to areas where irrigation is available. The later-flowering sorghum tended to produce fewer harvestable panicles but overall yields were similar among introduced and local cultivars. N13 and Dobbs, two poorly-adapted lines, were low-yielding exceptions.

The *Striga* resistance of the introduced sorghums was of particular interest to us. Although sorghum cultivars resistant to *S. hermonthica* in Africa have been identified, resistance frequently does not hold up across geographical regions. It has been suggested that the existence of intraspecific physiological variants of the parasite may cause variable performance of host resistance. Investigation of potential physiological variants of the parasite in Niger was beyond the scope of this study but we were interested in comparing performance of sorghum varieties reported to be *Striga*-resistant in other parts of Africa under conditions of natural infestation in Niger.

Two cultivars, SRN39 and IS9830, were particularly resistant (Table 2). SRN39 is a tan plant zerazera derivative, and IS9830 is a feterita from the Sudan. Reduction in yield due to *Striga* infestation can often be very serious and grain yields on infested land may average only 30 to 50% of the yields obtained on *Striga*-free land. In the two years of this study the local cultivars produced, on infested land, an average of 53% of their normal yield. Yields of SRN39 and IS9830 were unaffected by *Striga* infestation. The other introduced varieties, under *Striga* attack, produced 57% of their normal yield.

Sorghum cultivars react differently to other types of stress including drought and high temperature. Genotypes with more stress tolerance have more stable yields in areas where that stress condition regularly occurs. We performed a stability analysis to demonstrate the superior performance of cultivar SRN39. Linear regression coefficients (b_1) from the regression of individual cultivar yields on the location mean of all cultivars are presented in Table 3. Since individual cultivar yields are plotted against the mean yield of all cultivars, the population mean has a regression coefficient of 1.0. Cultivars SRN39 and IS9830 showed superior adaptation across all environments with respective regression coefficients of 0.49 and 0.77 suggesting above average stability. Babadia Fara was the least sensitive of the local cultivars although it is below average stability ($b_1 = 1.48$). Another local cultivar, Bagoba, was the least stable (b_1 =

3.40), showing the most sensitivity to changes in the environment. SRN39 yielded as well as the local cultivars in favorable environments and outyielded them in the most stressful environments. Babadia Fara performed well in favorable and drought-stress environments but was susceptible to *Striga* attack. Bagoba was frequently the highest-yielding cultivar in stress-free environments but was very susceptible to both drought stress and *Striga* infestation.

Table 3. Linear regression coefficients (b_i) for individual variety yields regressed with site mean yields for sorghum grown in Niger in 1986-87.

Sorghum cultivar	Regression coefficients
Babadia Fara	1.48473bc
Bagoba	3.40374d
Tcholori	3.08275d
L30	2.39317cd
P967083	2.27152cd
Dobbs	2.35721cd
Framida	2.98426d
N13	2.55377cd
IS9830	0.76700ab
SRN39	0.48957a

The two criteria that have been used as indices of *Striga* resistance are *Striga* numbers and grain yield. *Striga* numbers can be reported either as a score (0-5 or 0-10), as actual counts per unit area or per host plant, or as an index. The *Striga* index is a weighted average of *Striga* number and height. Weights are numbers of *Striga* in each height category. The latter technique is laborious and appears to have no advantage over *Striga* counts. Of the four criteria of *Striga* infestation that we employed, the dry weight of *Striga* plants gathered at sorghum harvest was the most useful. Whether data from one or two years were considered, they showed consistent significant correlation with delay in flowering and reduction in host survival to maturity and yield.

Inheritance of Resistance to Striga hermonthica

Striga hermonthica is a parasitic weed of grasses causing major yield reductions in the principal cereal crops of semiarid Africa. Varietal resistance is the most economic control measure because adapted, resistant cultivars can be grown without additional input from the subsistence farmer. Information on the genetics of resistance to *S. hermonthica* is scant. This is partially attributable to the rarity of sorghum germplasms which exhibit stable resistance across geographical regions. The objective of this study was to determine if the stable resistance observed in cultivar SRN39 is heritable. Crosses were made between SRN39 and a susceptible parent, P954063. Parental, F_1, F_2 and backcross generations were grown in infested pots and development of both host and parasite was monitored. Significant variation among genotypes was observed for both host and parasite traits (Table 4). The F_1 did not differ significantly from the susceptible parent, suggesting recessive inheritance of *Striga* characters. However, hybrid vigor was exhibited by the F_1 which yielded and developed as well as the resistant parent. Broad sense heritability ranged from 0.19 to 0.55 for host characteristics and from 0.10 to 0.43 for *Striga* characteristics. Joint scaling tests showed that observed variation in each host or parasite trait consisted of additive and dominance components, suggesting possible progress to be made with selection. (Table 4).

Effect of Integrated Cultural Practices for Control of Striga

The major premise for this study was that while *Striga* resistant sorghum varieties per se offer economically feasible control measures, an even more effective level of control can be achieved in combination with one or more supplementary control methods. A study was thus conducted over two crop seasons in Niger to investigate the

Table 4. Generation means of sorghum and Striga characters from a cross between resistant and susceptible parents grown outdoors in Striga-infested pots.

Genotype	Sorghum ht (cm)	Sorghum wt (g)	Panicle (g)	Yield (g)	Days to emergence	Striga number 30 DAS	Striga number 37 DAS	Striga number 44 DAS	Striga number 51 DAS
P_R	127.07ab	88.85a	41.92a	30.88ab	41.79a	0.0000b	0.925d	0.5680c	1.1162c
P_S	79.47d	23.79d	8.73d	6.96d	31.77d	0.1982a	1.0311a	1.4933a	1.6789a
F_1	127.50ab	64.73bc	36.72abc	29.53ab	33.30cd	0.1293ab	0.8605ab	1.4253a	1.7375a
F_2	116.41bc	56.45c	30.46bc	23.64ab	34.66c	0.1017ab	0.6916b	1.2632a	1.6194a
BC_R	125.48a	73.27b	37.63ab	28.75	36.96b	0.0627ab	0.4605c	1.0458b	1.4332b
BC_S	108.14c	53.09c	26.51c	20.81bc	33.31cd	0.1508ab	0.8466ab	1.3765a	1.6783a

effects of varietal resistance, application of nitrogenous fertilizer and mode of tillage prior to sowing on infestation of *S. hermonthica*. Experiments were conducted in the fields of subsistence farmers in Niger.

The results of our study (Table 5) reaffirmed that application of urea (100 kg N ha^{-1}) significantly reduced *Striga* number and dry weight on both resistant and susceptible cultivars Framida and Dabar respectively. Percent reduction in *Striga* number on the two sorghum varieties was 67% and 55%, respectively. Percent reduction in *Striga* dry weight was, respectively, 82% and 71%. Application of urea at sowing and at the plant tillering stage delayed flowering of *Striga* and reduced mean *Striga* plant size. In the following year application of urea in the sandy field reduced the number of emerged *Striga* throughout the crop season. On the heavier soil it was effective only on variety Framida at the final *Striga* count. 100 kg ha^{-1} of nitrogen was insufficient to affect infestation on the local cultivar and the infestation on SRN39 was already so low that the effect here was not statistically significant. Previous reports indicate that under fertile conditions, adding nitrogen fertilizer reduced *Striga* infestation whereas on unfertile land with 10-fold reduction in *Striga* infestation, it increased *Striga* emergence. This was not our experience at Bengou.

Table 5. Effect of cultural treatments on sorghum yield in a Striga-infested field in Bengou, Niger.

Treatment	Plant weight	Panicle weight	Yield	100 Seed wt.
Nitrogen				
0	3,870.4b	1,271.9a	969.7b	2.038a
100	4,877.8a	2,301.1a	1,876.5a	2.422a
Tillage				
No-till	4,011.1a	1,507.2a	1,185.8a	2.086a
Plow	4,272.2a	1,721.1a	1,324.3a	2.239a
Plow/ridge	4,838.9a	2,131.1a	1,759.2a	2.366a
Cultivar				
Bengou local	3,722.2a	1,827.8a	1,361.0b	2.134b
Framida	4,866.7a	1,294.4b	1,043.2b	1.911b
SRN39	2,533.3b	2,237.2a	1,865.1a	2.646a

Application of nitrogenous fertilizer at sowing and after five weeks in 1986 resulted in a 162% increase in mean sorghum yield, 27% increase in straw yield and 13% increase in plant height, confirming past work in the Sudan. In 1987, nitrogen fertilization significantly increased straw and grain yields in both fields, but 100-seed weights were not affected, nor was panicle weight in the sandy field. Application of nitrogen fertilizer at sowing and after three weeks gave larger sorghum grain and straw yield increases than later applications. Others have reported a significant increase in sorghum grain number per head, head weight and straw yield as urea application increased from 0 to 215 kg ha^{-1}, and that as nitrogen application increased from 0 to 129 kg ha^{-1}, sorghum plant height, head weight, 1,000-seed weight and straw weight increased significantly.

Mode of field preparation has been reported to contribute to the control of parasitic weeds. Deep plowing was effective in reducing Orobanche infestation in New Zealand. *Striga hermonthica* seeds buried 50 cm deep in soil for three months were reported to lose their viability. In the Sudan, significantly greater *Striga* shoot yields were obtained on flat than on ridged plots. But use of tied-ridges in *Striga* sick plots in Burkina Faso in 1982 did not significantly reduce *Striga* numbers. Drought conditions in the following year resulted in crop failure in control plots whereas tied-ridges enhanced growth of both sorghum and *Striga*.

At Bengou, Niger in 1986, *Striga* infestation on subplots which had been worked by ox-drawn harrow and plow was higher than on no-till subplots. At harvest, increase in *Striga* numbers over that of no-till subplots was, respectively, 142%, 194% and 98% for harrow, plow and plow/ridge treatments. Dry weight of *Striga* was heaviest on plowed subplots, did not significantly differ between harrow and plow/ridge treatments and was lightest on no-till subplots. Increase in *Striga* dry weight over that of no-till subplots was, respectively, 160%, 369% and 215% for harrow, plow and plow/ridge subplots.

No-till subplots were weeded prior to planting with hand hoes, limiting soil disturbance to within 2-5 cm of the soil surface. Animal traction disturbed the soil to approximately 10 cm for the harrow and 20 cm for the plow and plow/ridge combination. None of the cultivation treatments buried *Striga* seed deeply enough to effectively reduce the seed bank in the soil. In fact, disturbing the soil to depths of 10-20 cm only served to increase *Striga* infestation. This observation supports findings by others, where in greenhouse experiments, germination of witchweed (*S. hermonthica*) seed varies with burial depth. Seed placed on the soil surface, at depths of 5-8 cm and at a depth of 24 cm showed low, high and moderate germination response, respectively. Tillage by animal traction may have chiefly served to increase the number of viable *Striga* seed in the upper soil layers where sorghum root number and dry weight is the greatest. In a dryer year (1987) tillage treatments were of most significance in the sandy field where improved water retention through ridging led to increased sorghum survival and panicle and grain yields. They did not significantly affect *Striga* infestation.

In the absence of data from additional years, the combined location analysis for cultivar Framida gives some feel for which fertilizer and tillage treatments are most useful in depressing *Striga* infestation and improving sorghum yield. The two year-two location (three environment) analysis detected no significant interactions whereas a two location analysis (1987) showed only location x treatment interactions to be significant. The effect of tillage treatments will vary considerably according to location, rainfall and even sorghum cultivar whereas nitrogen fertilization at the appropriate level will improve sorghum yield and reduce *Striga* infestation.

Publications

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Networking Activities

Workshops and Conferences

Undertook the organizational legwork of INTSORMIL Sudan Sorghum/Millet Workshop to be held in Year 11.

Participated in Sorghum Utilization (SICNA) Meeting held at Lubbock, TX. Feb. 1989.

Attended the American Society of Agronomy Annual Meeting. Nov. 1988, Anaheim, CA.

Participated in a review panel with the Africa Bureau of the USAID to develop plan for Strengthening Agricultural Research and Faculties of Agriculture in Africa. Nov. 1988.

Participated in the annual INTSORMIL PI Conference. Scottsdale, AZ. Jan. 1989.

Research Investigator Exchange

Dr. Sam Mukuru, ICRISAT/SAFGRAD, Kenya. June, 1989.

Dr. Osman I. Obeid, ARC/Sudan Sorghum Breeder. Sept. 1988.

Mr. Issoufou Kapran, INRAN/Niger Sorghum Breeder. Jan. 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 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 has 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 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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Summary

Sustainable yield of an adequate magnitude and quality at an economic level is productivity. The principal objective of this project 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 adequate resistances to biotic and abiotic stresses.

The drought resistance breeding program and the genetic/physiologic explanation of resistance continues. The glossy trait found in sorghum contributes to drought resistance through morphological means. Greater root system development occurs throughout the plant's life cycle. Glossy isolines showed greater capability to survive severe drought, recover, and resume growth sooner than the normal lines. The ability to stay green under severe stress was determined to be genetically dominant in B35 and recessively inherited in R9188.

The ability for some sorghums to remain fertile under low temperatures (approx. 10°C) at flowering is controlled by one or two pairs of genes. The system appears economically useful in the development of sorghum hybrids which can be used in both high altitudes and intermediate elevations.

The taxonomic groups of sorghum zerazera, nigricans, nigricans/feterita, durra-nigricans and caudatum-kaura combined well to produce high yielding hybrids in both the A_1 and A_2 cytoplasmic-genetic male-sterility systems.

Resistance to damage caused by the head bug that attacks sorghum in parts of West Africa may be related to a water/carbohydrate concentration in the developing grain and be only indirectly related to rapidity of dry matter accumulation.

A MDMV-strain A resistant restorer line (RTx2858) was released for use in areas of the USA and LDC's where virus is a problem in productivity. Also, GTPP7R was jointly released by Texas and Georgia. This material has excellent disease resistance as well as white grain, tan plant color and grain mold resistance. It will contribute significantly to programs throughout the CRSP.

A large amount of new germplasm was added to the program through introductions from LDC's which has been crossed or otherwise incorporated into the project improvement program. A large amount of germplasm of all types was distributed to LDC, other international, and domestic collaborators. The wide scale evaluation of both early generation breeding material and finished parents or hybrids provides both crop protection from diseases, etc., and consumers as well as the LDC grower.

The food type sorghums evolving from this project are beginning to impact the U.S. The sorghum industry is recognizing the benefits of white grain, tan plant color and a grain that will process into a food as well as being a superior poultry or livestock feed. Food use and new product development underway with sorghum will continue, and with a major shift in U.S. usage of these types of new sorghums, there will be economic improvement from sorghum in the U.S. as well as in those countries which already consume sorghum.

Objectives, Production and Utilization Constraints

Objectives

Develop stable, high yielding, agronomically desirable sorghums with high levels of disease, insect and agronomic stress resistance.

Develop food resource sorghums through evaluation of component parts and recombinations of high grain quality with weathering resistance, stable yield and resistance to environmental stresses.

Determine the nature of drought resistance and its behavior in high yielding sorghum germplasm.

Collaboratively screen or otherwise evaluate in the U.S. and host countries, sorghum germplasm enhanced for productivity and food uses of importance to the U.S. and LDC's.

Develop cooperative adaptation/productivity trials emphasizing grain quality, yield and improved disease and drought resistance; distribute, evaluate, and utilize in collaborative programs.

Develop and distribute improved parents of hybrids, lines, and early generation breeding materials possessing productivity and grain quality for use in Honduras, Mexico, Paraguay, Mali, Sudan, Zimbabwe and other unlisted host countries.

Determine relationships of heterotic germplasm and interactions with A_1 and A_2 cytoplasms.

Constraints

Productivity is the basis of a sustainable agriculture. Stability is a goal that lends continuity to crop production, however it is lacking in much of the sorghum producing areas of the world. The consistent yield of sorghum throughout the world is constrained by risks associated with biotic and abiotic factors. Unstable productivity is overcome by the introduction and adaptation of enhanced germplasm. Sorghum is generally grown under less than favorable environmental conditions in those areas of the world where human nutritional levels are at marginal standards of acceptability. Those risks to productivity which are attacked through this project are genetic limitations to yield, disease resistance, drought, inadequately developed germplasm, unimproved food quality and unavailability of improved seeds.

Sorghum production is expanding rapidly in Latin America and in some areas of South America. Constraints to continued growth are not only adequate high yielding stable lines or hybrids with acceptable drought and disease resistance, but also acceptable quality for end-use products. Maize is not capable of providing sufficient production for food needs, while sorghum can add substantially to the food supply. Sorghum quality traits are fairly well known in Africa and Asia. It is necessary to understand the components of quality for each major food system and recombine these in enhanced germplasm. In Mexico, Honduras and El Salvador as well as in most of Africa, a higher yield of improved quality grain is needed.

Drought is a serious constraint to sorghum production throughout most of the world since sorghum is a crop of importance in marginal resource areas. Within the sorghum germplasm reserves there exist large differences for reaction to drought and subsequent performance. Because Texas has a wide range of rainfall and spans both temperate and tropical climatic patterns, it is ideal for both large scale field evaluation of drought resistance phenomena and to validate laboratory screens of physiologic explanations of drought tolerance.

Because the environment of Texas represents the climates of world sorghum production regions so well, it is ideal to screen germplasm, incorporate yield and grain quality components as well as disease resistance, etc., prior to sending enhanced materials to collaborators. South and central Texas are ideal for screening and breeding sorghums with high levels of resistance to the more internationally important diseases.

In Mexico there is a need to understand cold temperature tolerance at or during anthesis. Similarly, food quality in sorghum is a constraint that must be coordinated with the legacy of maize. Drought tolerance and lodging resistance which must be associated with high plant populations and weed pressures are serious problems. Many of these problems exist throughout Latin America.

Paraguay has a severe need for cereal grain. There is a need for food quality in breads and in livestock feeds. The northern areas of the Chaco experience severe drought. Thus, there is a major need for drought tolerance, both pre- and post-types, in materials with excellent food quality. In some areas anthracnose has developed into a major problem as have greenbugs. Materials from Latin and Central American areas have direct usefulness in U.S. production.

Honduras presents constraints of disease (downy mildew, foliar diseases and grain weathering), food quality, and drought resistance. The maicillos criollos have developed under a specific photoperiod regime which does not select for weathering resistance.

In Mali, Sudan, Cameroon, Zimbabwe and Kenya those constraints our materials are affecting are drought resistance, higher yield potential, incorporated food quality, disease resistance, nonsenscence, tolerance to acid soils and brewing quality. It is apparent that sorghum materials developed, enhanced, and exchanged with these programs and others through TAM-121 will impact productivity.

Breeding for productivity has received attention in the U.S. but little in the framework of breeding sorghum for food quality. Stability of yield is important to all major constraints and to all sorghum producers whether in the U.S. or in L.D.C.'s. In order that progress can be made to improve stability across environments, multiple diverse sites must be used in selection and evaluation. TAM-121 has established international trials with special attention to identification of superior germplasm with food quality traits for testing across many different climatic regions.

Because of the erosion of germplasm and the continuing need for new diverse sources of resistance to pests, diseases, and environmental stresses as well as superior end-product use characteristics, there must be preservation and expansion of collections. Adequate evaluations of existing collections, new introductions, and converted lines are needed to determine usefulness of these materials as they impact worldwide sorghum productivity constraints.

Research Approach and Project Output

Existing breeding material was crossed with converted or partially converted collections from the TAES-USDA Sorghum Conversion Program, screened and evaluated for recombination of disease resistance and grain quality in cooperation with pathologists and cereal chemists. Disease screening was done in large field nurseries in south and central Texas utilizing natural infection and supplemented with artificial inoculation for downy mildew, anthracnose, MDM virus and Sorghum Yellow Banding Virus.

New breeding materials generated from planned crosses among drought tolerant and susceptible cultivars were evaluated in replicated field trials at College Station and Lubbock, Texas as well as in greenhouse controlled environments. These trials were designed to describe modes of resistance and inheritance of response(s).

Crosses were made to generate populations among various disease resistant sources, agronomically superior lines, and those possessing drought tolerance. These materials were screened in field nurseries at locations in the U.S., other countries and in the laboratory. Where possible, replicated trials were used for critical evaluation.

Crosses were developed to intergress superior previously identified food quality traits into high yield, nonsenscent, disease resistant inbred lines. These materials were then selected in large field nurseries at several locations with diverse climatic patterns. Elite inbred lines have been used for further screening in collaborating LDC cooperative trials. Hybrids among these materials were produced for screening in areas prone to weathering problems. Advanced generation lines and hybrids were incorporated into various standard replicated trials for more critical and extensive evaluation at several locations in Texas, other states, and in other collaborating countries where these constraints need to be addressed.

Cytoplasmic diversity and heterotic pools among taxonomic groups were tested by selecting examples of each taxonomic group and crossing with two diverse representatives from each of the currently useful cytoplasmic-genetic sterility systems, A_1 and A_2. Parents and F_1 hybrids were grown in replicated trials at locations representative of tropical and temperate climatic regimes.

Materials possessing different responses to fertility at anthesis in cold temperatures were identified, crossed in all possible combinations, and prepared in an elaborate replicated trial for testing in the highlands of Mexico. Correlated trials were conducted in Texas in the greenhouse and temperature controlled chambers to obtain information about possible associated growth and development traits.

Introductions from Cameroon, Mexico, Argentina, China, Honduras, Mali and Sudan which possess grain quality traits, forage quality, cold tolerance for germination and fertility at anthesis, disease and insect resistance were crossed to elite Texas and U.S. lines for enhancement. Materials from these intercrossed materials have been sent as early generation materials to collaborating LDC's, Honduras, Argentina, Mexico, Guatemala, Mali, Zimbabwe, Sudan and China. Several new germplasm collections were introduced through plant quarantine into the Texas program. These will be evaluated for specific traits as they become available.

Research Findings

Productivity is a summation of a program to include genetic, physiologic, pathologic, and cultural results into a delivered crop cultivar. The productivity breeding program continues to use results from related CRSP projects and germplasm resources from collaborating LDC's in combination with elite breeding lines. Large field screening nurseries grown in areas of significant climatic variation are used to select the necessary recombinations for yield, stability, drought tolerance, disease resistance and grain quality. Emphasis has been placed upon tropically adapted genotypes with non-senescence and high yield. The 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 TAM-126 new sources of food quality grain were identified and placed in crosses. These materials were grown in large field screening trials across Texas, and in several collaborating countries (Mexico, Honduras, Paraguay, and Zimbabwe), smaller more specific trials were grown for selection. Materials selected from these trials as well as early generation populations were sent to LDC's in 1988-1989. Subsequent generations will be selected in cooperator nurseries and returned to Texas for further selection and inbreeding as well as critical testing for food use.

During this period a new parental line, RTx2858, was released to private seed companies. RTx2858 and its hybrids are highly resistant and maintain that resistance to MDMV. It has good combining ability and produces mid-to-early maturity hybrids. The line and its hybrids maintain high green leaf retention throughout the season. This enhanced germplasm item provides the first MDMV resistant R-line distributed from a public agency. The material appears to be quite useful in Southern Africa. Materials possessing differential capabilities have been assembled, distributed and interpreted for sorghum virus potential cooperatively with TAM-124. Table 1 lists the distribution of 16 ISVN trials (International Sorghum Virus Nurseries).

A tan plant, white seeded, foliar disease resistant population (GTPP7R) was developed and released cooperatively with R.R. Duncan, University of Georgia. The original base of this population was TP-24 developed at College Station with subsequent screenings for resistance to anthracnose (*Colletotrichum graminicola*), grey leaf spot (*Cercospora sorghi*), rough leaf spot (*Ascochyta sorghina*), zonate leaf spot, (*Gloeocercospora sorghi*), leaf blight (*Exserohilum turcicum*) and rust (*Puccinia purpurea*) during appropriate cycles of random mating in Georgia and Puerto Rico. GTPP7R has predominantly combine height genotypes with open to semi-open panicles, white seed with and without mesocarps, no pigmented testas, tan plant color, and excellent foliar disease resistance. The population will be a useful source of germplasm with good agronomic characteristics, corneous endosperm types, and adaptation to tropical and subtropical.

A group of 40 lines represented by 14 different pedigrees which were selected at multiple locations in Guatemala and across environments in Texas are proposed for release to private industry. These inbred lines are all $\underline{Dw_2}$ three dwarf heights, lack a pigmented testa, possess an array of plant colors and seed colors. This germplasm provides a unique combination of several grain quality factors, plant types, disease resistances, and yield which are needed in the U.S. seed industry and in LDC's. 24 of the 40 lines have tan plant color and white or white translucent seed colors.

Table 1 presents the amount of germplasm distributed through this project during the 1988-1989 period. This reflects both inbred lines, early generation materials and specific trials. The narrow germplasm base in many LDC sorghum programs has led to an increased genetic vulnerability and a severe limitation on genetic grain. Genetic diversity in sorghum is our best protection against vulnerability. The distribution of these enhanced sources of broader genetic base to collaborators not only provides greater protection against disease or pest outbreaks but also provides an opportunity to make impacts upon productivity.

Table 1. Germplasm distribution related to technology transfer including both public and commercial requests and numbers of items distributed from College Station, TX, 1989.

	Public Agencies		Commercial		
	USA	International	USA	International	Total
Numbered requests	66	73	18	6	163
Number of lines (R-lines)	91	452	57	11	611
(A/B lines)	90	545	87	54	776
(Forages)	78	51	25	1	155
Number of trials					
ITAT	12	25	--	2	39
IFSAT	10	15	1	2	28
IFSVT	6	10	--	2	18
ISVN	7	7	1	1	16
Modified hybrid trials	41	9	18	6	74

A modified ITAT (International Tropical Adaptation Test) was used to evaluate adaptation to different environmental conditions across climatic regimes. Table 1 shows that 39 ITAT's were distributed to collaborators with 37 going to public agencies. Of this total 25 were sent to international sites. This replicated trial which contained representative types adapted to tropical and temperate environments was sent to collaborators in Mexico (7), Guatemala (9), Honduras (4), Paraguay (2), Argentina (2), Zambia (1), Cameroon (2), Mali (1), Zimbabwe (1), and People's Republic of China (1). ATx378*RTx430 serves as a widely adapted check hybrid and its performance is good (above the mean yield) in most locations. Hybrids with Dorado, an ICRISAT selected line, provide good yield as does an ICRISAT selected female re-selected in Texas as A.Var-1. This female has excellent resistance to lodging and most diseases. It combines well with Texas males, especially 80C2241, RTx435, and R.8505. This particular trial has provided information on hybrids subsequently released for production in Mexico, Guatemala, Paraguay, Argentina, and People's Republic of China.

Food quality is of high priority in this project. Quality parameters are determined in close cooperation with TAM-126. However, without yield and equal or superior agronomic performance the material will not be useful to growers in the U.S. or LDC's. This trial was established with 40 entries comprised of both varieties and hybrids with three replications. The trial was prepared as a mechanism to evaluate food quality hybrid sorghums chosen from elite and widely adapted germplasm to use in several different food systems. There were 28 total trials sent to collaborators with 25 going to public agencies of which 15 were international. These were sent to Mexico, Honduras, Paraguay, Mali, Sudan, Ghana, Ethiopia, Cameroon, Zambia, and People's Republic of China. Table 2 provides an example of the performance of these materials across a wide range of environments. The highest yielding materials are 2-dwarf which is consistent with previous responses. Grain quality and plant color are independent of yield performance. Panicle size, openness of panicle, quality and shape of the grain were consistent across environments. In People's Republic of China, ATx631*R.8505 was exceptionally good. Other combinations of superior quality and performance were ATx631*80C2241, ATx631*R8511, ATx623*R8509, A155*R8509, and AVar-1*80C2241, which was a tighter panicle. Similar performance was observed at other locations. R.8505 and 80C2241 are proposed for release and distribution to private industry as parental inbreds. Both A.Var-1 and A.155 will be proposed for release.

In an effort to move improved food quality parental stocks into LDC collaborator programs, a trial which

Table 2. Grain yield (kg/ha) of selected food sorghum hybrids (plus check varieties) at Comayagua, Honduras; Jalisco, Mexico; Weslaco and College Station, Texas.

Entry No.	Designation	Comayagua	Jalisco	Weslaco	College Station	Mean
1	Sureño	7152	7976	8460	8549	8034
2	Dorado	6289	2482	7609	5153	5383
3	CS3541	2696	1334	7060	2763	3463
4	ATX623*R8509	6150	3942	5458	5951	5375
5	ATX625*CS3541	1517	1217	8609	4807	4037
6	ATX626*R8605	5892	5908	6884	4849	5883
7	ATX629*RTAM428	6445		6026	4945	5805
8	ATX623*RTX2817	5502	6017	6802	4041	5591
9	ATX630*RTX435	5912	4823	8915	5504	6289
10	ATX630*R8505	8021	5126	7026	4802	6244
11	ATX631*CS3541	5476	6229	7467	7197	6592
12	ATX631*Dorado	6265	5470	9378	7363	7119
13	ATX631*RTX2817	5014	5134	7422	4821	5598
14	ATX631*RTX432	6262	5573	7735	5435	6251
15	ATX631*RTX435	5799	5540	8094	4793	6056
16	ATX631*R8504	4837	6350	7310	4078	5644
17	ATX631*R8505	5749	6132	7385	5707	6243
18	ATX631*R8509	7850	3798	8930	6616	6799
19	ATX631*R8608	3560	2442	6817	5278	4524
20	ATX631*80C2241		4058	7735	6103	5966
21	AVAR*R8608	6926	2688	8086	5268	5742
22	AVAR*R8606	6588	3858	7161	4904	5627
23	AVAR*RTX435	5131	2707	7190	4683	4928
24	A155*CS3541	5304	4111	7086	7261	5940
25	A155*Dorado	8435	7543	10759	8299	8759
26	A155*RTX2817	4616	5570	6593	3811	5147
27	A155*RTX435	4864	4752	7750	4101	5367
28	A155*R8504	5938	5042	7862	4618	5865
29	A155*R8505	4194	5507	8094	4272	5517
30	A155*R8509	6367	5673	9475	6819	7084
31	A155*80C2241	5180	5516	6578	4752	5507
32	A8207*Dorado	6900	4173	7459	6666	6299
33	A8207*RTX435	4916	5779	7056	3054	5201
34	ATX378*SC103*12E	4523	7549	6466	5924	6116
35	ATX631*R8607	4645	3556	7362		5188
36	ATX378*RTX430	7535	7346	6167	3709	6189
37	A1*R8505	6679	6873	7511	5029	6523
38	A1*RTX2817	5334	3449	7564	4401	5187
39	ATX623*Tortillero	8037	4547	9177	3286	7512
40	ATX630*R3338WX	7721	5628	7273	4553	6293

consisted of 25 elite white grain types as inbred lines was developed. The material included in the trial was selected from the best NaOH screenings, those which made the best tô, tortillas and ugal. Table 1 shows that 10 sets were sent to collaborators in Honduras, Ghana, Zimbabwe, Mali, PRC, Niger, Sudan and Paraguay. This material will be used in breeding programs and in direct introductions. Related to this material is the germplasm sent to Zimbabwe (ICRISAT). Table 3 is taken from a report prepared by A. Tunde Obilana which shows the performance of TAM-121 developed R-lines at Matopos, Zimbabwe in 1988-89. Hybrids with R.8609 (9.33), R.8505 (8.83) and (8.58), R.Tx430 (8.64), R.8615 (8.42), R.8606 (8.25) and R.8512 (8.17) all yielded more than 8 tons/ha. This indicates that the project's materials combine very well with ICRISAT females. Relative performance of 474 females from ICRISAT showed 6.06 tons/ha to 5.54 tons/ha for 166 Texas females. Similarly, the relative performance of 134 males from ICRISAT showed 5.46 tons/ha compared to 6.41 tons/ha for TAM-121 developed males.

Table 3. Selected experimental hybrids from sorghum testcross evaluation (STCE-2) 1988-89 (Whites), Matopos, Zimbabwe.

No.	SDSH#	Pedigree	Grain yield t ha-1	Remarks
1	300	ICSA 20 * SDS170	7.33	Whites
2	301	ICSA 20 * SDS2690	7.25	
3	302	ICSA 20 * SDS2690-2	7.50	
4	303	ICSA 20 * LARSVYT-3-85	8.58	
5	304	ICSA 20 * R8609	7.33	
6	305	ICSA 20 * R8509	7.38	
7	306	ICSA 20 * R8510	7.58	
8	307	ICSA 20 * R8615	8.42	
9	308	ICSA 20 * R8614	7.25	
10	309	ICSA 20 * R8512	8.17	
11	310	ICSA 20 * R8502	7.96	
12	311	ICSA 20 * RTx432	7.21	
13	312	ICSA 21 * LARSVYT-4-85	7.83	
14	313	ICSA 21 * RTx430	8.64	
15	314	ICSA 21 * RTx435	7.50	
16	315	ICSA 21 * R8609	9.33	
17	316	ICSA 21 * R8512	7.46	
18	317	ICSA 21 * R8505	8.58	
19	318	ICSA 21 * R8614	7.50	
20	319	ICSA 21 * R8606	8.25	
21	320	ICSA 19 * SDS238	7.83	
22	321	ICSA 19 * R8606	7.92	
23	322	ICSA 19 * RTAM428	7.50	
24	323	ICSA 19 * Tx2816	7.50	
25	324	ICSA 19 * R8505	8.83	
26	325	ICSA 12 * SDS2690	7.46	
27	326	ICSA 12 * SDS238	9.00	
28	327	ICSA 12 * LARSVYT 58-85	7.54	
29	328	ICSA 12 * LARSVYT 46-85	8.50	
30	329	ICSA 12 * R8505	7.58	
31	330	ICSA 12 * RTx434	7.38	
32	331	ICSA 12 * R8511	7.67	
33	332	ICSA 12 * R8510	7.75	
34	333	ICSA 12 * R8504	8.17	
35	334	A8609 * SDS5332	7.42	
36	335	ATx * SDS2302-1	7.42	
37	336	A8608 * SV-1	7.42	
38	337	A8611 *A6352	7.54	
39	338	A145*A6352	7.67	
40	339	ATX631*A6352	7.33	

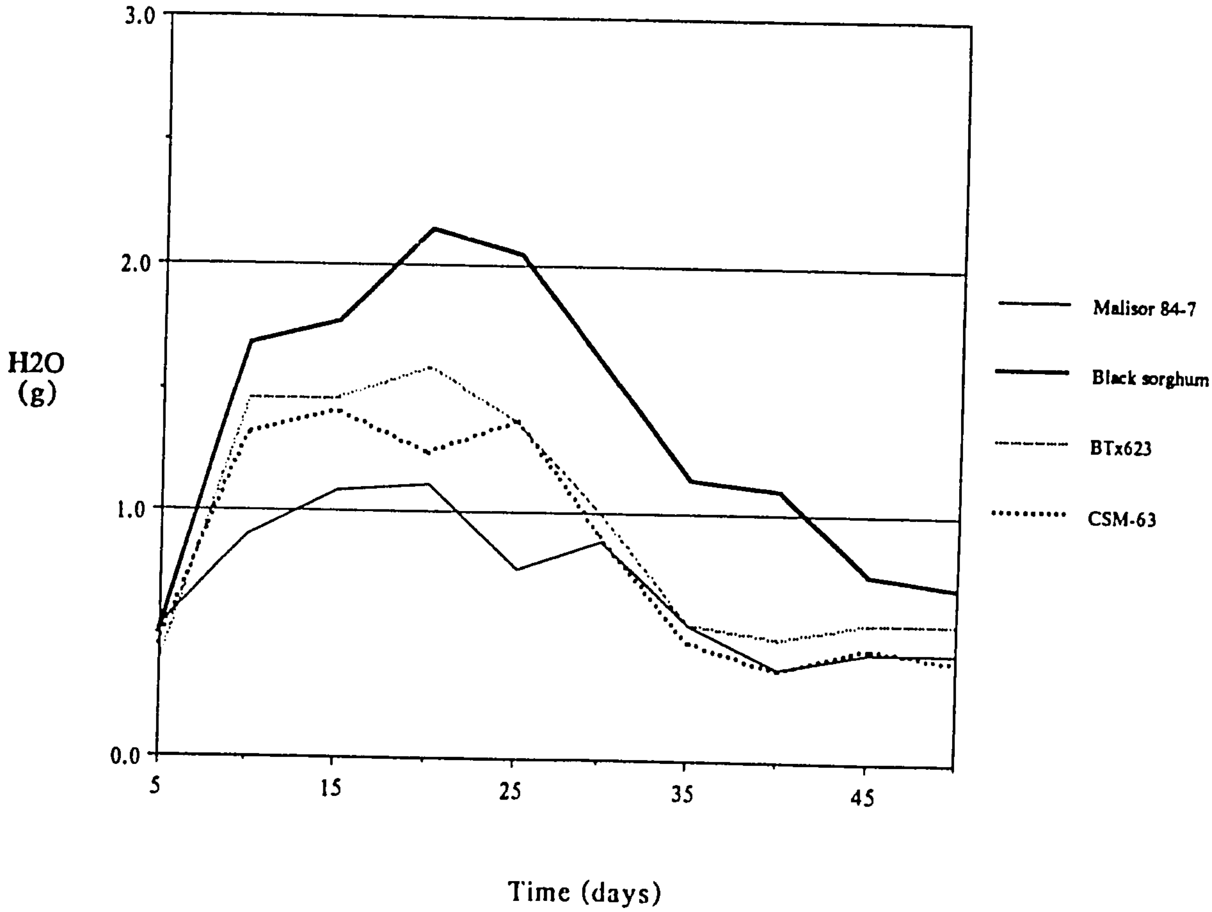
Taken from: A. Tunde Obilana

Previous data collected in Mali showed that Malisor 84-7 developed by Scheuring has a level of resistance to head bugs. This indicates that progress could be made in the further development of head bug resistance. It appears that rapidity of seed fill may be a clue to the nature of resistance. A. Toure from Mali has evaluated grain filling rates and determined that Malisor 84-7 consistently beginning at day 5 following anthesis until 35 days past anthesis has a lower water content in the developing caryopsis when compared to four other sorghums. CSM-63, also a West African guineense type, had a lower water content than BTx632, a zerazera/kafir deviate. The black sorghum (caudatum type from western Sudan) contained a very high water content through the duration of the developmental period and also during the dry-down phase (Figure 1). These preliminary data suggest that head bug resistance may be related to a water/carbohydrate concentration in the developing caryopsis and only indirectly to rapidity of dry matter accumulation.

The 'glossy' trait in sorghum was investigated in a series of experiments designed to determine whether this trait contributed to drought tolerance. Glossy showed consistent advantage over non-glossy under both adequate and deficit water supply. Difference in resistance was morphological. Glossy lines produced extensive rooting even as early as pre-emergence. These lines produced a significantly longer root system under stress. These differences were consistent in both vermiculite and fritted clay medias. Glossy isolines showed greater capacity to survive severe drought, recover and resume growth sooner than non-glossy. Evidence did not support the hypothesis that epicuticular wax load, and cuticular transpiration rates were the explanation for better performance of the glossy types.

Drought resistance was evaluated further in field trials using materials proving useful in Mexico, Paraguay, Sudan and Mali. TAM-122 project has shown that nonsenscence is related to drought response and that the 'stay green' trait can be transferred to some hybrids. A study was completed using 'B35' and 'R.9188' which possess different responses to stay green under stress in hybrid combinations. Inheritance studies indicated that one major dominant gene conferred stay green in B35 while a separate major recessive gene conferred stay green in R.9188. The study suggested that the stay green trait was inherited independently from total leaf area. Leaf architecture was different between these materials also; R.9188 had an average of 21 leaves with its largest leaf surface on leaf 14, while B35 had an average of 21 leaves, with the largest leaf surface in leaves 15 and 16. R.9188 had largest leaves two to four below the flag leaf whereas B35 spread medium sized leaves along the plant culm.

Figure 1. Mean differential quantities (four replications) of actual water content in 100 caryopses of four diverse Sorghum bicolor types when sampled from 5 to 45 days past anthesis.



Productivity of sorghum is limited by low temperatures at different stages of growth and development over millions of hectares throughout the world. In cooperation with ICRISAT/CIMMYT in Mexico and INIFAP Mexico a study was completed on the inheritance of resistance to low temperature sterility at anthesis. Using total caryopses per panicle and an index of total caryopses/length of panicle as the measures of fertility it was determined that one or two gene pairs would account for fertility. It was suggested that this explanation may be specific for the temperature regime at El Baton and Chapingo, Mexico. The direction of dominance was significant toward the cold tolerant parent, indicating that the gene(s) involved were dominant and contained in the tolerant parent. When heterosis for cold tolerance was determined, significant dominance of cold tolerance was found, especially when the Mexico line VA-110 was the source. This suggests the possibilities of creating cold tolerant hybrids, which could have high yield capacity as well as wider adaptation. From a practical point of view, it could be possible to produce cold tolerant hybrids which could be sown at intermediate levels where low temperatures at flowering significantly reduce grain production, and still planted at lower altitudes without detrimental effects on yield.

Further study of the potentials for expanding genetic/heterotic pools in sorghum was made. Previous work has shown that A_1 and A_2 cytoplasms were not significantly different in yield abilities with inbred lines that were developed for use with A_1 females. This study used 27 representatives from 16 taxonomic groups out of the sorghum conversion program. The two A_1 females ATx378 and ATx623 were A_2Tx632 and $A_2$8602 [(SC120*Tx7000)*Tx430]. Taxonomic groups zerazera, nicricans, nigrican feterita, durra-nigricans, and caudatum-kaura produced highest yield combinations in both cytoplasms. However, more variation for yield ability was observed among A_1 hybrids. In A_2 cytoplasm, few low yielding hybrids were produced. This suggests, with development, from the same or different taxonomic classes, the potentialities of the A_2 cytoplasmic genetic sterility system to produce more constant, high yielding hybrids. Of course, the use of a second system would greatly reduce genetic uniformity and vulnerability.

Publications and Presentations

Publications

Rosenow, D.T., L.E. Clark, F.R. Miller, G.C. Peterson, and A. Sotomayor-Rios. 1989. Utilizing exotic sorghum germplasm through genetic conversion. Agron. Abst. 97.

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Yang, Y-W, F.R. Miller and R.J. Newton. 1989. Salinity tolerance in Sorghum:I. Whole plant response in S. bicolor and S. halepense. Crop Sci. (Submitted).

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Masud, S.M., R.D. Lacewell, and F.R. Miller. 1988. Economic implications of sorghum as an energy feedstock. Texas Agricultural Experiment Station, College Station, Texas.

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Pietsch, D., F.R. Miller, L. Reyes, D.T. Rosenow, and G.C. Peterson. 1988. Grain sorghum performance tests in Texas Agricultural Experiment Station, College Station, Texas. MP-1659.

Presentation

Miller, F.R. Breeding sorghums for adaptation and food quality. Field for INTSORMIL graduate students. College Station, Texas, June 27-July 1, 1989.

Networking Activities

Developed field lectures for international exchanges in Beeville, Berclair, Corpus Christi, Weslaco, Lubbock/Halfway and College Station. Provided field activities for Kansas State University Graduate Students 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 1,705 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, 39 International Tropical Adaptation Trials, 28 International Food Sorghum Adaptation Trials, 16 International Food Sorghum Variety Trials, 16 International Sorghum Virus Nurseries, and 74 Modified Hybrid Evaluation Trials were distributed to collaborators (Table 1).

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

Participated in the release and distribution of two sorghums - R.Tx2858 and GTPP7R(H)C5.

Acted as major professor for 12 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 Exchange

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

Dr. Osman Ibrahim, El Obeid, Wad Medani, Sudan

Honduras, December 9-14, 1988, review of INTSORMIL/SRN collaborative research, and interacted with sorghum workers in Escuela Agricola Pan Americana (EAP).

External Evaluation Team discussions and presentations in South Texas, July 11-15, 1988 and North Texas, September 19-22, 1988.

Dr. Paula Bramel-Cox and graduate students visited College Station research program. July 28-29, 1988.

INTSORMIL Graduate Student Tour of South Texas programs - hosted 52 national and international graduate students plus 12 PI's. June 27 to July 1, 1989.

Breeding for Disease and Drought Resistance and Increased Genetic Diversity

Project TAM-122
Darrell T. Rosenow
Texas A&M University

Principal Investigator

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Mr. Moussa Adamou, Sorghum Breeder, INRAN, Maradi, Niger
Mr. Louis Mazhani, Sorghum/Millet Breeder, MOA, Sebele, Botswana
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Ing. Ricardo Ortiz, Pathologist, CENTA, El Salvador
Ing. Lindolfo Fernandez, Agronomist, SRN, Comayagua, Honduras
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Dr. A. Sotomayor - Rios, Geneticist, Tropical Agriculture Research Station, Mayaguez, Puerto Rico

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 collaborating 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 with several breeding lines and parental lines ready for release, as well as some new converted lines. New cultivars were introduced into the U.S., evaluated, and used in crosses. A large amount of new germplasm containing a large number of desirable traits was generated by the new crosses. Large numbers of germplasm lines of all categories were distributed to LDC, other international, and domestic collaborators.

A white seeded, tan plant, food type, foliar disease resistant population, GTPP7R(H)C5, was cooperatively released by Georgia, Texas, and Puerto Rico. It carries high levels of resistance to anthracnose, rust, and other foliar diseases in a diverse genetic background, as well as possessing grain with desirable food properties.

The new female parental lines with high levels of post-flowering drought resistance, charcoal rot resistance, and lodging resistance are being released. The two lines, A35 and A1, to be released as ATx633 and ATx634, should be very useful as parental lines in hybrids in the U.S. as well as in LDC's as parental lines or germplasm sources.

The Malian developed improved line, Malisor 84-7, has excellent head bug resistance. Crosses of this line with elite, high yielding lines were made and showed excellent breeding potential in both Texas and Mali.

The ICRISAT/CIMMYT developed female parental line, A&B Var 1, was found to possess excellent post-flowering drought resistance and head smut resistance. It is a white seeded, tan plant, good food type line.

Several new converted lines and recently introduced exotics were identified as having excellent drought resistance. The outstanding new recently introduced exotics included: Segaolane, a Kafir line from Botswana; El Mota, a Caudatum from Niger; and two Sudanese Feterita varieties, Ajabsido and Koro Kollo. All four showed outstanding resistance to severe pre-flowering drought stress. Many of the new lines were crossed to U.S. elite lines to transfer the drought resistance into improved agronomic types.

New exotics were introduced from northern Nigeria and Somalia, and should be useful as sources of drought resistance.

Objectives, Production and Utilization Constraints

Objectives

1. Develop and distribute early generation breeding materials involving disease and drought resistance specifically for selection and use in host countries with emphasis on Honduras, Sudan, Mali, and Niger.

2. Screen and evaluate in the U.S. and host countries, sorghum germplasm sources for drought tolerance and for resistance to diseases of importance in the U.S. and in LDC's.

3. Develop high yielding cultivars with resistance to internationally important diseases with emphasis on downy mildew, charcoal rot, grain mold, weathering, anthracnose, head smut, head blight, viruses, and acremonium wilt.

4. Develop through breeding and selection, agronomically desirable types with superior combinations of pre- and post-flowering drought tolerance and lodging resistance for use in the U.S. and host countries.

5. Develop cooperative disease and drought trials and distribute, evaluate, and utilize improved disease and drought resistant breeding materials, and new germplasm sources in host countries.

6. 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 post-flowering drought tolerance, perform as expected regarding drought response in other countries of the world, including Sudan, Mali, and Niger.

Diseases are often region or site specific, and on-site evaluation is necessary to determine severity and possible race differences. Most of the internationally important diseases are present and are serious constraints in Texas, especially downy mildew, charcoal rot, grain mold, weathering, head smut, head blight, and MDMV. Many other diseases such as anthracnose, leaf blight, rust, zonate, gray leaf spot, and acremonium wilt are also present in Texas. The Texas environment, particularly South Texas, is ideal for screening and breeding sorghums with high levels of resistance to most internationally important diseases.

The major constraint in Sudan is drought, and drought related production problems. Moisture stress related charcoal rot and subsequent lodging is a serious disease problem. Many U.S. sorghums perform quite well in Sudan, but improved drought resistance, local adaptation, and Kisra food quality are needed.

Mali and Niger are both drought prone areas. Thus, drought tolerance, including both the pre- and post response, is extremely important to both countries. Soil problems are also a serious constraint to sorghum production in Mali and Niger. Foliage diseases such as anthracnose and sooty stripe are important in parts of Mali. Improved high yielding 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. Thus, much of the collaborative research in West Africa involves providing source materials and studying the traits of the West African sorghums which make them uniquely adapted to the area. 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.

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 non-photoperiod 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

1. Introductions from Mali, Sudan, Niger, Honduras, Botswana, and Senegal, including both locals and improved breeding lines with desirable drought resistance, disease resistance, or specific desirable grain or plant traits, were intercrossed in Texas with elite U.S. lines and elite breeding materials. F_1's were grown in the winter nursery in Puerto Rico. Seed of early generations was sent to the LDC's, especially Honduras, Sudan, and Mali, for selection of appropriate traits and adaptation. Assistance was provided, as time and travel permitted, in the selection and evaluation of such breeding material in the host country.

2. Converted and partially converted lines from the Sorghum Conversion Program, exotic lines, new introductions, and breeding materials were screened and evaluated for sources of resistance to internationally important diseases in a cooperative program with pathologists. Emphasis was on large disease screening nurseries utilizing natural infection in South Texas, along with lab screening for downy mildew. Large field drought screening nurseries in West Texas were used to screen germplasm, similar to that described above, for drought tolerance. Selected materials were evaluated for disease and drought at several host country sites.

3. New breeding material was generated from crosses among various disease resistant sources, agronomically elite lines, and new sources of disease resistance. The material was screened and selected in large field disease screening nurseries described above. Advanced generation materials were incorporated into various standard replicated trials for more critical and extensive evaluation at several locations in Texas, other states in the U.S., and in other countries where diseases and competent personnel exist.

4. Crosses among identified sources of drought tolerance (i.e., pre- and post-flowering drought tolerance), elite, high yielding lines, and new drought tolerant converted lines were made. Progeny were selected under field conditions for pre- and post-flowering drought tolerance at several locations in Texas which

varied in their degree and timing of moisture and heat stress.

5. Selected advanced materials from the disease resistance and drought resistance breeding programs were distributed to LDC host countries, selected developed countries and U.S. sites for selection and use. Standard replicated disease and drought trials were developed collaboratively with other INTSORMIL researchers. Seed was increased, and tests were packaged at Lubbock and distributed to host country and U.S. collaborators.

6. New germplasm was introduced into the U.S. through the quarantine greenhouse, and evaluated in Puerto Rico and Texas for useful traits. Some of the introductions were collected by the principal investigator during overseas travel. Based on known traits, or upon evaluation in U.S., selected lines are entered into the cooperative TAES-USDA Sorghum Conversion Program. There, they are converted to shorter, photoperiod insensitive genotypes through a backcross procedure. Converted lines were crossed to various A lines and combining ability of new germplasm determined.

Research Findings

Disease resistance breeding continued with emphasis on new crosses involving resistance to downy mildew, anthracnose, grain mold, charcoal rot, head smut, and MDMV. Many new breeding progeny were generated to enhance the resistance to mold and other diseases in food type sorghums. Many of these F_2's were sent to Honduras for selection and use.

The drought resistance breeding program continued with the use of large field nurseries under the low rainfall environment of West Texas to screen for pre- and post-flowering drought tolerance, overall adaptation, and lodging resistance. Emphasis was placed on developing new germplasm from crosses involving new introduced drought tolerant exotic lines from Niger, Mali, Sudan, Botswana and Senegal as well as new converted lines which have shown good drought tolerance. F_2 seed of these were sent to Sudan, Niger, and Mali for selection and use. In some cases, F_3's, F_3 bulks, or advanced generation germplasm will be sent to collaborating scientists.

A random mated population, GTPP7R(H)C5, developed cooperatively by Georgia, Texas, and Puerto Rico, was released. It is a white seeded, tan plant, food type, foliar disease resistant population. It was developed by selection within TP24R, a broad genetic base white seeded, tan plant population developed in Texas. It was then selected for foliar disease resistance (especially anthracnose and rust) and adaptation in Georgia and Puerto Rico with subsequent random matings.

Malisor 84-7 was found to have excellent tolerance to head bugs in Mali. It is the only non-guineense sorghum which appears to possess a level of head bug resistance that is equal to the traditional guineense sorghums found in West Africa. As such, it becomes an extremely important breeding line for use in breeding sorghums for West Africa. A large number of crosses were made at Lubbock of Malisor 84-7 x various elite U.S. and international sorghums. A few of these F_2 's as well as some other F_2 's were sent to Mali in 1988, with some showing excellent breeding potential (Table 1).

Table 1. F2's from Texas which showed promise at Cinzana and Samanko, Mali, 1988.

Pedigree	Desirability rating[1]
(Sureño x 4C7730)	1.8
(Sureño x VG153/(Wa1-1xIS9327)	2.0
(Sureño x 6E0362/(R5646xSC326-6))	2.1
(R9408 x Malisor 84-7)	2.6
(Malisor 84-7 x M90318)	1.8
(Malisor 84-7 x SC1207-2)	2.5
(7E0366/(TAM428x(Tx432xCS3541))xSureño)	2.0

[1] Rated on 1-5 scale: 1 = very good, 5 = very poor

A white seeded, tan plant female parental line, called A & B Var 1, (a line originally obtained from Dr. Vartan Guiragossian, then breeder at ICRISAT/CIMMYT) was found to possess excellent and dominant resistance to head smut in South Texas. Also, the line expressed dominant "stay-green" reaction in hybrid combination when exposed to severe post-flowering drought stress. Therefore, this line should be extremely useful in breeding new food type A&B lines containing these two elusive traits.

The two new post-flowering drought tolerant, charcoal rot resistant, lodging resistant parental lines (A&B pairs), A&B 35 and A&B1, are in the final stages of preparation for release. A35 imparts a high level of these traits to its hybrids (Table 2), whereas the traits in A1 are less dominant in nature and their level in F_1 hybrids is influenced by the male parent. The line A1 also shows good pre-flowering drought tolerance. A1 hybrids have high yield potential and show wide adaptation, whereas A35 hybrids are well adapted to low rainfall, dryland conditions, or conditions where drought stress generally occurs during the grain fill stage of growth. These lines should be very useful immediately in the U.S., and experimental hybrids with them are being evaluated in several LDC's.

Table 2. Total yield, yield from standing plants, and loss to stress lodging for five hybrids, Chillicothe, Texas.

	Kg/ha of grain		
Hybrid	Total yield	Standing yield	Loss to lodging
A35 x Tx430	3473	3457	16
A35 x Tx2737	2438	2438	0
DK-46 (DeKalb)	3396	3244	153
ATx399 x Tx430	3282	1146	2136
ATx623 x Tx430	2901	821	2080

Several of the new yellow endosperm breeding lines developed in the collaborative drought breeding program involving Texas A&M, Purdue (Ejeta), and Sudan (O. Ibrahim) performed well under severe drought stress in hybrid combination with A35 and/or A1 in Texas and Sudan. Several of these new male lines are being readied as a cooperative release. These lines could have immediate use in both the U.S. and Sudan.

Several breeding lines from the ADIN which were developed by TAM-122 and other material from Texas showed excellent breeding potential for yield and adaptation in Mali in 1988. They include 80B2892(SC748-5xSC630-11E), 86EON362 and 86EON374 ((Tx432xCS3541)xSC326-6), Tx2767 (midge resistant line), and several lines from the NaOH selection breeding material and from the synthetic TRPSS. The NaOH and TRPSS lines showed some tolerance to head bug damage.

Several new converted lines and recently introduced exotics from INTSORMIL collaborative countries have been identified as possessing excellent drought resistance, through field drought screening trials in West Texas. Several of these also possess excellent sources of resistance to important diseases (Table 3). Many combine these traits with desirable agronomic traits.

Publications and Presentations

Publications

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Krieg, D. R., S. P. Kidambi, F. S. Girma, and D. T. Rosenow. 1989. Water Use Efficiency in Sorghum. In Proc: 16th Biennial Grain Sorghum Release and Utilization Conference. Feb. 19-22, 1989. Lubbock, TX. p.169.

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Wanous, M. K. 1989. Inheritance of stay green, a post-flowering drought resistance response in sorghum bicolor (L.) Moench. M.S. Thesis, Texas A&M Univ. College Station, TX. p.81.

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Romo-Calderon, E. 1989. A study of the inheritance of flowering stage cold tolerance in sorghum bicolor (L.) Moench. Ph.D. Dissertation, Texas A&M University. College Station, TX. p.155.

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Presentations

Rosenow, D.T. Sorghum improvement program. Texas Agricultural Experiment Station Field Day, Lubbock, TX. Sept. 13, 1988.

Rosenow, D.T. Drought resistance breeding and sorghum conversion program, Commercial Company Sorghum Field Day, Lubbock, TX. Sept. 22, 1988.

Rosenow, D.T. Breeding for disease resistance. INTSORMIL EEP Review, Corpus Christi, TX. July 11-15, 1988.

Rosenow, D.T. Breeding sorghums for drought resistance and exotic germplasm conversion and use. INTSORMIL EEP Review, Lubbock, TX., Sept. 19-21, 1988.

Rosenow, D.T. Descriptive traits in sorghum. Plant Variety Protection Workshop, Lubbock, TX. Sept. 23, 1988.

Table 3. Selected converted and exotic sorghum lines with drought tolerance and other desirable traits.

Designation	IS No.	Group	Country of origin	Type of drought[1] resistance	Other[2] traits
Koro Kollo	-	Caud (Fet)	Sudan	Pr	
Ajabsido	-	Caud (Fet)	Sudan	Pr	
El Mota	-	Caud	Niger	Pr	
Segaolane	-	Caffr	Botswana	Pr	
SC23	-	Dur	Ethiopia	Pr+Po	DM,HS
SC33	12553C	"	"	Po	DM,HS
SC35	12555C	"	"	Po	HS
SC38	12558C	"	"	Po	DM,HS
SC52	2501C	"	Sudan	Pr	DM,HS
SC55	2451C	Caud	"	Pr	
SC56	12568C	Cau Nig	"	Po	
SC62	12572C	CauNigConsp	"	Pr	A,Mi
SC63	12573C	CauNig	"	Pr	HS
SC103	2403C	Caud	S. Afr.	G	A,HS
SC118	2801C	Caud	Zimbabwe	G	
SC146	12637C	CauNig	Ethiopia	Po	A,HS
SC265	6705C	Consp	B. Faso	Pr+Po	
SC279	7419C	"	Nigeria	Pr+Po	A
SC283	7173C	"	Tanzania	Pr+Po	A
SC328	8263C	Dobbs	Uganda	Po	
SC330	8187C	NigFet	Uganda	G	HS
SC334	3499C	Caud	Sudan	G	HS
SC336	3589C	Caud	"	G	HS
SC405	3464C	CauGuin	"	G	
SC414	2508C	CauKaf	"	Pr	A,DM,HS
SC502	3598C	DurNig	"	Pr	DM
SC504	6895C	NigFet	"	Pr	
SC563	7444C	Caud	Nigeria	Pr	A
SC564	3909C	Caud	Uganda	Pr+Po	HS
SC575	3553C	CauDur	Sudan	G	A,DM
SC587	3874C	Nandyal	India	G	
SC599	17459C	CauBic	USA	Po	
SC701	3462C	Caud	Sudan	Pr+Po	A,HS
SC963	2864C	Caud	So. Afr.	G	A

[1]Pr = Pre-flowering; Po = Post-flowering; G = General
[2]DM = Downy Mildew (P3); HS = Head Smut; A = Anthracnose; MI = Midge

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Rosenow, D.T. Drought resistance, disease resistance, and germplasm research in sorghum. INTSORMIL Graduate Student Tour, Corpus Christi, TX.. June 30-July 1, 1989.

Nguyen, H. and D.T. Rosenow. Genetic improvement of heat tolerance in grain sorghum. Texas Seed Trade Prod. and Util. Conf, Jan. 25, Irving, TX.

Networking Activities

Workshops

Participated in and presented an invited paper at the Sixth East African Regional Sorghum and Millet (EARSAM) Workshop, July 20-27, 1988, Mogadishu, Somalia.

Participated in Sixth CLAIS (Commission of Latin American Sorghum Investigators) Meeting, Dec. 6-9, 1988, San Salvador, El Salvador.

Participated in and presented two invited papers at the International Sorghum and Millet CRSP Conference, Jan. 2-6, 1989, Scottsdale, AZ.

Participated in the International Conference on Dryland Farming, August 15-19, 1988, Amarillo, TX.

Participated in and presented three papers at the Sixteenth Biennial Grain Sorghum Research and Utilization Conference and SICNA Meetings, Feb. 19-22, 1989, Lubbock, TX.

Participated in INTSORMIL EEP Review, July 11-15, 1988 at Corpus Christi and College Station, TX.

Helped plan and participated in the INTSORMIL EEP Review, Sept. 19-21, 1988, Lubbock, TX.

Participated in INTSORMIL USAID Management Review, May 3-5, 1989, College Station, TX.

Helped plan and participated in the Commercial Sorghum Field Day, Sept. 22, 1988, Lubbock, TX.

Participated in the INTSORMIL Graduate Student Tour, gave presentations and led field tours, June 27-July 1, 1989, College Station and Corpus Christi, TX.

Research Investigator Exchanges

To Mali, Oct. 8-18, 1988, to review INTSORMIL, IER, and ICRISAT research, and discuss and plan collaborative research.

To Somalia, July 20-27, 1988, to attend Workshop, visit research plots, and discuss sorghum research with NAR scientists from East Africa.

To El Salvador, Dec. 6-9, 1988, to attend CLAIS meeting, visit research plots, and discuss research plans with Latin American sorghum scientists.

To Honduras, Dec. 9-14, 1988, to evaluate INTSORMIL/SRN/EAP/AID collaborative research and develop future plans with Honduran scientists.

Discussed and led field tours of disease and drought breeding plots and discussed student research with INTSORMIL graduate students from Purdue, Nebraska, Kansas, and Texas A&M at the INTSORMIL Graduate Student Tour, June 27-July 1, 1989 at College Station and Corpus Christi, TX.

Met LDC PI's and discussed collaborative activities at the Sorghum and Millet CRSP Conference, Jan. 2-6, 1989, Scottsdale, AZ.

Osman El Obeid Ibrahim, August 24-28, 1988.

Jay Siebert (ATIP-Botswana) and Doug Carter, August 18, 1988.

Germplasm and Research Information Exchange

Germplasm Conservation and Use

Thirty nine sorghum cultivars from Somalia were introduced through the quarantine greenhouse into the U.S. These were acquired from Dr. H. Porter as a result of travel to Somalia. Most are local sorghum cultivars of the small, tight headed Durra type which are grown under very droughty conditions in Somalia. A few were from other international programs. These will be evaluated in Texas and Puerto Rico for use and/or inclusion in the Sorghum Conversion Program.

The 84 local sorghum cultivars from the droughty sandyland areas of Northern Nigeria (A.B. Obilana) were evaluated in Texas and Puerto Rico, and seed increased in Puerto Rico. Twenty-nine were selected for entry into the sorghum conversion program. Many of these appear similar to the dune-adapted durra types from Niger and Mali which have shown tolerance to the acid soil toxicity problem in Niger and Mali.

Twenty sorghums were collected during visits to the sorghum nursery in Mali, and introduced through quarantine into the U.S. Most of these were elite breeding lines developed in Mali, Burkina Faso, or ICRISAT in India, with good yield potential and good food type grain quality.

Seed Production and Distribution

A large number of sorghum breeding and germplasm lines, including F_2 to advanced generation breeding lines, A, B, and R lines, converted lines, and experimental hybrids were increased and distributed to international and domestic collaborators. These contained sources of desirable traits such as 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 include: Mali (150 + items), Sudan (350 + items), Honduras (250 +), Niger (300 +), Zimbabwe (SADCC/ICRISAT) (150 +), Mexico (ICRISAT) (80), Brazil (200 +), Senegal (50), and Paraguay (40).

Impact

Sureño, the INTSORMIL/SRN cooperative release in Honduras, performed well for farmers in 1987 and 1988 and is now rather widely used in southern Honduras.

Sorghum germplasm developed by or distributed by this project is used extensively by National Sorghum Improvement Programs in Honduras, Sudan, Niger, Mali, Mexico, Paraguay, and Brazil.

Assistance Given

Joint evaluation of germplasm was done collaboratively with national scientists in Mali, Honduras, El Salvador, and Somalia. 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.

Breeding metholodogy training was given to Dr. Osman El Obeid Ibrahim, as well as providing nursery supplies and equipment for his use in Sudan.

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 University

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Summary

Germplasm lines resistant to sorghum midge (21 lines) or biotype E greenbug (10 lines) have been developed and released. The lines represent a significant improvement in the diversity of elite germplasm available with resistance to either insect. In addition to superior resistance the lines are widely adapted, being suitable for use in most sorghum production areas, and possess excellent yield potential in either the presence or absence of the insect pest. The lines in hybrid combination should contribute to greater yield stability, reduce susceptibility to biotic stress, and contribute to less dependence on chemical control of the insect pests.

Results from a field study with two grain sorghum genotypes, three water levels and three nitrogen fertilizer rates indicate a genotype x water x N rate interaction on evapotranspirational water use efficiency and nitrogen use efficiency. Preliminary results indicate a significant effect of N level on transpiration water use efficiency under field conditions.

Preliminary evaluation of results from a lysimeter study conducted under a rainout shelter indicates significant effects of phosphorus level and sorghum genotype on transpirational water use efficiency. Nutrient uptake was related to biomass production and transpiration. Highest water use efficiencies were obtained at the lowest water level.

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.

Production and Utilization Constraints

Grain sorghum production in LDC and DC agricultural ecosystems is constrained by numerous biotic and abiotic stress factors. Subsequent yield instability depends on the degree of stress severity. Research to reduce the impact of stress factors will result in more environmentally fit crop genotypes suitable for use in higher yielding, more stable production systems. The alleviation of plant stress through combining genetic resistance to more than one stress (either biotic or abiotic) in a single genotype will further reduce the inherent environmental risk and contribute to improved productivity in LDC and DC production systems.

In all areas of sorghum production insects pose a production risk. The severity of damage depends on the insect and local environment. As local production ecosystems (relative to cultivars and technology) experience induced evolutionary change the evolved natural balance between cultivars and biotic stress will be changed and insect damage will become increasingly severe. The sorghum midge is the only sorghum insect pest present in all areas of sorghum production and is probably the most destructive insect pest of sorghum. As LDC programs cross indigenous genotypes with exotic germplasm for improved agronomic traits the resulting cultivars will become more photoperiod insensitive and midge damage will become increasingly severe. Development of cultivars resistant to insects as part of an integrated production and stress control strategy will readily integrate with other required inputs in an ecologically sound approach with large potential benefits in subsistence and mechanized agriculture. Host plant resistance to insects is a continual effort in response to a dynamic, continually changing production ecosystem.

It has long been assumed that water was the first limiting factor to plant growth in much of the semiarid tropics. However, Stroosnijder and his associates from the University of Wageningen have shown conclusively that due to a lack of nutrients, principally N and P, usable water is left on the soil profile even by native range plants. We have determined that on Alfisols in Texas (same soil family as many in SAT areas of Africa) usable water is left in soil zones of low nutrient supply. Consequently, increasing grain production under simultaneous low soil water supply and low soil fertility is important as well as conditions of low soil fertility with adequate water.

Research Approach and Project Output

Research Methods

Germplasm is obtained and evaluated for insects of economic importance in a cooperative program with entomologists. Sources of new germplasm include elite germplasm from other programs (including ICRISAT), plant introductions, and partially or fully converted exotic genotypes from the sorghum conversion program. Germplasm is evaluated in large field nurseries or in greenhouse facilities, depending upon the insect.

New sources of resistance are identified and included in a crossing program with elite breeding material. The resistance mechanism and genetics of inheritance is determined when possible. Advanced elite materials are evaluated in nurseries at diverse locations for adaptation and reaction to additional stress factors. Based upon data collected, crosses are made among elite lines to produce new germplasm for subsequent evaluation. Additional adaptation and stress resistance traits (disease resistance and/or drought tolerance) 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 germplasm for inheritance and entomological studies. These populations are then 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

Eight introductions from ICRISAT with excellent resistance to sorghum midge (rated between 2.5 and 5.0 on the midge damage rating scale of 1 = no damage to 9 = 90%+ damage) and acceptable agronomic type have been selected for inclusion in the crossing program to produce new genetic populations. Utilization of these lines will further diversify the genetic base of TAM-123, particularly in the area of white tan food types.

New restorer (A1 cytoplasm) germplasm lines resistant to sorghum midge were proposed for release and seed increased. The 21 lines significantly broaden the genetic base of sorghum with respect to elite sorghum midge resistant germplasm available for use throughout the world. The lines have significantly improved resistance and superior yield potential when compared against previous sorghum midge resistant germplasm releases. Seed of the germplasm lines, designated Tx2869-Tx2890, will be distributed during INTSORMIL Year 11.

Grain sorghum restorer (A1 cytoplasm) germplasm lines resistant to biotype E greenbug were proposed for release and seed increased. The 10 germplasm lines, designated Tx2859-Tx2868, represent genetic combinations not presently available and will be of use in regions where greenbugs are a production constraint. Each line possesses an excellent level of seedling stage resistance and some possess excellent yield potential under severe greenbug infestation. In yield trials in which widely grown susceptible check hybrids sustained severe damage, resistant hybrids sustained little damage while maintaining green leaves and excellent yield potential. The germplasm lines will be distributed during INTSORMIL Year 11.

Results of hybrid tests planted at numerous locations showed that the new germplasm releases produce excellent yielding, widely adapted hybrids. In Texas over several years midge resistant hybrids performed well in trials in the absence of midge, in some instances outyielding midge susceptible hybrids when midge were suppressed. Results from numerous yield trials indicated possible existence of an ecological production niche in which midge resistant hybrids would perform very well. This hypothesis is being tested utilizing midge resistant and midge susceptible hybrids in a date of planting study.

Evaluation of germplasm developed in TAM-123 continued at numerous locations domestically and internationally. Results of trials containing advanced B- and R-lines indicated the lines possessed excellent resistance, in many instances sustaining approximately 40% less damage than a resistant check and being nearly as resistant as the most resistant check under high midge density. The lines appeared to be widely adapted and potentially useful at numerous locations. With each cycle in the recurrent selection and crossing program the level of resistance to sorghum midge and agronomic type improve. Yield potential of new experimental midge resistant hybrids appears to be approaching that of susceptible hybrids.

In addition to the midge line, midge hybrid, and ICRISAT-MSIP 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 is continuing to diversify the program genetic base, especially by use of multiple genes for resistance to sorghum midge and by incorporating genetic resistance to more than one stress factor into a single genotype. Most midge resistant hybrids appear to have some level of pre-flowering 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. Breeding material resistant to biotype E greenbug is being developed with improved levels of resistance to specific diseases. Progeny have been identified which in addition to greenbug resistance possess resistance to one or more of the following diseases: headsmut, pathotype 3 downy mildew, anthracnose, and rust. 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.

In Olancho state, Honduras, midge resistant germplasm is well adapted and appears to be able 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 continued. Evaluation of lines provided by TAM-123 from the sorghum conversion program in addition to other germplasm continued. As results emerge from studies currently in progress, TAM-123 provides additional germplasm upon request.

Research has shown that nutrient deficiencies under rainfed conditions results 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 cooperative field study with TROPSOILS was conducted at Lubbock with the following objectives:

- Delineate the effects of the interaction between sorghum genotype, nitrogen nutrition and available soil water on crop water use efficiency.
- Determine the effects of the interaction between sorghum genotype, N nutrition and available soil water on photosynthesis, stomatal conductance and leaf water potential as they relate to water use efficiency.

The study consisted of two sorghum breeding lines grown at three water levels regulated by drip irrigation and three nitrogen levels, 0, 20 and 80 lbs/A. 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 (post flowering drought resistance) which MB9 does not have and MB9 yields well under low fertility and low available water conditions. Grain yields, evapotranspiration, water use efficiency and nitrogen use efficiency as affected by treatment and sorghum genotype are given in Table 1. Grain yields ranged from 2480 lbs/A to 6410 lbs/A for MB9 and from 1300 lbs/A to 4540 lbs/A for B35. Both sorghum lines produced their lowest yield at the lowest water and N while highest yields were produced at the highest level of water and N. MB9 yield increased as water supply increased for each N rate. However, B35 responded to increased water only at the highest N level. Evapotranspiration was generally independent of N rate and yield for MB9. However, at the low and moderate water levels, N applications increased ET for B35. Increased grain yields (and therefore N levels) resulted in increased water use efficiencies (WUE_{ET}) with MB9 having much greater WUE_{ET} than B35 for any given treatment combination. However, the highest WUE_{ET} was not obtained at the highest grain yield but rather at the highest N rate at the moderate water level. MB9 had higher nitrogen use efficiencies (NUE) than B35 when based upon either grain weight per unit of N in the above ground tissue (Gw/Nt) or given weight per unit of nitrogen supply (GW/Ns). In general NUE decreased with increasing N rates and increased with increased available water for both Gw/Nt and Gw/Ns for MB9 and for Gw/Ns for B35. Analysis of variance indicated a strong water level x N rate x genotype interaction effect on grain yield, WUE_{ET} and Gw/Nt.

In order to determine the effect of N fertilizer on transpirational water use efficiency (WUE_T) under field conditions, data were obtained for use in a crop water model. Data collected included soil water content, soil temperature, soil evaporation using microlysimeters and leaf area index (LAI) for the high water low N and high N plots of MB9. These data along with daily weather data were used to calibrate the model. Leaf area index and soil water content were collected periodically on all plots and daily weather data for the entire season. While all the model calculations are not complete, preliminary results indicate a 30.9% decrease in evaporation due to a 61.7% increase in LAI with the application of 80 lbs/A at the high water level. This coupled with a 100% increase in yield indicates an increase in WUE_T due to N application.

Table 1. **The effect of nitrogen fertilizer and irrigation level on grain yield, evapotranspiration, water use efficiency and nitrogen use efficiency of two grain sorghum breeding lines at the Texas Agricultural Experiment Station, Lubbock, Texas, 1988.**

Irrigation[1] level	Sorghum line	Fertilizer rate (lbs/A)	Grain yield (lbs/A)	ET[2] (inches)	WUE[3] Grain yield/ water used (lbs/A/inch)	NUE[4] Gw/Nt	NUE[5] Gw/Ns
W1	MB9	0-40-0	2480 ghi[6]	14.7f	169 d	60.8	155.6
		20-40-0	2800 cfg	14.8f	189 d	52.9	73.0
		80-40-0	2730 fgh	14.9f	183 d	38.5	28.7
	B35	0-40-0	1300 k	14.6f	89 f	39.9	88.5
		20-40-0	2120 ij	16.0c	133 e	34.4	53.7
		80-40-0	2820 cfg	15.9c	178 d	31.7	25.8
W2	MB9	0-40-0	3300 c	18.5 cd	178 d	57.3	216.5
		20-40-0	3990 d	19.0 c	211 c	69.6	119.2
		80-40-0	5900 b	19.3c	306 a	50.8	63.2
	B35	0-40-0	1530 k	18.0 d	86 f	40.3	106.5
		20-40-0	2100 ij	18.5 cd	114 e	38.8	62.1
		80-40-0	4170 cd	19.1 c	219 c	31.7	41.1
W3	MB9	0-40-0	3190 cf	25.0 ab	128 c	74.0	205.3
		20-40-0	4160 cd	24.6 b	168 d	74.5	126.0
		80-40-0	6410 a	25.7 a	249 b	54.9	67.4
	B35	0-40-0	1740 jk	24.7 b	70 f	41.7	98.5
		20-40-0	2240 hij	24.9 b	90 f	38.4	73.8
		80-40-0	4540 c	25.1 ab	181 d	37.9	49.6

1 W1 - - Preplant (4.0 acre inches/A) plus 2.2 acre inches/A June 10
W2 - - Preplant (4.0 acre inches/A) plus 2.2 acre inches/A June 10, then weekly irrigation to replace approximately 50% of evapotranspiration beginning July 25 (8.2 acre inches/A after planting).
W3 - - Preplant (4.0 acre inches/A) plus 2.2 acre inches/A June 10, then weekly irrigations to replace approximately 95% of evapotranspiration beginning July 18 (16.0 acre inches/A after planting).
2 Evapotranspiration -- Total water input after planting -- rainfall, irrigation and soil water depletion.
3 Water use efficiency.
4 Nitrogen use efficiency - grain wt/unit N in plant tissue above ground.
5 Nitrogen use efficiency - grain wt/unit N in soil
6 Values followed by the same letter are not significantly different (0.05 Duncan Test).

Photosynthesis, leaf conductance and leaf water potential measurements will be coupled with the above measurements in 1989 in an effort to delineate the relationships between these parameters and WUE_T under field conditions.

The second study was conducted as a cooperative effort between INTSORMIL and TROPSOILS projects. It was carried out in minilysimeters under a rainout shelter by a Malian graduate student, Mr. Abdoul Sow. His research encompassed the determination of plant and soil components contributing to phosphorus use efficiency, response to phosphorus in sorghum, and the interaction between available soil water, sorghum genotype and available phosphorus. He utilized the Malian sorghum CSM-63 and the Improved TX 7078. These sorghums were grown on factorial treatments of four phosphorus levels and two water levels. Plants were harvested and roots recovered at three growth stages. Transpirational water use and phenological measurements were made on the plants. Plant tissue has been analyzed for nitrogen and phosphorous.

Preliminary evaluation of results indicates significant effects of phosphorus level and genotype on transpirational water use efficiency. Nutrient uptake was related to biomass production and transpiration. Highest water use efficiencies were obtained at the lowest water level.

Publications and Presentations

Publications

Peterson, G.C., A.E.B. Ali, G.L. Teetes, J.W. Jones, and K. Schaefer. 1989. Grain sorghum resistance to sorghum midge by yield loss vs. visual scores. Crop Sci. 29: 1136-1140.

Peterson, G.C. and A.B. Onken. 1988. Response of converted exotic sorghum cultivars to iron chlorosis. Agronomy Abstracts p. 91. 27 Nov.-2 Dec. 1988, Anaheim, CA.

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.

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.

Teetes, G.L., G.C. Peterson, F.R. Miller, H. Thindwa, and D.R. Pietsch. 1989. Resistance to biotype E greenbug among sorghum hybrids in a state performance test. TAES PR-4655.

Presentations

Peterson, G.C. and A.B. Onken. 1988. Response of converted exotic sorghum cultivars to iron chlorosis. Presented at the American Society of Agronomy annual meeting 27 Nov.-2 Dec. 1988, Anaheim, CA.

Peterson, G.C. and A.B. Onken. 1989. Correlation of chlorophyll content and iron deficiency chlorosis in grain sorghum. Presented at the American Society of Agronomy annual meeting 15-20 Oct. 1989. Las Vegas, NV.

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Networking Activities

Research Investigator Exchanges

G.C. Peterson. December 6-9, 1988. El Salvador. Participated in the 6th Annual Clais meeting as representative of INTSORMIL.

G.C. Peterson. December 9-14, 1988. 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 requests received for such. Samples were sent to several states, and to countries/programs including but not limited to Honduras, Guatemala, Botwana, Peoples Republic of China, Taiwan, ICRISAT-MASIP, Argentina.

Planted 4.0 acres of hybrid seed production crossing blocks for collaborative research.

Increased seed of sorghum germplasm lines designated Tx2859-Tx2890 for release.

Sorghum Improvement in Honduras and Central America

Project TAM-131
Dan H. Meckenstock
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Principal Investigator

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Ing. Miguel Lopez, Economist, EAP/PRF-105 , El Zamorano, Honduras
Ing. Julio Lopez, Entomologist, EAP/MSU-105, El Zamorano, Honduras
Ing. Hector Portillo, Entomologist, EAP/MSU-105, El Zamorano, Honduras
Ing. Lorena Lastres, Entomologist, EAP/TAM-125, El Zamorano, Honduras
Ing. Sonia Morales, Sorghum Breeder, CENTA, San Andres, El Salvador
Agr. Manuel Santos, Maicillo Breeder, CENTA, San Andres, El Salvador
Ing. Edgar Salguero, Maicillo Breeder, ICTA, Jutiapa, Guatemala
Ing. Oscar Martinez, Agronomist, ICTA, Zacapa, Guatemala
Ing. Manuel Marquez, Agronomist, ICTA, Escuintla, Guatemala
Dr. Tom Hash, Sorghum Breeder, ICRISAT/CIMMYT, El Batán, Mexico
Agr. René Clará, Sorghum Breeder, ICRISAT/CIMMYT, El Batán, Mexico
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Dr. G.C. Peterson, Sorghum Breeder, TAM-123 Texas A&M University, Lubbock, TX
Dr. R.A. Frederiksen, Pathologist, TAM-124, Texas A&M University, College Station, TX
Dr. F.E. Gilstrap, Entomologist, TAM-125, Texas A&M University, College Station, TX
Dr. L.W. Rooney, Cereal Chemist, TAM-126, Texas A&M University, College Station, TX
Dr. H.N. Pitre, Entomologist, MSU-105, Mississippi State University, Mississippi State, MS
Dr. J.H. Sanders, Agric. Economics, PRF-105, Purdue University, West Lafayette, IN

Summary

Sorghum breeding project TAM-131 has operated in Honduras since 1981. Its overall objective is to improve the quality of life of farm families in Honduras that produce sorghum through the conservation of biodiversity and enhancement of traditional sorghum varieties. The project operates under a memorandum of understanding with the Honduran Secretaría de Recursos Naturales (1981) and with the Escuela Agrícola Panamericana (1988). The Government of Honduras and AID/H provide significant local currency support for activities through the Title XII PL480 program. Regional networking is conducted via information, germplasm, and scientist exchange, and collaborative research with the Ministries of Agriculture in El Salvador and Guatemala, and ICRISAT. TAM-131 also collaborates with nine INTSORMIL projects representing four universities and provides backstopping to INTSORMIL students conducting research in Honduras. Four advanced degrees have been completed and five are in process.

Near term goals emphasize the enhancement of improved varieties and hybrids which make up roughly 10% of the sorghum acreage in Honduras. These goals have been met with the introduction and joint release of sorghum cultivars Tortillero (1983), Catracho (1984), and Sureño (1985). Farm level studies indicate that Sureño

and Catracho increase grain yield over traditional technologies by 68 and 113%, respectively. This translates into an increase in family income from $1.60 per day ha^{-1} to $2.70 with Sureño and $4.40 with Catracho.

Midterm goals focus on conservation and enhancement of tropical landrace sorghum called maicillo criollo. Maicillo is traditionally intercropped with maize on marginal land by resource poor farmers who use it as "drought crop insurance". Enhanced maicillo varieties will upgrade small farmer food production for self-sufficiency and sustain conservation of local germplasm and biodiversity associated with intercropping. The new maicillo will facilitate *in-situ* conservation via an informal network of village level landrace custodians that will forge a rural landscape mosaic of modern, enhanced traditional, and traditional varieties and technologies. Enhanced maicillos have produced up to 58% more grain yield than their maicillo parent and are resistant to sorghum downy mildew.

Long term goals call for the extension of enhanced maicillo varieties to hybrids for the purpose of maximizing small farmer benefit and shifting subsistence agriculture towards production agriculture. Forty-three experimental half-sib maicillo hybrids outproduced their maicillo parents by 94% (3.1 vs 1.6 t/ha, respectively) over three locations in 1988. In another test at the same locations, an enhanced maicillo hybrid produced 4.6 t/ha. Male sterilization of enhanced maicillo lines are on schedule and the first lines will have completed five backcrosses by December 1989.

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 publications of research results.

Year 10 Objectives

<u>Conservation and evaluation of maicillo diversity</u>. Collect landrace sorghum populations used by traditional farmers and identify useful genes in these populations. Also, determine the fertility reaction of 30 maicillo accessions to A1, A2 and A3 cytoplasms and identify their testa and height genotypes.

<u>Maicillo enhancement</u>. Increase genetic diversity within the maicillo population by introducing elite genes or blocks of genes for yield stability, higher yield potential, production efficiency, insect and disease resistance, and improved grain quality. Also, identify superior cultivars for on-farm testing.

<u>On-farm research</u>. Conduct 100 on-farm demonstrations with Sureño and Catracho in the Departments of Choluteca, Valle, El Paraíso and Comayagua for the purpose of introducing farmers to new high yielding cultivars and other production technologies. Also, determine the potential impact of new technologies on small farmer income.

<u>Hybrid maicillo</u>. Determine the yield advantage of maicillo hybrids and complete two backcross generations in the male sterilization program of dwarf maicillo lines for use in photoperiod sensitive hybrids. Also, determine the height and testa genotypes of parental lines.

<u>Sorghum downy mildew</u>. Monitor "hot spots" of *P. sorghi* for changes in virulence and transfer exotic resistant genes into maicillo cultivars.

<u>Basic seed</u>. Maintain pure seed of released varieties and hybrids, and the Sorghum Downy Mildew (SDM), Dwarf Maicillo Variety (DMV), and Maicillo Criollo (MC) germplasm banks.

<u>Germplasm exchange</u>. Distribute enhanced maicillo varieties for evaluation and use in Honduras, Guatemala, El Salvador, and other sorghum programs.

<u>Graduate student research</u>. Coordinate research activities between SRN and INTSORMIL graduate students.

Constraints

<u>Low yield potential</u>. National sorghum yield in Honduras is less than one metric ton per hectare. This in part is a reflection of the adverse environment in which sorghum is grown and the predominant use of landrace populations called maicillo criollo which have low but stable yield. Low yield potential is considered the

primary constraint to maicillo production and before new technologies can become economically feasible, the genetic potential of traditional varieties to respond with increased grain production must be developed

Traditional farming systems. Maicillo is an old world crop that has successfully adapted to neotropical slash and burn agroecosystems. Late maturing maicillo is customarily intercropped with early maturing maize. More than 90% of the sorghum planted in Honduras and El Salvador are maicillo. Attempts to replace them with temperate sorghum have failed because introduced varieties and hybrids lack essential traits for traditional intercropping. Maicillo's sensitivity to photoperiod and ability to withstand shading are key to its adaptation to these systems. Because of the uniqueness of maicillo germplasm and traditional farming practices, much of the world's sorghum and existing information cannot be adopted without modification. Research to elucidate how sorghum-maize intercropping systems work will accelerate this process.

Photoperiod sensitivity. Maicillo is very sensitive to photoperiod and day lengths of 12 h or less are required for floral differentiation. In southern Honduras, floral initiation occurs during the first fortnight of October regardless of spring planting date. Because of its photoperiod requirement, maicillo fails to mature in the United States. Consequently, maicillo improvement must be carried out in the region (between 12^{o} to 15^{o} N lat.).

Insect pests. A complex of early season lepidopterous defoliators called langosta and late season stemborers (*Diatraea* spp.) are the predominent insect pests of maize and sorghum. The fall armyworm (*Spodoptera frugiperda*), along with other lepidopterous larvae (*S. eridania*, *Metaponpneumata rogenhoferi*, and *Mocis latipes*), wreak havoc among farmers and extension agents each spring by chaotically attacking fields of seedling sorghum and maize with little warning. Understanding the complex, its species diversity, density, time of occurrence, and origin, is necessary for developing and targeting control strategies.

Sorghum downy mildew. Sorghum downy mildew is a recently introduced disease that is endemic in the region. Compounding the threat of this disease is the fact that the most virulent pathotype of *Peronosclerospora sorghi* in the Americas is reported in Honduras. This pathotype was detected at the Las Playitas Experiment Station, Comayagua in 1986 and has been designated P5. Because maicillo and most U.S. genotypes 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 to resource poor farmers.

Political and economic crisis in Central America. The political and economic crisis in Central America continues to affect sorghum improvement. In El Salvador, travel to nurseries is often unsafe and must be postponed. Although recent peace initiatives are beginning to pacify the region, the economic crisis has seen little improvement. National resources for agricultural research are scarce and the international donor community continues to support the bulk of this work. Devaluation and inflation have cut local currency support for sorghum research in Honduras by as much as 80% in terms of real dollars.

Research Approach and Project Output

Conservation and Evaluation of Maicillo Diversity

Collection and evaluation are the first steps toward germplasm conservation. It is through these processes that useful genes are identified for conservation. Once identified, both plant and man are best served by deploying them in new cultivars that go back to the field. Not only does this capitalize on a vast extension of established sorghum acreage for *in-situ* conservation, but evolutionary processes are allowed to continue.

On-farm research is used to access local landrace populations. Participating farmers are asked to contribute 50 to 100 g seed of their traditional varieties to the MC germplasm bank which is maintained at the EAP. Linking collection to on-farm research targets conservation of local varieties most likely to be replaced and adds a dimension of cultivar performance that is often lacking in collection excursions.

Twenty-four maicillo accessions were made by SRN collaborators in the 1989 primera (spring season), thus bringing the Honduran MC germplasm bank to 225 accessions. Collections were made on farms from 10 municipalities in the Departments of Choluteca (n = 16), Valle (n = 7), and La Paz (n = 1). New landrace names added to the collection were Mostacio, Banqueño, Culantro, Maceta Floja, and Gorrudo.

The MC germplasm bank is a working collection of landrace sorghum collected in El Salvador, Guatemala, and Honduras. It is grown alternately in two of four locations each year in Honduras (El Zamorano, La Lujosa, Las Playitas, and Rapaco). Entries are evaluated for resistance to insect pests, prevalent diseases, and overall performance. Accessions with superior levels of resistance and agronomic performance are selected for enhancement. Selected accessions also pass through the

INTSORMIL collaborative network for assessment in other countries. Superior accessions with unique characteristics are entered in the TAMU-USDA Sorghum Conversion Program to extend their usefulness and as an additional measure of conservation.

Accessions in the MC germplasm bank have many desirable traits and have the potential to make a significant contribution to sorghum production and utilization worldwide. Several INTSORMIL projects are working to tap this reservoir of useful genes. In addition to screening for insect and disease resistance, maicillo accessions are test crossed to determine fertility reaction to A1, A2, and A3 cytoplasms, and to determine testa and height genotypes. This information is used to match parents for crossing in the maicillo enhancement effort.

Thirty maicillo accessions were evaluated for reaction to A1, A2, and A3 cytoplasms at the EAP (Table 1). Another 46 and 41 accessions were topcrossed to A1 and A2 cytoplasms, respectively, for evaluation in 1989. Tester lines used were A155, A160, ATx629, A2Tx632, and A3Tx430. All testers had $dw_1Dw_2dw_3dw_4$ height genotype (single symbols represent homozygosity at the indicated loci) and b_1B_2 testa genotype with exception of A3Tx430 which was b_1b_2. Paired crosses (i.e., male and F_1 hybrid) were planted in adjacent head row plots to facilitate evaluation for height. A late planting date (14 September) was used to synchronize flowering between pairs for backcrossing. Hybrid panicles were bagged before flowering to determine percent seed set.

Table 1. Fertility reaction of maicillo accessions in three male-sterile cytoplasms, 1988.

Cytoplasm	n	Sterile	Partial sterile†	Fertile	Segregating
A1	30	6	11	10	3
A2	16	0	9	5	1
A3	18	13	3	1	0

†5% to 75% seed set.

Six accessions (Caturra-68, Gigante-16, Largo-122, Mano de Piedra-174, Piña-61, and Riñon-188) were male-sterile in milo cytoplasm (A1). These lines were backcrossed to their respective male parent to begin sterilization. Although extreme plant height (3-4 m) makes maicillo male-sterile lines impractical for commercial use, these lines will be used in combining ability studies to determine the optimum concentration of maicillo germplasm in hybrids for maximizing grain yield.

Ten accessions restored fertility in at least one cytoplasm. Accessions: MC3, Leche-173, Cacho de Chivo-169, Cubano-175, and Porvenir-z restored A1 cytoplasm; Apretado-187, Largo-117, Liberal-3, and Norteño-72 restored A1 and A2 cytoplasms; and Liberal-63 restored fertility in all three cytoplasms. The A2 and A3 restorers will be used to develop elite male lines that can be deployed in more than one cytogenetic system. The development of maicillo hybrids in A1 and A2 cytoplasm is a long term goal that 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).

Twenty-seven of the above maicillo accessions had testa genotype B_1b_2, the other three (Paragüe-8, MC3, and Pelota-162) were b_1. Pelota-162 is a new addition to a short list (n = 5) of accessions known to possess the b_1 gene. Maicillo genotypes with the b_1 gene can be crossed with conventional white seeded male-sterile lines to produce food type hybrids; however, these flower three to four weeks earlier than true maicillo when planted in the *primera*.

Most accessions in the MC germplasm bank are assumed to be one-dwarf (i.e., only one of the four known height loci has recessive genes). By comparing the height of paired rows, it was possible to identify nine accessions (Cola de Perico-164, Gigante-16, Largo-117, Largo-122, Lerdo-104, Liberal-63, Manzano-177, Paragüe-8, and Pelotón-99) as having $Dw_1dw_2Dw_3Dw_4$ height genotype. Another 13 were Dw_2. Genotypes were not determined for the remaining accessions because increased height of the hybrid was not sufficient to rule out heterosis. A longer growing season would have produced a better separation of heterotic and complementary gene effects.

Other INTSORMIL projects assist in evaluation of maicillo accessions outside Central America. This is advantageous because, as in the case with diseases like anthracnose and charcoal rot, resistant genes appear to be widespread within the maicillo population, but evaluation cannot be accomplished in country because of low disease incidence. A case in point is a survey of sorghum diseases in four departments in Honduras conducted between 1983 and 1985. Although anthracnose was present early in the season, it never developed to epidemic proportions.

Twenty of 52 maicillo accessions had high levels of resistance to *Colletotrichum sublineolum* (syn. *C. graminicola*) at Sete Lagoas, Brazil in early 1989 (TAM-124). In comparison, most of the entries in the 88ADIN and introductions from Botswana, Zambia, and China developed high levels of anthracnose. Other sorghum evaluated at Sete Lagoas with widespread resistance were from Cameroon, Togo and to a lesser extent Mali.

Four of the accessions (Billy, Enano de Corpus-23, Nance Dulce-79, and Porvenir) screened at Sete Lagoas showed excellent combined resistance to *C. sublineolum*, *Puccinia purpurea*, and *Cercospora scalariforme*. Resistance to *C. sublineolum* in these accessions also holds in Puerto Rico (TAM-121). With exception to Enano de Corpus-23, these accessions are being converted for use in temperate zones and their converted lines are designated SC1370, SC1375, and SC1371, respectively. These lines will be useful to breeding programs developing cultivars for the humid tropics and southern United States.

Maicillo Enhancement

Cultivation of uniform varieties and hybrids over vast areas reduces genetic variability and increases the risk of crop loss. The introduction of exotic germplasm adds to this problem when landrace populations are displaced. In an effort to conserve maicillo germplasm, the SRN-EAP-INTSORMIL sorghum improvement program has focused on upgrading traditional varieties rather than their replacement. Enhancement of traditional varieties has two advantages in sustaining sorghum production: 1) genetic diversity is increased and 2) derived cultivars provide a broader genetic defense because they are buffered with local genes which have evolved with native insect pests and pathogens.

Germplasm collection, introduction, and hybridization are the principal technical thrusts applied in maicillo enhancement. Broad crosses between elite introduced germplasm and superior maicillo landrace accessions are made to increase genetic diversity within the maicillo population. Traits being transferred to maicillo include tan plant color for improved food quality; resistance to *Cercospora sorghi, Puccinia purpurea*, and *P. sorghi* to decrease yield loss and improve forage quality; and reduced height to augment grain yield by increasing grain sink size relative to stem sink. Maicillo traits being maintained or selected include sensitivity to photoperiod and cereal properties for tortilla utilization.

Because of broad genetic differences between maicillo and exotic lines, particularly with regard to height, maturity, and testa, large F_2 populations are required to select desirable phenotypes. To increase selection efficiency, an enhanced maicillo germplasm bank has been formed from maicillo x exotic derivatives. This gene pool currently has 99 entries which are designated with a dwarf maicillo variety (DMV) number. These materials are primarily two-dwarf photoperiod sensitive varieties consisting of 25% to 100% maicillo germplasm. These varieties serve to bridge the gap between maicillo and exotic lines and increase the probability of selecting desirable F_2 phenotypes when used in crosses. Depending upon the direction of the cross, F_2 populations segregate either for maturity or height, but not both.

The scope of the 1988 enhancement effort at the EAP entailed the use of 29 maicillo, 65 enhanced maicillo, and 28 exotic lines to produce F_1 seed on 214 hand emasculated crosses. From these crosses, 1369 F_1 transplants were established in a greenhouse on 5 Jan. 1989. Of the transplants started, 880 produced seed, 236 did not flower or were immature at harvest, 218 did not germinate, and the remaining 35 either died before or after transplanting. Highest yielding F_1 plants were DMV134*Brandes and 86EON362*DMV106. Maicillo parents with best general combining ability were MC30-2, Pelota-162, and San Bernardo III. Best enhanced maicillo combiners were (SEPON77*Santa Isabel)-6-2-4, DMV106, DMV143, and DMV180. Exotic lines with best combing ability were 86EON362 [syn. (Tx432*CS3541)SC326-6], BTx631, and Brandes.

Multilocation testing is used to develop cultivars with wide adaptation and resistance to multiple diseases. Early generation materials are evaluated in head row plots at two to four locations (El Zamorano, La Lujosa, Las Playitas, and Rapaco) and selected for the above criteria plus broad adaptation, non-senescence, and drought tolerance. Specific resistance characteristics selected at each site are: La Lujosa = gray leaf spot, acremonium wilt, and high temperature; Las Playitas = SDM (pathotype 5), ladder spot, and gray leaf spot; Rapaco = zonate leaf spot, rust, and late season drought; and El Zamorano = rust, gray leaf spot, and SDM (pathotype 1).

Observation of F_2 families in Rapaco revealed that excellent progress can be made with crosses between enhanced maicillo varieties. One outstanding F_2 population, DMV180*[SPV346(81LL691*Billy)-7]-36, produced all white seeded, tan plant progeny that were fairly uniform for height and maturity. This permitted a greater number of desirable plants with leaf disease resistance, drought tolerance and yield potential to be selected. Other noteworthy F_2 populations were BTx631*[(SC326*SC103)Liberal]-40, [(SC326*SC103)S.B.III]-12*CSV11,and ICSV120* (Billy *CS3541)-1.

In an attempt to get these materials and others into the hands of collaborators, 163 lines drawn from 26 F_2 families in Rapaco and 106 F_3 through F_8 lines with resistance to SDM in Comayagua were placed in the 1989 CLAIS dwarf maicillo nursery. This collaborative nursery was composed of 766 early generation materials contributed by sorghum programs in El Salvador, Guatemala, and Honduras. The Honduran contribution consisted primarily of choice food type varieties (i.e., white seed and tan plant color) and 97 experimental hybrids. Review of the nursery's pedigrees indicated that the other countries were making use of previously distributed Honduran breeding materials.

In addition to distribution of early generation materials that can be selected according to the needs of country programs, advanced materials are distributed in the International Improved Maicillo Yield Trial (IIMYT). Entries are selected on the basis of agronomic merit and are assigned a DMV number. Nineteen new varieties were included in the 1988 IIMYT which consisted of 44 treatments. This replicated yield trial was distributed to national programs in El Salvador, Guatemala, and Honduras.

The best performing dwarf maicillo varieties were DMV165 (4.2 t/ha), DMV184 (4.0 t/ha), and DMV179 (3.8 t/ha) (Table 2). Entry DMV179, with pedigree (SPV346*Gigante Pavana)-1 F_6, is a particularly attractive food type variety with above average resistance to rust, gray leaf spot and SDM (pathotype 1). This enhanced maicillo was designated for seed increase for farm level testing in Honduras for 1990.

The enhanced maicillo (S1LL691*Porvenir)-16-bk, is scheduled for on-farm testing in Guatemala in 1989. This food type variety has broad appeal because of its high yield potential and above average leaf disease resistance which enriches its grain and forage utility.

On-farm Research

Because of its manpower and existing infrastructure for transferring technology, the SRN has the lead role in on-farm research. The current on-farm work ties into the SRN Extension Service and Natural Resource Management Project as well as other developmental organizations working in southern Honduras. This coordination serves to reduce duplication and increase efficiency of programs working towards a common goal. In order to satisfy both research and extension mandates, the on-farm effort acquaints farmers with new technologies and evaluates their acceptance and potential impact. Ing. Evelyn Oviedo, working with the Honduran Sorghum Program at Choluteca, is charged with the coordination and supervision of this activity. In addition, Purdue University Ph.D. candidate Miguel Lopez (PRF-105) was hired by the EAP to conduct a farm level economic analysis of new sorghum cultivars and other new technologies in southern Honduras.

Because farmers have different levels of risk, demonstration plots with graduating levels of technology were used to obtain crucial information for determining potential impact at different technology levels. On-farm trials in 1988 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 participants. Cultivars evaluated were the recently released sorghum hybrid Catracho (1984) and variety Sureño (1985). Respective pedigrees are ATx623*Tortillero and (SC423*CS3541)E35-1. Plots were pure stand planted on hillside terraces in the *postrera (fall season)*.

Data were obtained from 47 sites (Table 3) and Sureño and Catracho increased grain yield over local cultivars when traditional practices were used by 23% and 38%, respectively. The magnitude of their yield advantage increased considerably when seed was treated with a systemic insecticide (37% and 63%, respectively) and when seed treatment was combined with 60 kg/ha nitrogen applied at floral differential (68% and 113%, respectively). These results demonstrate the superiority of improved germplasm at both low and high input levels and strike a blow against the persistent belief that improved germplasm does not perform as well as traditional varieties when grown under traditional management. Catracho also exhibited the quantum jump in productivity that can be achieved with hybrids.

Honduran farmers are receptive to innovation and will adopt new technology when it works and is within reach. They also look upon Sureño and Catracho with admiration and speak highly of these cultivars. Economic analysis indicates that family income increases on average from $1.60 per day/ha to $2.70 with Sureño and $4.40 with Catracho when the highest technology level is used (amounts are based on the official rate of exchange: L.2.00 to $1.00). Considering that per capita income in Honduras is about $188.00 and that the current minimum wage is $3.33 per day, this is a significant increase.

Both Sureño and Catracho were developed under multilocation testing programs and are widely adapted. In Mexico, they have produced test plot yields as high as 10.1 and 11.4 t/ha, respectively (TAM-121). In Ghana, Sureño is used extensively by Global 2000 and has produced spectacular results. In Honduras, Sureño has produced record yields as high as 6.4 t/ha in production fields at the EAP. One report of Sureño's adoption without assistance comes from the area of San Jerónimo, Comayagua, where several farmers planted Sureño in relay with rice to take advantage of residual moisture. Neighbors were

Table 2. Performance of the IIMYT at three locations in Honduras, 1988.

DMV no.	Pedigree	Z† t/ha	CM† t/ha	LL† t/ha	Mean t/ha	Flower date	Ht m	P1‡ %	P5‡ %	Rust Z	GLS‡ LL
	A155*[(326*103)S.B.III]-12 F1	6.:	4.2	3.0	4.6	14-Oct	2.2	1	6	2.6	3.0
003	Variedad Blanca	6.3	4.0	2.8	4.4	20-Oct	3.4	1	3	3.9	4.0
165	(TAM428*S.B.III)-3-1 F6	6.6	4.0	2.1	4.2	29-Oct	2.5	0	20	2.9	3.0
184	(TAM428*Porvenir)-30-1 F9	4.6	5.1	2.3	4.0	2-Nov	2.0	0	1	4.0	2.7
179	(SPV346*Gigante Pavana)-1-1 F6	4.7	4.8	1.8	3.8	7-Nov	2.3	0	11	2.8	2.3
177	(S.B.III*TAM428)-6-1 F8	4.4	4.1	2.3	3.6	3-Nov	2.6	0	6	2.3	2.6
002	Lerdo Ligero	6.4	2.7	1.6	3.6	15-Oct	2.3	9	28	4.6	4.5
137	(TAM428*Porvenir)-29-2 F6	4.7	3.9	2.0	3.6	2-Nov	2.1	0	5	3.6	2.3
172	(GPR148*S.B.III)-1-1 F6	3.8	3.8	2.5	3.5	8-Nov	2.9	5	12	4.1	4.1
	A155*(CS3541*Liberal)-6 F1	5.0	2.8	2.2	3.3	11-Oct	2.3	0	17	2.9	3.0
164	(TAM428*Pelotón)-9-1-5-2	4.0	3.8	2.2	3.3	10-Nov	2.1	3	15	3.7	2.2
	A155*(81CV1176*MC40)-1 F1	3.9	2.5	3.2	3.2	6-Oct	2.5	0	5	2.9	-.-
183	[(TAM428*Porvenir)(MB9*Liberal)]	4.1	3.6	1.9	3.2	1-Nov	2.2	0	1	3.6	3.3
107	(81LL691*Porvenir)-16-1 F6	4.7	2.5	2.2	3.1	5-Nov	2.1	1	3	3.0	2.5
143	(TAM428*S.B.III)-23 F7	4.5	3.1	1.5	3.0	5-Nov	2.3	3	0	3.0	3.7
138	(TAM428*PORVENIR)-30 F7	3.9	3.1	2.2	3.0	7-Nov	2.0	0	3	3.7	3.3
	San Bernardo III	4.4	3.1	1.5	3.0	4-Nov	2.8	18	28	3.5	3.5
142	(TAM428*S.B.III)-18 F7	4.5	2.1	2.2	3.0	28-Oct	2.1	14	49	4.1	3.0
185	84ES-104-1-1-1-bk	3.7	3.0	2.0	2.9	9-Nov	3.0	1	3	2.6	2.9
171	(D71020*Billy)-48-2 F8	4.2	2.6	1.9	2.9	6-Nov	1.9	0	2	3.4	2.5
169	(Billy*CS3541)-1-1 F7	3.6	2.5	2.6	2.9	27-Oct	1.9	0	2	3.9	2.9
186	84ES-2-1-1-1-bk	3.3	2.6	2.7	2.9	6-Nov	2.1	0	1	3.6	3.7
180	(TAM428*77CS3)GPR148]Billy}-24	3.3	3.2	2.1	2.9	28-Oct	2.5	1	0	4.1	3.0
	Porvenir	3.7	2.0	2.7	2.8	10-Nov	3.2	14	31	3.7	4.3
166	[(TAM428*S.B.III)Billy]-7-1 F7	2.7	3.2	2.4	2.8	26-Oct	1.7	0	1	4.1	2.9
157	(SPV346*Peloton-99)-14-2 F6	4.3	1.6	2.4	2.8	7-Nov	2.5	0	6	2.9	2.4
133	(TAM428*Porvenir)-20-2 F8	4.0	2.2	1.9	2.7	2-Nov	2.2	0	4	3.1	2.7
149	(81LL691*Porvenir)-16-3 F8	3.4	2.4	2.2	2.7	7-Nov	2.3	2	15	3.3	2.5
	Peloton	4.1	2.5	1.3	2.6	12-Nov	2.9	4	20	3.7	3.7
173	(ICSV138(81LL691*Porvenir)]-2 F4	3.4	2.7	1.8	2.6	22-Oct	2.4	1	28	3.7	3.9
170	(BTx623*Pespire I)-1-1 F6	3.4	2.1	2.2	2.6	4-Nov	2.2	4	10	3.0	3.2
182	(TAM428*Peloton)-8-1 F8	3.3	2.5	1.8	2.6	4-Nov	1.8	0	0	4.1	2.7
162	(TAM428*Peloton)-1-4-3 F7	3.4	2.4	1.9	2.6	29-Oct	1.9	0	9	3.6	2.7
159	(TAM428*77CS3)GPR148)PN]-52F7	2.9	2.5	2.2	2.5	31-Oct	2.2	0	6	3.9	2.0
176	(MB9*Liberal)-17-1 F7	3.0	1.9	2.2	2.4	29-Oct	1.8	1	6	3.3	3.2
178	(SC414-12*Peloton)-2-2 F7	2.8	2.1	2.2	2.4	23-Oct	2.0	0	3	4.2	4.3
163	(TAM428*Peloton)-25-1 F7	2.7	2.4	1.8	2.3	1-Nov	1.7	0	4	3.4	4.0
181	(TAM428*Peloton)-1-2 F7	2.4	2.9	1.4	2.2	27-Oct	2.1	0	2	3.8	3.2
187	Angel de Limon	1.8	2.4	2.2	2.1	6-Nov	2 3	5	41	3.1	2.3
174	(IS12611*SC108)Liberal-5177]-5 F4	3.2	1.7	1.3	2.1	18-Oct	3.3	10	18	3.4	3.7
158	(SPV346*Peloton-99)-26-1 F6	3.1	1.3	1.6	2.0	2-Nov	1.8	0	13	2.7	2.1
001	San Miguel No. 1	2.5	1.2	2.0	1.9	4-Nov	2.3	26	60	3.7	3.3
151	(CS3541*Lerdo-104)-3-1 F6	2.9	1.2	1.0	1.7	1-Nov	1.9	0	19	2.1	2.8
175	(IS12611*SC108)Norteno-71]-4 F4	1.5	0.6	1.5	1.2	16-Oct	2.0	0	29	3.9	4.0
	Gran mean	3.8	2.7	2.1	2.9	30-Oct	2.3	3	12	3.4	3.1
	L.S.D. 0.05	1.5	1.4	1.1	1.1	16.7	0.3				
	Planting date	7/13	7/27	7/28							
	Precipitation (mm)	817	567	1446							
	Temperature, min-max (°C)	18-28	19-29	22-33							
	N-P applied (kg/ha)	112-52	65-0	45-0							

†Z = El Zamorano, Francisco Morazán; CM = Las Playitas, Comayagua; LL = La Lujosa, Choluteca.

‡P1 = Peronosclerospora sorghi pathotype 1, P5 = pathotype 5, GLS = Grey leaf spot.

so impressed with its performance that they bought the grain as seed the following year at a price of L. 2.00 per pound. That is 10 times the market value of grain! Because of these kinds of events, Sureño is rapidly becoming the Ministry's best released sorghum variety.

On a down note, a few Sureño whorl stage plants in a spring 1989 production field at the EAP were infested with bacterial soft rot. This disease occurred in a new field that was previously star grass (*Cynodon nlemfuensis*) pasture. Bacterial soft rot is not a common disease among maicillo and this incident serves as a reminder of the narrow genetic defenses of introduced germplasm. Sureño fields will be monitored to determine if the disease develops elsewhere.

Table 3. Farm level performance of Sureño and Catracho compared to traditional varieties and practices in southern Honduras, 1988.

Technology level	Sureño (t/ha)	Catracho (t/ha)
Traditional variety and practices	1.08	1.20
Improved variety with traditional practices	1.33	1.65
Improved variety with seed treatment	1.48	1.96
Impro. d variety, seed treatment, and fertilizer	1.81	2.55
	n = 33	n = 14

Hybrid Maicillo

The genesis of hybrid maicillo will maximize small farmer productivity and help shift subsistence agriculture toward production agriculture. Although maicillo hybrids are still in their infancy, the general concept is to create two- and three-dwarf photoperiod sensitive parental lines that make use of complementary height genes to restore acceptable plant height in hybrids. Key to sustaining this new biotechnology is development of combined maicillo male-sterile lines that will make commercial seed production economically feasible.

Hybrid maicillo offers a striking contrast to conventional hybrids in both appearance and use. Major differences in crop phenotype are brought about through manipulation of maturity and height genes. Maicillo hybrids are taller, later maturing, and restricted to the tropics because of their extreme sensitivity to photoperiod.

Conventional hybrids are defined by the ma_1 maturity gene and for the most part by the dw_1, Dw_2, dw_3, and dw_4 height genes. In contrast, maicillo hybrids will be defined by the Ma_1, Ma_2, Ma_3, and Ma_4 maturity genes, but will have considerably more variability among height genes since six homozygous and eighteen heterozygous two-dwarf genotypes are possible. These changes in genes that regulate growth, coupled with maicillo's presumed lower respiration rate which enables shade tolerance, will make maicillo hybrids better adapted to intercropping with maize than their commercial counterparts.

National programs in El Salvador and Guatemala are striving to improve maicillo production. Although these programs are excited about maicillo hybrids they have emphasized varieties because of lack of adequate A-lines (conventional male-sterile lines produce hybrids that are too early and generally brown seeded). Elite male-sterile maicillo lines will fill a niche that will allow these programs to maximize yield potential of their new varieties.

A paired progeny backcross method is employed to develop male-sterile lines and an off season nursery (Jan-May) is utilized to accelerate this process. In addition to making five paired backcrosses per line, eight panicles are bagged before flowering to determine percent seed set. Lines with partial sterile panicles are discarded.

Sterilization of elite maicillo derivatives began in 1986 at the EAP and the first A-lines to finish five backcrosses will be completed December 1989. These experimental lines are derived from BTx623*Pespire (n = 21), MB9*Liberal (n = 35), and Redlan*Coludo-110 (n = 95). Once sterilized, they will be screened for combining ability and desirable agronomic traits. Release of several lines will follow once merit is proven. Another 13 dwarf maicillo lines representing an array of height and maturity genotypes as well as tan plant color began sterilization in 1988.

This is a critical stage in the development of maicillo hybrids because those genes that define parental lines will be selected. Preliminary data suggest that certain height genotypes are associated with higher yields than others. Because determination of the yield advantage of maicillo hybrids is important, special care must be taken to ensure that the best available genotypes for optimizing yield are evaluated. Contemplated research will focus on the development of male-sterile lines with superior combining ability and the effect of height on yield, particularly heterozygous versus homozygous genotypes. Information on the effect of heterozygosity at height loci will be critical for engineering parental lines.

Quantification of the yield advantage of maicillo hybrids has relied on topcrosses with conventional A-lines. Several accessions and enhanced maicillo lines have been evaluated, but one apparent drawback is that hybrids are considerably earlier than males. Consequently, growth and development of the hybrid's panicle occur under environmental conditions dissimilar to those of their parents when planted in the *primera*. Once maicillo females are available, formation of later maturing hybrids will enable evaluation of photoperiod sensitive males and hybrids under more similar environments. Another aspect of maicillo hybrids which requires investigation is the relationship between percent maicillo germplasm and yield.

In 1987, 19 photoperiod sensitive cultivars and their topcrosses with ATx623 were evaluated in La Lujosa, Las Playitas, and El Zamorano. Due to a late season drought that claimed 85% of the nation's maicillo harvest, hybrids significantly outperformed their maicillo parents (2.8 vs 0.6 t/ha, respectively). Because hybrids were 25 days earlier on average, much of their yield advantage was due to their ability to escape the drought rather than withstand it.

A similar test utilizing 43 hybrids and 29 maicillo males topcrossed to ATx629, A155, and A160 was conducted in the same three locations in 1988. Planting dates ranged from July 6 to 27. As in the previous year, hybrids out performed maicillo varieties (3.1 vs 1.6 t/ha, respectively). Although a normal *postrera* increased yield in maicillo males compared to the previous year, hybrids on average produced a 94% yield advantage. Depending on location, hybrids ranged from 14 to 22 days earlier and 0.3 to 0.8 m taller than their maicillo parents.

In the 88IIMYT that included both varieties and hybrids, the top of the test over three locations was hybrid A155*[(SC326*SC103)San Bernardo III]-12 with 4.6 t/ha (Table 2). This hybrid produced a 53% yield advantage over its maicillo source, San Bernardo III (3.0 t/ha). Interestingly, this two-dwarf hybrid was heterozygous at the Dw_2 and Dw_3 loci and outperformed all varieties which were homozygous at these loci.

A late season grow-out block (19 Sept. planting date) including 18 dwarf maicillo males and 26 of their hybrids was conducted at the EAP. The objective of this activity was to identify complementary height and testa genes, and the fertility reaction of the enhanced maicillo males. Yield was also measured and hybrids produced 46% more grain on average than their male parents (2.8 vs 1.9 t/ha, respectively). As in the 88IIMYT, the best yielding hybrids were two-dwarfs with heterozygosity at the Dw_2 and Dw_3 loci. The highest yielding hybrid in each height genotype class is shown in Table 4.

Although the grow-out test was not designed to evaluate the effect of heterozygosity at height loci on yield, results suggest that this relationship merits further study. Conventional females showed higher combining ability than dwarf maicillo females, but this may have been an effect of the late planting date which hastened development under shorter day lengths. Comparison of the performance of A155*[(SC326*SC103)San Bernardo III]-12 in a 13 July planting (6.1 t/ha, Table 2) versus the 19 September planting (4.4 t/ha, Table 4) at the EAP suggests that photoperiod sensitive hybrids do better under a longer growing season.

In summary, maicillo hybrids produce more grain than their maicillo parents. Preliminary tests indicate that hybrids will outproduce traditional varieties 53 to 94%. Considering that the alternative to hybrids is varietal improvement and that conventional plant breeding methods have resulted in gains at the rate of 1 to 2% per year over the last two decades, the development of maicillo hybrids would advance sorghum improvement by at least 25 years. Ninety-seven dwarf maicillo hybrids were made for testing in 1989. Ten of these were selected in an off season nursery to be included in the 89CLAIS or 89IIMYT regional yield trails. One of the more promising two-dwarf food type hybrids was ATx631*DMV180.

Control of Sorghum Downy Mildew

Sorghum downy mildew presents a significant threat to sorghum production and control of this disease has focused on monitoring "hot spots" for changes in virulence and distribution, and on incorporating new sources of resistance into maicillo cultivars. Monitoring of pathogen virulence with 10 differential lines provided by TAM-124 indicated that P1 and P5 were the predominant pathotypes at Las Playitas and El Zamorano, respectively. No change in virulence was apparent at either location. Also, percent infestation in Las Playitas has not returned to the high level observed in 1986, when pathotype 5 was detected; however, incidence in 1988 was greater than in 1987 when a severe late season drought occurred.

Even though 1987 and 1988 were not good years for SDM in Las Playitas, on-farm testing has increased awareness of the disease and it was observed for the first time in Valle Arriba, Moroceli, El Paraíso and Las Cañas, San Marcos de Colon, Choluteca. It is not known whether the disease was present the year before since this

Table 4. Yield and height comparisons between dwarf maicillo hybrids and their male parent.

Hybrid	Height genotype†	Male t/ha	F1 t/ha	Male m	F1 m
A155*[(SC326*SC103)Liberal]-55	Dw_2dw_2 Dw_3dw_3	0.9	4.8	1.0	1.7
A155*(CS3541*Liberal)-6	Dw_2dw_2 Dw_3dw_3	2.7	4.7	1.3	1.9
A155*[(326*SC103)S.B.III]-12	Dw_2dw_2 Dw_3dw_3	3.5	4.4	1.1	1.6
ATx629*(81LL691*Porvenir)-16	Dw_2dw_2 Dw_3dw_3	3.4	4.0	1.5	2.2
A155*(CS3541*Plano Namasigüe)-9	Dw_2Dw_2 Dw_3dw_3	2.3	2.8	1.8	1.6
A(623*Pespire)-1*[(SC326*SC103)SBIII]-12	Dw_2dw_2 Dw_3Dw_3	3.5	1.9	1.1	1.5

†All hybrids are dw_1dw_1 and dw_4dw_4 with exception of ATx629*(81LL691*Porvenir)-16 which is a heterozygous one-dwarf.

was the first year the project worked in these areas. However, a first time sighting was reported in Rapaco, El Paraíso where the project has been screening materials for drought tolerance since 1986. The disease appeared to have established via secondary infection on susceptible plants. This incident serves as a reminder of the potential threat of the disease and reemphasizes the importance of deploying resistant cultivars to deter its dissemination.

Twenty-eight of the hand emasculated crosses producing seed in 1988 were effectuated with the objective of incorporating resistance to pathotype 5 into the enhanced maicillo lines. Resistant sources used were eight Indian sorghum lines introduced in 1987. Sixteen additional test crosses between the Indian sorghum lines were also made in an attempt to identify different resistant genes. The white seeded tan plant line IS 3443 was used as the tester.

Basic Seed

A cold room (14.5 m^2) was negotiated at the EAP for storage of germplasm and the SDM, DMV, and MC germplasm banks. Self pollinated seed of the enhanced maicillo varieties: (TAM428*San Bernardo III)-23 (45 kg), (TAM428*Porvenir-20-2-6 (14 kg), and (81LL691*Porvenir)-16-bk (14 kg) was increased for SRN on-farm trials in 1989. Basic seed of ATx623 (10 kg), BTx623 (3 kg), and Tx2784 (10 kg) was distributed to EAP and SRN so that seed production of the new SDM resistant forage hybrid (ATx623*Tx2784) could begin.

Publications and Presentations

Publications

Castro, M.T., H.N. Pitre, and D.H. Meckenstock. 1988. Potential for using maize as a trap crop for the fall armyworm, Spodoptera frugiperda (Lepidoptera: Noctuidae), where sorghum and maize are intercropped on subsistence farms. Florida Entomol. 71:273-278.

Castro, M.T., H.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. Trop. Agric. 66:259-264.

Craig, J., G.N. Odvody, G.C. Wall, and D.H. Meckenstock. 1989. Sorghum downy mildew loss assessment with near-isogenic sorghum populations. Phytopathology 79:448-451.

Gomez, F., D.H. Meckenstock, E. Oviedo, and M. Lopez. 1989. Transfer of new sorghum technology: Sorghum demonstration plots in Honduras, 1988. (In Spanish). National Sorghum Program Rep. No. 1, SRN, Tegucigalpa, Honduras.

Meckenstock, D.H. 1988. Sorghum Improvement in Honduras and Central America. p. 124-136. INTSORMIL Annual Report 1988 (AID/DAN-1254-G-SS-5065-00). Sorghum/Millet Collaborative Research Support Program), Lincoln, NE.

Meckenstock, D.H., 1988. The sorghum revolution in Honduras. A.I.D/S&T/AGR Science and Technology Agricultural Reporter (STAR) 1(2):1-2, Washington, D.C.

Meckenstock, D.H., A. Palma, and F. Gomez. 1988. Sorghum improvement in Honduras, 1987. (In Spanish) p. 61-78 In Proc. 6th Workshop CLAIS, San Salvador, 6-9 Dec. 1988. MAG/CENTA, San Salvador, El Salvador.

Trabanino, C.R., H.N. Pitre, K.L. Andrews, and D.H. Meckenstock. 1989. Effect of seed size, colour, number of seeds per hill and depth of planting on sorghum seed survival and stand establishment: Relationship to phytophagous insects. Trop. Agric. 66:225-229.

Presentations

Meckenstock, D.H. Sorghum improvement in Honduras. 6th CLAIS Workshop, San Salvador, El Salvador, 6-9 Dec. 1988.

Rodriguez, R. How INTSORMIL can best assist Honduras' five and ten year plans. INTSORMIL PI Conference, Scottsdale, AZ, 3-5 Jan. 1989.

The following five INTSORMIL graduate students presented a seminar on their research findings to 25 SRN extension agents in Choluteca.

Lastres, L. The role of two predators, Doru taeniatum Dorhn, and Solenopsis geminata Fabricius, as control agents of the fall armyworm in Honduras.

Lopez, J. Antibiotic effects of maicillo on fall armyworm.

Lopez, M. Farm level economic evaluation of new technologies in southern Honduras.

Oviedo, E. System and genotype effects on yield in maicillo-maize intercropping.

Portillo, H. Insect pest ecology, population dynamics and partial crop life tables and loss assessments in intercropped sorghum and maize in southern Honduras.

Eight presentations were made at the thirty-fifth annual meeting of the Central American Cooperative Program for the Improvement of Food Crops (PCCMCA) Conference, San Pedro Sula, 3-7 Apr. 1989. Two received recognition for outstanding research (*).

Gomez, F. Transfer of new sorghum technology in Honduras.

Lastres*, L. The role of ants as predators of fall armyworm larvae on the ground.

Lastres, L. The importance of predators of the fall armyworm in Central America.

Lopez, M.A. Economic budgets as a basis for evaluating new agricultural technologies in Honduras: The case of new sorghum technologies.

Lopez*, M.A. Intercropping systems and the adoption of new technologies: New sorghum cultivars and soil conservation techniques in southern Honduras.

Meckenstock, D.H. 1989. The case for hybrid maicillo.

Oviedo, E. System and genotype effects on yield in maicillo-maize intercropping.

Palma, A. Evaluation of 38 enhanced maicillos in Honduras, 1988.

Networking Activities

Research Investigator Exchange

Mr. Miguel Lopez, a Ph.D. candidate at Purdue University (PRF-105), was employed by the EAP for eight months (Jul. 1988 thru Feb. 1989) to conduct a farm level economic evaluation to determine the potential impact of new technologies introduced by SRN-EAP-INTSORMIL on the income of small farmers.

Mr. Delroy Collins (TAM-124) visited Honduras in late November to assist in evaluating nurseries for sorghum diseases. Drs. Miller (TAM-121), Rosenow (TAM-122), and Peterson (TAM-123) also visited Honduran nurseries to review the maicillo improvement work and make observations in collaborative TAMU nurseries that were sent to Honduras for evaluation.

Germplasm Exchange

Breeder quantity seed of elite breeding lines, early generation enhanced maicillo materials, and experimental maicillo hybrids were distributed to El Salvador (n = 647), Guatemala (n = 417), and Nicaragua (n = 41). Seed of the forage hybrid, ATx623*Tx2784, was provided to the Animal Science Department at the EAP for a student's thesis on a comparative study with star grass for forage and meat production. Results will be included in the contemplated bulletin of the pending forage sorghum hybrid release. Over 275 kg of seed of five cultivars was given to the SRN to be distributed for 1989 on-farm demonstrations. Approximately 32 kg of Manzano maicillo was obtained from Cujulero, Valle and sent to the cereal quality laboratory at Texas A&M University for tortilla cooking trials.

Assistance Given

Travel was provided for one representative from SRN and EAP to attend the sixth annual CLAIS meeting in El Salvador, the INTSORMIL PI conference in Scottsdale, Arizona, and the 35th annual PCCMCA meeting in San Pedro Sula, Honduras.

Office supplies and equipment (electric typewriter, overhead projector, and 20 Mb hard disk) were donated to the SRN to support the national sorghum program. Current sorghum information including reports (n = 5), reprints (n = 11), student theses (n = 1), proceedings (n = 1), and how-to manuals (n = 1) were distributed to the Agricultural Document and Information Center (CEDIA) of the SRN to update their references on sorghum research in Honduras.

A subscription to CAB Sorghum and Millets Abstracts and two INTSORMIL reports were provided to the EAP Library.

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, Lorena Lastres (TAM-125), Julio Lopez (MSU-105), Miguel Lopez (PRF-105), and Hector Portillo (MSU-105) worked on various aspects of their research in Honduras.

Evelyn Oviedo completed his course work at the EAP for the *Ingeniero Agronomo* degree and returned to the SRN where he now heads up on-farm sorghum research in Choluteca. Mr. Oviedo conducted his thesis research with the sorghum project at the EAP on sorghum-maize intercropping systems.

Agronomo Manuel Santos from CENTA, El Salvador, was invited to spend two weeks at the EAP in mid-November in order to participate in the maicillo breeding program. Objectives of his visit were to familiarize him with project operations and to transfer elite maicillo germplasm into maicillo lines being developed at CENTA. SRN-EAP-INTSORMIL nurseries at four sites were visited to demonstrate principles of multilocation testing in the development of host plant resistance to multiple diseases. Seed from 52 crosses that Manuel effectuated between El Salvadoran and Honduran germplasm was later sent to El Salvador for use in the CENTA sorghum improvement program. Manuel also received instruction in the paired progeny backcross procedure which is used for developing male-sterile lines.

All hybrids are dw_1dw_1 and dw_4dw_4 with exception of ATx629*(81LL691*Porvenir)-16 which is a heterozygous one-dwarf.

Entomology

Executive Summary

The principal insect pest constraint to stand establishment in sorghum-maize intercropping systems in southern Honduras has been identified to include a complex of lepidopterous species collectively referred to by the local farmers as langosta. The fall armyworm appears to be the most abundant of the species encountered annually on the crops, but three other species contribute to stand reduction or even complete crop destruction. Information on the diversity, density and time of occurrence of the langosta on crops during the past two years provides the basis for developing sampling procedures for the specific insect pest species, as well as timely application of control measures. The spatial and temporal relationships between the langosta and non-crop vegetation and crop plants has been further defined in the dynamics of the different species in the langosta, strengthening recommendations for use of effective weed management practices for this pest complex.

Sorghum-maize-legume (cowpea) intercropping reduced fall armyworm infestation and increased predator population in the crop production system. The legume crop influenced the pest population, and has value in the diet of subsistence farmers. These studies emphasize development of non-chemical insecticides in production areas where financial investment in crop production must be held to a minimum.

Host plant resistance research was emphasized and antibiosis mechanisms were further investigated with Honduran landrace sorghums and improved varieties, as well as converted lines. Genes for antibiosis plant resistance appear to be widespread in Honduran landraces, and at least 25 converted lines show promise of resistance to leaf feeding by fall armyworm larvae. The development of resistant germplasm is a necessity for the success of integrated pest management. (MSU-105)

Project TAM-125 is developing insect control strategies for sustainable sorghum/millet production, namely, plant resistance and biological control.

Collaborative research activities are in Botswana, Mali, and Honduras. Insects on which major effort is made for development of insect resistant cultivars are sorghum midge, sugarcane aphid, greenbug, and panicle feeding bugs. Insects of major focus for biological control are sorghum and millet stalk borers, millet head girdler, fall armyworm, and aphids. Ancillary support research is conducted on insect pest and natural enemy biology and ecology, sampling, life tables, density/damage relationships, and other related research to support implementation of technology to developing and developed agriculture systems.

Sources of sorghum resistance to the sugarcane aphid in Botswana were identified and biological control agents have been shown to suppress density increases of several aphid species. In Niger, alternate host plants of millet stalk borers were identified and related to the complex of naturally occurring parasite species. Parasite biology was studied, and several related biological habits such as oviposition preference were identified. Parasite efficacy was evaluated. Parasites of the millet head girdler were identified, and the damage caused by the pest was assessed. Predators of fall armyworm are being evaluated in Honduras.

In Mali, a program of research was begun on panicle-feeding bugs of sorghum. The first year of research was initiated following the development of a research protocol that is multi-institutional and multi-disciplinary. (TAM-125)

Biological and Ecological Investigations and Management of Insect Pests on Sorghum

Project MSU-105
Henry N. Pitre
Mississippi State University

Principal Investigator

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Dr. Nasr Eldin, Entomologist, Agricultural Research Corporation, Gezira Research Station, Wad Medani, Sudan.
Dr. El Hilu Omer, Plant Pathologist, Agricultural Research Corporation, Gezira Research Station, Wad Medani, Sudan.
Dr. Billy Wiseman, Entomologist, Insect Biology and Population Management Laboratory, United States Department of Agriculture, Agriculture Research Service, P.O. Box 748, Tifton, Georgia, USA.
Dr. Sonny Ramaswamy, Entomologist (Insect Physiologist), Department of Entomology, P.O. Drawer EM, Mississippi State, Mississippi, USA.
Dr. Lynn Gourley, Plant Breeder (MSU-104), Department of Agronomy, P.O. Box 5248, Mississippi State, MS, USA.

Summary

The principal insect pest constraint to stand establishment in soybean-maize intercropping systems in southern Honduras has been identified to include a complex of lepidopterous species collectively referred to by the local farmers as "langosta". The fall armyworm appears to be the most abundant of the species encountered annually on the crops, but three other species contribute to stand reduction or even complete crop destruction. Information on the diversity, density and time of occurrence of the "langosta" on crops during the past two years provides the basis for developing sampling procedures for the specific insect pest species, as well as timely application of control measures. The spatial and temporal relationships between the "langosta" and non-crop vegetation and crop plants has been further defined in the dynamics of the different species in the "langosta", strengthening recommendations for use of effective weed management practices for this pest complex.

Sorghum-maize-legume (cowpea) intercropping reduced fall armyworm infestation and increased predator population in the crop production system. The legume crop influenced the pest population, and has value in the diet of subsistence farmers. These studies emphasize development of non-chemical or other pest control approaches utilizing minimum amounts of chemical insecticides in production areas where financial investment in crop production must be held to a minimum.

Host plant resistance research was emphasized and antibiosis mechanisms were further investigated with Honduran landrace sorghums and improved varieties, as

well as converted lines. Genes for antibiosis plant resistance appear to be widespread in Honduran landraces, and at least 25 converted lines show promise of resistance to leaf feeding by fall armyworm larvae. The development of resistant germplasm is a necessity for the success of integrated pest management.

Objectives, Production and Utilization Constraints

Objectives

Study Biology, Ecology, Behavior and Population Dynamics of Pest and Beneficial Insects.

Conduct biology and ecology studies with *Spodoptera eridania, S. frugiperda* and *Metaponpneumata rogenhoferi* in small fields in the hills and on the plains in southern Honduras. This lepidopterous pest complex annually is responsible for significant sorghum and maize stand reductions or complete crop destruction in the production fields in this area. This complex of pests damages sorghum and maize in other areas of Honduras. Emphasis will be on determining relationships between pests and non-crop host plant and crop plant vegetation, including feeding preferences and movement outside, into and within cultivated fields during May and June.

Survey panicle feeding insect pests, including identification, species diversity and density, occurrence, relationship to panicle type and damage (loss estimates) in sorghum and sorghum/maize intercropped systems in southern Honduras.

Develop Host Plant Resistance to Insect Pests.

Sorghums, both Honduran native maicillos criollos and improved types, were evaluated for resistance to the fall armyworm. Antibiosis, non-preference and tolerance studies were conducted to determine mechanisms of insect resistance in sorghums.

Develop Insect Pest Management Strategies for LDC's.

Studies were planned and coordinated with farmers and conducted on small subsistence farms in the hills and on the plains in southern Honduras to verify the results of small plot research (conducted in 1985-87) on the use of planting strategies as methods for management of pests on intercropped sorghum and maize. Studies were completed in evaluations of the influence of intercropping pigeonpea or cowpea with sorghum and maize on densities of pest and beneficial arthropods in central and southern Honduras. Additional verification studies were conducted on small farms to evaluate the efficacy of insecticide seed treatments and other insecticide application methods (e.g., sprays) used alone and in combination on early and mid-whorl stage plants.

On-farm research was conducted to control non-crop vegetation in and around sorghum/maize intercropped production fields for management of lepidopterous defoliators during the first growing season in southern Honduras.

MSU-105 will continue linkage relationships with collaborator entomologist in Agricultural Research Corporation (ARC) in the Sudan. This involvement of MSU-105 is at the request of the Purdue University INTSORMIL project. This will involve entomology graduate students supported by ARC or other funding source to conduct research in Sudan and complete academic studies at Mississippi State University.

Constraints

Insect and other arthropod (e.g., millipedes) pests, particularly soil inhabiting species that damage or destroy the seed and seedling plants, stem and stalk borers that weaken or kill plants, and head feeding species that destroy the seed are responsible for reductions in sorghum and maize yields. The above constraints to sorghum and maize production in Honduras have been identified and will be further investigated in 1990. The insect pest problems in Honduras differ in the various regions of the country due to differences in environment, topography and agricultural production practices. Investigations during the first nine years have been concentrated mostly in the southern region where sorghum is intercropped with maize on small farms by subsistence farmers. The MSU-105 project will continue emphasis on entomological research in this area of the country. The area is represented typically by two types of crop production, one on hillsides and another on the plains. The climate in the southern region is hot and dry. In addition to the abiotic stresses on crops, the complex of insect pests attacking the sorghum and maize plants from seed planting to harvest results in significant reductions in crop growth and productivity. Therefore, a range of insect pest management tactics have been evaluated to ascertain the effective practices that have application in the developing countries in this Central American Ecogeographic Zone of operation. Principal emphasis has been on development of non-chemical or other pest control approaches utilizing minimum amounts of chemical insecticides in production areas where financial investment in crop production must be held at a minimum. These control methods have emphasized host plant resistance, and cultural control and biological control tactics.

Several insect pests common to the Americas have been investigated in the United States (Mississippi and Georgia) 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

1. Studies on biology, ecology, behavior and population dynamics of pest and beneficial insects.

Lepidopterous pest complex on intercropped sorghum and maize in southern Honduras. The lepidopterous species responsible for reduced sorghum and maize stands and crop destruction during the first growing season in southern Honduras have been identified. For the second year production fields were used for study and cooperation solicited from subsistence farmers in the hills and plains areas of southern Honduras. Sorghum and maize seed were provided by INTSORMIL so that the same variety was planted in each field.

Because of the large numbers of crop plants destroyed during the sampling period, arrangements were made with the farmers for monetary compensation. Replicated fields in each respective area had similar cropping practices, soils, non-crop vegetation and slope, as well as the same history of insect pest problems. Lepidopterous larvae were systematically collected, identified and quantified at intervals after seedling emergence. As in 1988 the most abundant species during the early part of the growing season in both production areas were the fall armyworm, *S. frugiperda*; the southern armyworm, *Spodoptera eridania*; *Metaponpneumata rogenhoferi*; and the grass looper, *Mocis latipes*. These insects are collectively referred to by the local farmers as the "langosta".

Information on species diversity, density, and time of occurrence in the crop systems in different geographical areas will allow for development of sampling procedures for specific insect pest species, as well as timely application of control measures.

Relationship of non-crop vegetation with lepidopterous pest populations. Studies were conducted for a second year to determine the biological, ecological and phenological spatial and temporal relationships between non-crop vegetation and the lepidopterous pests in the "langosta" complex, as well as between crops and these pests. Samples of insect populations were associated with plant species in different growth stages in and around production fields in southern Honduras.

S. eridania and *M. rogenhoferi* fed on the non-crop vegetation, especially on young seedlings of broad leaf plants. Broad leaf weeds identified in the study fields in southern Honduras included *Melampodium divaricatum*, *Portulaca aleracea, Portulaca sp.*, *Amaranthus* sp., and *Cassia* sp. Grasses included *Setaria* sp., *Echinocloa* sp., *Cynoden dactylon, Ixophorus unisetus*, *Panicum* sp., and others not yet identified. Before broad leaf weeds and grasses became abundant in and around the crop fields, a grass, *Ixophorus unisetus*, was used as a food host by the fall armyworm, southern armyworm and grass looper. This grass is the most abundant weed in fields in the plains and some fields in the hills. *M. rogenhoferi* appeared to prefer to feed on broad leaf weeds during the early part of the crop growing season. The lepidopterous species in the "langosta" complex were not collected on any of the broad leaf weeds after their occurrence in the early part of the crop growing season. Fall armyworm larvae increased in numbers on the crops during June, *S. eridania* was collected in small numbers, and *M. rogenhoferi* was not collected on the crops. This information might suggest the limited time sorghum and maize is vulnerable to attack by certain lepidopterous species, thus allowing for the development and timing of specific insect pest management strategies, e.g., cultural and chemical methods of insect control.

M. rogenhoferi has been observed to have limited development potential feeding on sorghum and/or maize. In previous feeding trials both species showed increased mortality in time feeding on these host plants. In one previous study, both species did not survive through two generations when larvae were fed sorghum. In a study conducted in 1989, *M. rogenhoferi* (3rd-5th instars) was collected on broad leaf weeds and fed either broad leaf or grass weeds collected in the field. Nine plant species, including six broad leaf weeds, one grass weed sp., sorghum and maize were included in this test. Larval and pupal weights, larval and pupal developmental times, mortality, and adult longevity were recorded. Only a small percentage of *M. rogenhoferi* reached adult stage on any host plant and no eggs were laid by the females. The insects were not parasitized and they did not appear to be infected with disease agents. The biological relationships between *M. rogenhoferi* and non-crop and crop host plants need further investigation.

S. eridania was evaluated as above and was successful in developing to adults on several host plant species; females laid fertile eggs. These observations suggest that both *M. rogenhoferi* and *S. eridania* are polyphagous species and appear to have a number of host plants available, other than sorghum and maize, in the crop production areas of southern Honduras.

Knowledge of the biological and ecological relationships between insect pest species and non-crop vegetation in and around production fields will be useful in developing cultural, non-chemical insect pest management practices.

Insect biology. The fall armyworm has been identified as composed of two genetically differentiated strains, each exhibiting different host specificities for either corn, or rice and Bermuda grass. Migration of this insect into the United States from southern latitudes and the possible existence of host associated sibling species have raised some controversies over the origin of the fall armyworm occurring in the United States, control procedures, diapausing capabilities, and host plant relations. Previously, MSU-105 reported similarities and differences in the biology and susceptibility to insecticides of fall armyworm populations from the United States, Central America and the Caribbean in attempting to identify strain relationships of insect populations from these different regions. The larval development time was shorter for insects collected on sorghum in Mississippi than those in Honduras when reared under similar conditions in the laboratory. The relationship of fall armyworm populations was further investigated in the laboratory in measuring calling rhythm and pheromone titers in moths from Mississippi and Honduras. Mississippi females exhibited peak calling at 2300 h and Honduran females at 0300 h. Pheromone titers approximately paralleled calling rhythms. Electrophoretic analysis of the two laboratory colonies suggest that the two colonies are genetically similar to corn strains. These differences between fall armyworms collected in Honduras and the United States suggests that Honduras may not be the source of migrating fall armyworm moths. Further studies are planned to elucidate the biological relationships of fall armyworm populations from different geographical regions in the Americas. This information, plus knowledge of the levels of susceptibility of the pest to insecticides, will enable development and or refinement of pest control tactics using insecticides, particularly in the United States.

Mid-to-late season pests on intercropped sorghum and maize. A characterization of the soil inhabiting insect pests of seed and seedling sorghum and maize and the early season langosta complex was done by MSU-105. Additionally, the fall armyworm has been investigated as the principal sorghum-maize production constraint in southern Honduras. Recently, studies have been completed in which insect pests, other than fall armyworm, have been identified as economic pests attacking the leaves and stalks of sorghum and maize, and their populations and damage to the crop plants have been quantified. Comparisons were made between fields with burned stubble from the previous crop and fields with some mulch but not burned to determine if burning affects the incidence and density of selected pests in fields in the plains and fields in the hills in southern Honduras.

The neotropical cornstalk borer was the principal insect pest on the foliage and in the stalks of sorghum and maize in the late whorl and reproductive stages of plant growth. Numbers of this stalk borer were larger in the stalks of sorghum in fields with burn than in fields without burn in the hills; damage to sorghum was also somewhat greater in the burned fields. Peak numbers of neotropical cornstalk borers in the stalks occurred in early October, indicating that the larvae moved from feeding sites on the leaves in the whorl to the stalks, where the most serious damage occurs. Numbers of neotropical cornstalk borer larvae in sorghum stalks declined from October to late November. Whereas burning practices appeared to be responsible, in part, for larger numbers of neotropical cornstalk borers in sorghum in fields in the hills, this practice of burning crop residues did not increase infestations of this pest on sorghum in fields in the plains.

Control measures recommended for neotropical cornstalk borer in some areas of Central America include crop rotation, crop residue destruction, early planting and good soil fertility. The cropping system used in slash and burn fields may be viewed as a type of crop rotation. However, in the hills, burned fields not planted to sorghum or maize the previous season often have higher infestations of neotropical cornstalk borer larvae than fields not burned that were planted to the crops the previous season. Adult neotropical cornstalk borers may have infested these fields from adjacent fields. This indicated that in these farming systems, crop rotation is of little value for reducing neotropical cornstalk borer infestations in southern Honduras.

The recommendations for control of the neotropical cornstalk borer in other regions are difficult to practice in sorghum-maize cropping systems on subsistence farms in Honduras. The excessive cost to the farmer to increase soil fertility is prohibitive, and early planting does not appear to be an effective control measure with photosensitive sorghums. However, late plantings may be damaged less by this pest.

In both hills and plains regions of southern Honduras, the peak period of neotropical cornstalk borer larvae on foliage was followed by an increase in stalk infestation. The timely application of an effective insecticide may significantly reduce numbers of this pest on sorghum, reduce damage to the stalks and improve crop yield. (In the sorghum-maize intercropping system in Honduras, maize is harvested before the neotropical cornstalk borers can cause serious damage to this crop.)

Intercropping legumes with sorghum and maize. Cropping systems in the tropics commonly include the practice of growing together two or more crops in the same space and with some overlap of their growing period (intercropping). Crop associations may consist of cereal-cereal or cereal-legume systems. Intercropped cereals and legumes have been recognized to have yield advantages over monocultures. It would appear that cowpea and pigeonpea would be promising legumes for intercropping with sorghum and maize in the hot, dry region of southern Honduras. Thus, studies were conducted to determine the effects of cowpea or pigeonpea on insect infestations on sorghum and maize in the sorghum-maize-legume intercropping system.

Intercropped sorghum and maize was compared with intercropped sorghum-maize-pigeonpea plots at RAPACO, El Paraiso, and with sorghum-maize-cowpea at RAPACO and El Zamorano, Francisco Morazan, Honduras. Infestations of fall armyworm on sorghum and maize were similar for plots with or without pigeonpea. Plots with cowpea had lower fall armyworm infestations than plots without cowpea at the two locations. Infestations of neotropical cornstalk borer were not affected by intercropping pigeonpea or cowpea with sorghum and maize. Numbers of the earwig predator *Doru taeniata* adults and eggs were similar for plots with or without pigeonpea, but higher in plots with cowpea. No influence of cropping system was observed on parasitoid occurrence. Cowpea appears to have a negative effect on the incidence of fall armyworm in intercropped sorghum and maize, whereas the number of predators increased in this system. The sorghum-maize-cowpea intercropping system appears to have advantages such as the potential of reducing fall armyworm and increasing earwig predator populations over intercropped sorghum and maize in Honduras.

Maize yield was not affected by this intercropping practice, although sorghum yield was reduced. The additional legume yield from the cowpea or pigeonpea in this cropping system may be of great value in the diet of subsistence farmers.

2. Host plant resistance to insect pests.

Host plant resistance to insects in Honduran native sorghums. A unique group of tropical landrace sorghum called maicillos criollos are grown in Central America. Very little is known about their genetics; however, they are primarily caudatum-kafir and caudatum-durra integrated races. It is unclear how long (> 100 years) sorghum has been grown in Honduras. It is plausible that over this period higher insect pest infestations have resulted in survival of genotypes that contribute genes to resistance in landrace sorghum grown in Honduras and Central America where sorghum-maize intercropping is practiced. The MSU-105 and TAM-131 projects are working cooperatively in studies to determine if known sources of resistance to fall armyworm can be attributed to antibiosis and to evaluate several Honduran sorghums for resistance to this pest. Previous studies on host plant resistance have not shown high levels of resistance in field screening tests. Identification of new sources of resistance will provide additional breeding material for sorghum improvement programs.

Three fall armyworm feeding trials were conducted in the laboratory using young leaf material collected daily from different sorghum genotypes. Mortality, pupal weight, generation time, intrinsic rate of increase (r_m), and relative fitness were used to make inference about antibiosis (adverse biological effect on insect). Experiment 1 determined whether known sources of resistance were due to antibiosis. Three genotypes from Honduras were also included. Moderately resistant 1821 c.m. performed like the susceptible check Huerin Inta. However, cohort performance was significantly reduced when reared on landrace San Bernardo III. The resistance mechanism in 1821 c.m. did not appear to be antibiosis. Experiment 2 compared San Bernardo III and several improved maicillos criollos to TAM 428 and AF-28 sources of resistance. Cohort performance on San Bernardo III was comparable to TAM 428 and AF-28, but its derivative (San Bernardo III x TAM 428)-1 was superior to both parents, suggesting transgressive segregation. San Bernardo III and AF-28 manifested antibiosis differently but had similar fitness. San Bernardo III cohorts had lower mortality (14%) than AF-28 (46%), but this was offset by lower pupal weight, suggesting lower fecundity for insects fed San Bernardo III. The suppression of pupal size on San Bernardo III source suggests antibiosis resistance may be polygenic. Experiment 3 determined whether other maicillos criollos possess antibiotic genes. Landrace Hilate-179, Pina-61, and Lerdo-104 manifested antibiosis similar to San Bernardo III in Experiment 2. Again, maicillos criollos mortality (16-30% vs 42%) and pupal weight (184-191 vs 261 mg) were lower compared to AF-28. Genes for antibiosis appear to be wide spread in Honduran landrace sorghum. This may have resulted from differential selection and increased selection pressure brought about through intercropping sorghum with maize.

The concept of host plant resistance capitalizes on the natural defense mechanism 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. 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.

3. Develop insect pest management strategies.

Management of non-crop vegetation for insect pest control. Fields in southern Honduras identified at the beginning of the Research Approach section were established as the universe for this pest management study. The effect of weeds and grasses on insect pest populations was studied. The crops were planted "golpe alterno" (alternate sorghum and maize hills planted in the same row). Different levels of weed control in designated plots was accomplished using Atrazine herbicide and hand weeding. Weed control was combined with insecticide use (as required) for evaluation of lepidopterous complex pest control in the intercropping system utilized in this area of southern Honduras. Fertilizer, seed and insecticide were provided to the farmers in return for their cooperation (compensation for plants removed from the treatment plots during the study period and yield reduction in plots where insecticide was not used). Data recorded included soil samples for soil inhabiting insect pests of seed and seedling plants, damaged or lost seed, foliage samples for lepidopterous pests, and weed samples for identification, relative abundance and insect plant relationship.

Soil inhabiting insects most frequently encountered were adult carabids (*Selenophorus* sp. and *Anisocremus* sp.), tenebrionids (*Blapstinus* sp.), and larvae of chrysomelid leaf beetles, wireworms and white grubs. As indicated above, *Ixophorus unisetus*, a grass type weed, was the predominant weed host for several foliage feeding pest species, particularly *S. frugiperda*. Cutworms, lesser cornstalk borer, *Elasmopalpus lignosellus*, and the maize seedling weevil, *Listronotus dietrichi*, were common and responsible for 5-20% reduction in plant stand in both hill and plains fields. The fall armyworm, acting like a cutworm, contributed to this stand reduction.

The role of broadleaf weeds and certain grass species in the establishment and development of insect pest infestations in and around crop production fields has been elucidated, in part, as a result of the studies conducted in southern Honduras during the past two years. The use of good weed control programs cannot be overemphasized in insect control recommendations to subsistence farmers growing sorghum and maize in Honduras and other countries in Central America where these crops are grown in similar cropping systems.

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Networking Activities

Germplasm and Research Information Exchange

Sorghum cultivars (native Honduran landraces, maicillos criollos, and improved types from the TAM-131 breeding program in Honduras) received from Honduras (TAM-131) for evaluations for fall armyworm leaf-feeding resistance at the seedling, whorl and panicle stages in the greenhouse in Georgia were delayed until 1990. The seed will be evaluated also in bioassay tests in the laboratory. Defined studies on mechanisms of resistance will be conducted.

Additional studies with converted sorghums will be conducted to evaluate fall armyworm leaf-feeding resistance. The host plant resistance to insects research program in Georgia (Wiseman, MSU-105) is designed, in most part, to evaluate and develop sorghum with resistance to leaf feeding lepidopterous pests, particularly fall armyworm. Research completed with the new collections of sorghum (PI) from Ethiopia and Yemen represents the international scope of the plant resistance research program (MSU-105) at Georgia. Studies combining host plant resistant sorghum and biological control are in progress and will provide information for use in developing effective integrated insect pest management programs in high technology as well as low technology sorghum production systems.

Each year MSU-105 contributes supplies and equipment to the INTSORMIL program in Honduras. These are used by MSU-105 graduate students in conducting their entomological research programs. In 1988 a new pickup truck was purchased with MSU-105 funds and shipped to Honduras to be used by INTSORMIL personnel and collaborators.

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
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Summary

Project TAM-125 is developing insect control strategies for sustainable sorghum/millet production, namely, plant resistance and biological control.

Collaborative research activities are in Botswana, Mali, and Honduras. Insects on which major effort is made for development of insect resistant cultivars are sorghum midge, sugarcane aphid, greenbug, and panicle feeding bugs. Insects of major focus for biological control are sorghum and millet stalk borers, millet head girdler, fall armyworm, and aphids. Ancillary support research is conducted on insect pest and natural enemy biology and ecology, sampling, life tables, density/damage relationships, and other related research to support implementation of technology to developing and developed agriculture systems.

Sources of sorghum resistance to the sugarcane aphid in Botswana were identified and biological control agents have been shown to suppress density increases of several aphid species. In Niger, alternate host plants of millet stalk borers were identified and related to the complex of naturally occurring parasite species. Parasite biology was studied, and several related biological habits such as oviposition preference were identified. Parasite efficacy was evaluated. Parasites of the millet head girdler were

identified, and the damage caused by the pest was assessed. Predators of fall armyworm are being evaluated in Honduras.

In Mali, a program of research was begun on panicle-feeding bugs of sorghum. The first year of research was initiated following the development of a research protocol that is multi-institutional and multi-disciplinary.

Graduate student training is in progress and several students have returned to research positions. Technology transfer has occurred through publications and exchange visits. 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 head bug research: The objectives are to develop practical techniques for screening sorghums for resistance to head bugs and to relate resistance to glume, kernel, and grain texture characteristics; relate head bug abundance and kernel damage to pathogen infection; and relate head bug abundance and kernel damage to food quality.

Niger millet stalk borer and millet head girdler biological control research: The objectives were to determine biological control agents and assess natural enemy efficacy of stem borers and head girdler of millet.

Honduras sorghum midge, fall armyworm, and sorghum stem borer research: The objectives are to field screen and evaluate sorghum midge resistant sorghums, and to determine biological control agents and assess natural enemy efficacy of stem borers, fall armyworm and other pests of sorghum.

Constraints

Insect and mite pests of sorghum/millet are major contributors to reduced and unstable yields in many developing countries, and to higher production costs in the U.S. The negative impact of aphids, head bugs, stem borers, armyworms, sorghum midge, and head girdler in traditional farming systems is dramatically increased by plant improvements through breeding and changed cultural practices. These negative impacts further constrain yield increases and stability, and increase risk to crop production. TAM-125 focuses on developing insect/mite control strategies applicable to sustainable agriculture; namely, plant resistance and biological control. These integrated pest management components were selected because of established expertise, their broad regional applicability, mutual benefits to developed and developing agriculture and because their successful use requires limited producer input. These two control tactics are also ecologically compatible, safe to humans and effective through time. However, their development and use requires support by ancillary biological and ecological research to ensure their proper implementation in developed and developing agriculture. The research is located in West Africa (Mali), Southern Africa (Botswana), and Central America (Honduras).

Research Approach and Project Output

Research Methods

Botswana sugarcane aphid research: Greenhouse cultured aphids are used to screen converted exotic sorghum lines, local varieties and ICRISAT entries. Sorghums are planted in rectangular plastic pots in a soil mixture, and three-day old seedlings are infested with aphids of mixed developmental stages by brushing aphids onto the soil surface and allowing aphids to move onto the seedlings. A resistant check, TAM428, and a susceptible check variety, Segaolane, are used as standards for comparison. Damage ratings are taken when the susceptible check shows evidence of aphid damage, usually in about seven days, and evaluations continue at seven-day intervals until the susceptible check is killed. Nonpreference is determined by providing aphids with choices of resistant and susceptible sorghums. Tolerance resistance is determined by comparing aphid number to subsequent plant damage. Antibiosis is measured by recording survival and rate of reproduction.

Mali sorghum head bug research: A screening nursery of 100 sorghum lines from U.S., West African, and ICRISAT sorghum breeders was assembled and planted at Sotuba. Head bug abundance and kernel damage ratings are used to compare resistance levels. Malisor-7 is used as a standard. A trial consisting of 16 sorghum entries, planted on two dates, is used for detailed evaluation as a means of determining screening techniques appropriate for breeders. In a split-plot design with three replications, panicles are allowed to be naturally infested, or protected from bug infestation using bags, or insecticide. Within and among sorghum entries, comparisons are thus possible. Bug abundance, kernel damage and weight, mold, germination, and decortication are the parameters measured to determine levels of resistance.

Niger millet stalk borer and head girdler biological control research: The purpose of the research was to identify the spectrum of alternate host plants of the millet stalk borer (MSB), *Haimbachia (Acigona) ignefusalis* (Hampson), and the host insect affinities of associated parasites on each host plant. These studies were conducted during 1986-87. Millet and other potential hosts of the MSB were examined in different locations for the presence of MSB. Collected stages were reared to adults, emerging parasites were identified, and samples of host plants were curated and identified. These studies were to provide a broader knowledge of MSB on alternate host plants of MSB.

A second objective was to conduct life table studies on the MSB to characterize the suppressive impact of extant natural enemies. A study field was established at the ICRISAT field station near Niamey. Plots were established and caged with specially constructed exclusion cages. Half of the cages permitted free entry and exit of parasites and predators, and the other half excluded all parasites and predators. All cages were artificially infested with MSB. Regular samples were taken from all cages and the data summarized into life tables for analysis of impact of selected mortality sources.

To identify and characterize the biology of a MSB parasite species, a MSB parasite was selected for conducting a quantitative biology study under laboratory conditions. Information collected included that needed for calculating an intrinsic rate of increase and for estimating the potential impact on MSB abundance.

Study fields of millet were established at the Kolo Field Station near Niamey to describe the population dynamics of the MSB and the millet head girdler. Samples of MSB and associated natural enemies were taken at regular intervals. These samples were plotted to create a dynamics curve of activity and reproduction for the MSB. Ovipositional preference of the MSB on different substrates (artificial and natural) was determined using selected potential oviposition substrates within cages to reflect the ovipositional sites and habits for MSB. A large number of samples were taken from infested and uninfested millet produced in local fields and at the Kolo Station. These samples were used to determine the type of relationship (correlation) between damage due to millet stalk borer and millet grain weight. Panicle characteristics were measured in order to relate the impact of MSB on millet yields.

Honduras sorghum midge resistance sorghum evaluation: Converted exotic sorghum lines and improved sorghum midge resistant parent lines and hybrids were evaluated in Honduras, El Salvador and the U.S. in order to compare resistance levels. Nurseries established in Texas are used to evaluate segregating material. Resistant lines selected from the Texas nurseries are used as non-segregating material and F_1 hybrids for evaluation in Central America.

Honduras natural enemy efficacy of stem borers and fall armyworm: To measure the respective roles of the yellow-striped earwig, *Doru taeniatum*, and the tropical fire ant, *Solenopsis gerninate* (F.) causing mortality to the fall armyworm, studies were conducted in fields of sorghum and/or corn in southern Honduras. Plots for studies on earwig and fire ant were created and consisted of equal numbers of plots with earwigs and without earwigs, with fire ants and without fire ants. Plots with earwigs were manually infested with earwigs from laboratory cultures, and those without had earwigs removed by hand. Plots with fire ants contained naturally occurring nests of ants, and an insecticide was used to eliminate ants for plots without ants. Samples were taken weekly from all plots.

The impact of the yellow-striped earwig on fall armyworm mortality was studied at three selected predator densities in replicated caged field plots. Sorghum was planted in each cage and infested with selected numbers of fall armyworm at the appropriate time of plant development. Following infestation with fall armyworm, each cage will be infested with the appropriate number of earwigs. Quantitative observations were taken in each cage at regular intervals. Laboratory studies were used to ascertain the numbers of fall armyworm killed and/or consumed by a single earwig. Methodology will be as previously used to determine consumption and development rates.

Replicated fields of sorghum and corn were used to identify and measure the impact of biotic mortality agents on eggs and pupae of fall armyworm in plots managed with conventional versus no tillage practices. Plots were established in each field for sampling. Some plots were tilled according to conventional methods for Honduras, and others were not tilled at all. Samples of fall armyworm were taken at regular intervals. The results of these samples were used to ascertain the effects of tillage on various mortality agents affecting fall armyworm.

Research Findings

Botswana sugarcane aphid resistance screening: An up-to-date report on the progress of this research was included in last year's annual report. Significant progress has been made since that time, but only a very general account can be reported here since Mr. Manthe has not taken time to prepare a detailed report as he is working under a severe time limitation to complete his Ph.D. degree. Mr. Manthe moved to Zimbabwe for the last year of his dissertation research and is being directed by Dr. Klaus Leuschner, SADCC/ICRISAT entomologist at the Matopus Station. I have been assured by Dr. Leuschner that Mr. Manthe has finished the general screening of at least all the Texas lines, that he has partly completed the studies of resistance mechanisms, and is presently doing the inheritance tests in the field and laboratory. Mr. Manthe is to return to Texas in December of this year to write and defend his dissertation. Mr. Manthe has identified high levels of resistance to the sugarcane aphid and also has interesting results with greenbug biotypes in Zimbabwe.

Millet stalk borer and head girdler research: The millet stalk borer (MSB) was collected in Niger from 14 plant species and seven gramineous and non-gramineous families, with *Andropogon gayanus* being the most commonly infested plant over locations studied. MSB apparently utilizes these non-crop plants primarily as a diapause refuge. *Euvipio* sp. attacked MSB on more host plant species than other parasites. Though several parasites attacked MSB in millet, densities of MSB are not suppressed by these parasites, supporting a decision to import additional parasites from other parts of the world into Niger. *Bracon hebetor*, a common parasite of MSB in millet, has a short life cycle and a high rate of population increase, is easy to culture in the laboratory, and if released in large numbers has potential for reducing pre-diapausing populations of MSB. Our studies indicate that MSB causes serious damage to both early and late planted millet, though greater numbers of MSB occurred in early millet. Studies on MSB preference for ovipositional sites indicated that green millet stalks with intact leaf sheaths were more preferred than flat green or dry leaves. This behavior would probably complicate attempts to control MSB with insecticides because larvae bore into the stalks immediately after hatching. Studies on MSB damage versus millet grain production showed a negative correlation between grain weight and numbers of exit holes in mature plants. Diapausing MSB larvae occurred in all stalk internodes but were most numerous in internodes distal to the plant base. Damage was greatest when MSB occurred on internodes distal to the plant base.

Honduras natural enemy efficacy on stem borers, fall armyworm and other pests of sorghum: Regarding characterizing and evaluating predatory mortality to fall armyworm, the tropical fire ant and the yellow striped earwig were identified as very important for early and late season mortality to fall armyworm. Field studies revealed lower infestation by fall armyworm in plots where fire ants were present. Fire ants also seemed to reduce infestation by *Listronotus*, a weevil pest of corn and sorghum seedlings. In the field, the earwig caused no reduction in infestation by fall armyworm. This was probably due to the low numbers present at the time of the experiments. Five hymenoptera and two tachinid parasitoids, a parasitic nematode, and two fungi were identified as mortality agents of fall armyworm. *Chelonus insularis* (Hymenoptera: Braconidae) was the most abundant parasitoid recovered from field-collected larvae. Percentage parasitism was highest during the first planting season, reaching 80%. Fall armyworm infestations were lower during the second planting season than during the first. This was probably due to abundance of predators. Under cage-study conditions, the earwig did not feed on second instar larvae infesting sorghum and corn plants when plants were younger than three weeks old. The earwig did stay in the whorls of plants three weeks old and older, and preyed on small larvae thereafter. On the ground, mortality of second instar fall armyworm larvae in a reduced tillage corn field averaged 93% The most abundant ground predator of second instar larvae was the tropical fire ant, accounting for a mean 79% mortality at a density of 67 ants per m^2. Other ant species accounted for 13% mortality at a density of 45 ants per m^2, and spiders accounted for 1% mortality. Additional studies on the earwig are in progress. Cropping systems seem to have very little impact on pests or their potential biological control agents. Numbers of fall armyworm and neotropical corn borer in monocultures versus mixed plantings were usually more abundant in corn than in sorghum, usually greatest in mixed sorghum/maize plantings than in sorghum monoculture, and essentially the same in mixed maize/sorghum as in maize monoculture. These results suggest that differences among the cropping systems are not sufficiently important to recommend either monoculture or mixed plantings of maize and sorghum as a way of minimizing damage from pests.

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Publications

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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 establish a collaborative research project with Dr. Y. Doumbia, IER entomologist. The project deals with the very severe situation of sorghum panicle-feeding bugs.

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 24 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.

Food Quality and Nutrition

Executive Summary

This project was involved in collaborative research with ARC in Sudan. Major achievements in Sudan included developing a technique for measuring fermented kisra batter consistency, evaluating the *in vitro* protein digestibility of heat extruded sorghum/peanut instant weaning food blends, and characterization of the microorganisms responsible for the natural sorghum fermentation used for making a number of Sudanese foods. The method for measuring batter consistency should be a useful tool for screening breeders' sorghum samples for kisra quality. We found that the protein in a heat extruded sorghum/peanut instant weaning food was highly digestible even after cooking. Further tests on the acceptability and nutritional quality of the instant weaning food are presently under way. If positive results are obtained from these tests, plans are being made to produce and distribute the instant weaning food in Sudan.

This project also provided basic information relative to our knowledge of sorghum endosperm proteins. We have isolated and purified a gamma-type kafirin protein from sorghum grain. This protein contains high levels of the amino acids cysteine, proline, and histidine with low levels of aspartic acid and lysine. In maize, a zein protein similar to gamma-kafirin, plays a role in the restoration of hardness in modified opaque-2 maize (quality protein maize). Further research will determine whether the gamma-kafirin has a similar function in the development of high-lysine hard endosperm sorghum. Due to the high content of cysteine in gamma-kafirin this protein may also influence the protein digestibility of sorghum. (PRF-103B)

Because of additional funds and personnel, and because of our recent certification as a plant quarantine laboratory authorized to carry out germination assays for *Striga*, the research on *Striga* has entered a new phase. Using the germination assay we have found that sorghum roots may produce water-soluble germination stimulants in addition to sorgoleone, the water-insoluble stimulant we previously identified, and that sorghum cultivars differ greatly in their capacity to produce water-soluble stimulants but appear to vary only slightly in their production of sorgoleone. We have found that extracts of *Striga* plants are quite toxic to cereal seedlings, and can reproduce the symptoms of *Striga* infestation on the plant. Apparently *Striga* produces a toxin which largely accounts for its harmful effects on its host plant. We have found that sorghum cultivar SRN39, previously identified as having superior resistance to *Striga* in several African locations, likewise exhibits superior characteristics in our laboratory bioassays. It produces almost no *Striga* seed germination, and it is relatively little affected by the *Striga* toxin. The reason for the broad and strong *Striga* resistance of SRN39 may be that it utilizes two independent mechanisms of resistance: low stimulant production and low sensitivity to *Striga* toxin. Because these characteristics can be readily evaluated in laboratory bioassays, it should be possible to screen for them in crosses of SRN39 with other genotypes and thus to carry out the early stages of breeding for *Striga* resistance efficiently here in the U.S. With Dr. Ejeta, we are pursuing this goal. (PRF-104B)

Project TAM-126 focuses on improving the utilization of sorghum and millet by development of new technology and processing methods to produce new food products and through cooperation with breeding programs to develop sorghum and millets with built-in improved quality.

Milri, a rice-like product produced by parboiling and dehulling pearl millet, was developed. The parboiling process consisting of boiling, steeping for 12 hours, boiling and air drying significantly increased the yield of decorticated millet. The product can be boiled and consumed similar to rice. It is a new product from millet that appears to have enhanced storage stability. Control of the cooking and drying procedures for parboiling millet is critical to avoid checking of the kernels. Investigation of this product continues.

Experiments on parboiling of sorghum in Mali confirmed our laboratory results and encouraged initiation of village level trials in Mali. Parboiling may be an effective method of enhanced use of soft sorghums. The soft floury high lysine (P-721) and a brown bird resistant sorghum had very high yields of decorticated grain after parboiling. Raw grain of these cultivars cannot be effectively decorticated. The storage stability of parboiled sorghum appears to be improved. Changes in composition and structure during parboiling were documented. Parboiled sorghum has about the same nutritional value as nonparboiled sorghum when fed to rats.

Pearl millets with white endosperm have been selected for increase because they appear to produce food products with improved color and aroma. Extrusion expanded pearl millet materials are useful for snacks, breakfast cereals and other products.

Fundamental studies of proteins, starches and phenols continue to provide useful information. The starch of hard endosperm sorghums has lower apparent molecular weight and is more easily solubilized than the starch of soft endosperm sorghums. Once solubilized, the starch from the hard endosperms retrogrades more rapidly to form a firmer tô. Floury endosperm starches do not retrograde as fast and the tô is softer. These observations must be confirmed for additional samples. If true, it could explain why certain sorghums produce poor quality tô.

Black sorghums originating in the Sudan were found to have exceptionally high levels of anthocyanidin pigments. Grain of converted black sorghum lines had a large variation in phenolic compounds. A black sorghum line without a pigmented testa had very high levels of anthocyanidin pigments in the pericarp which could be easily removed by decortication. The anthocyanidins may have useful properties.

A procedure for germinating sorghum and measuring its malting properties was developed and is being applied to sorghums with varying kernel characteristics. Malting quality of sorghum is quite important in Africa where fermented beverages and porridges are widely used. (TAM-126)

Chemical and Physical Aspects of Food and Nutritional Quality of Sorghum

Project PRF-103B
Allen W. Kirleis
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Summary

This project was involved in collaborative research with ARC in Sudan. Major achievements in Sudan included developing a technique for measuring fermented kisra batter consistency, evaluating the *in vitro* protein digestibility of heat extruded sorghum/peanut instant weaning food blends, and characterization of the microorganisms responsible for the natural sorghum fermentation used for making a number of Sudanese foods. The method for measuring batter consistency should be a useful tool for screening breeders' sorghum samples for kisra quality. We found that the protein in a heat extruded sorghum/peanut instant weaning food was highly digestible even after cooking. Further tests on the acceptability and nutritional quality of the instant weaning food are presently under way. If positive results are obtained from these tests, plans are being made to produce and distribute the instant weaning food in Sudan.

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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, 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 back-slop from a previous kisra fermentation is added and then fermented at ambient temperature 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 the 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. Therefore, we have developed an objective method to measure the consistency of fermented kisra batter as a means to evaluate the kisra making quality of sorghum.

We used a Bostwick consistometer (CSC Scientific, Inc, Fairfax, VA) to measure the flow resistance of a fermented sorghum batter. After fermentation the batter was mixed for 5 minutes with a mechanical mixer (beater-type), allowed to stand for 4 minutes, and finally mixed for an additional minute before testing. The mixed suspension was poured into the Bostwick consistometer reservoir and allowed to stand for 15 seconds before opening the consistometer gate which allows the batter to flow down a trough. Batter flow readings (cm distance traveled by the batter front) were taken at 15 and 30 seconds as a measure of batter consistency.

Preliminary results using the Bostwick consistometer method indicates that we can detect batter consistency differences among sorghum varieties. We found a high correlation between Bostwick batter consistency and sorghum flour water retention capacity ($r = -0.95$). Work is presently under way with our Sudanese cooperators to relate the Bostwick batter consistencies to the quality of kisra.

Isolation of a High-Cysteine Kafirin Protein

We used immature sorghum kernels to obtain a protein body fraction rich in Mr 30 kD kafirin protein. The fraction was obtained by homogenizing immature kernels with buffer, filtration through cheese cloth to remove the high fiber components, and centrifugation to sediment a starchy pellet containing a protein body fraction rich in Mr 30 kD kafirin. The protein was separated from the starch by extracting the pellet with 20% 2-ME. The protein extract was subjected to reverse phase high performance chromatography (RP-HPLC) using a C-18 column. SDS-PAGE was used to determine that a protein peak eluting at 27 minutes contained the Mr 30 kD kafirin.

A second purification method, based on differential solubility of the Mr 30 kD kafirin, was also used to purify this kafirin from the starchy pellet. In this purification procedure the starchy pellet was first extracted with a dilute salt solution, followed by extraction with 20% 2-ME. Upon SDS-PAGE analysis, the directly extracted Mr 30 kD protein resolved into a single band nearly identical in shape and apparent molecular weight to the RP-HPLC isolated protein.

These purified proteins were subjected to amino acid analysis and compared to gamma-zein from corn. The amino acid analysis of both of our purified Mr 30 kD kafirins was very similar to values published for gamma-zein (Table 1). These proteins are high in proline, glutamine, glycine and cysteine, and low in lysine and aspartic acid. The high amount of cysteine is probably what necessitates the use of solvents with high concentrations of reducing agent to extract this protein.

Table 1. Amino acid composition of Mr 30 kD kafirin isolated by RP-HPLC and direct extraction, and gamma-zein

Amino acid	Mr 30 kD kafirin RP-HPLC	Mr 30 kD kafirin Direct	Gamma zein[a]
		Mole %	
Asx	2.3	0.6	0.3
Thr	3.5	4.2	3.1
Ser	5.2	5.0	6.5
Glx	13.0	13.8	16.2
Pro	20.9	22.6	25.8
Gly	10.9	8.6	6.8
Ala	7.0	6.3	5.3
Cys	7.2	6.9	6.3
Val	8.1	5.8	7.1
Met	1.0	1.0	0.8
Ile	3.6	2.6	2.0
Leu	8.8	9.0	9.4
Tyr	2.0	2.1	2.2
Phe	2.7	1.8	1.3
His	5.2	6.9	5.8
Lys	1.4	0.4	0.1
Arg	0.7	2.0	3.0

[a]From Esen et al., 1981. Cereal Chem 58:534-537

Western blot analysis was done to further investigate similarities between Mr 30 kD kafirin and gamma-zein. There was a strong cross-reaction between gamma-zein antibodies and both of our isolated Mr 30 kD kafirin proteins. Such cross-reactivity suggests structural similarity between gamma-zein and Mr 30 kD kafirin. It has been shown that gamma-zein is localized around the periphery of maize protein bodies. There is also evidence which suggests that gamma-zein plays a role in restoration of hardness in modified opaque-2 maize (hard endosperm high lysine maize or quality protein maize). We are currently raising antibodies against the Mr 30 kD kafirin. With the antibodies we will examine the relationship between the Mr 30 kD kafirin, and restoration of hardness in modified high lysine sorghum. The antibodies will also be used to determine the subcellular localization of this protein in developing sorghum seeds, and the influence of this protein on sorghum protein digestibility.

Kafirin Nomenclature

Kafirins, the storage proteins of sorghum, have traditionally been fractionated based on their solubility in aqueous alcoholic solvents. Extraction of kafirins by the traditional Landry-Moureaux fractionation method separates kafirins into two classes: "true" kafirins (soluble in 70% 2-propanol) and "cross-linked" kafirins [soluble in 70% 2-propanol plus 0.5% 2-mercaptoethanol (ME)]. It has been reported that the two kafirin fractions do not differ greatly in electrophoretic properties and amino acid composition. When determined by sodium dodecyl sulfate - polyacrylamide gel electrophoresis (SDS-PAGE) the kafirins polypeptides have relatively low molecular masses of Mr 14-30 kD, which are similar to maize zeins. The typical SDS-PAGE banding pattern reported in the literature for kafirins shows a major band at Mr 21-24 kD, minor bands at Mr 27-30 and 19-21 kD, and sometimes a minor band around Mr 14-16 kD. Other than identification by molecular weight, little has been done in the past to classify the kafirin polypeptides. Accordingly, any nomenclature system based on apparent size designations by SDS-PAGE are arbitrary, as they depend upon exact reproduction of experimental conditions and upon the standard proteins used for calibration.

By contrast a nomenclature system for zeins, the storage proteins of maize, has been developed on the basis of the primary amino acid sequences of the zein proteins from cDNA clones. Four structurally distinct zein types have been identified: the Mr 19 and 22 kD alpha-zeins, which are the most abundant, are proteins solubilized by aqueous alcohols; and the Mr 14 and 16 kD beta-zein, Mr 27 kD gamma-zein, and the Mr 10 kD delta-zein all require a reducing agent to be solubilized in alcoholic solvents. Polyclonal antibodies have been raised against the alpha-, beta-, and gamma-zein fractions. We have used these zein antibodies to identify structural similarities between the maize zeins and sorghum kafirins.

Extracts of total zein and total kafirin were obtained from defatted maize and sorghum endosperm flour, respectively. The extraction procedure involved stabilization of total endosperm proteins in an alkaline buffer containing SDS and 2-ME, with subsequent precipitation of non-zein and kafirin proteins by the addition of ethanol to 70%. Analysis of the zein and kafirin proteins was done by SDS-PAGE with Coomassie blue staining and by Western blotting with polyclonal antisera specific for the alpha-, beta-, and gamma-zeins (antisera obtained from B. Larkins). The SDS-PAGE separated endosperm storage proteins from maize (lane 2) and sorghum (lane 3) are shown in Figure 1. Western blots of the zein proteins confirmed that the Mr 23 kD and doublet bands at 26 kD were alpha-zeins, the Mr 15, 17, and 18 kD bands were beta-zein, and the Mr 28 kD band was gamma-zein. We were unable to detect the low molecular weight beta-zein on our gel. As we used different electrophoretic conditions, our apparent molecular weights for the zeins differ slightly from those given above.

Western blots of the SDS-PAGE separated kafirins with the zein antisera showed that: the alpha-zein antisera strongly reacted with Mr 23 and 25 kD kafirin bands; the beta-zein antisera reacted weakly with only the Mr 20 kD kafirin band; and the gamma-zein antisera reacted with the Mr 28 kD kafirin band (Figure 1). The Mr 16 and 18 kD kafirin bands showed no cross-reactivity with any of the zein antisera. The lack of cross-reactivity may be due to the low protein concentration in these kafirin bands. The observed cross-reactivity between the zein antisera and kafirin proteins indicates the existence of common epitopes and structural similarities between maize and sorghum storage proteins. On the basis of these similarities we have adopted an alpha-, beta-, and gamma-kafirin nomenclature system for the sorghum storage proteins (Figure 1).

Extrusion Processed Instant Weaning Food

The Food Research Centre (FRC) in Sudan has an ongoing effort to promote the use of locally grown sorghum and millet. One of the traditional uses for these grains is a fermented preparation sometimes used as a weaning food called "nasha".

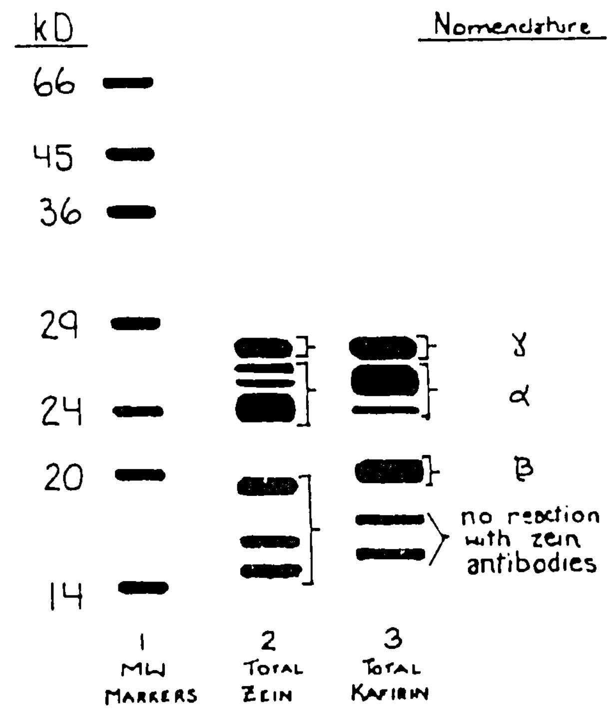

Figure 1. Outline of recommended nomenclature for sorghum endosperm kafirin proteins, based on SDS-PAGE. Across, lane 1 molecular weight marker proteins, lane 2 total zein, and lane 3 total kafirin.

Work that was initiated at Purdue University by Dr. Laila Monawar in 1981 led to the development of a weaning food called instant nasha by the FRC. The instant nasha is a drum dried powder which can be reconstituted to make a ready-to-eat gruel simply by adding water. Instant nasha is substantially improved nutritionally compared to the traditional product, having approximately three times the caloric density of traditional nasha, as well as a greater amount of protein due to the addition of non-fat dry milk.

However, the FRC's drum drying process for manufacture of instant nasha is very energy intensive and consequently expensive. If the drum drying process were used to commercially manufacture instant nasha, the resulting product cost would probably limit its market. Dr. P. Rod Crowley (USDA/OICD) recommended a potentially less expensive extrusion cooking process for the production of an instant nasha like product.

Accordingly, in late 1987 Dr. Monawar worked at Colorado State University with Ronald Tribelhorn and Judson Harper to determine the feasibility of extrusion cooking to produce an instant nasha like product. A number of sorghum, peanut, and soybean oil formulations were heat extruded in an Anderson extruder. As sorghum and peanuts are locally available in Sudan these ingredients were selected as raw materials for the instant heat extruded weaning food. After extrusion the products were supplemented with non-fat dry milk, vitamins, and minerals to meet Codex Alimentarius guidelines for supplementary foods. The characteristics and consistency of the extruded products were judged to be similar to drum dried instant nasha by Dr. Monawar.

The *in vitro* protein digestibility of the ingredients and extruded weaning food blends were determined in the cereal laboratory at Purdue University. Table 2 shows the pepsin digestibility of the uncooked and cooked material. Examination of the raw ingredients showed that the protein digestibility of peanut flour was unaffected by cooking. Sorghum protein digestibility, however, showed a typical decrease of approximately 20% due to cooking. The decorticated/sorghum soybean oil blend heat extruded at 138° C was slightly less digestible than the decorticated sorghum flour, although after cooking these products had about the same protein digestibility. A marked increase in protein digestibility was found when the decorticated sorghum/peanut flour blend was extruded at 156° C. In fact the extruded blend was more digestible than the raw ingredients both before and after cooking. The extruded sorghum/peanut blend was also slightly more digestible than the instant nasha product.

Table 2. In vitro pepsin protein digestibility of raw ingredients and heat extruded sorghum based weaning foods.

Sample	% Protein digestibility[a] Uncooked	Cooked
Ingredients:		
Decorticated sorghum flour	84.2	65.9
Peanut flour	100.0	100.0
Decorticated sorghum flour (82%) /Peanut flour (18%)	86.4	79.4
Extruded products:		
Decorticated sorghum flour (92%) /Soybean oil (8%) Extrusion temperature 138°C	78.0	64.9
Decorticated sorghum flour (82%) /Peanut flour (18%) Extrustion temperature 156°C	89.1	85.6
Instant nasha	...	83.2

[a]Values are means of triplicate determinations

On the basis of these promising preliminary findings the FRC plans a production run of the heat extruded sorghum/peanut instant weaning food to evaluate the product's consumer acceptability in Sudan and to determine its nutritional quality with a biological assay. If these tests give positive results, plans are being made for producing the heat extruded sorghum/peanut instant weaning food in Sudan.

Sudanese Sorghum Fermentation

A natural fermentation is commonly used in Sudan for making a number of sorghum foods, i.e., kisra, aceda, and nasha. A back-slop, prepared by fermenting sorghum flour for about 24 hours, is added to fresh flour to initiate the fermentation. We have found that this natural fermentation improves the protein digestibility of sorghum. Therefore, we are interested in identifying the microorganisms involved in the fermentation and their role in improving the protein digestibility of sorghum.

Sorghum obtained from Sudan was fermented at 30°C for 24 hours. At the end of the 24 hour fermentation period the sorghum batter pH dropped to 3.75 and had a lactic acid content of 0.8%. The bacterial population increased with fermentation time and reached a plateau at about 18 hours (Figure 2). The microbial population after 24 hours of fermentation consisted of *Lactobacillus* species, coliforms, and yeasts/molds. The lactic acid bacterial population was estimated to be less than 10 in the sorghum flour and increased to 10^9 after 24 hours of fermentation. The yeast/mold count remained at about 10^2 until 15 hours of fermentation and then increased to 10^4 at 24 hours. Colonies of lactic acid bacteria and yeasts were picked from the agar plates and identified by the use of biochemical tests. Isolated *Lactobacillus* species were identified as *L. confusus*, *L. murinus*, and *L. alimentarius*. These organisms are heterofermentative bacteria producing lactic acid, acetic acid, ethanol and CO_2 along with small amounts of succinic acid and oxalic acid. *Sac-*

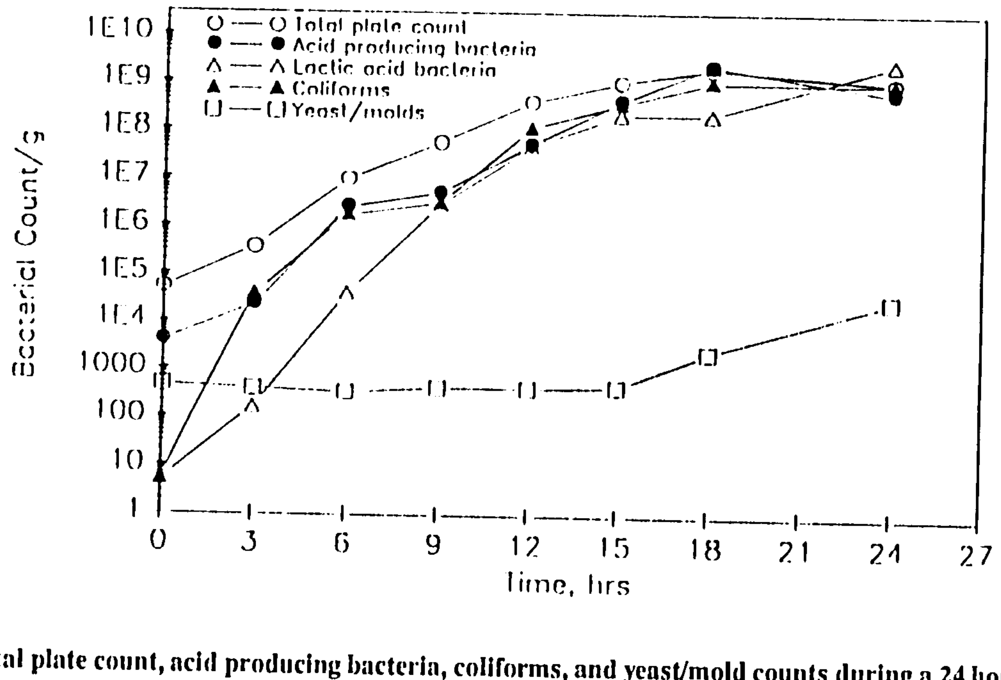

Figure 2. Total plate count, acid producing bacteria, coliforms, and yeast/mold counts during a 24 hour fermentation of sorghum flour.

charomyces carevisiae and *Candida intermedia* were the yeast species identified from the fermented sorghum. Isolated colonies of coliform bacteria are presently being identified.

The isolated organisms will be used to ferment a sterilized sorghum flour to determine their role in the fermentation and in the improvement of sorghum protein digestibility. As work is currently underway at the Food Research Centre to develop a mechanized process for commercially producing kisra, identification of the organisms responsible for the natural fermentation will provide a means for developing a pure starter culture. The starter culture will be important for controlling the sorghum fermentation in a commercial kisra production process, thereby making it possible to produce a more uniform quality kisra.

Publications and Presentations

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Presentations

The four abstracts listed above were from presentations made at the American Association of Cereal Chemists 73rd Annual Meeting, San Diego, CA, October 9-13, 1988.

Networking Activities

Workshops

Helped plan the Sudan Workshop Technical program. The workshop is scheduled for October 29-November 2, 1989 in Wad Medani, Sudan.

Research Investigator Exchange

Dr. Abdel-Mageed Abass Mohamed from the Department of Food Science and Technology, University of Gezina, Wad Medani, Sudan worked in my laboratory as a visiting professor during Year 10 (1988/89) on sorghum proteins.

Dr. Osman Ibrahim El Obeid, ARC sorghum breeder, Wad Medani, Sudan visited my laboratory in August 1988 to review our cooperative work on sorghum food quality evaluations. In addition, he was trained to use the IBM PS/2 computer sent to Sudan by the ARC/INTSORMIL Sudan country program.

Assistance Provided

Laboratory supplies have been provided for the Food Research Centre, ARC, Khartoum, Sudan.

Tannins and Other Phenols: Effects on Sorghum Production Utilization

Project PRF-104B
Larry Butler
Purdue University

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Summary

Because of additional funds and personnel, and because of our recent certification as a plant quarantine laboratory authorized to carry out germination assays for *Striga*, the research on *Striga* has entered a new phase. Using the germination assay we have found that sorghum roots may produce water-soluble germination stimulants in addition to sorgoleone, the water-insoluble stimulant we previously identified, and that sorghum cultivars differ greatly in their capacity to produce water-soluble stimulants but appear to vary only slightly in their production of sorgoleone. We have found that extracts of *Striga* plants are quite toxic to cereal seedlings, and can reproduce the symptoms of *Striga* infestation on the plant. Apparently *Striga* produces a toxin which largely accounts for its harmful effects on its host plant. We have found that sorghum cultivar SRN39, previously identified as having superior resistance to *Striga* in several African locations, likewise exhibits superior characteristics in our laboratory bioassays. It produces almost no *Striga* seed germination, and it is relatively little affected by the *Striga* toxin. The reason for the broad and strong *Striga* resistance of SRN39 may be that it utilizes two independent mechanisms of resistance: low stimulant production and low sensitivity to *Striga* toxin. Because these characteristics can be readily evaluated in laboratory bioassays, it should be possible to screen for them in crosses of SRN39 with other genotypes and thus to carry out the early stages of breeding for *Striga* resistance efficiently here in the U.S. With Dr. Ejeta, we are pursuing this goal.

Objectives, Production and Utilization Constraints

Objectives

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

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

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

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

Constraints

Major constraints to sorghum and millet production in much of Africa include predatory birds and *Striga*. Major constraints in India include weathering and stored grain insects. In the southeastern U.S., predatory birds and weathering are significant constraints. The evidence indicates that the phenolic materials of these plants (including tannins in the case of sorghum) provide some degree of resistance to these constraints, except for *Striga*. However, it is widely recognized that the presence of these phenolic materials in the seed of sorghum and millet also constitutes a formidable constraint to their utilization as food. Phenolic materials diminish the palatability and digestibility of the food prepared from sorghum, and create undesirable colors in both sorghum- and millet-based foods. Until now it has been considered necessary, in several areas of the world, to accept the utilization constraints in order to overcome the production constraints by growing "high-tannin" sorghums.

Our results suggest that it may be possible to develop cultivars with altered phenolic metabolism which are resistant to the production constraints, yet with high nutritional quality, and thus satisfy our major objective (see above). For *Striga*, no effective means of control is available, although a few resistant or tolerant genotypes have been identified.

Research Approach and Project Output

Research Methods

Striga

A broader approach on *Striga* is now possible because this year we have been certified by APHIS as a plant quarantine laboratory authorized to carry out germination assays on *Striga* seed. We utilize this assay for determining the germination stimulant activity of isolated materials as well as crude root exudates, and for characterizing the effects of soil conditions on *Striga* germination. We have also obtained alcoholic extracts of *Striga* (both *hermonthica* and *asiatica*) and have been testing them for the presence of a toxin which would inhibit metabolism of its host plant. This is done by submerging trimmed roots of sorghum seedlings in aqueous solutions of *Striga* extract (or water or other plant extracts for controls) and closely observing them for the next few hours to detect wilting and/or leaf rolling as seen on field plants grown in the presence of *Striga*. The *in vitro* tissue culture work has been somewhat redirected toward the *Striga* problem. We have initiated suspension cultures of selected genotypes in order to select for resistance to the *Striga* toxin we obtain from *Striga* extracts.

Bird Resistance

We are putting major emphasis on bird resistance this year. We are evaluating 12 selected genotypes biweekly throughout grain development for resistance to wild birds, and weekly for total phenols, flavan-4-ols, proanthocyanidins and vanillin-responsive condensed tannins.

Weathering and Molding

We are evaluating 10 selected genotypes weekly for flavan-4-ols, 3-deoxyanthocyanidins, surface glucose and total carbohydrate, and fungal colonies (both number and identity). Dr. Ejeta is evaluating these (and others) for mold and weathering.

Tissue Culture

The major activity has shifted from culturing and regenerating plants from culture to evaluation of the resulting plants. This involves extraction of polyphenols from thousands of individual heads, and analysis of the extracts for total phenols, flavan-4-ols, and proanthocyanidins.

Research Findings

Striga

Using our newly approved plant quarantine facility, Dr. Hess found that sorghum genotypes vary widely in the effective output of *Striga* germination stimulant. Using *Striga* seeds grown in North Carolina on maize as a host, Dale found that susceptible sorghum cultivars and maize stimulate virtually complete germination of the *Striga* seeds dispersed throughout an agar gel in which the roots of the cereal seedlings develop. In contrast, millet seeds do not cause germination of significant numbers of *Striga* seeds, suggesting that the *Striga* introduced into the Carolinas was host specific for sorghum (maize has not been grown in the presence of *Striga* long enough for maize-specific *Striga* strains to develop). Most importantly, some sorghum cultivars previously reported to be somewhat resistant to *Striga* germinate relatively small numbers of *Striga* seeds, and two cultivars (SRN39 and Framida) do not germinate significant numbers of *Striga* seeds at all. It is clear that low stimulant production is involved in the ability of these cultivars to produce relatively well in the presence of *Striga*.

In contrast, all sorghum cultivars including SRN39 and Framida, when tested by growth on filter paper in Petri dishes, produced essentially equivalent amounts of sorgoleone, the hydrophobic root exudate which we previously identified as a *Striga* germination stimulant. Either SRN39 and Framida do not produce sorgoleone when grown in agar (this is likely, because the higher levels of moisture inhibit its production), or the sorgoleone they do produce is far less effective as a germination stimulant than the stimulant produced on agar plates by the susceptible cultivars. The virtually complete germination on agar plates caused by strongly susceptible cultivars is unlikely to be due to sorgoleone, which is too unstable and too insoluble to produce the observed germination. It seems likely that sorgoleone is only one of perhaps several *Striga* germination stimulants which can be produced by sorghum roots in various conditions. Others are completely water soluble but as yet unidentified. We hope to be able to identify them.

The results of the bioassay for resistance/tolerance to *Striga* toxin are less clear, but nevertheless promising. Unfractionated extract of *hermonthica* produces a rapid (4 hours) wilting and leaf curling (typical symptoms of *Striga* infestation) of millet and of sorghum cultivars known to be susceptible to *Striga*. In contrast, SRN39 is much less affected, showing wilting only after 24 hours of exposure, and never exhibiting leaf rolling. Less response of susceptible cultivars is seen to various fractions of the extract, suggesting that multiple components acting synergistically may be responsible for the effects. Extract of *asiatica* has greatly differing proportions of components from those of *hermonthica*, and is less toxic. In this bioassay, control plants are exposed to water put through the same solvent extractions as the *Striga* extracts, but in the future we plan to utilize extracts of other plants, preferably plants related to *Striga*, as controls so that we are sure the toxic effect we measure is specifically associated with *Striga*.

These recent *Striga* results indicate that we can conveniently assay in the laboratory for characteristics (low stimulant production, tolerance to toxin) which contribute to resistance to *Striga*. This capacity should immensely speed up the process of breeding for *Striga* resistance, which otherwise must be carried out in Africa under conditions which are seldom reproducible. Dr. Ejeta has a series of crosses of SRN39, Framida and other promising resistant genotypes which have been selected into the F_5 generation. Until now there has been no means of evaluating them for *Striga* resistance without taking them all back to Africa. We will now apply these selection procedures to screen them for *Striga* resistance so that only the most promising will be evaluated in Africa. The promising results with SRN39 suggest that its unique resistance to *Striga* in different geographic areas may be because it contains multiple mechanisms of resistance (low stimulant production and tolerance to *Striga* toxin).

Grain Molding and Weathering

We reported several years ago that assays for flavan-4-ols provided better correlation with mold resistance than assays for tannin or any other chemical component of sorghum grain which had been evaluated. Subsequent work with our ICRISAT collaborators has confirmed this result, although it does not explain the apparent mold resistance of a few white sorghums which do not contain flavan-4-ols. Our collaborators Nicholson and Netzly have recently independently reported that the 3-deoxyanthocyanidins, which are direct metabolic products of flavan-4-ols, are fungitoxic and Netzly found that in his assays flavan-4-ols are not fungitoxic. If these reports hold true for seeds (Nicholson works only with seedlings), perhaps the correlation with mold (fungi) resistance would be even better with 3-deoxyanthocyanidins than with flavan-4-ols. We are therefore repeating the study, and for the first time we are including 3-deoxyanthocyanidins in the chemical assays. The results are not yet complete, but already suggest that mold resistance correlates better with flavan-4-ols, as we previously reported, than with the newly reported fungitoxic 3-deoxyanthocyanidins. We will be exploring the ramifications of this finding, but it seems clear that our earlier recommendation of flavan-4-ol assays for predicting mold resistance is still relevant.

Bird Resistance

In the past year, two sorghum genotypes said to be both tannin-free and bird resistant have been independently brought to our attention by our collaborators. If these reports are true and if either of these genotypes proves to have good nutritional quality, these genotypes could greatly benefit areas where bird problems constrain sorghum production. In field tests this season we have confirmed the strong bird resistance of both genotypes and in laboratory tests we have confirmed the absence of tannin. We will be evaluating their nutritional value in feeding trials in the coming year. Because of the importance of this problem and the potential of these genotypes, I have submitted a proposal to PSTC/USAID which involves evaluation of their bird resistance by collaborators in both Brazil and Kenya as well as short term training in evaluation of polyphenols and nutritional quality here at Purdue.

Tissue Culture

We have evaluated thousands of regenerated clones for growth characteristics, and a manuscript describing the results is in press in Theoretical and Applied Genetics. We found large numbers of somaclonal variants, and were able to calculate the somaclonal variation rate/frequency as a function of genotype (all are high tannin genotypes), explant source (mature embryos, immature embryos, or immature inflorescence), length of time in culture, and in some cases, composition of the culture medium. Potentially interesting or useful variants were passed on to our breeder collaborators. The primary purpose of these experiments was to produce somaclonal variants with respect to tannin biosynthesis, and evaluation for this characteristic is much more laborious. This work involves multiple polyphenol assays on individual panicles, and will require at least another year to complete. It is sufficiently complete, however, to draw early comparisons of the somaclonal variation rate with respect to tannin biosynthesis and to functional photosynthesis. The somaclonal variation rate for loss of functional photosynthesis, as determined by the proportions of albino plants produced, was quite high (up to 6.8% for one genotype). In contrast, the somaclonal variation rate for loss of tannin biosynthesis was zero. Not one regenerated plant had lost its ability to synthesize tannin. In a few cases the amount of tannin produced was somewhat diminished (to approximately half that of the parent control), and more often the amount of tannin produced was significantly increased, rather than decreased or lost completely. Curiously, the ability to carry out photosynthesis, a trait crucial for survival, is readily lost in culture whereas the ability to make tannin, a trait unnecessary for survival as attested to by the occurrence in the World Collection of more tannin-free sorghums than tannin-producing sorghums, apparently cannot be lost in culture. Growth in culture, in which nutrients are supplied in the medium so that functional photosynthesis is not necessary, apparently permits unrestrained mutations in genes specifying photosynthetic components; similar effects have been reported in parasitic plants which have lost their ability to carry out photosynthesis. The failure to produce somaclonal variants which have lost their ability to synthesize tannin suggests that this ability is somehow useful in culture. We are beginning to culture tannin-free sorghums to determine if this is the case.

Publications and Presentations

Publications

Journal Articles

"Incorporation of ^{14}C-Phenylalanine into Sorghum Tannin" (with V. Reddy), J. Agric. Food Chemistry 37:383-384(1989).

"Choosing Appropriate Methods and Standards for Assaying Tannin" (with A. Hagerman), J. Chem. Ecology 15:1795-1810(1989).

"Separation of High Molecular Weight Sorghum Procyanidins by High Performance Liquid Chromatography" (with Lesley Putman), J. Agric. Food Chemistry 37:943-946 (1989).

"Efficient Plant Regeneration from Embryonic Calli Initiated from Immature Inflorescences of Several High Tannin Sorghums" (with T. Cai), Plant Cell, Tissue and Organ Culture, in press.

Chapters and Proceedings

"Sorghum Polyphenols" in P. R. Cheeke (ed): Toxins of Plant Origin: Volume IV Phenolics, CRC Press Inc, Boca Raton, Florida (1989) p95-121.

"The Role of Polyphenols in the Utilization of ICRISAT-mandated Crops and Application of Biotechnological Methods for Improved Sorghum Utilization" in J. M. J. deWet (ed): Biotechnology in Tropical Crop Improvement: Proceedings of the International Biotechnology Workshop, ICRISAT, Patancheru, A. P. India (1988) p147-152.

"Effects of Condensed Tannin on Animal Nutrition," in R.W. Hemingway and J. J. Karchesy (eds): Chemistry and Significance of Condensed Tannin, Plenum, New York (1989) p391-402.

"Salivary Proline-rich Tannin-binding Proteins as a Defense Against Tannins" (with S. Mole) in Proceedings of 14th International Conference of the Groupe Polyphenols, August 1988, Brock University, St. Catherines, Ontario, p111-114.

"Striga: A Model for Collaborative Interdisciplinary Research" (with G. Ejeta and D. Hess), in Proceedings of International Sorghum and Millet CRSP Conference, Jan. 3-5, 1989, Scottsdale, AZ, INTSORMIL, U. of Nebraska, Lincoln NE, p119-122.

"Sorghum Polyphenols: Assays and Nutritional Significance," Proceedings of the 16th Biennial Grain Sorghum Research and Utilization Conference, Feb. 19-22, 1989, Lubbock, TX, p39-42.

"Striga: Scourge of African Cereals," INTSORMIL publication # 89-1, University of Nebraska, Lincoln, 1989.

Abstracts

"Proline-rich Salivary Proteins as a Defense Against Dietary Tannins" (with S. Mole, J. Rogler, G. Iason and C. McArthur), Bulletin of the Ecological Society of America (supplement) 69:236(1988).

"Somaclonal Variation in High Tannin Sorghum" (with T. Cai), INTSORMIL Conference, Jan. 3-5, 1989, Phoenix, AZ.

"Mechanisms of Antinutritional Effects of High Tannin Sorghum" (with J. Rogler and S. Mole), INTSORMIL Conference, Jan. 3-5, 1989, Phoenix, AZ.

"Phenolic Compounds in Striga-resistant and Striga-susceptible Sorghums" (with D. Hess, R. Vogler, and G. Ejeta), Agronomy Abstracts, p85 (1989).

Presentations

"Biotechnology Research on Striga," IITA Striga Workshop: Combating Striga in Africa, Ibadan, Nigeria, 22-24 Aug., 1988.

"Mechanisms of Antinutritional Effects of High Tannin Sorghum" (with S. Mole and J. Rogler), 4th Gordon Conference on Plant-Herbivore Interactions, Jan. 30-Feb.3, 1989, Oxnard, CA.

"Somaclonal Variation in High Tannin Sorghum," International Plant Biotechnology Network Conference, Nairobi, Kenya, Jan. 9-12, 1989.

"Striga Research Update," Striga Research Meeting, Old Dominion University, Mar. 2, 1989.

Networking Activities

Workshops

IITA *Striga* Workshop: Combating *Striga* in Africa, IITA, Ibadan, Nigeria, Aug. 22-24, 1988.

Research Investigator Exchange

Tishu Cai, Beijing Agricultural University, People's Republic of China

Germplasm and Research Information Exchange

Germplasm (low tannin, bird resistant) was obtained from:

Dr. John York, University of Arkansas
Dr. Antonio Bahia Filho, EMBRAPA, Brazil

Assistance Given

Polyphenol analyses were provided for several of the collaborators listed above, and for others not listed.

Laboratory supplies were provided for Dr. A.G.T. Babiker, ARC, Sudan.

Food and Nutritional Quality of Sorghum and Millet

Project TAM-126
L.W. Rooney
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Principal Investigator

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Dr. C. Paul, Sorghum Breeder, ICRISAT-CIMMYT, El Batan, Mexico

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Dr. D.S. Murty, Sorghum Breeder, ICRISAT, PMB 3491, Kano, Nigeria

Dr. S. Da Head, Sorghum & Millet Research, IBRAZ, Farakoba Experimental Station, Bobodioulasso, Burkina Faso

Dr. Octavio Paredes-Lopez, Professor of Food Science, Centro de Investigacion y de Estudios Avanzados del IPN, Unidad Irapuato, Irapuato, GTO, Mexico

Ing. Helbert Almeida-Dominguez, Professor, Instituto Tecnologico de-Merida, Merida, Yucatan (currently - Graduate Student, Texas A&M University) College Station, TX

Dr. S. Bedolla, Professor and Head, Dept. of Grades & Standards, State of Sonora, Hermosillo, Sonora, Mexico.

Dr. J.O. Akingbala, Senior Lecturer, Food Science Department, University of Ibadan, P.O. Box 1864, Ibadan, Nigeria

Mr. N. Ochanda, Sorghum Breeder, Alupe Agr. Res. Centerr, KARA, Busia, Kenya

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Ms. M. Gomez, Food Technologist, SADCC/ICCRISAT, P.O. box 776, Bulawayo, Zimbabwe

Dr. Chitsika, Willard Foods, Inc., Harare, Zimbabwe

Dr. L. Butler, Professor of Biochemistry; Dr. A. Kirleis, Professor of Food Science, Purdue University, W. Lafayette, IN

Prof. D. Andrews, Millet & Sorghum Breeding, University of Nebraska, Lincoln, NE

Dr. Bill Stegmeier, Millet Breeding, Kansas State University, Hays, KS

Drs. F.R. Miller, , G. Teetes, R.A. Frederiksen, Texas A&M University, College Station, TX

Drs. D.T. Rosenow, G. Peterson, A. Onken, Texas Agricultural Research & Extension Center, Lubbock, TX

Dr. G. Odvody, Assistant Professor, Texas A&M University, Corpus Christi, TX

Summary

This project focuses on improving the utilization of sorghum and millet by development of new technology and processing methods to produce new food products and through cooperation with breeding programs to develop sorghum and millets with built-in improved quality.

Milri, a rice-like product produced by parboiling and dehulling pearl millet, was developed. The parboiling

process consisting of boiling, steeping for 12 hours, boiling and air drying significantly increased the yield of decorticated millet. The product can be boiled and consumed similar to rice. It is a new product from millet that appears to have enhanced storage stability. Control of the cooking and drying procedures for parboiling millet is critical to avoid checking of the kernels. Investigation of this product continues.

Experiments on parboiling of sorghum in Mali confirmed our labortory results and encouraged initiation of village level trials in Mali. Parboiling may be an effective method of enhanced use of soft sorghums. The soft floury high lysine (P-721) and a brown bird resistant sorghum had very high yields of decorticated grain after parboiling. Raw grain of these cultivars cannot be effectively decorticated. The storage stability of parboilied sorghum appears to be improved. Changes in composition and structure during parboiling were documented. Parboiled sorghum has about the same nutritional value as nonparboiled sorghum when fed to rats.

Pearl millets with white endosperm have been selected for increase because they appear to produce food products with improved color and aroma. Extrusion-expanded pearl millet materials are useful for snacks, breakfast cereals and other products.

Fundamental studies of proteins, starches and phenols continue to provide useful information. The starch of hard endosperm sorghums has lower apparent molecular weight and is more easily solubilized than the starch of soft endosperm sorghums. Once solubilized, the starch from the hard endosperms retrogrades more rapidly to form a firmer tô . Floury endosperm starches do not retrograde as fast and the tô is softer. These observations must be confirmed for additional samples. If true, it could explain why certain sorghums produce poor quality tô

Black sorghums originating in the Sudan were found to have exceptionally high levels of anthocyanidin pigments. Grain of converted black sorghum lines had a large variation in phenolic compounds. A black sorghum line without a pigmented testa had very high levels of anthocyanidin pigments in the pericarp which could be easily removed by decortication. The anthocyanidins may have useful properties.

A procedure for germinating sorghum and measuring its malting properties was developed and is being applied to sorghums with varying kernel characteristics. Malting quality of sorghum is quite important in Africa where fermented beverages and porridges are widely used.

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 agro-processing 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 subjected to physical, chemical, structural processing and food product evaluations. Some of the highlights of these findings will be presented in the following sections.

Milri - A New Food from Pearl Millet

The parboiling process was applied to four pearl millet samples to determine its potential use in producing shelf stable processed foods with good acceptability. Preliminary trials were conducted using two millets from Kansas, one from Nebraska and one from Mali. The samples were brought to boil, soaked for 12 hours, brought to boil again and the cooked millet was air dried or dried in a forced air oven using various times and temperatures.

The method of drying greatly affected decortication yields of the parboiled millet. Air drying at room temperatures (25 C, for three days) gave the best results. Forced air drying procedures above room temperature (50 C) caused very extensive fissuring of the millet kernels with significantly increased breakage during dehulling (Figure 1). The method of drying is more critically important for millet than it is for sorghum. Air drying of cooked millet in Mali (in December) did not cause noticeable fissures and dehulling yields were significantly increased. However, ambient drying during the hot season in Mali might cause fissuring.

Parboiling (air drying) enhanced the yields of decorticated grain significantly from all the millets. However, the greatest response was for decorticated yields of the soft, floury millet from Mali which increased from 48.5% (nonparboiled) to 80.2% for parboiled. The color of the parboiled decorticated millet grain is much darker than the nonparboiled decorticated grain; however, the color of cooked decorticated parboiled grain is similar to or slightly darker than that of cooked, decorticated grain (control).

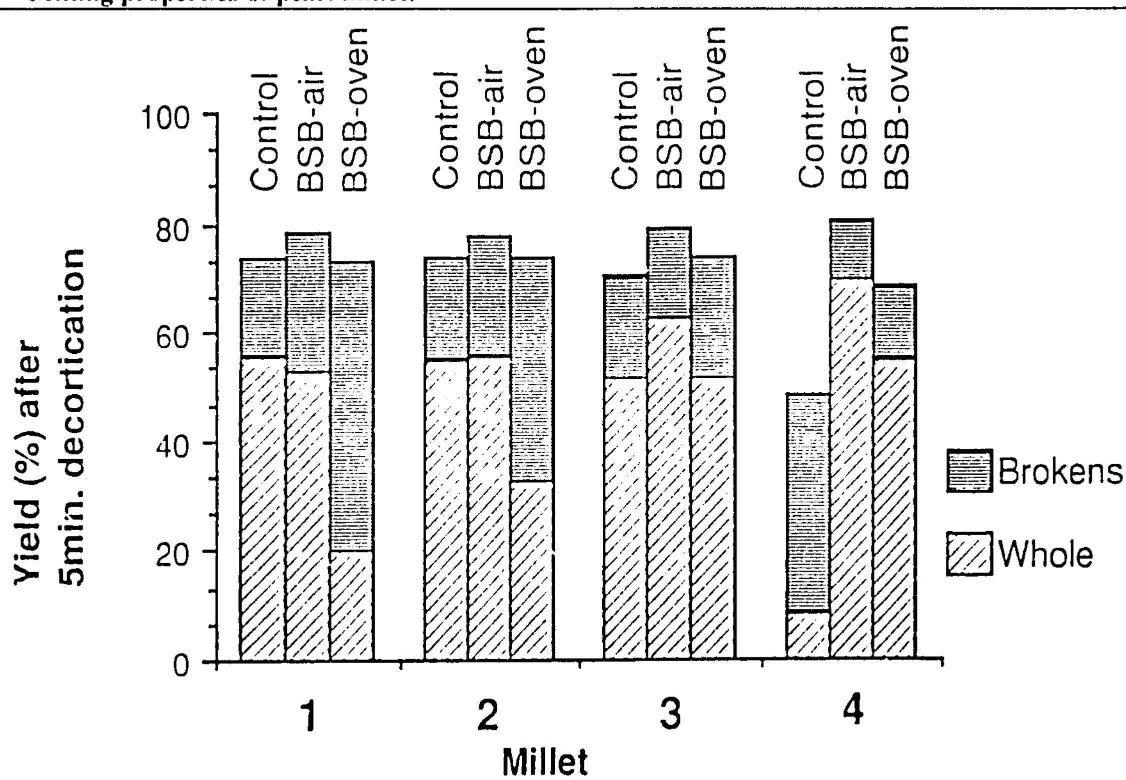
The texture of the boiled decorticated grain is firmer than that of the control. The cooking time is similar for the parboiled decorticated millet possibly because of fissures in the grains. From 2.06 to 3.46% dry matter is lost during boiling and soaking in the cooking water.

Experiments to evaluate the keeping quality and stability of parboiled millets have been initiated. They suggest that parboiled millet has significantly improved stability to development of off odors. The volatiles generated during storage increased significantly more for the control sample. More experiments are needed to clarify these observations.

Extrusion of Pearl Millet

Millets from Nebraska and Kansas were decorticated using an abrasive mill. The ground decorticated millet was extruded[1] with a twin screw extruder using four different moisture levels (12.5, 13.6, 15.0 and 16.3%) and three decortication levels (0, 12 and 24% weight removed). Pearl millet was easily extruded into a wide array of extrudates with varying expansion ratios and bulk densities. Bulk densities were lowest and expansion ratios were highest with the most completely decorticated grain and the intermediate moisture levels. Whole grain did not expand as much during extrusion because of its high lipid content and reduced levels of starch compared to the decorticated millet samples.

Figure 1. Milling properties of pearl millet.



Millet has an interesting and unique flavor and could be used for snack foods and breakfast cereals. The fiber of millet is under evaluation for its efficacy against cholesterol and colon cancer. Extrusion is costly in terms of equipment and operational costs. It is unlikely that extrusion will be applicable in many less developed countries. A low technology based method of expanding millet is necessary. Efforts to find a low technology, low cost, village method continue.

Pearl Millet Food Quality

Pearl millet lines with white or yellow endosperm color were identified in the Nebraska and Kansas millet improvement programs. These lines may have improved characteristics for various foods. Selections of these millets are being increased for future food processing studies. The aroma from ground yellow millet appears to be less offensive compared to the aroma of blue or purple pigmented millets. Pearl millets with a white endosperm may have improved grain quality for parboiling. These millets are being increased for processing studies.

Parboiling Pearl Millet Varieties

Fourteen pearl millet samples were parboiled using the boil, soak, boil procedure to determine the effect of variation in kernel characteristics on dehulling yields and cooking properties. The parboiling process greatly increased the milling yields of all the millets with the largest increase for the floury pearl millets. The color of dehulled Milri was slightly darker than the color of raw dehulled pearl millet. Variation among the varieties was large.

Sorghum Parboiling

The changes in physical, chemical and structural properties during parboiling were evaluated for several sorghum varieties ranging from a soft, floury high lysine (P-721) to a brown bird resistant sorghum. P-721, the high lysine sorghum, cannot be dehulled very efficiently. Brown sorghums are usually quite soft and cannot be effectively dehulled. Parboiling hardens the endosperm which results in high yields of decorticated sorghum. The cooking quality of the parboiled, decorticated P-721 grain was quite acceptable. The brown bird resistant sorghum after parboiling can be decorticated to remove most of the condensed tannins from the kernel by abrasive milling.

Figure 2. The effect of parboiling on kernel appearance. The floury appearance of the control (C) is eliminated by parboiling and drying with air (A) and a hot oven (O).

Parboiled sorghum and millet have hard translucent kernels (Figure 2) because the starch granules swell, partially gelatinize and soluble starch fills the void. Then, during drying the structure is set and forms a continuous phase which diffuses very little light. Hence, the cut kernel surface is smooth and glassy appearing. Improper drying can set up stresses inside the kernel which produce checked kernels. This is especially true of rapid drying procedures using forced air. Checked kernels break during decortication and increase the percentage of small endosperm particles.

Changes in chemical composition during parboiling occur but they are minor and related to milling losses. Milled parboiled sorghum generally has a slight increase in protein, fat and ash content with a slightly reduced level of starch. Rat feeding trials conducted at INCAP in Guatemala indicated that there were no essential differences in nutritional quality of parboiled and nonparboiled sorghums. We have not determined levels of B vitamins which should be a little higher in parboiled sorghums. The nutritional quality of parboiled sorghum appears to be similar to that of nonparboiled decorticated grain.

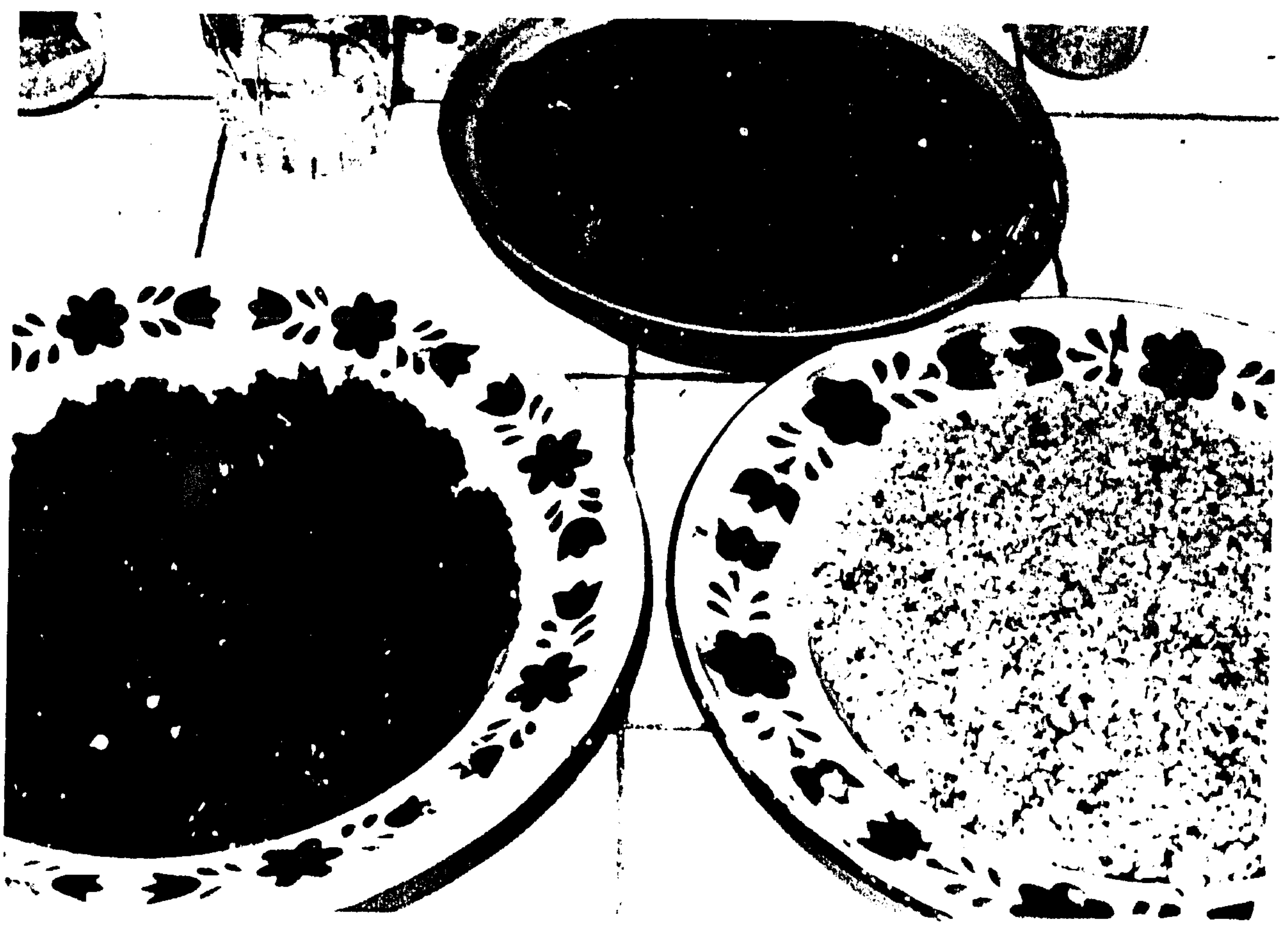
The work in our laboratory has been applied in the Food Technology Lab in Mali with promising results so far (Figure 3). Dr. Da Sansan of Burkina Faso was shown the process in Mali. He will atttempt to introduce the concept in Burkina Faso.

Additional studies continue in our laboratory to determine optimum processing variables, fundamental changes in starch, protein and other components and the effects of parboiling on storage properties.

Starch Properties of Thick Porridges (Tô)

Fresh warm tô from hard, corneous sorghums contained larger quantities of soluble starch than fresh tô

Figure 3. Parboiled sorghum ready to eat with peanut sauce (right side) and a parboiled sorghum stew ready for consumption (left side). Research conducted in the Malian Food Technology Laboratory by M. Haidara, Food Technologist, IER in Bamako, Mali.



from a soft, floury endosperm sorghum. However, the soluble starch content when the tô cooled one hour was lowest for the corneous sorghum. This observation was consistent for tô from flour and isolated starches. Soluble amylose content followed the same trend. These observations indicate that during cooking the harder sorghums produce more soluble starch which retrogrades more rapidly during cooling to form firmer tô texture. The soluble starch content of the cooled tô was lowest for the hard sorghums. This was true for tô from both flour and their isolated starches.

In tô cooled for one hour, the soluble solids content was inversly related to firmness. Thus, the hard sorghums produce more soluble starch which undergoes rapid retrogradation which forms a firmer tô. Sodium Stearoyl 2-Lactylate added to tô caused softer tô texture, probably because the amylose was complexed and unavailable for retrogradation.

Corneous endosperm starch had higher apparent molecular weight amylose and lower apparent molecular weight amylopectin than floury endosperm starch. The apparent molecular weight of amylose was 4.0 to 6.0 x 10^5 and 2.0 to 3.0 x 10^5 from corneous and floury starches respectively. These data obtained with high performance size exclusion chromatography must be repeated for other sorghums; but they do suggest that differences in starch characteristics play the critical role in tô quality. These studies continue as a portion of dissertation research by Mr. Bello from Nigeria on factors affecting tô quality.

Alkali Cooking Properties of Sorghum

Advanced breeding lines and progeny from the Honduras program were received for tortilla quality evaluations and tests. The sample size precludes actual cooking so preliminary tests will be done including pericarp removal, water uptake, dry matter losses and optimum cooking time tests. The most promising will be subjected to additional cooking trials.

The effect of nixtamalization on calcium uptake in sorghum and corn tortillas is being determined using rat feeding trials. Studies using dry heat processing to produce dry masa continue. We are trying to revive our collaborative work with the University of Sonora on alkaline cooking.

Tannins and Phenols in Black Sorghum

Shawaya, a special sorghum grown in western Sudan, has a very intense black kernel with a thick pericarp and a pigmented testa. It has a very high level of total phenols and intermediate levels of tannins. The anthocyanidin content was very high compared to other sorghums. The original Shawaya was crossed with ATx430 to convert it into a short early maturing form of Shawaya for growth in temperate regions. Selections from the conversion process were grown at College Station in 1987 and 1988 to provide grain for analysis to determine if unique phenolic compounds were present and to determine the level of tannins and pigments. Data for phenol analysis of different lines selected from conversion of Shawaya are presented in Table 1.

Table 1. Changes in phenolic compounds during maturation of converted black Shawaya grain.

Maturity (DAA)	Total phenols (mg/g)	Anthocyanidins (Abs/ml/g)	Flavan-4-ols (Abs/ml/g)	Flavan-3-ols (Abs/ml/g)
10	11.4	19.7	35.7	13.7
14	8.6	14.8	27.0	14.4
21	4.9	16.7	14.4	5.4
28	5.9	31.9	15.8	9.2
35	8.2	37.3	16.9	10.9
42	6.7	27.6	13.6	8.6
LSD (0.05)	0.24	0.8	0.8	1.2
C.V.	1.2	3.4	5.2	2.1

DAA - days after anthesis

The amount of anthocyanidin and flavan-4-ol compounds increased with increasing black pigmentation of the pericarp. The converted black sorghum did not contain any condensed tannins with the vanillin-HCl method. During conversion, the black grain selected did not have a pigmented testa which explained why total phenols were lower than the original Shawaya grain from the Sudan. The testa was present in the other lines selected but the level of anthocyanidins decreased with decreasing intensity of black pericarp.

The black converted line of Shawaya, without a pigmented testa, was grown in College Station in 1988. Grain was collected at 10, 14, 21, 28, 35 and 42 days post anthesis and analyzed for total phenolic compounds, condensed tannins and anthocyanidin pigments. At ten days after anthesis, the grain contained the maximum amount of total phenolic compounds when calculated on a dry weight basis (Table 1). However, calculation of the results on a per kernel basis showed that the high values obtained was because immature kernels contain relatively more pericarp than mature kernels, and that the total phenolic compounds actually reached a maximum of about 8 mg/g at 35 days after anthesis. The anthocyanidin pigments increased through maturity, reaching a maximum about 35 days after anthesis.

Bright field microscopy of the pericarp of Shawaya revealed the location of the pigments to be mainly in the pericarp, with some secondary pigmentation in the cross and tube cell area of the more intensely pigmented cultivars. It also revealed the absence of a testa in the black pigmented cultivar, thus explaining the absence of condensed tannins observed earlier in this cultivar. The testa appears to have been lost in the conversion process, since the original grain obtained from the Sudan contained a well-developed testa. The cultivars with more red than black pigmentation, however, have retained the testa, which explains the fairly high levels of tannins observed for those cultivars (Table 2). The black pigments could easily be removed from the sorghum kernel by abrasive milling to remove the pericarp. The endosperm of the converted Shawaya line was yellow.

Table 2. Phenolic compounds in grain from sorghum lines segregating for black pericarp color.

Cultivar (grain color)	Tannins (mg/g)	Anthocyanidins (Abs/ml/g)	Flavan-4-ols (Abs/ml/g)	Glavan-3-ols (Abs/ml/g)
Black[1]	0.0	27.6	13.6	8.6
Mostly black	6.7	18.5	11.8	20.4
Mostly red	17.1	9.5	8.7	38.7
Red with black specks	26.2	8.5	8.8	43.3
Brown	20.2	7.5	9.0	39.6
White II	11.1	3.0	1.7	22.3
White III	27.0	6.3	4.4	44.4
Controls:				
BTx623 (Type I)	0.0	1.1	0.4	0.5
Early Hegari (Type II)	4.1	2.2	2.7	24.3
Atx623xSC103 (Type III)	23.6	3.6	4.9	41.2
LSD (0.05)	1.6	0.8	0.8	1.2
C.V.	5.9	3.5	5.2	2.1

[1]Without a pigmented testa. All other sorghum lines had a pigmented testa present.

Work continues to characterize the pigments present in the converted black sorghum line and to identify the flavonoids present in this apparently unique material. More of the original Shawaya is being increased for comparative purposes.

Malting of Sorghum

Malted sorghum is used in production of fermented gruels and beverages in Africa where they are a major portion of the diet in some countries. Malt is used to produce infant foods and many other products from sorghum and millet.

Industrial production of sorghum malt is expanding in many areas, especially Nigeria where barley malt is not being imported. Thus, we have initiated long term research on identifying the essential kernel characteristics of sorghum that affect malting quality. A laboratory procedure for malting sorghum varieties was standardized and applied to a set of five sorghum varieties as part of a collaborative test designed by ICRISAT. The diastatic power for grains of TAM2566, SPV-475, IS14384, M-35-1 and CSH-1 was 21.9, 13.3, 22.78, 15.7 and 17.8 sorghum diastatic units respectively. The data were repeatable over several days. The diastatic power determination is cumbersome and will be modified. The malting losses appear to be a little higher than 20% losses reported in the literature. The diastatic power compares favorably with that reported in South Africa. The laboratory malting procedure and diastatic power test are being used to evaluate the malting properties of sorghum parents and hybrids grown at several locations.

Phenols and Tannins in Kenyan Brown Sorghums

Last year we reported very high levels of phenols and condensed tannins in sorghum grown in western Kenya. These cultivars were grown again in 1988 in western Kenya and analyzed to verify their phenol and tannin content. The 1988 crop year samples contained only 10% to 50% of that found in analysis of 1987 samples (Table 3).

Table 3. Phenols and condensed tannins of sorghum cultivars grown in western Kenya.

Cultivar	Tannins[1]		Phenols[2]	
Sabina	1.2	(4.7)[3]	2.0	(3.3)
Olusi	1.6	(6.3)	2.6	(4.1)
Serena	1.1	(5.8)	1.5	(3.8)
Seredo	2.1	(4.3)	2.1	(3.3)
Nyarika Molio	2.2	(7.1)	3.2	(5.9)
Nylon	2.6	(14.8)	6.0	(10.8)
Wesisia I	2.0	(11.6)	5.3	(8.6)
Elisa II	1.9	(11.6)	2.8	(10.2)
Mosongianilil	1.1	(17.0)	2.0	(14.7)
Combine Shallu [I][4]	0.0		0.5	
Hegari [II]	0.4		1.2	
SC103-12 [III]	0.7		1.5	

[1]Vanillin-HCL assay on 1% HCL in methanol extracts of ground grain. Blanks were substracted. Expressed as catechin equivalents.

[2]Folin-Cascalteu assay for total phenols on same extracts.

[3]Numbers in parentheses were reported in previous years report. (1987 crop year)

[4]Numbers in brackets refer to sorghums with no tannins [I], with a pigmented testa [II] and with a pigmented testa and a dominant gene [III].

The levels of tannins from 1988 grain samples are higher than that of SC103, a type III sorghum; but they are not extraordinarily high. We are attempting to obtain samples of those sorghums grown in another year to determine which values are real. Many known and unknown factors affect tannin analyses so additional data are needed.

Phenols and Insect Resistance

Bioactivity of sorghum tissue extracts was determined in Dr. Bill Wiseman's laboratory using the fall armyworm (FAW) bioassay. Fresh or frozen samples of grain, stalks and leaves were extracted with 1% hydrochloric acid in methanol and absorbed onto microcrystalline cellulose (alphacel).

The alphacel with plant extract was incorporated into the diet of the FAW and the weight of the FAW after nine days was recorded. The reagent blank did not affect FAW growth.

Extracts from grain of SC630-11E (with intensifier) inhibited FAW growth more than did CS3541 (e.g., 6 vs. 48 mg, respectively). The FAW on the control diet gained 222 mg. SC630-11E has a red pericarp and is moderately grain mold resistant; whereas CS3541 has a white pericarp and is moderately susceptible to grain molding

Extracts from the stalks of MN960 (tan plant color) inhibited FAW growth more than MN1500 and AtlasxBMR-12 (red plant color cultivars), (e.g., 69 vs 195 and 110 mg, respectively).

Extracts from the leaves of tan plant color cultivars inhibited FAW growth more than red or purple plant color cultivars. The range of FAW weights was 2-30 mg for tan, 60-130 mg for red and 9-48 mg for purple plant color cultivars.

These preliminary results indicate the presence of potent bioactive compounds in grain, stalks and leaves of sorghum. There appears to be variability within cultivars for these bioactive compounds. Moreover, grain molding resistance appears related to increased inhibition of FAW growth.

Interaction with Plant Breeders

This project cooperates closely with other members of the Texas A&M sorghum program to incorporate the best quality characteristics into sorghum. Samples from the breeding programs and from the sorghum food quality tests grown at several locations were subjected to physical chemical and processing analyses. The information is used to select tan plant sorghums with good processing properties. Parents for white, tan plant food sorghums were released in the U.S. Some of them look good in international trials as well.

The alkali test has been applied to select sorghums with excellent food quality since 1978. Sorghum lines produced by this procedure have hard kernels, good resistance to weathering and sometimes have low levels of pigments. These lines appear to have excellent grain quality and many of them performed well in African and South American locations. Because they are very hard, they have some of the best grain quality attributes found in introduced sorghums in Mali. These results emphasize that for progress to occur, there must be a long term interaction between breeders and food scientists.

New Food Type Hybrids Have Desirable Properties for Feed

Texas A&M has released several parents that can be used to produce tan plant, white sorghum hybrids. The new hybrids have outstanding food processing properties and produce highly desirable light colored formulated feeds. The U.S. sorghum industry has recently learned that these white sorghums could appreciably expand or at least maintain its international sorghum markets because international feeders do not like the dark color of feeds produced with U.S. reddish brown sorghums.

Our work on sorghum quality improvement is of direct assistance to U.S. producers and consumers as well as international consumers of sorghum. Improved white sorghums with better resistance to grain molds and weathering are needed for the Southern U.S. The key requirement is for hard white, tan plant sorghums that are at least partially resistant to grain molds and weathering that frequently occurs when the grain matures under hot, humid conditions in south and central Texas. These same characteristics are needed in sorghum consuming nations. Thus, the goals of INTSORMIL are compatible for both domestic and international sorghum improvement.

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Networking

West Africa

Dr. L.W. Rooney traveled to Mali twice to interact with Malian personnel and to set up equipment provided by INTSORMIL for grain quality testing in the Institute Economic Rurales Food Technology Laboratory. Analytical data on parboiled sorghum and pearl millet were provided to Md. Haidara of the food technology laboratory. Trials to evaluate village level parboiling were planned. Dr. Da, Head of Cereal Breeding in Burkina Faso, traveled to Mali to interact with Malian sorghum and millet researchers on breeding and quality evaluation. He will begin more extensive quality testing in the Burkinan Cereal Improvement program.

Mr. A.B. Bello, Nigerian graduate student, Texas A&M University, conducted analyses on sorghum and pearl millet samples to determine factors affecting tô quality.

Mexico and Central America

Dr. Benjamin Ramiriz completed his Ph.D. on techniques for masa and tortilla quality evaluation in spring of 1989, returned to the University of Sonora and is initiating his research program which will involve sorghum inprovement for human foods, especially tortillas. Ms. Patricia Torres completed an MSci in January 1988 and returned to the University of Sonora to initiate work on food chemistry. INCAP in Guatemala conducted rat feeding trials on parboiled and raw decorticated gorghums.

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 by presenting technical papers on sorghum quality at the 16th Biennial Grain Sorghum Research and Utilization Conference in Lubbock, Texas, and the annual Cereal Chemistry Conference in San Diego. These conferences provided for exchange of information among domestic and international participants. A special invited presentation to the National Grain Sorghum Producers Association summarized our current knowledge of sorghum improvement for feed, food and industrial purposes. The need for white, tan plant sorghum grains to improve sorghum quality for formulated feeds is partially understood by the sorghum industry in the U.S.

L.W. Rooney has served on the Ecogeographic Zone Council for INTSORMIL and as Country Coordinator for Mali. Drs. Waniska and Rooney participated in the INTSORMIL project investigators conference. L.W. Rooney met with a steering committee in Montpellier, France to plan a sorghum utilization conference to be held as part of sorghum in the 90's.

Pathology

Executive Summary

Sporisorium sorghi, the causal agent of covered kernel smut in sorghum, occurs throughout the world and may be especially severe in lesser developed countries where seed dressings are not commonly used. Seventy genotypes from the Texas A&M University All Disease and Insect Nursery (ADIN) were evaluated over a five-year period for tolerance to covered kernel smut. Three genotypes, B35-6, SC414-12, and Sureño were immune whereas those with tolerance (less with 5% infected panicles) include 80C2241, 82DM499, BT4378, R4244, R6078, R6956, SC630-11, and TX2783. These materials were tested against only one race of the smut fungus and it would be most beneficial if they were evaluated in other countries to determine potential race specificity problems.

A sorghum specific *Fusarium moniliforme* species has been identified in sorghum plant materials from Kansas and Texas. This new species appears to be specific to sorghum and efforts are in progress to evaluate sorghum materials from other countries. Some isolates from this group have characteristics similar to several *Fusarium* species. If confirmed, then several genera will require redescription which may simplify the taxonomy of this very complex and important stalk and root rot pathogen.

Attempts to utilize a dot-immunobinding assay for detecting *Pseudomonas avenae* in pearl millet seeds was unsuccessful. Problems were encountered with cross reactions as members of the genus *Pseudomonas* are known to share very similar epitopes or antigens. Our polyclonal antisera lacked the necessary specificity for distinguishing between *P. avenae* and the saprophytes. Perhaps only monoclonal antiserum would possess the desired specificity. (KSU-108)

The relationship between plant growth and development and some stress mediated diseases can be explained in part by the continual production application of juvenile hormones in sorghum. Sorghums with high levels of naturally produced cytokinins are naturally resistant to charcoal rot. A normally susceptible cultivar was "converted" to a resistant cultivar by application of these hormones in Sudan.

Approaches to understanding grain mold include the effects of pericarp genes and the function of glumes. Glumes contain polyphenols similar to those of the plant; additionally, these polyphenols respond both quantitatively and qualitatively to the presence of grain mold causing fungi. Numerous new sources of resistance to anthracnose have been identified in collaborative programs with Brazil. Many of these anthracnose resistant sorghums will be evaluated in Zambia and Zimbabwe.

The international sorghum antiserum bank supplied antiserum on request to six cooperators in four LDC's and three in the U.S. The international sorghum virus nursery was distributed and grown in three countries in 1989. The positive identification of MDMV-A in sorghum was studied. MDMV-B reduced the height, panicle length, and stem diameter 40%, 40%, and 25% respectively. Seventeen isolates of the sugarcane mosaic virus-maize dwarf mosaic virus complex were studied. Serological interrelationships provided evidence to reclassify MDMV and SCMV strains and isolates. Using electro-blot immunoassay with cross absorbed polyclonal antibodies directed towards surface-located, virus specific N-termini of coat proteins, it was demonstrated that the 17 strains belong to four distinct potyviruses, i.e., Johnsongrass mosaic virus, maize dwarf mosaic virus, sugarcane mosaic virus and sorghum mosaic virus. A new maize dwarf mosaic virus resistant germplasm was released in 1989 in cooperation with Fred Miller (TAM-121). The material was released as RTx2858. (TAM-124)

Anthracnose was epidemic in the copperbelt and Mansa regions of Zambia on many introduced sorghums including some with resistance to the disease at other global locations. IS18688 from the ICRISAT Regional Anthracnose Resistance Nursery appeared to be immune to anthracnose at Mansa. The sorghum line IS2057 from the International Anthracnose Virulence Nursery was resistant to anthracnose at Henderson station, Zimbabwe; it may be useful as a differential to help characterize *Colletotrichum graminicola* in the SADCC region since it is adapted, has some leaf blight resistance and displays anthracnose susceptibility in the U.S.

Several sorghums with known resistance to sooty stripe were defoliated by leaf blight at Golden Valley, Zambia. Only cultivars with some resistance to both diseases had low damage from foliar diseases at this location. Resistance to both *Exserohilum turcicum* and *Ramulispora sorghi* would be desirable in those areas where sooty stripe is an endemic but sporadic threat in the SADCC region. Introduced natural foliar lesion inoculum augmented sooty stripe development in the Golden Valley foliar disease screening experiment. A laboratory technique was developed to produce large amounts of virulent conidial inoculum of *P. sorghi*. SC326-6 and SC326-6 derived sorghums had good general resistance to foliar diseases with good adaptation to many SADCC regions. A chytrid fungus parasitic to soilborne oospores, *Gaertnariomyces* spp, reduced incidence of systemic sorghum downy mildew on sorghum when applied to soil in field microplot studies. (TAM-128)

Identification and Quantification of Nematodes in Interactions with Bacterial and Fungal Incitants in Stalk Rot Complexes of Millet

Project KSU-108

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Summary

Sporisorium sorghi, the causal agent of covered kernel smut in sorghum, occurs throughout the world and may be especially severe in lesser developed countries where seed dressings are not commonly used. Seventy genotypes from the Texas A & M University All Disease and Insect Nursery (ADIN) were evaluated over a five-year period for tolerance to covered kernel smut. Three genotypes, B35-6, SC414-12, and Sureño were immune whereas those with tolerance (with less than 5% infected panicles) include 80C2241, 82DM499, BT4378, R4244, R6078, R6956, SC630-11, and TX2783. These materials were tested against only one race of the smut fungus and it would be most beneficial if they were evaluated in other countries to determine potential race specificity problems.

A sorghum specific *Fusarium moniliforme* species has been identified in sorghum plant materials from Kansas and Texas. This new species appears to be specific to sorghum and efforts are in progress to evaluate sorghum materials from other countries. Some isolates from this group have characteristics to several *Fusarium* species. If confirmed, then several genera will require redescription which may simplify the taxonomy of this very complex and important stalk and root rot pathogen.

Attempts to utilize a dot-immunobinding assay for detecting *Pseudomonas avenae* in pearl millet seeds was unsuccessful. Problems were encountered with cross reactions as members of the genus *Pseudomonas* are known to share very similar epitopes or antigens. Our polyclonal antisera lacked the necessary specificity for distinguishing between *P. avenae* and the saprophytes. Perhaps only monoclonal antiserum would possess the desired specificity.

Objectives, Production and Utilization Constraints

Objectives

1. To ascertain the importance of *Pseudomonas avenae* and *Xanthomonas campestris* pv. *pennamericanum* as seedborne pathogens contributing to yield losses in pearl millet.

2. To identify and characterize *Fusarium moniliforme* isolates from LDCs with respect to mating type and vegetative compatibility group.

3. To determine the relative importance of seedborne vs. soilborne strains of *F. moniliforme* as causes of stalk rot.

4. To evaluate various sorghum accessions for tolerance to covered kernel smut.

Constraints

1. Very limited information is available concerning bacterial diseases of pearl millet although they are commonly observed in West Africa. The relatively high prevalence of these diseases would suggest that they are seedborne. In addition, no research has been conducted on the potential effect of reducing the quality and quantity of grain production.

2. Only limited information is available on sexual races, mating types and vegetative compatibility groups of *F. moniliforme* isolates from lesser-developed countries. In particular, the relative frequency of *G. thapsina* is unknown. Since the fungus appears to be particularly virulent to sorghum seedlings in preliminary tests, more information on its distribution is desperately needed. Information of this kind is of critical importance since the races present in LDCs may be different from those present in the United States, and because some races may preferentially attack some cultivars and ignore others. Studies of nitrogen metabolism filamentous fungi other than *Aspergillus* and *Neurospora* are in their infancy.

3. The importance of seedborne (vs. soilborne) *F. moniliforme* in the cause of stalk rot has not been established. Identification of a primary inoculum source will aid in the design of cultural practices to reduce this disease.

4. Covered kernel smut of grain sorghum is one of the more important constraints to sorghum production in LDCs. In Southern Africa, prevalence of covered kernel smut approached 50% in some fields. This is attributable to lack of availability of seed treatments or insufficient funds to purchase chemicals. Grain sorghum inbreds and cultivars have not been evaluated for tolerance to covered kernel smut.

Research Approach and Project Output

Research Methods

1. Semiselective media and/or immunological tests are viable experimentation techniques for detecting limited numbers of plant pathogenic bacteria in or on the surface of seeds. To detect *Pseudomonas avenae* and *Xanthomonas campestris* pv. *pennamericanum* in pearl millet seeds, a dot-immunobinding assay using antisera prepared against these two causal organisms was used. For semiselective media, a previously described medium (MXP, Claflin, et al. 1987) was found to be useful for the xanthomonads. Despite extensive testing, a semiselective medium for *P. avenae* was unreliable as other contaminants would grow as well. The dot-immunobinding assay using polyclonal antisera was not highly specific and the test failed to detect limited numbers of cells ($< 10^4$ cells/ml).

2. Our approach to this problem is to test sorghum stalks and seeds from different geographic locations for their endogenous *Fusarium*. We will identify these *Fusarium* according to their race, their mating type and their vegetative compatibility group or VCG (see below for details). We are particularly interested in the *Gibberella thapsina* isolates which have so far been recovered only from sorghum plants (Klittich and Leslie, 1988b). From these studies we will determine if the variability within the fungal population is geographically limited. We expect the strains recovered from this diverse sample to differ widely in their ability to cause stalk rot, and anticipate that different fungal isolates may affect different host cultivars differently. We anticipate that we may identify very aggressive strains, which could be used in breeding for resistance, and that we may identify weakly virulent strains which could be used in a biological control program. Since we will eventually test multiple fungal isolates against multiple host cultivars, we may also detect pathological races of the fungus. Such races would be pathogenic on some cultivars but not on others. Genes for resistance to particular pathological races could then be introduced via conventional breeding methods.

F. moniliforme isolates will be characterized as to their sexual race, their mating type, and their VCG. *F. moniliforme* can be divided into four races - A, B, C, and D - (Hsieh et al., 1977; Kathariou, 1981), or varieties *moniliformis* (=A), *sacchari* (=B), *fujikuroi* (=C), and *intermedia* (=D) (Kuhlman, 1982). We have added two additional races to this list, *subglutinans* (=E) and *thapsina* (=F) (Leslie, Klittich and Correll, 1988; Klittich and Leslie, 1988b). Within each of these races, individuals may be identified as either "+" or "-" mating type. Strains that belong to the same race, but which are of opposite mating type, may cross with one another to form the sexual stage and complete the life cycle. All of the fungal isolates used to deliberately infest soils in this study will be sexually fertile to enable further genetic analysis of these strains as needed. All isolates used in this study will be classified by both race and mating type.

3. Fungal isolates will also be placed into a vegetative compatibility group, or VCG (Correll, Klittich and Leslie, 1987). The VCG to which a particular fungal isolate belongs is determined by its genetic composition at a number of loci, termed *vic* loci, which are scattered throughout the organisms' genome. Enough *vic* loci exist to specify over 4,000 different clones of *F. moniliforme* (Puhalla and Spieth, 1985; Klittich and Leslie, 1988a). We will use the specificity of the VCG type to follow our strains through the infection and demise of the plant. Using this marker, we will be able to distinguish the fungal strain we introduce into the soil from other strains that may infect the plant. We have been using this technique to characterize *F. moniliforme* isolates for several years (Leslie, Klittich and Correll, 1988; Leslie, 1988), and do not anticipate any problems with these analyses. If variability is found within a local population, as preliminary studies have indicated, then we will study variability in the mitochondrial DNA to determine if the variability we are observing is due to migration (mtDNAs should be different) or sexual recombination (mtDNAs should be similar).

4. *Sporisorium sorghi*, the causal agent of covered kernel smut in grain sorghum, occurs throughout the world wherever the crop is grown. Losses occur as the individual ovaries of the flowers are replaced by smut sori. Prior to the development of effective seed treatments, covered kernel smut was the most destructive disease of grain sorghum. It has been nearly 50 years since the last report (Melchers, 1940) where sorghum germplasm was evaluated for potential tolerance to smut.

Seventy genotypes from the Texas A & M University All Disease and Insect Nursery (ADIN) were evaluated over a period of five years. Prior to planting, seeds were mixed with teliospores (0.5%, w/w) and planted in early May. The genotypes were rated at physiological maturity for prevalence of smutted panicles.

Research Findings

1. The dot-immunobinding assay is an ideal test for detecting seedborne bacteria as the procedure is fast (within 24 hours), simple and inexpensive. However, our test with *P. avenae* failed as cross reactions were observed with other saprophytic Pseudomonads. Development of monoclonal antibodies for use in the test would likely have prevented cross reactions. Research in developing a semiselective medium for the target bacterium in pearl millet seeds will continue.

2. *Fusarium* taxonomy as it applies to those *Fusarium* spp. commonly found on sorghum and millet is going through an important revision. Much of this revision is attributable to new techniques, e.g., sexual compatibility tests, and to new isolates being recovered from sorghum and millet in Africa by INTSORMIL cooperators. Differences observed from many African isolates are more distinct than those observed in isolates from the United States. Thus the isolates from the LDCs are being used to better define the taxonomy of this set of fungi. Even more important however is the fact that many of these isolates produce potent toxins and/or carcinogens whose characterization has just begun. Since many of these isolates are recovered from apparently healthy grain, the extent of this problem in either LDCs or the United States is not yet manifest.

3. Research to determine the relative importance of seedborne vs. soilborne strains of *F. moniliforme* as causes of stalk rot has been in progress for only slightly over a year. During this time a novel *Fusarium* spp has been identified. This new species appears to be specific to sorghum and has so far been found in material from Kansas and Texas. We are now beginning to screen material from outside the United States for the presence of this "sorghum-specific" phenotype. Some members of this group appear to have characteristics to two different *Fusarium* species. If this finding is confirmed, then most of the species in the *Liseola* section of the genus will require redescription. Confusion of this type over taxonomy makes disease diagnosis difficult since several different fungal species with quite different abilities can easily be lumped together in one group. Meaningful generalizations, e.g., species xxx is responsible for disease xxx, are then exceedingly difficult to make.

4. Three genotypes, B35-6, SC414-12, and Sureño were resistant to covered kernel smut. Genotypes with tolerance (less than 5% infected panicles) include 80C2241, 82DM499, BT4378, R4244, R6078, R6956, SC630-11, and TX2783. These materials were tested against only one race of the smut fungus and may not exhibit tolerance or immunity to other races. Three races have been reported in North America whereas it is unknown if additional races exist in other countries.

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Networking Activities

Workshop

An indepth workshop on bacterial diseases is being planned for March, 1990 at the SADCC/ICRISAT Headquarters in Bulawayo, Zimbabwe in cooperation with Dr. Walter deMilliano. The program would emphasize practical laboratory experimentation for SADCC personnel who are responsible for diagnosing plant diseases in their countries. The lectures and laboratories will emphasize practical and also recently developed techniques utilized in biotechnology.

Research Investigator Exchange

Dr. El Hilu Omer from Sudan spent a week in the Department of Plant Pathology, KSU, in January, 1989. Dr. Hilu visited with several other faculty members and learned several techniques such as preparing semiselective media and performing dot-immunobinding assays.

Assistance Given

Scientific reprints were sent to CRSP collaborators in Nigeria, Niger, Mali, Zimbabwe, Mexico, and Costa Rica. Approximately ten years of the scientific journals *Plant Disease* and *Phytopathology* were donated to Mr. Molapo Qhobela and the Lesotho Ministry of Agriculture.

Scientific research supplies consisting of antibiotics, nitrocellulose paper and chemicals were provided to Dr. Hilu which will be utilized in his research program in Wad Medani, Sudan.

Sorghum and Millet Disease Control

Project TAM-124

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Summary

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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

- Assist in characterizing the new pathotype of *Peronosclerospora sorghi* in Honduras.
- Evaluate sources of resistance to *Peronosclerospora sorghi* in Honduras.

Brazil

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

Mexico

- Define races of various pathogens including strains of virus present in sorghum growing regions of Mexico using the International Sorghum Virus Nursery (ISVN) and the Antisera Bank.
- Characterize populations of the leaf blight pathogen and determine host management strategies to reduce genetic vulnerability.
- Collaborate in development of head blight resistant sorghum populations.

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-21 and 22) 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 assist 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 Approaches and Project Output

Charcoal Rot and Long Smut

During the previous growing season (1987), Dr. El Hilu demonstrated the effect of applications of the cytokinin 6-benzylamino purine (BAP) in reducing charcoal rot. These trials were repeated in 1988 using the hybrid Hageen Dura-1 (Table 1). The effect of BAP on Hageen Dura-1 was essentially identical with its effect on the inbred Tx623. We believe this supports the concept that selection for plants with tolerance to withstand plant senescence is similar to or strongly correlated with the plant's ability to resist charcoal rot.

Table 1. Effect of 6-benzylamino purine (BAP) on charcoal rot in Hageen Dura-1 at Wad Medani, Sudan, 1988.

Treatment	Greenleaf* rating	Charcoal Rot % Infection	Mean No. nodes crossed	Yield grs/head
Stress + BAP	2.11	3.2	0.1	28.3
Stress + DW	1.51	20.3	1.2	27.5
Normal irrigation + BAP	3.45	0.0	0.0	36.1
Normal irrigation + DW	2.40	0.0	0.0	36.2
S.E.±	0.068	---	---	2.13

The long smut program was continued in both Niger and Sudan. In Niger, we had only natural infection, because the stored inoculum failed to survive the dry season. The model proposed is that natural infection could be used in most years for selecting plants resistant to disease. Data from Sudan in which plants were inoculated appear to be much more useful than the plot ratings made at Kollo (Table 2). Tests on infection of sorghum and inoculations of long smut were continued during the dry season.

In Mali, M. Diourte observed the incidence of long smut in nine villages in the Balte region. The incidence of plants with smut varied from a low of 1.2% to a high of 13.27%. M. Diourte's data from 1984-1986 reflect the increased level of disease in drier regions. Regions with 500 to 600 mm of rainfall during the growing season had nearly 20% incidence of smut whereas areas with 900 mm or more had essentially no long smut.

Downy Mildew and Foliar Diseases

At Comayagua, Honduras, pathotype 5 of *Peronosclerospora sorghi* decreased in prevalence in 1988. In 1986, 19% of the central plants had the disease, in 1987 8% and in 1988 only 5%. This could reflect decreasing levels of inoculum, or unfavorable conditions for spread of the pathogen by conidia. Sorghum downy mildew is considered to be among the more threatening diseases of sorghum in Honduras.

In 1988, sorghum rust, gray leaf spot, and ladder spot were the most important foliar diseases. SC236 and other parental stocks have been used to increase the level of resistance in maicillos criollos.

Total genomic DNA of sorghum downy mildew pathotype 3 was found to be an efficient hybridization probe when radioactively labeled by nick-translation. The probe was successfully applied to detect sorghum downy mildew inoculum in seeds and leaf tissues infected by *P. sorghi*. The DNA fragments of *P. sorghi*, pathotype 3 clones in *E. coli*, DH5 are being selected for specific probes which can be used to differentiate *P. sorghi* isolates distributed in different geographical areas, and the different species of *Peronosclerospora*.

Table 2. Incidence of long smut in the International Disease and Insect Nursery inoculated at Wad Medani, Sudan and naturally infected at Kollo.

Entry No.	Designation	Long smut — Sudan: Percent of plants with smut	Sudan: Mean rating*	Niger: Plot rating**
1	B35-6	80	1.95	R
2	RTX2817	68	1.90	S
3	SC326-6	15	1.30	R
4	SC414-12E	90	2.75	S
5	SC630-11E	15	1.15	R
6	BTX626	0	1.00	MR
7	BTX631	50	1.85	S
8	BTX2755	65	2.30	R
9	BTX623	75	2.50	S
10	RTX378	15	1.15	R
11	B8106	35	1.18	R
12	RTX2794	85	2.65	S
13	RTX2767	55	1.15	S
14	RTX435	95	2.85	S
15	RTX430	95	2.10	S
16	RTAM428	5	1.10	R
17	RTX7078	90	3.05	R
18	RTX2783	20	1.25	S
19	RTX433	30	1.55	S
20	RTX434	75	2.45	S
21	QL3 (India)	0	1.00	R
22	R9188	45	1.80	R
23	R4317	35	1.55	S
24	R8505	60	2.05	S
25	84C7730	95	2.85	S
26	Sureño	35	1.60	S
27	SC1207-2-1-1	29	1.65	S
28	87L3450 (6EON362)	29	1.35	R
29	B1	49	1.95	R
30	84C9408	23	1.40	R
31	Hageen D-1	100	3.00	
32	Gadan Echaman	45	1.40	
33	Dabar	60	2.10	

* Rating method suggested for east and west Africa long smut proposed nursery (mean of two replicates).

** A visual estimate of plants that had a (R) 2 or less on the long smut rating scale above and a (S) 3 or more.

Anthracnose

Many sorghum cultivars have resistance to anthracnose. Seventeen converted lines have been resistant in Georgia, Puerto Rico, and Brazil (Table 3). Some of the lines were grown in 11 seasons. During the past two growing seasons over 30 other sorghum accessions with high levels of resistance to anthracnose were identified. Part of the work being carried out between the U.S. and Brazil has been to develop sorghums with high levels of dilatory resistance (lines in which the disease develops slowly). In 1989, at College Station, excellent differences among lines for dilatory resistance were observed. Lines with dilatory resistance will be monitored in Brazil during the 1989-90 growing season.

Table 3. Reaction of potential differential cultivars for Colletotrichum graminicola at Sete Lagoas, M.G., Brazil; College Station, TX; and Griffin, GA.

	Anthracnose Reaction		
Cultivar	Brazil	Texas	Georgia
QL3	4.0	1.0	4.3
SC283	2.0	1.0	3.4
SC326	2.5	1.0	1.8
SC167	1.0	1.0	1.3
SC328	3.5	4.2	5.0
SC414	3.5	1.0	4.5
SC748	3.0	1.0	1.0
SC9659	3.0	1.0	1.8
TAM-428	5.0	4.0	5.0
BTX378	4.5	5.0	5.0
BTX398	5.0	4.0	5.0

Colletotrichum graminicola and *C. subineolum* are fungal pathogens causing anthracnose. Current hypothesis suggests that *C. subineolum* attacks sorghum in Africa and *C. graminicola* in the Americas, but more likely based on the current taxonomy both species are present in Africa. In the U.S. and Brazil, we know that there are many pathotypes of *C. graminicola* and that these need to be more accurately defined. RFLP's represent an important tool in defining populations of this pathogen group. Currently, Carlos Casela and Phil Guthrie have made a genetic library of *C. graminicola* and seven putative probes for the initial characterization of DNA from isolates collected in Texas, Georgia, Puerto Rico, and Brazil.

Seed transmission of *Peronosclerospora sorghi* in sorghum was repeated by growing plants grown from seeds with or without glumes harvested from the systemically infected cultivar SC283(IS7173C).

Grain Mold

Grain mold remains as one of the significant disease/quality factors in programs to improve production of sorghum in Africa. Sorghums with the highest yield potential flower during the rainy season. This promotes moldy grain. Naturally occurring sorghum strategies that tend to reduce grain mold include a) photosensitivity (plants flowering during the dry season), b) presence of a testa, c) corneous endosperm, and d) an inverted inflorescence with large umbrella-like glumes that keep the grain dry.

As a part of his graduate study, Mr. A. Mansuetus has examined the role(s) that glumes play in the grain mold complex. Fifteen different cultivars were grown based on known mold resistance ratings (Table 4). Inoculations were made with a suspension of a mixture of isolates of *Fusarium moniliforme* from glumes, grains, and peduncles of sorghum. A hypodermic syringe was used for the inoculations at boot while a hand held aspirator was used at anthesis and seven days after anthesis. Glume samples from the boot stage of growth, taken 48 hrs after inoculation, were evaluated for free phenolic compounds (FPC). Foliar ciocalleau method was used to quantify these compounds.

Table 4. Cultivars, plant characteristics*, and mold rating.

Cultivar	Mold rating (1-5)	Plant color	Glume color	Glume length	Glume cover (%)**	Pericarp color
8C 630-' 1E (II)	2.0	R	R	S	40	R
84BH5629,31	2.0	T	dT	S	45	R
8C 279-14	1.5	R	R	L	65	R
8C 791-11E	1.5	P	R	S	35	R (PT)
IS 9530	2.0	P	rP	S	40	R
BTX 826	2.0	R	dP	S	30	R
Sureño	2.0	T	dT	S	40	W
84BH5734	2.0	T	T	S	30	W
6BH6077	2.0	P	dP	S	30	R
80B2892	2.0	P	B	S	30	R
CS3541	3.5	T	T	S	35	W
TX2536	4.5	P	frP	S	36	W
SC 170-6-17	4.0	R	R	S	35	W
CSM63	2.0	R	R	L	75	W (PT)
Malisor-7	3.5	T	dT	S	50	W

* W = white, R = red, PT = pigmented testa, T = tan, P = purple, dT = dark tan, dP = dark purple, rP = red purple, B = black, frP = faded red purple.

** 0% - grain completely exposed
100% - grain fully covered

Glumes of both inoculated and non-inoculated cultivars differed significantly in their FPC content (Table 5). Moderately resistant cultivars had higher levels of FPC than susceptible cultivars. Resistant cultivars had a higher increase in FPC in response to inoculation than susceptible cultivars. Cultivars with a red pericarp had a higher response to inoculation than those with a white pericarp. It is evident that glumes have a physiochemical as well as a morphological role in protecting grain from damage. One important characteristic of a good glume includes a substantial amount of FPC without staining the grain. Cultivars like Sureño fall into this category. Glumes of resistant cultivars have higher levels of FPC and respond faster to infection than those of a susceptible cultivar.

Table 5. Cultivars, polyphenol content, and % change in polyphenol content.

Cultivar	Average free polyphenol content of glumes: Control	Inoculated	% change in free polyphenol content
SC 630-11E (II)	10.5 c	18.6 b	77
84BH5629, 31	9.1 d	15.8 d	74
SC 279-14	6.7 fg	11.3 g	69
SC 719-11E	8.2 def	12.9 ef	57
IS 9530	9.0 d	13.9 e	54
BTX 626	12.1 b	18.4 b	52
Sureño	8.3 de	12.6 ef	52

Cultivar	Average free polyphenol content of glumes: Control	Inoculated	% change in free polyphenol content
6BH6077	14.3 a	20.2 a	41
80B2892	11.8 bc	16.7 c	41
CS3541	6.5 g	8.6 h	32
TX 2536	7.0 efg	9.1 h	30
SC 170-6-17	7.2 efg	9.2 h	28
CSM 63	7.0 eg	8.5 h	21
Malisor-7	7.8 defg	8.3 h	6

Means followed by the same letter are not significantly different at the 0.05 level of probability.

Mr. J. P. Esele has initiated a study on the association of known genes affecting the pericarp of sorghum with their resistance to grain mold. Genes being studied include genes for pericarp color (R-Y-) pericarp thickness (22), presence or absence of a testa (B_1-B_2-), and intensifier (II) and spreader (SS) genes. This work should assist breeders and pathologists in developing a more comprehensive cooperative program for developing grain mold resistant sorghum by defining the role(s) each of these pericarp related genes play in the disease process. Complementary crosses are being made using elite sorghum in Uganda.

Head Smut

Head smut remains as a major disease of sorghum as do other smuts of sorghum and pearl millet. Over the past few decades, little work has been carried out on the host-parasite interactions of these pathogens. Head smut caused by *Sporisorium reilianum* represents an important pathogen on which to initiate studies using advanced technologies. The pathogen affects the host by a variety of methods including changes in floral development, maturity and growth. The approach is to use pathogen DNA produced in the host as a probe to detect changes of host DNA during growth and differentiation. Similarly, the relations between growth regulators produced by the pathogen in vivo are the subject of much interest. *S. reilianum* produces cytokinins and probably gibberellins in culture. The effect of these growth regulators in smutted plants provides a tool for determining the role of selected growth regulators in plant gene expression. Restriction fragment length polymorphisms (RFLP's) between isolates of *S. reilianum* are being sought as a taxonomic tool and for defining genes for avirulence/virulence.

Virus Diseases

A large number of potyvirus isolates currently classified as strains of sugarcane mosaic virus (SCMV) are reported to infect maize, sorghum, and sugarcane in various parts of the world, although isolates originating in maize have been frequently referred to as strains of maize dwarf mosaic virus (MDMV). The taxonomic status and the serological interrelationships of these strains have never been clearly defined. We have compared 17 SCMV/MDMV strains from Australia and the United States on the basis of their reactivities, in electro-blot immunoassay, with cross-absorbed polyclonal antibodies directed towards surface-located, virus-specific N-termini of coat proteins. Our results clearly demonstrate that the 17 SCMV/MDMV strains belong to four distinct potyviruses for which the names "Johnsongrass mosaic virus (SCMV-JG and MDMV-O)", maize dwarf mosaic virus (MDMV-A, MDMV-D, MDMV-E, and MDMV-F), sugarcane mosaic virus (MDMV-B, SCMV-A, SCMV-B, SCMV-D, SCMV-E, SCMV-SC, SCMV-BC, and SCMV-Sabi), and sorghum mosaic virus (SCMV-H, SCMV-I, and SCMV-M) have been proposed.

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. Differencces 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 resistance. In the 36 CVS assessed, virus accumulation increased for 32 days after inoculation (DAI) and increased 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 at 24-30 C. Both resistant and susceptible sorghum genotypes produced the highest 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.

Publications and Presentations

Publications

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Networking Activities

Research Investigator Exchanges

R. Frederiksen met with Issafou Kollo in Niger in August and October 1988. Collaboration and research goals were discussed. Dr. L. Claflin accompanied us in a review of millet diseases as well as bacterial diseases of sorghum. Dr. J. Werder ICRISAT/Sahelian Center discussed his millet program with us and in particular with Mr. Kollo. During the August trip, Mr. M. Diourte of Mali and Dr. El Hilu Omer of Sudan met in Niamey, Niger to outline collaboration on all African long smut collaboration. Mr. C. Casela collected anthracnose data from cooperative nurseries with EMBRAPA in Brazil and Mr. D. Collins worked with Dr. Meckenstock in Honduras to obtain information on pathotype 5 of *Peronosclerospora sorghi*.

Examples of collaborators or visitors to our program included:

Dr. J. Shepherd	Reading University, England
Dr. R. Duncan	University of Georgia
Dr. G. Still	USDA Plant Gene Expression lab
Dr. O. Tal	Director-General, IER, Mali
Dr. D. Morris	University of Missouri
Dr. B. Phinney	UCLA

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 cooperation with TAM-122. The International Sorghum Virus Nursery was 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.

The international sorghum virus nursery was sent to Venezuela, Zambia, and Zimbabwe. Sorghum antiserum was supplied to Brazil, Venezuela, Zambia, and India.

Identified, isolated and developed and released a new source of Maize Dwarf Mosaic Virus Resistance designated RTx2858 sorghum in cooperation with TAM-121.

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
G.N. Odvody
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Summary

Anthracnose was epidemic in the copperbelt and Mansa regions of Zambia on many introduced sorghums including some with resistance to the disease at other global locations. IS18688 from the ICRISAT Regional Anthracnose Resistance Nursery appeared to be immune to anthracnose at Mansa. The sorghum line IS2057 from the International Anthracnose Virulence Nursery was resistant to anthracnose at Henderson station, Zimbabwe; it may be useful as a differential to help characterize *Colletotrichum graminicola* in the SADCC region since it is adapted, has some leaf blight resistance and displays anthracnose susceptibility in the U.S. Several sorghums with known resistance to sooty stripe were defoliated by leaf blight at Golden Valley, Zambia. Only cultivars with some resistance to both diseases had low damage from foliar diseases at this location. Resistance to both *Exserohilum turcicum* and *Ramulispora sorghi* would be desirable in those areas where sooty stripe is an endemic but sporadic threat in the SADCC region. Introduced natural foliar lesion inoculum augmented sooty stripe development in the Golden Valley foliar disease screening experiment. A laboratory technique was developed to produce large amounts of virulent conidial inoculum of *R. sorghi*. SC326-6 and SC326-6 derived sorghums had good general resistance to foliar diseases with good adaptation to many SADCC regions. A chytrid fungus parasitic to soilborne oospores, *Gaertnariomyces* spp, reduced incidence of systemic sorghum downy mildew on sorghum when applied to soil in field microplot studies.

Objectives

Evaluation of cross pathogenicity and virulence of *Macrophomina phaseolina* collected from diverse hosts in Southern African (Botswana). Determine if host preference and other differences of isolates can be detected and analyzed in pure culture tests.

Deploy TAES nurseries and other sorghum to SADCC/ICRISAT for use at several SADCC locations to evaluate resistance to specific pathogens and to characterize pathogen populations. Diseases for specific evaluation include leafblight, sorghum downy mildew, unknown viruses, sooty stripe, gray leaf spot, and anthracnose.

Develop improved inoculation and field screening techniques for sooty stripe and other diseases in the SADCC region.

Research Approach and Project Output

Charcoal Rot

The reaction of the small number of *M. phaseolina* cultures from several hosts in Botswana was different than that of similar U.S. hosts but, similarly, gramineous and non-gramineous host isolates could be distinguished. However, the number of isolates tested was too small to critically define host preference differences among isolates. Approximately 50 charcoal rot samples each were collected from infected sorghum, maize, millet, cowpea, and sunflower at Sebele in April, 1989 by B. Motalaote for subsequent isolation and evaluation in culture tests in the U.S.

Deployment of Nurseries

Several TAES sorghum nurseries designed to evaluate specific and general resistance to one or more diseases were planted at strategic SADCC sites. The variable severity of some diseases at specific locations across seasons was again apparent in 1988-89. The very low occurrence of virus infections in sorghum at the Mt. Makulu station, even in the ZSV-1 spreader rows, was in sharp contrast to the incidence of virus the previous year. Sorghum downy mildew was also more variable this season but results were still consistent with a race or races different from those in the Americas.

Anthracnose

The International Anthracnose Virulence Nursery (ISAVN) was planted only at the Henderson station in Zimbabwe where anthracnose incidence was low and variable but sufficient to determine that IS2057 had resistance to *Colletotrichum graminicola* at this location. This entry may be valuable as a differential for anthracnose in the SADCC region since it is susceptible in the U.S. It is apparently adapted to the SADCC region and it has an intermediate reaction to leaf blight. Evaluation of anthracnose reaction on some entries was impossible or difficult due to lack of stand, late maturity, or extreme susceptibility to other diseases like leaf blight.

Anthracnose occurred in many other nurseries planted at other locations in Zambia, Zimbabwe, and in the Pandamatenga area of Botswana but it was of epidemic proportions on susceptible sorghums only in the Mansa and copperbelt (Mpongwe) regions of Zambia. This disease will be a limiting factor in these latter regions on shorter, earlier maturing introduced sorghums without host plant resistance, especially in years of higher rainfall. At Mansa we observed that IS18688, in the ICRISAT Regional Anthracnose Resistance Nursery, appeared to be immune to anthracnose; most other entries were susceptible and a few had intermediate levels of resistance. Initial inoculum at Mpongwe was apparently supplied from wild or local sorghums as large acreages never before planted to sorghum were devastated by anthracnose. Local sorghums several kilometers away from Mpongwe had anthracnose only on the lower leaves but their height and late maturity allowed them to escape serious losses from anthracnose and other foliar diseases.

Sooty Stripe

Several International Sorghum (IS) lines have previously shown good resistance to sooty stripe at various African locations and in limited U.S. field and greenhouse tests. The converted forms of many of these lines were grouped in a single nursery at Golden Valley, Zambia where sooty stripe (caused by *Ramulispora sorghi*) is an endemic disease problem. Naturally occurring soilborne inoculum was supplemented with sooty stripe lesion debris collected the previous season and distributed in the planting by G.Kaula. Differences in sooty stripe resistance and susceptibility were readily apparent as were the same reactions to leaf blight caused by *Exserohilum turcicum*. The need for leaf blight resistance in all sorghums at this location was demonstrated in this screening nursery where entries with resistance to both leaf blight and sooty stripe had the greatest amount of green leaf tissue. Several with high resistance to sooty stripe were severely affected by leaf blight. Resistance to both pathogens would be desirable in those areas where sooty stripe is an endemic but sporadic threat in the SADCC region. The introduction of natural sooty stripe lesion debris as inoculum appeared to contribute to increased sooty stripe development compared to adjacent uninoculated nurseries with the same and similar germplasm.

Inoculum Production of Ramulispora sorghi in Culture

We accomplished mass production of *R. sorghi* conidia on culture plates using common potato dextrose agar media and incubation under fluorescent lights for five to seven days at 25°C. Initial culture sporulation provided mucoid conidial masses that were then spread over other plates in a manner similar to the streaking of bacteria. Conidia produced on these "streaked" plates retained a high viability for at least one to two months if these culture plates were placed in storage at 6-10 C within a few days after maximum conidial production and maturity. Conidia were easily suspended and spray inoculated onto sooty stripe susceptible sorghum seedlings (4-5 leaf stage). Inoculated sorghum was incubated for 24 to 48 hours in a dewchamber at 25-26°C and placed on a greenhouse bench. Sooty stripe lesions appeared about 1.5 wk after inoculation. The conidia production and inoculation techniques need further refinement but could be useful to conduct initial screening of progeny where field evaluation is impractical or disease occurrence is sporadic. It might be useful to increase rate of natural disease development by doing early inoculation of sooty stripe susceptible sorghums planted as spreader rows in a field screening nursery. However, if sufficient sooty stripe-affected leaves are available, their collection and use as supplemental inoculum the next season is probably a superior method because of its ease of implementation and, if important, it provides a naturally variable pathogen source.

Leaf Blight

Converted sorghums (from the sorghum conversion program) and other cultivars with known leaf blight resistance were grown at the Henderson station in Zimbabwe. These included entries that were crosses with SC326-6 or those that had SC326-6 somewhere in the cross. SC326-6 has excellent general resistance to leaf blight and most other foliar diseases. This resistance is consistently evident at Henderson and other SADCC locations as is its good agronomic adaptation. At Henderson, progeny from SC326-6 crosses this year again generally displayed that same broad foliar disease resistance which could be valuable in the development of sorghums for the SADCC region. The F3's from a cross of SC326-6 and TX7078 (leaf blight susceptible) had widely varying agronomic types but their general leaf disease resistance, though variable, was still too good for our intended development of isogenic populations having low, intermediate and high levels of resistance to leaf blight.

Sorghum Downy Mildew

Sitsembile Kunene has conducted field and greenhouse tests to evaluate the efficacy of a parasitic chytrid (*Gaertnariomyces* spp.) in reducing the incidence of sorghum downy mildew (SDM). The chytrid is a known parasite of oospores of *Peronosclerospora sorghi* and other related fungi when applied to soil. Ms. Kunene was able to correlate that attack with an actual reduction in the incidence of SDM in sorghum in microplot experiments where a low (14% SDM) and high (10% SDM) rate of application of the oospore-parasite *Gaertnariomyces* significantly reduced SDM over the nontreated control (24% SDM). This represents a potential biocontrol treatment for SDM that may be useful by itself but can also help us to determine and understand the resident biocontrol organisms that naturally reduce oospore populations in soil.

Publications

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Networking Activities

The principal investigator traveled to Southern Africa in late March 1989 to evaluate disease nurseries planted in Zambia, Zimbabwe, and Botswana. Nurseries were evaluated in Mansa, Mpongwe, Golden Valley, Mt Makulu, and Lusitu with these scientists at some or all sites: W. deMilliano, G. Kaula, and B. Nath. In Zimbabwe nurseries were evaluated at Harare, Henderson station, Panmure station, and Matopos with these scientists at some or all sites: W. deMilliano, E. Mtisi, and J. Mushonga. In Botswana nurseries were evaluated at Pandematenga, Sebele station and several farmer's fields near Francistown with these scientists at some or all sites: W. deMilliano, B. Motalaote, and C. Manthe.

Socioeconomics

Executive Summary

Year 10 was very successful for completing fieldwork and obtaining the preliminary modeling results in Sudan, Honduras, Niger, and Burkina Faso.

The one project with the most progress has been on the introduction of new technologies in the eastern vertisols of the Sudan. This region is a large-farmer, mechanized, almost continuous monoculture sorghum production system. Preliminary model and field-survey results indicate that at the present price discount of the new small-seeded sorghum cultivars of 30 to 35%, there is no adoption in spite of the higher yields of the new cultivars. At a price discount of 18%, the new sorghum cultivars would substitute for the local varieties. This indicates the importance of further research on the demand side and several Agricultural Research Corporation economists are presently beginning work on the potential demand for the new sorghum cultivars in flour and other uses.

The modeling showed high potential profitability of chemical fertilizer input (46% increase in farm incomes). Due to foreign exchange shortages and even higher returns to fertilizer in the irrigated regions, fertilizer has not been available for this dryland region. The Sudanese government may need to give a much higher priority to the importation of chemical fertilizer for both regions since the potential returns to fertilizer are very high here as well as in the irrigated regions. Finally, moderate improvements in the mechanized farming corporations's recommended rotation, especially increases in sesame yields, could also raise farm incomes (25%) and increase the sustainability of the farming system. (PRF-105)

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

Project PRF-105
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Summary

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The one project with the most progress has been on the introduction of new technologies in the eastern vertisols of the Sudan. This region is a large-farmer, mechanized, almost continuous monoculture sorghum production system. Preliminary model and field-survey results indicate that at the present price discount of the new small-seeded sorghum cultivars of 30 to 35%, there is no adoption in spite of the higher yields of the new cultivars. At a price discount of 18%, the new sorghum cultivars would substitute for the local varieties. This indicates the importance of further research on the demand side and several Agriculturual Research Corporation economists are presently beginning work on the potential demand for the new sorghum cultivars in flour and other uses.

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yields, could also raise farm incomes 25% and increase the sustainability of the farming system.

Objectives, Production and Utilization Constraints

Objectives

To do field surveys of farmers to evaluate adoption of new sorghum technologies on the hillsides of Honduras and in the vertisols of Sudan. On the basis of these surveys, mathematical models of these farms have been constructed to analyze potential adoption and associated agricultural policies. These two areas have often been cited by other INTSORMIL scientists as priority areas for evaluating the impact of new cultivars and other new technologies. This fieldwork was completed in Year 10 and preliminary results from one M.S. and two Ph.D. theses are summarized here.

In Niger, new technology evaluation is underway based upon farm trials in the Niamey region. Preliminary results from a Ph.D. thesis are presented here and compared with earlier results from a Ph.D. thesis finished last year for INTSORMIL analyzing the same trials in the Maradi region.

Modeling of the shift from extensive to intensive technologies in the Central Plateau of Burkina Faso was continued this year. These results are especially relevant to the present concern with the introduction of sustainable technologies.

Production Constraints

In Sudan there is a large price discount for the new sorghum hybrid and other small-seeded sorghums. Demand-side constraints are very important here. For sustainability of the monoculture production systems on the eastern vertisols, chemical fertilizer will need to be made available and improvements made in the recommended rotations such as increased sesame yields and a grain legume.

In Honduras, new sorghum cultivars show economic potential. However, the basic sustainability issue on the hillsides is how to keep the fields from washing down into the valleys. Various walls and ditches are being tested in development programs. The potential effect of the water-retention devices and the new sorghum cultivars will be analyzed here.

In Niger, new cowpea cultivars have improved the profitability of the traditional millet/cowpea intercrop activity. There is increasing evidence that a concentration on earliness in millet cultivars is limiting the potential of new millet cultivars to respond to normal and late rains and to higher input levels. Insect attacks can also be especially serious for early millet cultivars.

In Burkina Faso, there is increasing pressure from population increase and land degradation to utilize more intensive production techniques to increase the productivity of land. The constraints to introduction of these techniques are the difficulties for farmer adoption of the simultaneous introduction of several new technologies, seasonal labor shortages for construction of the water-retention techniques, and cereal price collapses in good rainfall years.

Research Approach and Project Output

Field research and modeling technology evaluation continues in four countries -- Sudan, Honduras, Niger, and Burkina Faso.

Sudan

On the vertisols in the east, approximately 60% of the Sudanese sorghum is being produced. These are large-farmer, mechanized, extensive systems of production. There are small areas of sesame, millet and, in the recent past, cotton. The only soil-fertility measures have been rotations generally including fallow. As higher settlement densities have been established, continual monoculture sorghum is becoming the predominant activity and fallow areas reduced. Neither inorganic nor organic fertilization is utilized so soil mining is taking place.

The farm survey and modeling reported here review the extent of adoption of new technologies in this system, consider the potential economic effects of these technologies, and evaluate other constraints to the introduction of new technologies. The principal sorghum technologies of interest are new cultivars, chemical fertilizer, new rotations, and tied ridges. None of these technologies were being utilized in this region, according to survey results.

There has been substantial research activity to develop new sorghum cultivars in the Sudan. This includes the hybrid Hageen Dura 1 (H-D 1), Gadam el Hamam, and others. In field testing in dryland vertisols from 1979 to 1981, H-D 1 yielded 2.5 t/ha as opposed to 0.715 t/h for the local cultivar (Habash, 1989). After the 1984 drought, the Sudanese government and USAID actively promoted the introduction of H-D 1 in this vertisol region. In the sample, 25% planted H-D 1 in one or more of the years 1983-87. However, in 1988, no one in the sample planted H-D 1. Numerous reasons were cited but the predominant one was the market-price discount for a smaller, harder sorghum than the preferred Feterita or similar locally accepted sorghums.

This market-price discount is the principal explanation for the lack of introduction of the higher-yielding H-D 1 in both the producer survey and the modeling results. A 30 to 35% price discount was the estimated average difference given by the producers surveyed. If the discount were reduced to 18%, then H-D 1 substitutes for the local varieties in the modeling results. Measures on the demand side to find new uses for H-D 1, as in flour, and new governmental measures to equalize the price supports for the two types of sorghum, are both ongoing.

A new pressure to introduce a shorter, more uniform maturing sorghum, such as H-D 1, was brought about by the jump in wage rates in 1988. As a consequence of the good weather, many small farmers did not become seasonal laborers and the sorghum harvest was made more difficult. Large farmers in the eastern vertisols either harvested over a much longer period or left part of their sorghum. Ten to 30% of the sorghum was still not harvested as of May 1989. The predominant local varieties, such as Feterita, are tall and less uniform in maturing; hence, they are much more difficult to harvest mechanically than combinable varieties such as H-D 1 and Gadam el Hamam.

An important innovation for the vertisols is chemical fertilizer. The present system of continuous sorghum with small areas of other activities, such as sesame, mines the soils. (Experimental responses to sorghum in the region are summarized in Habash, 1989.) However, chemical fertilizer has not been available to these large farmers. Chemical fertilizer is imported and Sudan suffers from severe balance-of-payments problems and has not put a high value on these fertilizer imports. Most chemical fertilizers come in as concessional imports. These limited fertilizer quantities are applied in the irrigation districts, where the responses are higher and the risks lower than in the dryland region. Nevertheless, there is a substantial response to chemical fertilizers on these vertisols and this input would introduce sustainability into this production system. With fertilizer supply limited so that only one-third of the crop area could be fertilized and no fertilizer subsidies, farm income would be increased from L.S. 104,874 (Sudanese Pounds) to L.S. 152,660, a 46% increase with fertilization of the sorghum (see Note in Table 1 for the various exchange rates in Sudan), according to model results. The big constraint in obtaining these yield gains is the formulation of governmental policy to facilitate the importation of chemical fertilizer for both the rainfed and the dryland sectors.

Two other alternatives to improve farmers' incomes and the sustainability of these systems are tied ridges and the rotation recommended by the mechanized farming corporation (MFC). This rotation includes two years of sorghum, one year of sesame, and one year of fallow. Data were obtained from experimental and farm-level testing of these two alternatives (for tied ridges, Farah, 1989, ARC, unpublished results). These alternatives are compared for profitability and riskiness with mean values over the period 1981-1989 (Table 1). Profits can be increased and risk reduced with the introduction of tied ridges into either a continuous sorghum system or a rotation. When farmers are confronted with these alternatives, they put 11% of their area into sorghum with tied ridges and 10% into a rotation. The income effects are still very small with only a 2.4% increase in farm incomes, according to model results.

Table 1. Profitability and riskiness of various alternatives available to farmers in the vertisols of the northern Gedaref Region, 1989.

	(Sudanese Pounds Per Hectare)				
	Continuous sorghum	Continuous sorghum with tied ridges	MFC Rotation: sorghum, sesame, fallow	MFC Rotation plus tied ridges	Sesame
Expected profits [a]	351	420	304	244	245
Coefficient of variation	55	49	51	44	88

NOTE: The official international exchange rate in Jan.- Aug. 1989 was 4.5 Sudanese Pounds/$U.S. Banks gave 12.20 L.S. and the street rate was 18 L.S

[a] The gross margin concept of programming was utilized here.

From the sustainability perspective, the decline of soil fertility would be reduced with the introduction of the rotation. An increase in the very low sesame yields (average of 192 kg/ha over the 1981-89 period) by 25% makes the rotation with tied ridges substantially more profitable. This rotation would then substitute for continuous monoculture sorghum and become the principal crop activity. It would increase income from traditional activities by 11%. This type of yield improvement in sesame should be possible by reducing shattering or by other improvements. For future research to improve sustainability, it will be important to get a grain legume into this rotation.

Honduras

In southern Honduras, small farmers produce sorghum, corn, and field beans in extensive systems on the hillsides. The sorghum-corn and the corn-bean intercropping systems help to protect the farmer from rainfall variation and provide better soil coverage on the hillsides than monoculture. More sustainable systems would involve soil-retention measures, fertilization, and new cultivars. Various developmental agencies have been undertaking farm-level testing of all of these technologies. The Ministry of Natural Resources (MNR) and the Agricultural University of Zamorano were both involved in this surveying, which was financed by USAID and MNR. Based upon eight months of fieldwork and surveying by a team, mathematical models of these farms were constructed. Some preliminary results from this research are presented here.

These small farms are characterized by large families, small land areas, low educational levels of the household head, and mixed farming systems. Most of their income comes from off-farm labor and animal sales. Grain sales account for less than 10% of that income (Table 2). Less than 3% of their expenses and very low absolute quantities are spent on agricultural inputs. Twenty-nine percent of their expenses are for grain purchases. These farmers depend upon the grains for themselves and their animals. There is a rapidly increasing demand for animal feed in Honduras.

The introduction of new sorghum cultivars (Sureño and Catracho) substantially increases costs as these short-season, small-stature cultivars require more input purchases on fertilizer, insecticide, and herbicide. These cash expenses for new cultivars and chemicals almost double the expenses for maize-beans double crop and are nine times as high as expenses on the traditional sorghum (maicillo) (Lopez-Pereira et al., 1989, p. 12). Nevertheless, when these new sorghum cultivars are available, they would replace the traditional sorghum and increase crop incomes by 6%, according to model results. In spite of the large increases in purchased inputs required, even with higher levels of risk aversion, farmers still introduce new sorghum cultivars to replace the traditional sorghum.

When the improved soil-conservation techniques are also available, farmers adopt both these techniques and the new sorghum cultivar, increasing crop incomes by 13%. Crop income, including the value of home consumption, increases from $360 to $407/farm with the addition of new sorghum cultivars and soil-conservation techniques. These are still not large income increases but by reducing erosion, the new technologies stabilize the production system and make possible other future improvements in land productivity without shifting cultivation.

Niger

Numerous anthropological studies of small-farmer behavior have pointed out that Nigerien farmers often have substantial cash flows from remittances, off-farm labor, and sales of livestock (see the references in Shapiro, 1989). Therefore, credit is frequently not a constraint to the introduction of new technologies. For example, credit programs to encourage fertilizer consumption in the Sahel have been notably unsuccessful (Shapiro, 1989, p. 4). An alternative explanation for the observed failure of farmers to adopt fertilizer is that they may have alternatives outside agriculture or in livestock production that are more profitable and/or less risky than new technology activities in crop production. Most previous studies have considered only crop activities of the farm rather than other potential activities of the household.

Table 2. Annual cash income and expenses by small farmers in southern Honduras, 1988-89

Source of income or expense	Dollars per year	Percentage of total
CASH INCOME:		
Grain sales	101	10
Farm animal sales	243	23
Remittances	26	2
Off-farm labor	587	55
Forage, firewood	13	1
Other income (a)	91	9
Total cash income	1061	100
CASH EXPENSES:		
Grain purchases	304	29
Farm animal purchases	84	8
Farm labor hired (b)	10	1
Purchased agricultural inputs first season (c)	15	1
Purchased agricultural inputs second season (d)	10	1
Land and oxen rental (e)	60	6
Family-related expenses (f)	562	54
Total cash expenses	1045	100

SOURCE: Socioeconomic survey of farmers in southern Honduras, 1988-89.

(a) Includes sales of fruits and vegetables.

(b) Labor costs: Half of the required labor for one crop in the first season and one in the second season is hired. First-season crops: maize, beans, Ma/Be, or Ma/So. Second-season crops: maize, beans, sorghum, or Ma/Be.

(c) Two of the following crops are produced in the first season: Ma, Be, Ma/Be, or Ma/So.

(d) Two of the following crops are produced in the second season: Ma Be, So, or Ma/Be.

(e) 0.9 ha of land and a maximum of 1.5 days of oxen work are rented in the year.

(f) Includes food (other than cereal grains), clothing, medical and school expenses.

The farm-level modeling in the sandy dune soils near Niamey (Sahelo-Sudanian climatic zone, 350-600 mm of rainfall/year with 50% probability) includes some of these alternative investment opportunities. Dryland farming is based on millet-cowpea intercropping with mixed livestock holdings and minimal purchased inputs. Some of the dryland farmers have small areas (0.4 ha) in the irrigated projects on which they produce rice with high purchased input levels. This supplemental irrigation serves as a base income for these farmers. Nevertheless, these farmers also stay heavily engaged in their dryland crop activities.

The modeling considers the viability of several new dryland technologies in these farming systems. These technologies include new millet and cowpea cultivars with the cowpeas planted at low and at high densities. At the lower densities there were higher millet yields. It is necessary to utilize the higher densities of the improved cultivars to obtain the maximum effects from cowpeas. Secondly, fertilization with P and N is applied to the new cultivars. Expected farm incomes are increased by 38% per hectare with new cultivars at higher densities and by 51% with both new cultivars and fertilization, according to the budgeting analysis (Table 3).

Dryland farmers earn 116,710 FCFA ($392/U.S.) from their traditional millet/cowpea activities on 3.9 ha, according to model results. If fertilization and improved cultivars are available, only the improved millet/cowpea cultivars (with higher densities) are introduced and incomes are increased to 192,018 FCFA ($644/U.S.), a 64% increase in farm incomes. However, this is not a sustainable system as it will mine the soil nutrients.

Farmers prefer to utilize fertilizers during the crop season so that they can observe the rainfall and make adaptive decisions. When there is a 15% yield discount from the post- planting application of fertilizer as there is with low initial soil fertility, the later fertilization option is not selected by farmers in the model results. In contrast, on higher P level soils, there was no discount in yields and the fertilization option was utilized on small areas. However, this increased incomes only another 2%. Moreover, the fertilizer was not utilized when the rains began early. The reason for this apparently counter intuitive result is that only early or short-season improved cultivars are available. These cultivars are not able to take advantage of those years with a longer rainy season. If normal or late-season improved cultivars had also been in the crop mix, the model solutions would be expected to include them with fertilization when the rains are early.

The recent emphasis in millet breeding has been upon earliness. Early millet cultivars often experience a high incidence of head girdler (ragouva) infestation. Moreover, the earliness characteristic makes the new cultivars unable physiologically to take full advantage of the normal or longer rainfall season. So the breeding strategy of earliness introduced to reduce the risk from short seasons and irregular rainfalls reduces the potential for the material in better or even normal rainfall years.

Table 3. Yields and profitability of various new technologies in the dryland system, Niger, 1988.

Technologies	Millet yields	Cowpeas grain yields	Cowpea hay	Net returns[a]	
		(Kg/ha)		(FCFA/ha)	($U.S./ha)
Traditional millet cowpeas	272	22	416	34,797	117
Improved cultivars of millet/cowpeas (low density)	328	51	355	36,234	122
Improved cultivars of millet/cowpeas (high density)	292	47	732	47,808	160
Improved millet/ cowpeas with P and N[b]	426	61	764	52,732	177

Note: Historic yield and price data are from farm trials of INRAN and ICRISAT. These were combined with estimates of the probabilities of various states-of-nature based upon rainfall data. The above yield and profitability estimates are expected values. The average exchange rate in 1988, 298 FCFA/U.S.$, was utilized here.

[a] These are net returns to family labor, management, and land.
[b] The millet is fertilized with 100 kg of simple superphosphate and 50 kg Urea.

Since farmers choose a portfolio of cultivars and crops, research institutions need to make available material of different maturity periods.

Absolute incomes and income increases from traditional and new technologies were substantially higher in the Niamey region than in Maradi. With traditional technologies, farmers' expected crop incomes were $392 in the Niamey region and $178 in Maradi. With the improved agronomy, incomes were $644 and $222, respectively (Adesina and Sanders, 1989 -- income estimates adjusted to utilize the same exchange rates). Some factors contributing to these differences were the high values of cowpea hay in the Niamey region and slightly larger farm sizes there, 3.9 ha of dryland area in Niamey and 3.5 ha in Maradi.

Burkina Faso

Previous research demonstrated the economic viability of more intensive technologies on the better lands, i.e., tied ridges and chemical fertilization of sorghum. However, according to model results, farmers prefer to adopt animal traction and extend the cultivated area rather than to take full advantage of these intensive options (Sanders et al., 1989).

This farmer choice was consistent with the availability of land and labor. However, as the fallow system decreases in importance and farmers still do not purchase chemical inputs, soil mining continues. The supply of bush-fallow land, which once was easily accessible, becomes less so. The utilization of bush-fallow land then becomes more expensive. Crops now grown on these bush-fallow fields lying farther away from the farm household have a premium attached to them in terms of scarce labor hours spent getting there, an extra hour per work day on these fields in the modeling.

Before the utilization of bush-fallow became more time-intensive, traditional technologies could make $511/yr. Farmers facing the choice between extensive and intensive technologies would select the former and increase farm incomes to $588/yr, principally with the introduction of animal traction. When the farmer is confronted with higher costs of bush-fallow utilization, he chooses to expand intensive methods onto 0.7 ha of the 1.4 ha of the better soil area potentially available for this sorghum activity, thereby increasing farm income to $618 (Ramaswamy and Sanders, 1989). Without this shift to more intensive techniques, the increased time requirements for travel to the bush-fallow fields would have reduced incomes from traditional activities to $458. Hence, with an increasing supply cost of land, the intensive technologies enable a 35% increase in incomes. Moreover, this intensive technology is also sustainable on part of the farm as it builds up soil fertility and reduces the risk from the irregular availability of water with the construction of tied ridges.

The farmer is constrained from further area increase of the intensive technology by the seasonal labor-supply constraint, in spite of the utilization of donkey traction for several farm operations. Nevertheless, the modeling shows a clear evolution towards more intensive techniques as land supply becomes more inelastic. This is consistent with the theory of population pressure, encouraging more intensive utilization of the higher-quality land. The practical problem is the simultaneous introduction of a water-retention technique, chemical fertilizer, and animal traction. Farmers tend to adopt one component at a time rather than a series of technologies. Nevertheless, the modeling results indicate the potential of these combined innovations to increase incomes and sustainability of the system.

Networking Activities

In July John Sanders participated in a workshop at the University of Nebraska for World Bank-USDA officials on sustainability issues in agricultural development. He presented a paper on INTSORMIL research activities and sustainability in the Sahel.

In the winter Sanders served on the BIFAD-AID panel on sustainability in international agricultural development programs. As part of this activity he attended two two-day sessions in Washington and contributed to the report and recommendations of the panel.

In the spring Sanders collaborated in a project to study optimum colonization projects in areas cleared of river blindness in Burkina Faso. This study included the evaluation of the introduction of new agricultural technologies over time in these prime agricultural areas. Under the auspices of the study, two weeks of field time was spent in Burkina Faso and a paper analyzing the sources of income for settlers in six colonization projects was written. This project was managed by the World Bank and the Institute of Development Anthropology.

Publications and Presentations

Publications

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Presentations

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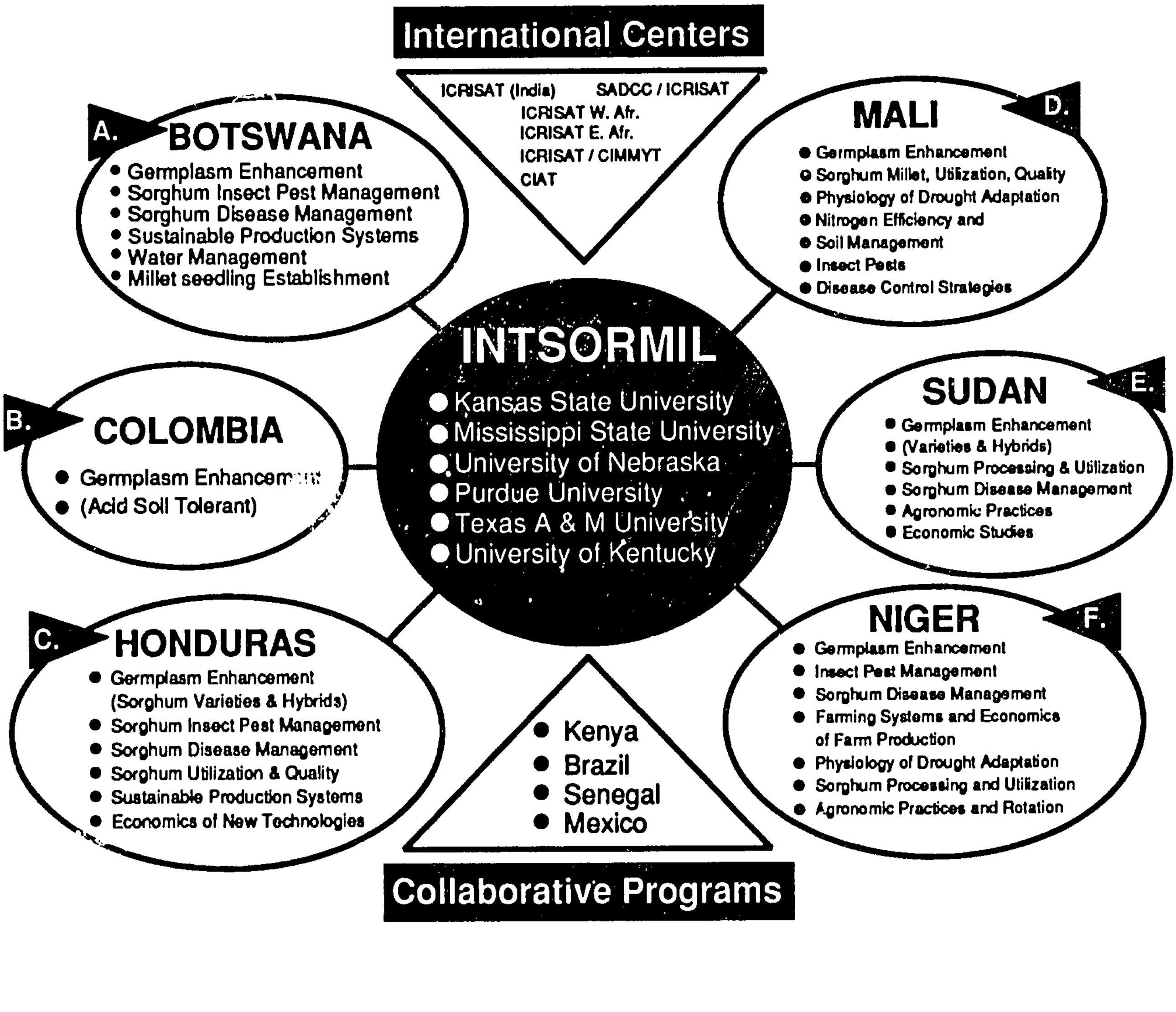
INTSORMIL Collaborative Sites



1989 Country Reports

Summary of Research Accomplishments

The Sorghum/Millet CRSP has developed an administrative structure where a U.S. Principal Investigator and a Host Country Collaborating Scientist serves as co-country coordinators for each of the Prime Sites and the Collaborating country sites. In most cases there is a country program budget which is passed through to the national program in support of local research and short term training activities. The country program concept was developed to encourage multidisciplinary collaboration at each of the international sites. The country coordinators are responsible for encouraging and developing this multidisciplinary cooperation. In most cases there are two to three U.S. Universities collaborating at each host country site involving three to five disciplines.

Funds from the country project budgets have been very useful in providing support for host country collaborators to visit counterpart programs in the United States, to obtain scarce research supplies in support of host country research , to purchase equipment to facilitate collaboration and to provide some limited recurrent research costs necessary to implement CRSP research in the country.

The annual Country Reports document the level of research collaboration that is taking place within a country program. It is significant to note the level of collaboration that is taking place. It is also important to note that the country reports in this document reflect joint planning, joint implementation of research and joint publication of research results.

The progress in this program is reflective of the interest and cooperative spirit that has developed between the U.S. researcher and the Host Country researcher under the collaborative mode.

Botswana

During the time that INTSORMIL has been involved with research at the prime site there has been a drought in Botswana--six of seven years. This has led to more effort being devoted to moisture conservation than originally planned. Dr. Douglas Carter of KSU-107 has been at Sebele for four growing seasons and has established several studies of soil management practices that influence the amount of water for crop growth. These studies involve the use of crop residues 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. As might be expected, any practice that results in more water in the soil will probably increase yields provided stand establishment and weed and pest control are not adversely influenced by the practice. The soil physicist position was added to complement the work being done by both the INTSORMIL and ATIP scientists at Sebele, Mahalapye, and Francistown. This builds on the soils report produced by the Soil Conservation Service, USDA/SMSS on data on 22 soils of Botswana.

Continued training and interaction between breeding, pathology, and entomology programs are strengthening the DAR research capability. However, additional training programs need to be initiated as qualified people become available.

Collaborative work in the area of phosphorus fertility, which would relate both to grain yield and forage quality for animal production, has been proposed.

Dr. Lucas Gakale has moved from Chief Arable Research Officer in DAR to Director of DAR.

Colombia

Research conducted by INTSORMIL in collaboration with ICA and other organizations in Colombia has attracted private sector funds to further long-term research goals in Colombia. The El Alcaravan Foundation has provided substantial operation and training funds for research conducted in the Territory of Arauca.

First generation Al-tolerant sorghum hybrids from Projects MSU-111 and MSU-104 are being evaluated for grain yield and agronomic desirability in Colombia, Niger, and the U.S. Additional R-lines and A/B-lines developed for the humid tropics at this collaborative site are being evaluated in Colombia, Brazil, Niger, Kenya, and in the SADCC region of Africa.

Three universities in Colombia, the National University of Palmira, University of Tolima, and University of Los Llanos have teaching staff collaborating with INTSORMIL on sorghum and millet research through student thesis research. This assists INTSORMIL and ICA to conduct research projects at a very reasonable cost and has the additional benefit of identifying students for graduate programs in INTSORMIL Universities.

Honduras

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 with 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. An estimated 244,600 pounds of planting seed of improved sorghum was produced in 1987, of which 150,900 pounds was of Sureño.

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 will be used in extensive on-farm trials in 1989. 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 to the local cultivars which should make them acceptable for food use.

The parental lines of the sorghum-sudangrass F_1 hybrid (ATx623xTx2784) were increased in anticipation of release in early 1990.

Major emphasis in the breeding program is to improve the traditional maicillos criollos which occupy approximately 90% of the sorghum growing area in Honduras and 70% of the sorghum growing area in Central America. Improved photoperiod sensitive maicillo breeding lines have been developed and are under intensive station and on-farm testing in Honduras as well as in El Salvador and Guatemala. Some lines appear very promising and should be released soon. Objectives are to improve yield potential, disease resistance, and grain quality. The improved maicillo lines not only show improved yield over the local maicillos criollos, but in certain intercropping systems with maize, their shorter height is apparently less competitive, and maize yields are increased.

Hybrid maicillos have shown a tremendous yield advantage over local maicillos criollos varieties. Breeding for hybrid maicillos has become a priority breeding objective. Some B-line improved maicillos have been identified and are being sterilized.

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 has been 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 sorghum line, AF28, and TAM 428 and several 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.

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 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. Seventy-five participants from eight countries presented 40 papers on food quality and utilization, production technology, disease and insect control, and genetics and breeding aspects of the maicillos criollos.

Mali

INTSORMIL has been in Mali informally since November 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 the efforts morally and financially through additional 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 PhD. degree in physiology at the University of Nebraska. Scientists trained in Food Technology, Pathology and Agronomy have returned to Mali and collaborate in the program.

Ten graduate students are training in INTSORMIL universities to provide personnel to continue the programs. The programs include Agronomy, Breeding, Physiology 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 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 reduce sorghum yields and reduce milling yields and give tô with unacceptable texture and keeping properties.

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 7 has shown some advantages in multiple cropping systems. Malisor 84-7 has excellent resistance to head bugs. It appears to be the only improved sorghum with the necessary level of 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.

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. Dr. Traore's program on drought physiology has been supported with acquisition of computers and major equipment for physiology research.

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

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 Nigerian 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. Ouendeba will undertake a pearl millet diallel using six agronomically superior millet populations. The project is collaborative between Dr. Kumar, Dr. Hanna and Dr. Gebisa.

Dr. Omer El Hilu, (ARC/Sudan) working with Richard Frederiksen (Texas A&M), and John Clark (Purdue/INRAN NAAR Project) will initiate 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.

Paraguay

Prior to this year's research program the INTSORMIL sponsored researcher left Paraguay to return to the U.S. This caused a substantial reduction in the activities, research and liaison which were needed. However, several trials of experimental sorghum hybrids for grain, food and livestock forage were continued by the Ministry of Agriculture and Mennonites in the Chaco.

Selected grain hybrids evaluated at Filadelphia were a continuation of the best tan plant, white grain types previously evaluated in Paraguay. The two top yielding hybrids A155*R8505 and AVar*RTx435 produced more than 40% more grain than Dorado which has a good history of production in Meso America. The hybrids produced more than 27% greater yield than the widely used red seed hybrid ATx378*RTx430. Yield of grain ranged from 3777 kg/ha to 2537 kg/ha in the trial at Filadelphia. There was very little variation in the time required to reach anthesis. Most hybrids required about 61-62 days. The more productive hybrids were from 1.1 to 1.4 m tall. These results were consistent with data collected previously at Filadelphia. This very dry environment produces grain of the white pearly types that is of excellent quality. This quality is important to the use of sorghum flour made from this grain.

During the last three years the Mennonites have developed the technology to produce hybrid sorghums for forage--grazing, silage and green chop. They are now producing four such hybrids for use throughout the colony. Production last season was near 70 tons of cleaned salable seed. It is planned for 1989-90 to plant 50 ha of Fredy; Chaco-1 20 ha; Chaco-01 20 ha; Chaco-88 20 ha; plus three others for a total seed production of 200 ha. With very little input and a great deal of patience there has been a significant development of the private seed production capability in the Chaco. Sorghum is now a real and productive commodity in this region. Its popularity continues to grow. The Mennonites now are ready to produce their own grain sorghum hybrids which require more sophisticated technology.

The experimental farms at Loma Plata and Para Todo have experimented with the forages which they produce. They have developed planting density, frequency of cutting, fertilization schedules, etc., for each type of hybrid produced. Data were accumulated at Para Todo for individual and total forage yields for Fredy, Chaco-88, Sudax SX121 and Greenleaf Sudangrass. Fredy produced more green biomass on the ratoon than on the first seeded crop, even though it lost some of its plant numbers in regrowth. Chaco 88, which was not as productive as Fredy, did ratoon better. The ratoon capability of Greenleaf Sudangrass was clearly demonstrated.

These results indicate the progress being made in Paraguay by the MAG and Mennonites to develop a sound sorghum industry. The constraints to sorghum development were misinformation, poor or no quality seeds for planting, and no understanding of the potentials for sorghum. Basic experiments and demonstration plots have aroused widespread interest in sorghum because of its drought tolerance and uses as feed, food and forage. Both MAG and the Colonies have developed a solid base of agronomic data for agronomy and seed production. There is a substantial need for some continued support by INTSORMIL to provide leadership and backstopping for this developing industry in a developing country.

The research information being obtained in Paraguay is strengthening the hybrid seed industry by demonstrating the multiple uses of sorghum, i.e., for feedstuffs as well as for human food. As we gain information on quality traits impacting food usage we expand our knowledge base for using sorghum as a food resource in the U.S.

Senegal

Because of strict adaptation requirements, both physical and biological, genetic material introduced from outside West Africa is unlikely to be successful in the normal rainfed conditions in Senegal. Accordingly, crosses were planned and made in 1988 and early 1989 between INTSORMIL pearl millet and sorghum stocks and Senegalese and other West African parents. The F_1's and F_2's will be grown for selection in Senegal in 1989.

Michigan State University is the lead institution for implementing the Senegal Agricultural Support Project II funded by USAID/Dakar (#685-0957) which terminates in June 1990. For cereals, this project, in accordance with the existing Senegalese government plan, focuses on diversifying cropping in the Senegal River Valley where a very large expansion in the irrigated area is planned. "Decrue" sorghum (a low input, low production system dependent on river flooding) will no longer exist, but irrigation will provide other opportunities for more productive cropping.

To plan the research, Mr. Fofana first visited the University of Nebraska sorghum and pearl millet improvement projects in October 1988. This was followed by a visit in December by Mr. Andrews to meet Drs. L. Cisse, Demba M'Baye, Claude Luce of ISRA, and Dr. Ouedraogo of Michigan State University. A tentative plan was drawn up where support was given to CNRA Bambey for the increase of sorghum and pearl millet materials in the 1988/89 off-season and to conduct funded tests in the Flueve Senegal, in both the following wet and dry seasons, at a total cost of about U.S. $50,000. Further material was sent directly for these tests from several INTSORMIL projects (NU-115, -116, -118, TAM-121 and 122).

Sudan

INTSORMIL activities in Sudan began in November 1980, with the signing of a memorandum of understanding with the Agricultural Research Corporation (ARC) and the University of Khartoum faculty of agriculture. This agreement led to the placement of Edward B. Reeves and Timothy Frankenberger (University of Kentucky economic anthropologist) in El Obeid from July 1981 through August 1982. These social scientists carried out farming and marketing system studies in 15 villages located within 50 km of El Obeid to collect baseline data for the western Sudan Agriculture Research Project, Kordofan Regional Ministry of Agriculture, and INTSORMIL. Among other things they found that the farmers of the region are producing millet and sorghum for home consumption and sesame and ground nuts for sale. They identified wind erosion, pests and diseases, low soil fertility and inadequate rainfall as the most important natural constraints limiting crop production. To combat inadequate rainfall, they recommended the introduction of early maturing drought-resistant varieties of present crops as well as new drought-resistant crops.

In March 1982, scientists and research administrators associated with ARC were interviewed and documentary data on research plans were collected by Larry Bush and William Lacy (University of Kentucky). They found that the ARC scientific community is well trained. The research conducted by ARC scientists is generally of an applied nature. They also found that while ARC scientists consider financial support and operating supplies and material the most important resources for their work, these same resources were also generally regarded either as the least adequate or often inadequate. Many of the findings from this study were used to develop the ARC/INTSORMIL cooperative scientist research program.

During the 1982 through 1984 cropping seasons, Tareke Berhe (Kansas State University) carried out agronomic research in the El Obeid area of North Kordofan. This agronomic work targeted many of the natural constraints identified by Reeves and Frankenberger. Major accomplishments of the research work included (1) identification of an early maturing millet variety (Ugandi, developed by the ICRISAT/Sudan program) having goo' 'eld potential with limited rainfall, and bristles rend. .ig protection from the birds, mice and grasshoppers, and (2) establishment of an on-farm sorghum/millet testing program in cooperation with the Kordofan Regional Ministry of Agriculture. This on-farm testing program continues to be used by the Regional Ministry today as a measure of introducing new crop varieties and technologies to farmers.

In collaboration with scientists at ARC and INTSORMIL, the ICRISAT/Sudan cooperative breeding program released the first sorghum hybrid (Hageen Dura-1) in January 1983. Hageen Dura-1 (HD-1) is a superior hybrid with yields of over 150% of those of improved local varieties under irrigated and rainfed conditions. HD-1 possesses several important attributes including high yields, drought tolerance, and good grain quality characteristics that helped its rapid spread and wise acceptance by farmers.

The Food Research Centre has demonstrated that HD-1 grain is easily decorticated. Thus, it produces a high yield of white sorghum flour suitable for making good quality bread with a composite flour containing up to 40% HD-1 decorticated flour. INTSORMIL sponsored a workshop on hybrid sorghum seed at Wad Medani in November 1983. Detailed discussions at the workshop, involving scientists, administrators, policy makers and interested private entrepreneurs, focused on effective marketing and government policy considerations that would encourage seed industry development in the Sudan. Concrete recommendations for developing a seed industry were submitted to the Government of Sudan.

A study of the communication of agricultural information in Sudanese villages was done by C. Milton Coughenour (University of Kentucky) and Saadi M. Nazhat (graduate student) around El Obeid in 1984. They found that INTSORMIL's farm trials conducted by Tareke Berhe provided an excellent means of informing farmers about the characteristics of new sorghum/millet varieties. They also learned that information about an innovation spreads among Sudanese farmers much as it does in more developed communities (an S-shaped growth curve over time).

The ARC/INTSORMIL research program at the Gezira Research Station has been designed to strengthen ARC sorghum/millet research and training activities. These have been combined to facilitate attainment of the long-term ARC objectives. Although the program started in 1980, INTSORMIL funds were not transferred to ARC until 1984. The primary disciplines involved in ARC/INTSORMIL collaboration are breeding, stress physiology, plant pathology, entomology, *Striga*, cereal quality and agricultural economics. Some of the major accomplishments from the ARC/INTSORMIL program are listed below.

Cooperative ARC/INTSORMIL crop physiology and breeding work on drought tolerance of sorghum has led to a better understanding of crop adaptation to stress. Sorghum lines with preflowering stress tolerance were found to accumulate a significantly higher concentration of certain metabolic osmolytes than drought susceptible cultivars. Sudan is an excellent location for screening for drought stress. Some of the best new sources of drought tolerance for use in the ARC and U.S. sorghum improvement programs have come from screening INTSORMIL germplasm in Sudan.

In 1981/82 over 40 Sudan sorghum varieties were collected in the Kadugli and El Obeid area and introduced in the U.S. for conversion and breeding lines. In addition, a number of elite Sudanese breeding lines have been selected and transported to the U.S. for the same purpose. These lines should be very useful in broadening the sorghum germplasm base available in the U.S. and as sources of desirable grain quality traits.

An inoculation technique for long smut has been developed in Sudan. This technique provides sorghum improvement programs with a method of evaluating germplasm for host resistance and is the first of its kind in the world. The inoculation technology was extended to Niger during the 1987 crop year. Work in Sudan on the histology of the infection has shown that long smut is not a seed born pathogen and can only infect sorghum flowers.

Work on the food quality of sorghum by ARC/INTSORMIL has shown that a fermentation process, commonly used to prepare most Sudanese sorghum foods, improves the protein digestibility of cooked sorghum products. This work has led to a better understanding of the factors that influence sorghum protein digestibility and work is now in progress to apply this new knowledge to improve the digestibility of sorghum when used as an animal feed in the U.S.

Botswana

R. L. Vanderlip
Kansas State University

Prime Site Coordinators

Dr. R. L. Vanderlip, Department of Agronomy, Kansas State University, Manhattan, KS 66506 (U.S. Coordinator)
Dr. Lucas Gakale, Director, Department of Agricultural Research, Gaborone, Botswana (Host Country Coordinator)

Collaborative Program

The Botswana project was initiated in July 1983 and staffed in April 1984. The project operates by approval of the U.S. Government under the provisions in Grant A.I.D./DSAN/XII-G-0149 to the University of Nebraska, The Management Entity (ME). The Memorandum of Understanding between the Government of Botswana, USAID/Botswana, and the INTSORMIL ME describes the operational procedures. Funding for the project is provided by the Government of Botswana, University of Nebraska (KSU-107) and the Agricultural Technology Improvement Project (ATIP-USAID project 633-0221).

The Department of Agricultural Research (DAR) provided the project with four technical assistants during the year, Mary Molefe, Luciah Morolong, Davies Chepete and G. Moroka. Mr. Neiso Mokete who recently earned his B.Sc. and returned from Kansas State University was seconded to the INTSORMIL collaborative program. Office space, supplies, agricultural implements and material, and casual labor were also provided by DAR. Project operational expenses are managed through an INTSORMIL revolving fund and an ATIP fund.

The program in Botswana can be divided into two interconnected, but very different components.

1. INTSORMIL researchers stationed in the country (KSU-107).

At the time the Agricultural Technology Improvement (ATIP) project was initiated in Botswana, a cereal agronomist position (Dr. Douglas Carter), which initially was to be part of the ATIP program, was shifted to INTSORMIL for salary and partial research support. In December, 1987, after approximately two years of planning and preparation, a second position in the area of soil physics (Dr. Naraine Persaud) was added. Both positions are considered administratively part of the Department of Agricultural Research (DAR) and are under the direction of the Chief Arable Research Officer. Primary emphasis for this part of the program has been on water management, both small scale and large scale water harvesting practices, an area which the DAR did not have researchers actively pursuing, and manure and residue management. With the addition of the Land and Water Management project from SACCR, this whole area has been greatly strengthened, and INTSORMIL researchers are working closely with them.

2. Direct scientist to scientist collaboration in the areas of agronomy, plant breeding, plant pathology, and entomology.

More complete details of the collaborative nature of these programs can be found in the individual project reports. Primary collaboration in the agronomic area has been between Dr. Max Clegg (NU-113) with Dr. Lucas Gakale of the Department of Agricultural Research, and between Dr. Richard Vanderlip (KSU-106) with ATIP agronomists Jay Siebert, Geoff Heinrich, Elijah Modiakgotla, and Syani Masikara. In plant breeding, the DAR plant breeder, Louis Mazhani, is working closely with David Andrews (NU-115). Plant pathology and entomology work has been collaborative between Texas projects TAM-128 (Dr. Gary Odvody) and Baikabile Motalaote and TAM-125 (Dr. George Teetes), and TAM-123 (Dr. Gary Peterson) and Chris Manthe, respectively. INTSORMIL scientists in Botswana have also been involved, ranging from collaboration in experiments to logistic and advisory capacities.

Financial Inputs from Local A.I.D Mission

AID/Botswana provides housing, utilities, health care and communica- tions for INTSORMIL scientists in Botswana and their R & R, home leaves, and the return to their home base in the U.S. Without this financial support, it would be impossible to maintain the in-contry program with the present INTSORMIL budget. ATIP has provided supplies, editorial assistance, and equipment for the INTSORMIL researchers. DAR provides office space, one vehicle, three technicians, additional casual labor, and the use of land and facilities with an estimated value of $30,000 per year.

Collaboration with Other Centers

The water harvesting work is being conducted in collaboration with the SACCR Land and Water Management project and ATIP. The plant breeding program has close linkage with the ICRISAT breeding program at Bulawayo, Zimbabwe, and has been used for off-season testing of material jointly developed by Louis Mazhani and David Andrews. Similarly, Chris Manthe's research program for his Ph.D work has been conducted at the Bulawayo site to reduce the competition for his time by day to day activities at Sebele. Chris will return to Texas A&M in the winter to complete his Ph.D. As the ICRISAT program at Bulawayo gets more fully underway, I would expect greater linkage with ICRISAT, not only in Botswana but in the other southern African countries.

The Planning Process

While exact mechanisms of research planning vary widely among the collaborative projects, in each case scientists and/or administrators of DAR are involved in the planning process. For example, Gary Odvody TAM-128 spent from March 27 through April 18, 1989 in Zambia, Zimbabwe and Botswana coordinating plant pathology research and evaluating pathological problems in southern Africa. Details of this trip and research program are available in his trip report and annual report. Most recently, R. L. Vanderlip, Botswana Prime Site Coordinator, and M. D. Clegg, NU-113 PI, participated in the DAR annual Planning Workshop.

Sorghum/Millet Constraints Researched

Production Constraints

As described in the global plan, the general constraints to sorghum/millet production in southern Africa in general, and Botswana in particular, are:

Botswana has extreme variation in the amount and distribution of rainfall, both from year to year and location to location. The farmers' practice of planting following each significant rainfall to reduce risks is indicative of this very uncertain weather pattern. Although most of the cultivated soils are sandy, they tend to crust, which increases runoff, cause problems in stand establishment, and have very low waterholding capacities. Added to these problems are insects, particularly sugarcane aphid on sorghum, weeds, and diseases.

Solutions to the constraints listed are also affected by the lack of producer incentives, place of crop production in the general farm economy, and the lack of trained personnel even at the baccalaureate level.

Research Methodology

Because of the diverse nature of research being conducted, it is not possible to outline specific research projects. The methodology, however, ranges from detailed measurements on experiments conducted on the research station at Sebele to simple on-farm trials in collaboration with ATIP researchers and surveys of problems in farmers' fields.

Research Progress

Results from the rainfall runoff study showed the soil moisture storage was significantly increased, however, subsequent poor plant establishment coupled with a severe infestation of stalk borers necessitated crop destruction and replanting. Any benefit from the additional stored soil moisture was negated by suboptimal management. Two items are important from this experience: a) water harvesting systems successfully captured runoff water which otherwise would not have been available to the crop and b) successful application of water harvesting technology must be linked to management practices which will achieve appropriate plant populations and pest control.

Results from the National Tillage trials showed that early tillage frequently increased soil water storage which in many cases was effective in increasing grain yields. At some sites this coupled with a small (15 kg P/ha) phosphorous application resulted in yields being doubled or tripled.

Disease problems in the region varied greatly. However, this did allow for identification of management practices and resistance to a number of diseases. For example, in Zambia, anthracnose varied from being devastating to having little effect. The lack of anthracnose problems in one area appeared to be related to growth stage of the sorghum rather than resistance. In Zimbabwe, in an area of pearl millet production with a fairly high incidence of ergot, the variety ICMPES 28 had no ergot and appeared to perform better than the hybrids present.

Collaboration continued with Mr. Louis Mazhani on pearl millet and sorghum breeding for Botswana.

Half-sib recurrent selection was continued on the Botswana adapted version of pearl millet population

Serere 6A, which is already widely grown by farmers. Besides selecting the best families for recombination, selfed plants from within a few superior families were identified to form an experimental variety. These recombinations were made at Mzerabani with the assistance of SADCC/ICRISAT.

In sorghum, the process of selecting superior lines and producing seed parents was continued with germplasm derived from crosses of Botswana varieties x NU-115 stocks. Sixty-two selections were retained and the testcrosses with some of these which were sterile were backcrossed. This was continued in the winter nursery. Mr. Mazhani conducted his thesis experiments at six locations in Botswana to look at stability characteristics of sorghum cultivars of different constitutions. The constitution types were single varieties, mixtures of varieties (variety multilines), hybrids, hybrid mixtures, and random-mating populations.

Mutual Research Benefits

Two specific examples of mutual benefit are:

1) Identification of resistance to the sugarcane aphid and identifica tion of predators that attack the aphid have been found. These should directly affect the problems of sugarcane aphids on sorghum in Botswana and provide known resistance should the aphid become a problem in the U.S. In addition, predators collected in Botswana likely have potential as biologi cal control agents of greenbug and other aphids in the U.S.

2) Because of the joint use of U.S. and Botswana materials in the sorghum and millet breeding programs in Botswana, the adaptation of the local materials is retained with the introduction of characteristics from materials from the U.S. Conversely, the introduction of pearl millet germplasm from a very drought prone area, such as Botswana, should benefit the emerging pearl millet breeding programs in the U.S.

Institution Building

Principal expenditures for research equipment, vehicles, etc., have been made in previous years and only modest expenditures for equipment for the soil physicist position and the usual day-to-day expenses of in-country research have been provided in this fiscal year. However, it should be noted that this is from the INTSORMIL projects directly stationed in Botswana, other collaborative projects, and from AID/Botswana support through ATIP.

Dr. Lucas Gakale, who received his Ph.D. from the University of Nebraska, was appointed Director of DAR. Mr. O. Mmolawa has been appointed Chief Arable Research Officer. Chris Manthe has completed his formal course work and qualifing examinations at Texas A&M University, is conducting research for his Ph.D. dissertation in entomology, and will return to Texas A&M to complete his Ph.D. Chris is the only entomologist in DAR in Botswana. Louis Mazhani, who received his M.S. degree at the University of Nebraska, has completed course requirements for the Ph.D. degree at Nebraska and is doing research toward his dissertation in Botswana. These ongoing degree program candidates are in addition to Baikabile Motalaote, who received an M.S. degree in plant pathology from Texas A&M in 1985, Elijah Modiakgotla, who received an M.S. degree from Kansas State University in 1985 and, although not funded by INTSORMIL, Phodiso Gaosegelwe who received an M.S. degree from Kansas State University in 1988 and returned to work at Gumare. Boi Sebolai, statistician at DAR, completed an M.S. degree in statistics at the University of Nebraska. Through the SADCC/ICRISAT/INTSORMIL training program, approximately 40 students from the SADCC countries were in the U.S. working on degrees at INTSORMIL institutions.

In addition to those scientists discussed in the section above who were in the U.S. at least part of the time working toward degree programs, Molapo Qhobela from Lesotho is working on a Ph.D. in plant pathology at Kansas State University and Dollina Malepa is working on a Ph.D. in soil fertility at the University of Nebraska. Each of the U.S. PIs associated with the research programs in Botswana, David Andrews (NU-115, NU-118), Max Clegg (NU-113), Gary Odvody (TAM-128), George Teetes (TAM-125), and R. L. Vanderlip (KSU-106 and KSU-107) was in Botswana and in many cases other SADCC countries during the year coordinating research or initiating new collaborative projects.

Networking

Because the INTSORMIL researchers are working directly with Department of Agriculture researchers, there is direct communication of research results. In addition, research plans and research reports of the Botswana project KSU-107 and, I'm sure, many of the other research reports, are shared with DAR. Because of the close linkage with ATIP, much of the research results also are disseminated in the Francistown and Mahalaype areas. Dissemination over the southern Africa region occurs primarily through contacts within SACCAR which is housed with DAR at Sebele and through the ICRISAT regional program at Bulawayo, Zimbabwe. The second global conference on sorghum and millet diseases was held at Harare, Zimbabwe, March 7-11, 1988. Approximately 30 scientists from all areas of the world attended the conference which was aimed at reviewing the progress which had been made since the 1978 conference and making recommendations for priorities in sorghum and millet pathology research in the future.

General Comments

I believe the greatest impact that INTSORMIL can have on sorghum/millet research in Botswana is through training local Batswana in research methodology and subject matter areas. With the small number of trained people available in the country, this will require training many more people simply to fill the positions available. As has already occurred with Lucas Gakale, researchers will move into administrative positions and, as has occurred with some of the people trained under the ATIP program, they will move out into private sector positions. One encouraging aspect is the development of a School of Agriculture in the University of Botswana. Incidentally, another of the INTSORMIL trained people, Miranda Mortlock, has been hired to teach two courses at the University of Botswana.

One problem associated with the lack of trained people in the country has been identified in Chris Manthe's research program. Since he was the only Ministry entomologist in the country, most of his time, after he returned to Botswana, was on the locust control program and not on his dissertation research. This happened with Mr. Manthe when all concerned knew it was not appropriate. He, therefore, did his research in Zimbabwe in order to be able to complete the Ph.D. program. Thus, the positive effects of students doing their research in their home countries are only effective if they have the time and resources to complete that research.

Work in Botswana should relate very well to the drier sorghum and millet growing regions of the other SADDC countries. It is fortunate that the SACCAR headquarters is at Sebele. The Land and Water Management project is based at Sebele and there are good working relationships with the ICRISAT/SADDC program in Zimbabwe.

Research Accomplishments

During the time that INTSORMIL has been involved with research at the prime site there has been a drought in Botswana - six of seven years. This has led to more effort being devoted to moisture conservation than originally planned. Dr. Douglas Carter of KSU-107 has been at Sebele for four growing seasons and has established several studies of soil management practices that influence the amount of water for crop growth. These studies involve the use of crop residues 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. As might be expected, any practice that results in more water in the soil will probably increase yields provided stand establishment and weed and pest control are not adversely influenced by the practice. The soil physicist position was added to complement the work being done by both the INTSORMIL and ATIP scientists at Sebele, Mahalapye, and Francistown. This builds on the soils report produced by the Soil Conservation Service, USDA/SMSS on data on 22 soils of Botswana.

Continued training and interaction between breeding, pathology, and entomology programs are strengthening the DAR research capability. However, additional training programs need to be initiated as qualified people become available.

Collaborative work in the area of phosphorus fertility, which would relate both to grain yield and forage quality for animal production, has been proposed.

Dr. Lucas Gakale has moved from Chief Arable Research Officer in DAR to Director of DAR.

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/U.S.A.I.D. collaboration with INTSORMIL/SRN sorghum research activities. This MOU was requested by U.S.A.I.D. to formalize its local currency contribution to Meckenstock through EAP. A MOU exists between INTSORMIL and the Honduras Institute of Anthropology and History (IHAH) but has been inactive the past three years.

Program Structure

The collaborative program in Honduras focuses on 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 returned to Honduras in late 1986 with a Ph.D. degree in plant breeding from Texas A&M University, and took a position as sorghum breeder and Head of the SRN National Sorghum Program. He is assuming a major role in the sorghum breeding effort and is located at Choluteca, the center of sorghum production in southern Honduras. Meckenstock offices at the Panamerican Agricultural School (EAP) at Zamarano, a short drive from Tegucigalpa. His major responsibilities include support and coordination for several 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 collaboration in breeding exists with D.T. Rosenow, TAM-122, F.R. Miller, TAM-121, and G.C. Peterson, TAM-123 of Texas A&M. Major collaborators in entomology include H.N. Pitre, MSU-105, Mississippi State University, and F.E. Gilstrap, TAM-125, Texas A&M. Pathology collaboration is with R.A. Frederiksen, TAM-124, Texas A&M, while in cereal quality, L.W. Rooney, TAM-126, Texas A&M, works with the Honduran program. In agricultural economics, J.H. Sanders, PRF-105, is the primary collaborator.

Financial Inputs and Management

The U.S.A.I.D./H Mission provides major financial support through ESF and PL 480 local currency funds to the SRN/INTSORMIL/EAP collaborative sorghum program. In 1989, they contributed $114,000 direct to SRN for sorghum research and $83,000 to EAP. The funds to SRN pay Gomez's salary and research support at Choluteca, plus research support at the research stations at Comayagua and Catacamus. The funds to EAP are for Meckenstock's use and INTSORMIL graduate student research support. A special fund for $7,000 from TAM-131 was set up for F. Gomez's use.

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 ICRISAT/CIMMYT and countries of the region through annual CLAIS meetings, regional CLAIS trials, seed and germplasm exchange, cosponsoring regional workshops, and through the annual PCCMCA meetings. Also, networking exists with Mexico (sorghum tortilla quality), Guatemala-breeding (ICTA) and quality (INCAP), El Salvador (CENTA and UES)-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 U.S.A.I.D. Graduate student research plans are developed annually and submitted to SRN for approval. Budgets for AID/H support are jointly developed each year by Gomez and Meckenstock, and submitted by SRN to A.I.D./H.

Constraints Researched

Production and Utilization Constraints

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 ares. 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 non-photoperiod sensitive material can be done in the U.S., with advanced material then sent to Honduras for evaluation.

Research Results

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 maicillos advanced breeding lines performed very well in yield trials, including the IIMYT (International Improved Maicillo Yield Trial), and the most promising will be used in extensive on-farm trials in 1989. 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 to the local cultivars which should make them acceptable for food use.

The parental lines of the sorghum-sudangrass F_1 hybrid (ATx623xTx2784) were increased in anticipation of release in early 1990. This hybrid combines high forage yield with resistance to pathotype 1 downy mildew.

The hybrid maicillo criollo program progressed very well with the sterilization of improved MC females, and the making and testing of a large number of experimental hybrids with various propositions of local maicillo germplasm vs introduced germplasm. Hybrid vigor was very evident, with hybrids outyielding the local varieties by an average of 94%.

Disease and adaptation screening, and midge research progressed well. Several midge resistant hybrids performed well at Olancho.

The principal insect pest constraint to stand establishment in sorghum-maize intercropping systems in southern Honduras was identified to include a complex of lepidopterous species collectively referred to by the local farmers as "Langosta". The fall armyworm appears to be the most abundant of the species encountered annually on the crops but three other species contribute to stand reduction or even complete crop destruction. Sorghum-maize-legume (cowpea) intercropping reduced fall armyworm infestation and increased predator population in the crop production system.

Host plant resistance research involving antibiosis to the fall armyworm indicates that a significant level of resistance exists in several Honduran landrace sorghums and that it can be transferred to improved genotypes.

Research on economic evaluation and technology transfer on small farms in southern Honduras indicates that the new sorghum cultivars, Sureño and Catracho, can have a potentially significant impact on farmers' cereal production and total income.

Pathotype 5 downy mildew screening continued at Comayagua, with several new sources of resistance identified.

Eight publications and 15 presentations were made by researchers reporting on Honduras/INTSORMIL collaborative research during the past year.

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 contribute to alternate uses of sorghum in U.S. and throughout the world.

Institution Building

Research Supplies and Support

The U.S.A.I.D./H Mission contributed $82,500 in local currency to the SRN national sorghum program plus $83,000 through EAP to Dr. Meckenstock for the calendar year 1988. For the calendar year 1989 the total U.S.A.I.D./H local currency contribution was $114,000 to SRN for sorghum research, and $83,000 to EAP for support of Meckenstock and his program and graduate student support.

An IBM model 80 computer was purchased for SRN and installed at Choluteca for Dr. Gomez's use. Other small equipment and supplies were provided to the SRN National Sorghum Program.

Training of Host Country Researchers

Dr. Francisco Gomez completed his Ph.D. in plant breeding at Texas A&M University (Dr. F.R. Miller) in 1986. He returned to Honduras as a sorghum breeder in the Honduras National Sorghum Program in SRN, and was named Head of the National Sorghum Program and the INTSORMIL liaison person in SRN. He is the primary host country collaborating scientist.

Carlos Trabanino completed his M.S. degree (research in Honduras) in entomology at MSU (Dr. H.N. Pitre) and took a position as entomologist with the U.S.A.I.D. sponsored MIPH (integrated pest management project) at EAP in late 1987.

Marco Castro (M.S-Pitre) completed his Ph.D. in entomology (research in Honduras) in 1988 and 1989 (Dr. H.N. Pitre-MSU) and took a position with FIAH in Honduras.

Host and U.S. Scientist Visits

To Honduras

Darrell Rosenow - Breeding - Dec. 1988
Gary Peterson - Breeding - Dec. 1988
Fred Miller - Breeding - Dec. 1988
Delroy Collins - Pathology - Nov. - Dec. - 1988
Henry Pitre - Entomology - May - 1989
John Sanders - Ag. Economics - Feb. - 1989

To U.S.

Roduel Rodriquez, Head, Dept. of Agricultural Research, SRN, Francisco Gomez, and Dan Meckenstock to International CRSP Conference, Scottsdale, AZ, Jan - 1989.
Dan Meckenstock - To Texas A&M - July 1988 and Jan. 1989.
Francisco Gomez - To Texas A&M - June 1989.
Alejandro Palma, EAP - To INTSORMIL Graduate Student Tour - College Station and Corpus Christi, TX. June 1989.

Other Travel in Area

Francisco Gomez and Dan Meckenstock to CLAIS Meeting, San Salvador, El Salvador, Dec. 1988.
Darrell Rosenow and Gary Peterson to CLAIS Meeting, San Salvador, El Salvador, Dec. 1988.
Francisco Gomez, Alejandro Palma, Dan Meckenstock, Miguel Lopez, Lorena Lastres, Evelyn Oviedo to Annual PCCMCA Meeting, San Pedro Sula, Honduras, April 1989 where each presented papers.
Francisco Gomez and Dan Meckenstock to Guatemala, Nov. 1988.

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 also used to distribute seed of the new cultivars. Graduate student studies are 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 contracts 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. 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. also attend and participate in these meetings and workshops, and make direct contacts and present research results. Another method of developing networking activities is by direct visits to countries such as El Salvador and Guatemala with exchange of sorghum breeding germplasm and other research activities developed through such visits.

General Comments

The INTSORMIL/Honduras Program has developed well. The return to Honduras of Dr. Francisco Gomez into a sorghum breeding position and head of the National Sorghum Program is a positive development and has strengthened the national program. However, additional Honduran collaborators are needed in SRN in pathology, entomology, agronomy, and breeding. Graduate students are needed in these areas along with a commitment by SRN for employment. The rapid turnover of upper level SRN administrators, the annual process of requesting and obtaining A.I.D./H funds, and delays in fund transfer through the Honduran financial procedures has created some problems. The EAP has provided some strength and long-term stability to INTSORMIL activities in Honduras. Their entomology program is strong and has provided excellent collaboration in that area. The National program is multidisciplinary but lacks involvement of INTSORMIL PI's in the areas of cropping systems, agronomy, and physiology. Dr. Clegg (Nebraska) has expressed interest in agronomy research and in advising a Honduran graduate student.

The Honduras research relates well to surrounding countries and to the entire Central American, Mexico, Caribbean Zone as outlined in the Global Plan. The concentration of research on the maicillos criollos complements well the other sorghum research activities of the area, which is primarily on photoperiod insensitive, commercial type hybrid and varietal work done by ICRISAT, Mexico, and commercial companies. The INTSORMIL activities in Mexico and Texas on food type sorghums, with emphasis on use of sorghum for tortillas, and the developments of sorghums with good tortilla quality has very direct application to Honduras. The INTSORMIL/Honduras program has developed good working relationships with the regional programs in the area such as CLAIS, CATIE, PCCMCA, and ICRISAT, and has actively participated in meetings and workshops in the Zone. A major regional workshop cosponsored by INTSORMIL and ICRISAT was held in Honduras in late 1987, with emphasis on maicillo criollo breeding, production, and utilization.

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 with 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. An estimated 244,600 pounds of planting seed of improved sorghum was produced in 1987, of which 150,900 pounds was of Sureño.

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 will be used in extensive on-farm trials in 1989. 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 to the local cultivars which should make them acceptable for food use.

The parental lines of the sorghum-sudangrass F_1 hybrid (ATx623xTx2784) were increased in anticipation of release in early 1990.

Major emphasis in the breeding program is to improve the traditional maicillos criollos which occupy approximately 90% of the sorghum growing area in Honduras and 70% of the sorghum growing area in Central America. Improved photoperiod sensitive maicillo breeding lines have been developed and are under intensive station and on-farm testing in Honduras as well as in El Salvador and Guatemala. Some lines appear very promising and should be released soon. Objectives are to improve yield potential, disease resistance, and grain quality. The improved maicillo lines not only show improved yield over the local maicillos criollos, but in certain intercropping systems with maize, their shorter height is apparently less competitive, and maize yields are increased.

Hybrid maicillos have shown a tremendous yield advantage over local maicillos criollos varieties. Breeding for hybrid maicillos has become a priority breeding objective. Some B-line improved maicillos have been identified and are being sterilized.

Grain quality research indicates that sorghum grain with certain traits can produce tortillas of comparable quality to that 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 has been 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 sorghum line, AF28, and TAM 428 and several 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.

Several Honduran and Central American students have been trained, with several conducting their research in Honduras. Francisco Gomez (Honduran) received his Ph.D. in plant breeding at Texas A&M University and INTSORMIL assisted in his placement as a sorghum breeder with the Honduran government (SRN). He now serves as Head of the Honduran National Sorghum Program. Carlos Trabanino (Honduras) received a M.S. in entomology at MSU and is now on the faculty at the Panamerican Agricultural School (EAP) at Zamarano. Other students include: Marco Castro (Honduras) - M.S. in entomology at MSU - currently working on a Ph.D. in entomology at MSU; Ronaldo Sequeira (Nicaraqua) - M.S. in entomology at TAMU; and George Wall (El Salvador) - Ph.D. in pathology at TAMU. U.S. students receiving advanced degrees involving research in Honduras include: Miriam Fordham (M.S.), Karen Thompson (M.S.), and Susan Duda (Ph.D.) in sociology/anthropology from UK; Robert Jones (Ph.D.) and Eunice McCullock (Ph.D.) in sociology from MSU; and Robert Jones (M.S.) in entomology from TAMU. 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 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. Seventy-five participants from eight countries presented 40 papers on food quality and utilization, production technology, disease and insect control, and genetics and breeding aspects of the maicillos criollos.

Mali

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Collaborative Program

The program in Mali is a coordinated effort among INTSORMIL, TROPSOILS, ICRISAT-Mali and the IER. This vital collaboration continues to provide efficient use of limited 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.

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 TROPSOILS and INTSORMIL has been developed from the inception of the Malian program.

Efforts are concentrated to strengthen research on breeding, crop physiology, soil and water relationships, entomology, pathology and food processing and technology. An effort to develop new food products from cereals and legumes is emphasized. Selection for drought resistance is a major concern. Major activities involve the introduction and use of new genetic materials in breeding programs to develop cultivars to increase grain yields with desirable food quality.

Memorandum of Agreement

A Memorandum of Agreement to allow transfer of funds was signed in Mali on October 10, 1984. The 1988-89 workplan and budget was developed and approved by the IER in July 1988. The sixth work plan and budget for 1989-90 was approved in July 1989.

New Opportunities

Long smut is an important disease of sorghum in Mali. Many of the new varieties have tight panicles which harbor insects that attack the grain after pollination. The kernels shrivel and molds enter the grain leading to losses of yield and food quality. The grain has low density and soft endosperm that cannot be dehulled efficiently. When tô is made it has poor texture and keeping properties. An integrated approach to control head bugs including entomology/pathology, breeding and food quality is underway.

Additional equipment and training of personnel for the Food Technology Laboratory is required. Work on pearl millet dehulling properties has been initiated. Expanded efforts to develop new foods from sorghum and millet are underway.

Research Progress

Breeding/Germplasm Improvement

Sorghum

The international food sorghum adaptation trial (IFSAT), the all disease and insect nursery (ADIN), a converted line test, selections from the Texas reduced phenol sorghum synthetic and advanced lines from the NaOH selection tests were grown in Mali . From these nurseries, some lines with outstanding agronomic and grain quality potential were selected by IER breeders for incorporation into advanced trials in 1989.

Maicillo criollo sorghums from Cental America and improved maicillo criollo breeding lines developed by Dr. Dan Meckenstock in the INTSORMIL/SRN program in Honduras were grown at Sikasso in southern Mali where late sorghums are desired. All of the maicillos were significantly later than the latest season locals. They were crossed to local Malian guineas in Puerto Rico and F_1s were sent to Mali. This breeding material will be used to develop late maturing photoperiod sensitive material for southern Mali.

Seeds of several F_2 populations involving lines which have shown promise in Mali were grown in Mali. They are from crosses made in Lubbock of Malian sorghums (Malisor 84-7, 84-2 and 84-1) with elite U.S. parents. This provides the Malian program with appropriate new germplasm and improves efficiency significantly since they often do not have trained personnel or the range of available germplasm to produce the best crosses.

Head bugs are a major constraint to the development and use of new and 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 extrememly difficult to utilize in a breeding program due to their low yield potential and many weedy type traits. Malisor 84-7 apparently possesses the necessary Guinea type grain/glume traits for head bug resistance, but 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 was crossed to several elite sorghums in Texas (those which have shown promise in Mali as varieties) such as Sureño, Dorado, VT153, M90318, 84C7730, M50009 and 86EO361. Segregating populations (F2's) were planted in Mali as well as in Texas, with some excellent progenies selected at both locations. This should be extremely valuable breeding germplasm in the Mali breeding program. Studies have been initiated to determine the nature and inheritance of the grain/glume traits of Malisor 84-7 which impart head bug resistance.

Pearl Millet

Dr. Oumar Niangado participated in the Nebraska on-site review in September, 1988 and discussed aspects of the Mali millet breeding program. F1 and F2 seeds were prepared in Nebraska of crosses between Mali varieties and NU-118 lines and planted in Mali in 1989. Backcross seed of these crosses to Mali parents were also made in the winter greenhouse to further support the Mali pearl millet breeding program.

Panicle Feeding Bugs of Sorghum

In 1989 a number of entomology experiments were initiated at Sotuba with Dr. Yacouba Doumbia, IER entomologist. The experiments are designed to meet two research objectives: (1) To develop practical methods for screening germplasm for resistance to head bugs. (2) To determine the relationship between head bug abundance and damage, and food quality.

Sixteen local and introduced sorghums, arranged in a splitplot design and replicated three times were used to test appropriate methods of screening for head bug resistance. Among the sorghums, panicles were allowed to be naturally infested, protected from bugs using bags, or protected from bugs using insecticide. This procedure allows for comparison of head bug damage between and within sorghum entries to determine a simple screening method.

Damaged and undamaged panicles and grain are used to determine the relationship between head bugs and mold and food quality. Based on preliminary results, it appears that an appropriate screening method will be to use a visual rating scheme of head bug damage and mold to delete very susceptible sorghum entries. Where more objective evaluations are required, head bug damage and kernel deterioration can be based on germination and decortication tests.

Development of New Sorghum/Millet Food Products

Parboiling of local sorghum and millet cultivars was evaluated in the Food Technology Laboratory. Parboiling (BSB) significantly enhanced the yield of sorghum and pearl millet cultivars (Table 1) especially sorghums with soft floury endosperm.

Table 1. Effect of parboiling treatment and decortication time on yield of Malian sorghum and millet samples using different milling systems

Cultivar	Parboiling treatment	Yield (%) with different milling systems at different decortication times (min)			
		TADD[a]			PRL[b]
		5	10	15	5
Pearl millet					
	Control	52.8	32.7	17.0	66.0
	BSB	62.3	41.1	26.7	78.3
Tukey's HSD	(=0.05)	1.3	3.4	2.7	-
Sorghum					
CSM 388	Control	77.5	60.9	21.5	79.2
	BSB	88.3	79.0	71.4	87.5
Tukey's HSD	(=0.05)	1.2	1.8	1.8	
CSM 219	Control	61.7	37.8	17.7	67.4
	BSB	85.6	76.0	66.8	61.0
Tukey's HSD	(=0.05)	0.5	3.2	1.2	-
ICSV-401[c]	Control	31.2	16.0	2.9	-
	BSB	82.0	67.0	54.7	-
Tukey's HSD	(=0.05)	1.9	2.6	2.9	-

[a]Tangential Abrasive Dehulling Device.

[b]Prairie Regional Laboratory mill, a horizontal axis dehuller used to decorticate 2kg of sorghum or millet.

[c]ICSV-401 is an improved sorghum which was severely damaged by head bugs. The kernel was soft floury and disintergrated during dehulling.

BSB refers to the boil, soak for 12 hours and boil process.

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 products. The process is relatively simple and uses existing equipment and skills.

The texture of the cooked parboiled sorghum is firm, resembling typical long-grain rice. The cooked kernels are intact, dry, fluffy and do not stick together depending upon the cooking method. The color and texture of cooked decorticated parboiled sorghum was very acceptable in informal taste trials conducted in the Food Technology Laboratory in Mali.

Work to evaluate the potential practical usefulness of parboiling is underway with village trials and other activities in the Food Technology Laboratory in Mali.

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.

The Food Technology Laboratory conducted cooking trials and presented a 30 minute program on Malian television to illustrate new products from sorghum and millet. The laboratory won a prize for its exhibits of new foods from sorghum/millet at the Malian National Industrial Fair held in Bamako. Village trials were conducted on feeding composite flours to weanling children. Trials to evalutate parboiling and alkali soaking to improve tô flour storage stability are underway.

Agronomy

Three sorghum genotypes were grown to measure and compare their nitrogen responsiveness to split application. A local variety was compared to the improved S-34 (Nigerian) and Malisor 84-7 variety. A nitrogen application of 46 kg/ha as urea was applied at preboot and tillering (elongation) growth stages.

Thus, 25, 50 and 75% of the urea was applied at the preboot stage while the remainder was applied at tillering.

All varieties responded significantly to applied nitrogen at both locations. However, the location with the greatest seasonal rainfall had the best response over all varieties. The local variety yielded considerably better over all treatments than the improved types due to the latter being very susceptible to head bugs and grain molds. The earlier maturing improved varieties matured during periods of high humidity and produced low density, soft grains. Other tests usually show greater yields for the improved types over the local. These experiments demonstrate the significance of head bugs on improved sorghums in Mali. There was no consistent pattern for varietal response to the split nitrogen treatments. The local appeared to favor an even rate split while the improved types performed better with the bulk of N being applied either early or late. A follow up experiment is now in progress using a third location.

A Malian graduate student, Abdoul Sow, conducted a study using minilysimeters under a rainout shelter to examine the effects of the interaction between sorghum genotype, phosphorous nutrition and available soil water on crop transpirational (T) water use efficiency. The sorghum genotypes were CSM63 (Malian local variety) and Tx7078 of similar maturity but differing in growth habit and drought resistance. Dry matter production was linearly and positively related to transpirational water use (Figure 1). Based on grain yield, Tx7078 had a higher water use efficiency than CSM63; however, based on total dry matter (including roots) CSM63 had a higher water use efficiency. Harvest index and water use efficiency were significantly related (Figure 2), suggesting that selection for crop growth and production automatically includes selection for water use efficiency.

Physiology/Drought

Proline content was measured in 15 sorghums subjected to drought. They differed significantly in accumulated quantities of proline. Four selections from NP9BR had the highest accumulation. Two Malian converted sorghums were medium in accumulation. There appeared to be inherent differences in abilities to accumulate proline. Techniques were perfected for bioassay and immunoassay of abscisic acid accumulation also. Studies were initiated in cooperation with KSU to investigate possible relations between proline accumulation and *Fusarium moniliforme* infective growth in sorghum. It was found that significantly greater quantities of proline accumulated in plants inoculated with fusarium than in uninoculated plants, possibly a result of induced stress.

In experiments conducted in Mali, it was found that plowing prior to seeding and crust breaking following seeding significantly improved seedling emergence and

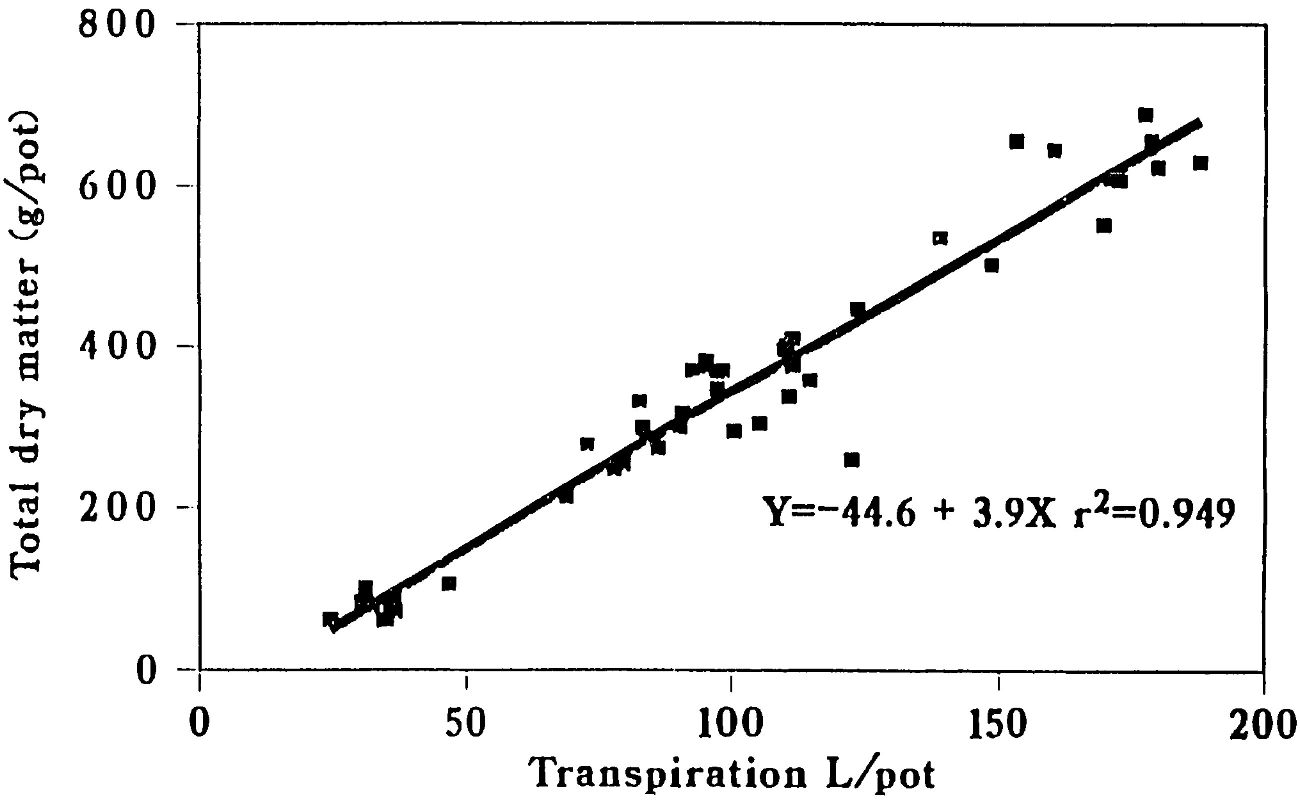

Figure 1. Relationships between total water transpired and total dry matter production.

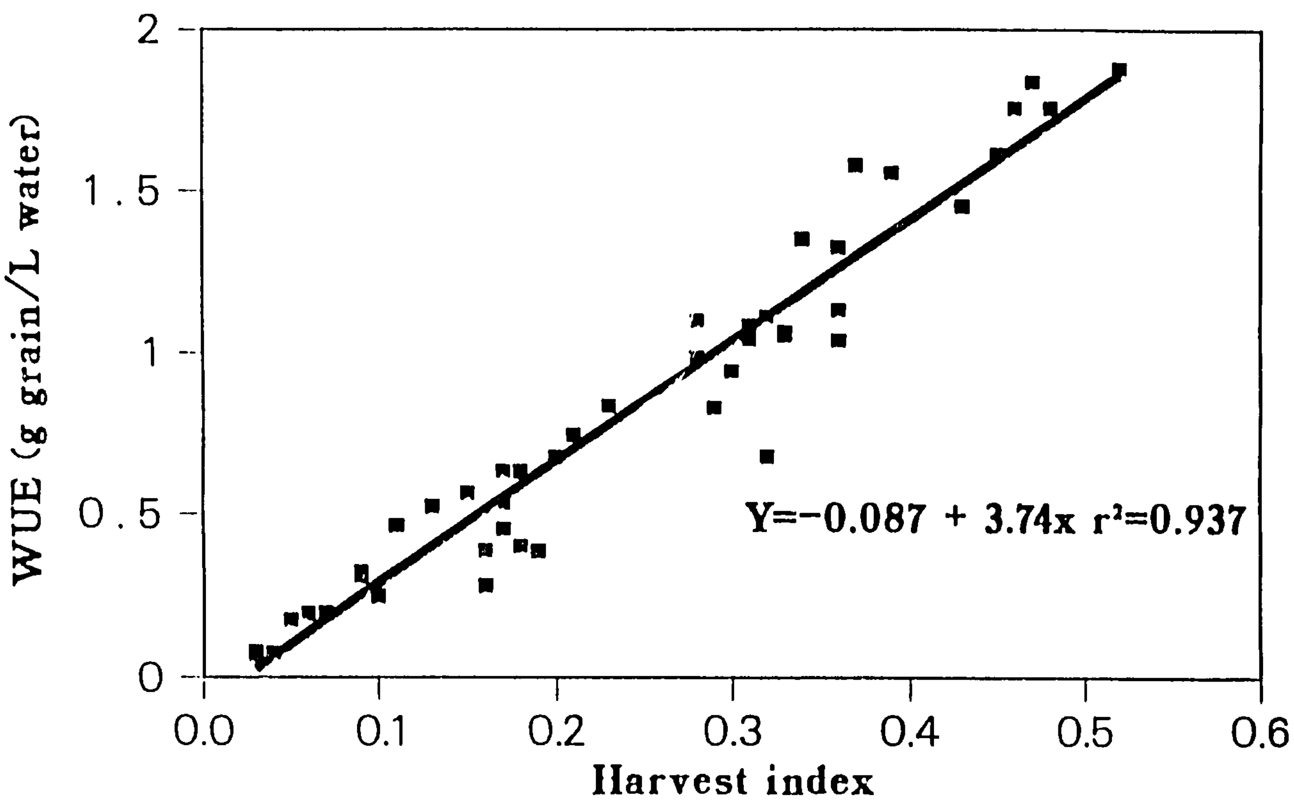

Figure 2. Relationships between WUE and harvest index.

decreased soil resistance to root penetration. There were also significant differences in genotype response to the treatments.

Institution Building

Equipment, supplies, chemicals and other support items were transferred to Malian scientists. Additional equipment for the Food Technology Laboratory included a dehulling device for milling sorghum, chemicals and supplies. Several students are training in key disciplines at various INTSORMIL institutions. A new Malian student initiated MSci agronomy research at Kansas State University with Dr. Vanderlip's project support.

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.

The effective close working relationship between the Food Technology Laboratory and the Malian breeding and agronomic programs is not found in most other countries in Africa. Malian sorghum and millet researchers met with extension specialists in a special workshop to review progress and current recommendations for sorghum/millet production and utilization in Mali. Dr. Tim Schilling represented INTSORMIL.

Malian investigators traveled to Cameroon and Nigeria to exchange information at the West African sorghum and millet network. Drs. Traore and Niangado, IER Mali, are regional coordinators for West African sorghum and millet workers, respectively. Dr. Da Sansan, Burkinan team leader for cereal research, visited Mali in 1988 to confer on grain quality and breeding research.

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 closer interaction with the regional program in West Africa. Current collaboration on insects, disease and quality is well underway. Opportunities for increased cooperation exist.

Training

Several Malians have completed degrees in INTSORMIL institutions and have returned to Mali to work in the sorghum/millet improvement programs. Ten Malian students are currently being trained in INTSORMIL institutions in breeding, agronomy, physiology and soil fertility/chemistry through INTSORMIL, TROPSOILS and ICRISAT-Mali collaboration. Each will provide critically required skills in key areas of the IER research program.

Travel

INTSORMIL travelers to Mali included: Dr. L.W. Rooney (two times); Dr. D.T. Rosenow, sorghum breeder, and Dr. G. Teetes, entomologist, all from Texas A&M University, Dr. C. Sullivan, physiology and Dr. T. Schilling, Associate Director, INTSORMIL, both of the University of Nebraska.

Dr. M. Traore, physiologist, Mr. Zana Sanogo, Head, D.R.A. and Mr. O. Tall, Director General, IER traveled to the U.S. to participate in the INTSORMIL P.I. conference in Arizona. Dr. O. Niangado, Director, CINZANA Station and millet breeder participated in the external evaluation review of the INTSORMIL millet programs in Kansas and Nebraska.

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Research Accomplishments

INTSORMIL has been in Mali informally since November 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 the efforts morally and financially through additional 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 PhD. degree in physiology at the University of Nebraska. Scientists trained in Food Technology, Pathology and Agronomy have returned to Mali and collaborate in the program.

Ten graduate students are training in INTSORMIL universities to provide personnel to continue the programs. The programs include Agronomy, Breeding, Physiology 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 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 reduce sorghum yields and reduce milling yields and give tô with unacceptable texture and keeping properties.

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 7 has shown some advantages in multiple cropping systems. Malisor 84-7 has excellent resistance to head bugs. It appears to be the only improved sorghum with the necessary level of 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.

Absicic 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. Dr. Traore's program on drought physiology has been supported with acquisition of computers and major equipment for physiology research.

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. In the past, the program involved participation by senior graduate students and post doctorates from INTSORMIL projects working in Niger during the crop season. A shift is now 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

The proposal to negotiate buy-ins through the U.S.A.I.D. Mission was developed in collaboration with INRAN. It is currently being discussed between A.I.D. and INRAN.

Collaboration with Other Organizations

Purdue/Niger Applied Agricultural Research (NAAR) Project
U.S.A.I.D./Niger
Institut National de Recherches Agronomique du Niger (INRAN)
TROPSOILS
ICRISAT Sahelian Center
Ministry of Rural Economy (DECOR)
Agricultural Research Corporation (ARC), Sudan
University of Nebraska
Texas A&M University
Kansas State 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 Mr. Jika Neino as host country coordinator 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:

Combining Ability of Al Tolerant Sorghum Cultivars

INRAN: Moussa Adamou. INTSORMIL: Lynn Gourley, John Axtell

Research by Moussa Adamou during the summer of 1988 required the evaluation of parent genotypes to be used in his dissertation research under Nigerien conditions. The sampling and analysis of sandy soils from the selected test locations was accomplished. Field evaluation of the parent genotypes was conducted at four locations: Kolo, Bengou, Koni and Tarna. The field trials were planted in June in randomized complete block (RCB) design with three replications at all four locations.

Notes were taken based on general appearance of the different varieties and by a stand count. In addition, 108 photoperiod sensitive aluminum-tolerant lines from Colombia were evaluated at Kolo and Bengou. Notes were made concerning the general appearance of the different lines and the stand count. For both types of trials, the data on grain and stover yield, plant height, bloom date, and 100 seed weight are to be sent to the U.S. collaborators for analysis. Soil samples were taken from all locations where trials were conducted. Soil was separated into two duplicate samples; one set for the INRAN soil laboratory, and the other set to be analyzed at Mississippi State University.

SEPON-82, A Promising Variety for Production in Niger and Other West African Countries

INRAN: Issoufou Kapran, John Clark. INTSORMIL: Gebisa Ejeta, John Axtell.

In 1983 the INTSORMIL Program at Purdue University sent a collection of 109 elite, tan plant lines with white or yellow grain to Niger National Agricultural Research Institute (INRAN) for evaluation (many of these lines were obtained from Dr. Gourley at Mississippi State University). The majority of the lines originated from the ICRISAT/Hyderabad Sorghum Elite Performance Observation Nursery (SEPON) and thus we designated this collection as the "SEPON" Collection and SEPON-82 was the 82nd entry in the Collection. The Collection was grown out in two row observation plots of six meters in a single replication at the INRAN Station of Kolo in the summer of 1983. Variety SEPON-82 produced the equivalent of 3,265 kg/ha of grain. It was subsequently selected for further yield testing with improved varieties, including L-30, 1/2 MSB, A4 D4, SST 722-7 and SST 731-11. The results of four seasons of yield testing are summarized in Table 1. In 1985 at Birni N'Konni, it produced 3265 kg/ha compared to 3277 kg/ha for the trial mean and 3750 kg/ha for the highest entry, SST 771-38-4. In 1986 it was the highest yielding entry with 3372 kg/ha at Bengou, at Lossa (1830 kg/ha) and better than the trial mean at Koni, 1371 kg/ha compared to 1148 kg/ha. In 1987 it was the highest entry with 2608 kg/ha at Koni and only slightly inferior to the trial mean at three other locations. In a trial conducted by the Kolo Agriculture School (IPDR) under irrigation in the 1987/88 off season, SEPON-82 was again the best entry, producing an impressive 7,299 kg/ha. SEPON-82 is a tan plant, yellow grain variety. Its height is approximately 1 1/2 m and it has a maturity cycle from 100 to 110 days depending on location and time of planting. It is currently in agronomic pre-extension trials prior to release for cultivation on dryland valley soils and on irrigated perimeters. It is also being utilized in the breeding program in crosses with local and introduced varieties.

SEPON-82 was placed in ICRISAT's West Africa Sorghum Varietal Adaptation Trial - Medium Cycle in 1989. Preliminary results indicate good performance in several countries in West and Central Africa. ICRISAT's designation for SEPON-82 is M90382. The pedigree furnished by Dr. D.S. Murty of ICRISAT's West Africa Sorghum Improvement Program (WASIP) in Kano Nigeria is (GPR148 x E35-1)-4-4 x CS3541.

Hybrid Development and Evaluation in Niger

INRAN: Issoufou Kapran, John Clark. INTSORMIL: Gebisa Ejeta, John Axtell.

IRAT initiated work on hybrid sorghum in Niger prior to INRAN's creation in 1975. Yields greater than 6 tons per hectare were obtained, but the hybrids generally had poor grain quality, i.e., floury, red grain. Under NCRP, hybrid yield trials were conducted at the Tarna Station from 1984 to 1987. The best hybrids, utilizing Texas A lines and local or improved variety R lines, yielded 3 1/2 to 5 1/2 tons/ha. In 1986 a systematic screening of parental lines was initiated by INTSORMIL and NCRP graduate students doing thesis studies in Niger. Issoufou Kapran reported that yield superiority over local and improved varieties was high, both under rainfed (49%) and irrigated (61%) conditions. Tom Tyler reported heterosis levels of 127% for exotic x exotic hybrids, 33% for exotic x improved variety hybrids, and 66% for exotic x local variety hybrids. Based on laboratory analyses and food quality tests, both authors concluded that the

Table 1. Grain yield (kg/ha) of sorghum variety SEPON-82 during four crop seasons.

	Location/Year								
	1985	1986			1987				1987/88
Cultivar	Koni	Bengou	Lossa	Koni	Bengou	Tarna	Koni	Lossa	Kolo
SEPON-82	3265	3372	1830	1371	818	1061	2608	2015	7299
Highest	3750	3372	1830	1809	1216	1473	2608	4264	7299
Trial mean	3277	2298	1326	1148	914	1091	1841	2245	4894
CV	24	21	42	34	48	38	36	28	18

hybrids had acceptable grain quality for local food preparation.

Additional hybrid trials in 1987 and 1988 demonstrated a clear yield advantage of the best hybrids over the best improved and local variety checks. Yield levels of the best hybrids at Kolo, which received only 410 mm of rainfall, were 2 1/2 to 3 1/2 tons per ha, compared with 1 1/2 to 2 1/2 tons for local checks. In general, hybrids with improved varieties as male parents were the most productive; hybrids with a local variety male parent, while also high yielding, were tall (3 m or higher), late, and had a tendency to lodge. The TAMU female, ATx623, had excellent combining ability for yield. The tan plant female, ATx631, also had good combining ability, but better grain quality, particularly in combination with a tan plant male line. Redlan, ATx378, produced the earliest hybrids, but being red seed is less desirable in Niger. ATx378 also has been consistently free of long smut, unlike ATx623 and ATx631 which are very susceptible. The Purdue A line, P954066, was best in combining ability with local varieties. Promising R lines identified include MR732, MR747, SuCr36, SST722-7 and SST722-20. Village level food quality preparation and taste trials conducted by DECOR and INRAN's Cereal Quality Laboratory confirmed the acceptability to farmers of two typical hybrids, Hageen Dura and ATx378 x RTx430.

Sorghum Striga Resistance Research in Niger

INRAN: John Clark, Issoufou Kapran, Oumarou Cherif Ari. INTSORMIL: Gebisa Ejeta, Dale Hess.

Studies of sorghum resistance to *Striga hermonthica* (Del Benth) were initiated in Niger under U.S.A.I.D.'s Niger Cereals Research Project. During 1986 and 1987 six varieties (N13, Dobbs, SRN39, P967083, Framida, IS9830) reported to be resistant were compared for yield and *Striga* resistance with four local cultivars. Variety SRN39 was superior to the other resistant varieties for agronomic performance as well as level of resistance to *Striga*. It produced grain yields comparable to the best local cultivars in the absence of *Striga* and was vastly superior under heavy *Striga* infestation.

Additional studies by the INRAN Sorghum Improvement Program addressed the effect of nitrogen fertilizer and tillage treatments on *Striga* infestation levels. Hess and Gebisa found that application of 100 kg/ha of urea significantly reduced the number of *Striga* plants, delayed the flowering of *Striga* and increased sorghum straw and grain yield. The difference in *Striga* number was highly significant due to mode of field preparation.

The no-till plot had reduced *Striga* infestation compared to harrowing, plowing and tied-ridging after plowing. These results suggest that cultural treatments could be used in combination with varietal resistance to reduce the damaging effect of *Striga*. In 1988 a trial was conducted on-station and on a farmer's field to evaluate the effect of a moderate nitrogen fertility difference on *Striga* numbers and sorghum grain yields of SRN39 and a *Striga* susceptible local variety.

Pearl Millet Breeding

INRAN: Botorou Ouendeba. INTSORMIL: Gebisa Ejeta.

Pearl millet will continue to be a major staple food crop in the Sahel zone because of its ability to withstand the adverse agroclimatic conditions prevalent during the growing season. The main constraints to the production of this cereal crop are inadequate and poorly distributed rainfall and the poor soils. The local millet populations are quite adapted to those environments but have limited yield potential. For a long time, research in Niger has dealt mostly with selection within populations (intrapopulation improvement) and a few varieties have been developed for the different millet growing regions in the country. In many of these regions, no significant difference in grain yield was found between improved varieties and existing local varieties. A new breeding approach is therefore needed to increase the yield potential of millet varieties for Niger. An inter population improvement approach using Nigerien and other African millet varieties could provide the necessary germplasm pool to effect a more productive selection program. The chance to breed for a high yielding variety will likely be enhanced.

The proposed genetic study will provide information on the heterotic patterns among various pearl millet populations. This will be useful for breeders in the Sahel and other African countries where millet is an important crop. The information on the relative magnitude of general and specific combining ability is very important in making decisions concerning the type of breeding procedure to use and in selecting germplasm material that is relevant for success. The germplasm resulting from intercrosses for this study could also provide a new gene pool that is currently unavailable.

Furthermore, African pearl millet germplasm has not been fully exploited for forages per se. In Niger there is increasing interest in initiating a breeding program for forage type millets. Dual purpose millet varieties or synthetics with good grain and forage yields will be of immediate benefit. African pearl millet germplasm may contribute important attributes for use as forage hybrids in the U.S. as well. The purpose of the combining ability study on forages is to investigate genetic variation for forage yield and quality among African millets and to test their heterotic relationship when used in combination with female parents developed in the temperate zone.

Pathology Report

INRAN: Issoufou Kolo, John Clark. INTSORMIL: Omer El Hilu, Richard Frederiksen.

Sorghum research priorities for Niger remain the same - long smut, sooty stripe, and *Striga*. The approaches will be for development of host resistance for control and determine the economic impact of long smut and to experimentally characterize the "fungi" causing sooty stripe in Niger. Millet research priorities will be on control tactics for downy mildew and *Striga*.

Excellent long smut developed at the Lossa Station in Dr. John Clark's breeding nursery. We made selections within segregating F_2 populations and within F_3 rows for plants with and without long smut for field evaluation in 1990. The hypothesis that we are testing states that in the presence of uniform natural disease pressure, unusually susceptible plants can be culled or possibly resistance can be achieved. The F_2 and F_3 populations were derived from crosses of resistant by susceptible lines.

John Clark and others noted that Tx631 is resistant to sooty stripe whereas Tx623 is susceptible. Data collected during the 1970's from the region would suggest that both Tx3197 and Tx378 would be resistant to this disease as well.

Mr. Issoufou Kolo made inoculations and confirmed that there are two different "types" of *Ramulispora sorghi* in Niger. One isolated causes typical sooty stripe, the other causes a foliar lesion that is similar to that caused by *Cercospora fusimaculans*. Mr. Kolo has also evaluated various production practices on development of *Striga hermonthica* infection in pearl millet. The studies in farmers' fields were incomplete because of the drought, whereas various fertility schemes had a major effect on the amount of infection.

Improvements at the Kolo station include the development of a fenced-off sorghum nursery for growing pot cultures of sorghum. These plants are for off-season studies on long smut. A laboratory was designed for research in plant pathology. The laboratory will greatly improve the work on disease management in Niger.

Economic Report

INRAN: Maliki Kadi, Mahaman Issa. INTSORMIL: John Sanders.

INRAN has been carrying out on-farm trials of new technologies since 1985 at three sites in Niger, one in the Maradi region and two in the Niamey region. The objective of the economics input has been the economic evaluation of the new technologies being tested. The technologies include improved varieties, P and N fertilizer, and agronomic improvements in plant density and geometry.

The previous budgeting done for all the sites and the whole-farm analyses of the Maradi site attributed considerable potential to the new technologies, but little adoption has been observed. The field surveys and farm modeling for the Niamey region have sought to explain this phenomenon. The hypothesis tested is derived from the fieldwork of anthropologists who have studied intensively in Niger (Raynaut, Sutter, Collion, and Painter). These anthropologists contend that cash is often available but farmers invest in alternative activities, such as small ruminants or off-farm activities. These take precedence over investment in rainfed agriculture, whose returns are often too low or too risky.

The results of the analysis support this hypothesis. Investment in small livestock is more profitable than the combination of technologies being promoted. One possible way to make these new technologies more attractive has been suggested by the work of Balcet, Candler and Adesina. Farmers follow different production strategies in different rainfall years. They make adaptive decisions at key points during the season to respond to changing rainfall conditions and thereby raise income. Use of improved short-cycle varieties in late rainfall years is one example. This adaptive behavior of farmers under uncertainty is modeled with Discrete Stochastic Sequential Programming. It involves dividing the season into key periods in which critical decision points occur. This is also the way in which farmers make decisions, so the economic modeling has application in the U.S.

The decision-making concept is applied to the use of fertilizer. This involves applying phosphorus after planting so the early-season rainfall can be observed. The efficacy of this strategy is shown to be dependent on the initial level of P in the soil. One implication of a better understanding of farmer decision-making is the need to diversify the cereal-breeding strategy with more emphasis on medium- and long-season cultivars. Another is to put more emphasis in research and development policy on the livestock/crop interactions.

Crop Physiology

INRAN: Abdourahmane Alou. INTSORMIL: Paresh Verma, Jerry Eastin.

The collaborative crop physiology research projects started in Niger three years ago are being continued. The emphasis of the program is on using results from physiological studies to improve existing millet/cowpea intercropping systems, improve grain production by use of crop residue, and sustain improved soil fertility (fixed N) under low input situations by enhancing cowpea growth in the intercropping systems. Results from the first two years of research have been very encouraging. Based on the results from artificial shading experiments, a new millet/cowpea intercropping arrangement was tried as an alternative to the recommended intensive intercropping system. Cowpea yield increases in the alternative system were substantial while the millet yields remained unchanged. Another system proposed for no fertilizer situations increased both millet and cowpea yields compared to the farmers' traditional system. The use of crop residue resulted in manifold increases in millet yield.

The research is now being conducted by Mr. A. Alou who is a physiologist in INRAN. Before taking over the program in 1989 he spent some time at the University of Nebraska to acquaint himself with some of the specific research techniques that have been adapted for use in Niger. The 1989 research results are not yet available. Research on water-use efficiency of millet and cowpea in a millet/cowpea intercrop is being continued at N'-Dounga. The crop residue experiment is being continued at Ouallam. A new experiment to study the effect of amount and method of application of P on cowpea growth and water-use efficiency, and thus N fixation, was started in 1989. The use of P fertilizer alone by the farmers is not a distant possibility and any increased N fixation as a result of increased cowpea growth would go a long way in sustaining productivity of millet/cowpea intercropping systems even without the application of any N fertilizer.

Nitrogen Contribution of Intercropped Cowpea

INRAN: Ibrahim Mohamadou, Maman Nouri. NAAR: Chandra Reddy. INTSORMIL: Steve Mason.

A three-year field study to evaluate the nitrogen contribution of intercropped cowpea harvested as forage and grain to pearl millet was initiated in 1987. This experiment includes three intercropping systems along with sole crops of both cowpea and pearl millet. Immediate nitrogen contribution is to be measured in 1987 and 1988, and residual nitrogen contribution in 1988 and 1989 by measuring yield and dry matter production, nitrogen removal, nitrogen concentration of critical plant parts, and nitrogen status of the soil.

Pearl Millet

In 1987 application of nitrogen from 0 to 150 kg ha^{-1} resulted in a quadratic yield increase from 780 to 1182 kg ha^{-1}. A similar response occurred in 1988 except the maximum yield of 1195 kg ha^{-1} occurred at the 100 kg ha^{-1} rate. In 1988 both the intermediate (improved variety, higher plant density) and intensive (intermediate plus nitrogen fertilizer) intercropping systems produced 300 to 350 kg ha^{-1} more grain than the traditional intercropping system. This trend was also present in 1987, but yield differences among cropping systems were smaller except for the intensive system with cowpea harvested for forage which had the greatest yield (1038 ha^{-1}). This was the only case when harvesting cowpea for forage (mid-pod fill) resulted in a pearl millet grain yield difference from systems where cowpea was harvested for grain.

Pearl millet stover yields were not consistent across years. In 1987 the greatest stover yields occurred with the traditional cropping system, whereas in 1988 this system produced the lowest stover yields. In the more intensive systems fertilizer application increased stover production in 1987, and for the sole crop system in 1988. Harvesting cowpea for forage (mid-pod fill) or for grain had no influence on pearl millet stover production.

Cowpea

The intermediate and intensive intercropping systems resulted in 250 to 390 kg ha^{-1} increase in cowpea grain yield over the traditional system. However, the sole cropped cowpeas produced approximately 450 (1988) to 1000 (1987) kg ha^{-1} more grain than the best intercropping system. The traditional intercropping system and the sole crop produced approximately 350 kg ha^{-1} more cowpea stover than the intensive intercropping system in 1987. The same trends were present in 1988, except that a crop failure occurred for the traditional cowpea intercropping system.

Pearl Millet Residual

In 1988 the residual effects of intercropping, cowpea, and nitrogen application were measured. Pearl millet produced the lowest yields following the traditional intercropping system with the highest yield of 1074 kg ha^{-1} occurring following the cowpea sole crop harvest for forage at mid-pod fill. Pearl millet yields following pearl millet previous crop which received 0 to 150 kg ha^{-1} were approximately 850 kg ha^{-1} while in plots receiving 50 or

100 kg ha^{-1} last year the yields were approximately 660 to 710 kg ha^{-1}. This unexpected result suggests that the greater grain yields at the 50 and 100 kg ha^{-1} rates in 1987 depleted the soil of nitrogen for the succeeding crop, while the zero and 150 kg ha^{-1} rates left some nitrogen in the soil.

Cropping Systems

INRAN: Charif Ari, Goube Gaoh. INTSORMIL: Jerry Maranville.

Work is centered on assessing the response of pearl millet to nitrogen supply in the Maradi area of Niger. An experiment was planted by Dr. Oumarou Cherif Ari on June 25, 1989 using millet varieties CIVT, DGP1 and GRP1 at four nitrogen levels applied as urea. Rates were 0, 30, 45 and 60 kg/ha N applied in three replications in a randomized complete block design. Results are currently being summarized in Maradi and will be made available to INTSORMIL as soon as possible.

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 Kolo.

Several boxes of scientific journals have been sent to the INRAN Library at Niamey.

A Toyota Land Cruiser and a Toyota Corolla Station Wagon were purchased in 1986 in time for harvest. Two motorcycles have also been purchased for transportation for INTSORMIL and INRAN collaborators.

Training of Host Country Researchers

Moussa Adamou, INRAN sorghum breeder, continues Ph.D. studies at Mississippi State University. He conducted thesis research in 1988 in Niger.

Three M.S. students from Purdue (Issoufou Kapran, Issoufou Kolo, and Charif Ari completed M.S. thesis research and returned to Niger.

Botorou Ouendeba is conducting Ph.D. training in millet breeding at Purdue.

Host Country and U.S. Visits by Scientists

<u>Visits by Niger Scientists to the U.S.</u>

Alou Abdourahmane, INRAN Physiologist; 4/27 - 5/20/89.
Issoufou Kapran, INRAN Agronomist; 1/2-30/89.

<u>Visits by U.S. Scientists to Niger</u>

Richard Frederiksen, Professor; Plant Pathology, Texas A&M; 8/13-21/88.
Larry Claflin, Assoc. Prof.; Plant Pathology, Kansas; 8/14-22/88.
Gebisa Ejeta, Assoc. Prof.; Agronomy, Purdue; 10/10-23/88.
Thomas Housley, Assoc. Prof.; Agronomy, Purdue; 10/10-23/88.
Richard Frederiksen, Professor; Plant Pathology, Texas A&M; 10/22-30/88.
Donald Paschke, Professor; Entomology, Purdue; 11/5-22/88.
Lynn Gourley, Professor; Mississippi State; 6/21-7/4/89.
Omer El Hilu, Agricultural Research Corporation, Sudan; 10/22-30/88.
Jerry Maranville, Professor; Physiology, Nebraska; 7/27-8/3/88.
Steve Mason; Assoc. Prof.; Agronomy, Nebraska; 7/24-8/3/88.
Moussa Adamou, Participant Trainee; Agronomy, Mississippi State; 5/14-8/15/88 and 6/4-25/89.

Networking

The major activity for disseminating research results within Niger has been the INTSORMIL/INRAN/NCRP Sorghum and Millet Workshop, which was planned during Year 6 and implemented during Year 7. The workshop was very successful for the 45-50 participants who presented papers and took part in discussions. The workshop proceedings have been published and distributed throughout the U.S. and LDCs. Additional research information exchange took place through INTSORMIL scientist visits to Niger. An EEP Review was successfully conducted in October 1986.

General Comments

Continual dialogue between INTSORMIL and INRAN scientists must continue over several years 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 must be improved. The joint workshop in Year 7 was extremely successful in lending a positive note to our collaborative research program in Niger. The excellent support of the U.S.A.I.D. Mission, including participation by the Ag Development Officer, Mission Director, and Ambassador Bogosian was very important to the success of the workshop and the project.

Two principal problems will face INTSORMIL during 1990 and they both 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 300 cfa/$1 dollar. This has significantly reduced our purchasing power of those dollars spent in-country for such items as gasoline, housing, labor costs and other expenses. The Purdue contract for Niger has been renewed for four years and INTSORMIL/NAAR cooperation will continue in 1990 as in the past. INRAN appointed Mr. Jika Neino in 1989 to serve as host country coordinator which will 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. Ouendeba will undertake a pearl millet diallel using six agronomically superior millet populations. The project is collaborative between Dr. Kumar, Dr. Hanna and Dr. Gebisa.

Dr. Omer El Hilu (ARC/Sudan), working with Richard Frederiksen (Texas A&M), and John Clark (Purdue/INRAN NAAR Project) will initiate 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.

Paraguay

Fred Miller
Texas A&M University

Coordinators

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Ing. Mercedes Alvarez, Country Counterpart, Maize/Sorghum Breeder, Ministry of Agriculture, Asuncion, Paraguay
Ing. Willie Giesbrecht, Servicio Agropecuario - Chaco Central, Col. Mennonite, Loma Plata - Chaco, Paraguay

Institutions Involved

Ministry of Agriculture of Paraguay
Instituto Agronomico Nacional
Cooperativa Colonia Unidas, Concepcion, Paraguay
Cooperativa Colonia de Mennonitas, Filadelphia, Paraguay

Collaborative Program

A Memorandum of Agreement to allow collaborative research, transfer of funds, and joint technical and scientific activities was signed in Asuncion, Paraguay, on September 27, 1985. The program was organized to incorporate the expertise of the Ministry of Agriculture (MAG), U.S.A.I.D. Mission to Paraguay and the International Sorghum and Millet Collaborative Research Support Program (INTSORMIL). In the early stages of this collaborative program the U.S.A.I.D. Mission to Paraguay provided a 'buy in' of INTSORMIL to provide leadership to develop sorghum in Paraguay. MAG provides most of the local support and in-country private groups provide additional funds, land and vehicles. MAG funds have been used to supply facilities, land and local supplies, plus some local labor. U.S.A.I.D. involvement has been substantially reduced in recent years. Private funds have been used to supplement off-station field trials. In the short period of activity in Paraguay and with low input of resources, numerous trials, demonstrations and research plots have been carried out with local research agencies, agricultural schools, cooperatives, credit agencies and private farmers.

The Paraguayan team meets and prepares a work plan annually. The local team prepares a final plan after review with the Director of IAN. This plan is reviewed with the U.S.A.I.D. agricultural development office and the INTSORMIL co-coordinator. Since the in-country INTSORMIL employee has gone the process is less solid.

Within the program there is input and activity between poultry producers, dairymen, cattle (beef) producers, and food users. Both grain for animal use and human consumption are studied as well as forages. There is continuing evaluation and exploration of hybrid seed production.

Constraints Researched

Prior to this year's research program the INTSORMIL sponsored researcher left Paraguay to return to the U.S. This caused a substantial reduction in the activities, research and liaison which were needed. However, several trials of experimental sorghum hybrids for grain, food and livestock forage were continued by the MAG and Mennonites in the Chaco.

Table 1 describes the response of selected grain hybrids at Filadelphia. These hybrids were a continuation of the best tan plant, white grain types previously evaluated in Paraguay. The two top yielding hybrids A155*R8505 and AVar*RTx435 produced more than 40% more grain than Dorado which has a good history of production in Meso America. The hybrids produced more than 27% greater yield than the widely used red seed hybrid ATx378*RTx430. Yield of grain ranged from 3777 kg/ha to 2537 kg/ha in the trial at Filadelphia. There was very little variation in the time required to reach anthesis. Most hybrids required about 61-62 days. The more productive hybrids were from 1.1 to 1.4 m tall. These results were consistent with data collected previously at Filadelphia. This very dry environment produces grain of the white pearly types that is of excel-

Table 1. Characteristics and performance of grain hybrid sorghums at Filadelphia, 1988-89.

Hybrid/Designation	Days to flower	Height (cm)	Panicle (cm)	Desirability	Yield (kg/ha)
A155*R8505	60	136	33	1.7	3777
AVar*RTx435	64	137	30	1.8	3740
ATx630*R8511	60	133	29	1.9	3666
ATx623*RTx430	61	125	33	2.4	3668
ATx631*R8510	62	129	34	1.9	3629
ATx630*R3338wx	61	135	32	2.3	3444
ATx631*R8504	61	136	37	2.0	3425
ATx631*80C2241	62	123	31	1.7	3333
ATx630*80C2241	62	133	29	1.9	3259
ATx623*Tortillero	67	150	36	2.1	3222
ATx630*R8504	61	144	35	1.9	3185
A155*R8509	62	154	36	2.2	3111
ATx630*R8510	64	130	32	1.8	2999
ATx378*RTx430	60	130	28	2.3	2972
ATx631*RTx2817	64	129	32	2.3	2888
A8207*R8511	63	113	33	2.2	2888
A155*80C2241	61	126	31	2.1	2814
ATx630*RTx435	62	136	31	1.8	2777
ATx629*R8505	60	119	28	1.7	2750
ATx631*RTx435	60	124	34	1.7	2749
A155*R8511	61	121	32	1.9	2740
Dorado	--	133	26	2.1	2722
CS3541	67	129	26	2.8	2667
ATx631*Dorado	63	137	31	1.9	2537
Chaco Pan					2667*

lent quality. This quality is important to the use of sorghum flour made from this grain.

During the last three years the Mennonites have developed the technology to produce hybrid sorghums for forage; grazing, silage and green chop. They are now producing four such hybrids for use throughout the colony. Production last season was near 70 tons of cleaned salable seed. It is planned for 1989-90 to plant 50 ha of Fredy; Chaco-1 20 ha; Chaco-01 20 ha; Chaco- 88 20 ha; plus three others for a total seed production of 200 ha. With very little input and a great deal of patience there has been a significant development of the private seed production capability in the Chaco. Sorghum is a real and productive commodity now in this region. Its popularity continues to grow. The Mennonites now are ready to produce their own grain sorghum hybrids which require more sophisticated technology.

Table 2 presents the fourth year data on number of days to anthesis of an array of A-lines to be used in production of grain hybrids by crossing with selected R-lines. These data on days to anthesis across years (environments) are required to make plantings which niche perfectly to produce a complete seed set. Isolation technology, seed processing technology, and a market base have been developed for the production of forages. In the next several years it is anticipated that this group will master the seed production technology required for high quality grain hybrids.

The experimental farms at Loma Plata and Para Todo have experimented with the forages which they produce. They have developed planting density, frequency of cutting, fertilization schedules, etc., for each type of hybrid produced. Table 3 presents the data accumulated at Para Todo for individual and total forage yields for Fredy, Chaco-88, Sudax SX121 and Greenleaf Sundangrass. Fredy produced more green biomass on the ratoon than on the first seeded crop, even though it lost some of its plant numbers in regrowth. Chaco 88 which was not as productive as Fredy did ratoon better. The ratoon capability of Greenleaf Sudangrass was clearly demonstrated.

These results indicate the progress being made in Paraguay by the MAG and Mennonites to develop a sound sorghum industry. The constraints to sorghum development were misinformation, poor or no quality seeds for planting, and no understanding of the potentials for sorghum. Basic experiments and demonstration plots have aroused widespread interest in sorghum because of its drought tolerance and uses as feed, food and forage. Both MAG and the Colonies have developed a solid base of agronomic data for agronomy and seed production. There is a substantial need for some continued support by INTSORMIL to provide leadership and backstopping for this developing industry in a developing country.

Table 2. Behavior of parental lines at Filadelphia, 1988-89.

Cultivar	Days to anthesis	Height (cm)	Length of panicle (cm)	Uniformity[1]
		Females		
ATx622	64	131	32	1.3
ATx623	63	120	35	1.3
ATx624	64	125	32	1.4
ATx625	71	106	28	2.0
ATx626	66	122	27	1.7
ATx627	67	120	28	1.8
ATx628	64	115	25	2.0
ATx629	63	123	27	1.4
ATx631	67	110	31	1.5
A_2Tx632	64	102	22	1.4
ATx378	63	113	24	1.2
		Males		
RTx430	63	120	24	1.4
RTx432	63	113	21	1.3
RTx433	63	110	23	1.3
RTx434	67	119	21	1.7
RTx435	65	108	32	1.5
RTAM428	70	107	22	2.8
SC599-11E	63	90	21	1.8
SC103-12E	63	88	26	1.6
TMTx430	63	180	28	1.5
80C2241	63	103	24	1.3
Greenleaf	70	182	27	1.8
RTx2737	63	106	26	1.4

[1]Uniformity 1.0 = very good

The research information being obtained in Paraguay is strengthening the hybrid seed industry by demonstrating the multiple uses of sorghum, i.e., for feedstuffs as well as for human food. As we gain information on quality traits impacting food usage we expand our knowledge base for using sorghum as a food resource in the U.S.

Institution Building

Paraguay staff of MAG and the Mennonites who have trained in Texas are the current builders of the developing sorghum revolution in Paraguay. This includes the graduate-degree-trained individual and the short-term training program developed for the agronomists. INTSORMIL-trained personnel are now National Sorghum Leader (MAG) and Senior Research Leader for Servicio Agropecuario - Chaco Central. Without funds for use in Paraguay there is no current human resource development strategy in place. When or if we receive funds for Paraguay this will be a very high priority.

Numerous supplies, pollinating equipment, bulk seeds and experimental seeds as well as data collecting supplies were provided to collaborators. Arrangements were made with seed companies and foundation seed sources to provide basic stocks for hybrid seed production

Networking

Collaborating scientists have completed several travels outside the country to strengthen their program. Ing. W. Giesbrecht has traveled to Argentina to consult with seed producers and has arranged for a seed producer of basic stocks in Argentina to come to Filadelphia for consultation. Ing. Giesbrecht has conducted several workshops, group meetings, and field days to strengthen the position of sorghum in the Colonies. Ing. Mercedes Alvaracz has conducted trials throughout Paraguay with rural associations, cooperatives, Peace Corps, agricultural loan agencies, etc. The program in Paraguay is gaining recognition in Argentina, Uruguay and Brazil where scientists are coming for development information.

Sorghum Seeds for the Chaco

Loma Plata- Colonia Menno - 1988

Characteristics of Different Varieties of Forage Sorghum and Sudangrass

Chaco 101 - Chaco 101 is a dual purpose forage sorghum that can be used for silage and also for grain production. It has a high quantity of panicles (23%) and leaves (15%) in relation to total weight of the plant. The silage of Chaco 101 is recommended especially for fattening steers. Chaco 101 has a height of 150 to 100 cm. It

Table 3. Sorghum forage yields from two cuttings at Para Todo (Co. Mennonite) 1988-89.

Variety	YIELD (KG/HA)[1]			No. plants/ha		Leaf disease[2]	
	I	II	Total	I	II	I	II
Fredy	34,000	38,250	72,250	136,500	127,125	2	2.5
Sudax SY121	35,250	36,750	72,000	143,375	135,875	2	2.0
Chaco 88CS	27,000	32,750	59,750	158,875	172,000	2	2.3
Greenleaf	11,750	19,750	31,500	202,250	253,000	4	3.8

[1]Date planted - Jan. 5; Harvest I - Feb. 22; Harvest II - April 21.

[2]1 = very good; 5 = very poor.

has good yield of 40,000 kg/ha of fresh silage. It is not bird resistant and has very good digestibility. Chaco 101 has high resistance to lodging and resistance to diseases.

Chaco 1 - Chaco 1 is a forage sorghum hybrid with excellent green biomass production of 55,000 kg/ha per average cutting. For its high production, it has good quantity of panicles (13-14%) and good quantity of leaves (14% by total weight of the plant). It is excellent for producing silage which is recommended highly for the production of milk. Chaco 1 has an average height of 250 cm to 300 cm. It has excellent resistance to lodging. With its very low content of tannin it makes a good dairy feed with excellent digestibility. It has very good resistance to disease.

Fredy - Fredy is a hybrid forage sorghum. For its high production and excellent capability to regrow, this hybrid makes an excellent pasture, for direct grazing or green chop. Its stems are soft and sweet, giving good palatability. Fredy has good disease resistance. At the Isla Poi experimental farm the hybrid registered a yield of 88,000 kg/ha annually from four cuttings.

Chaco 88 - Chaco 88 is a sudangrass type with good production and excellent regrowth. This sudan has fine stems and good palatability for either direct grazing or green chop when used in milk production and the production of meat. Chaco 88 has an annual yield of 75,000 kg/ha in four cuttings. It has very good resistance to diseases.

Chaco Pan - Chaco Pan is a dual purpose sorghum which can be used for silage, or it can be used to produce grain. The grain does not contain tannins. In those cases when one wants flour of sorghum it can be used to make breads. The mixture (composite flour) is 70% wheat flour and 30% sorghum flour (Chaco Pan).

Senegal

David J. Andrews
University of Nebraska

Country Coordinators

David J. Andrews, Department of Agronomy, University of Nebraska (U.S. Coordinator)
Dr. Demba M'Baye, Plant Pathologist, ISRA, CNRA Bambey (Host Country Coordinator)

Institutions Involved

Institut Senegalais de Recherches Agricoles (ISRA), 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. David J. Andrews, Millet and Sorghum Breeder, University of Nebraska, Lincoln, NE
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Dr. Jerry Eastin, Plant Physiologist, University of Nebraska, Lincoln, NE
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Dr. Ismael Ouedraogo, Economist and Chief of Party, MSU, Senegal
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Collaborative Program

The collaborative program to date has been limited to pearl millet germplasm and information exchange, there being no separate country budget. In 1986 and 1987 there was collaboration on millet food product research with the Institut Technologie Alimentaire in Dakar-Hann. One researcher, Mr. Adamu Fofana, was trained at the University of Nebraska in millet breeding. In the current year, a new initiative was taken in collaboration with Michigan State University and U.S.A.I.D./Dakar to increase INTSORMIL's participation in pearl millet and sorghum research in Senegal.

Sorghum and Millet Constraints

Production Constraints

Pearl millet and sorghum production in Senegal suffer from the same general farm and market constraints as in other West African countries. Pearl millet and sorghum are the countries' major dryland food cereals with pearl millet accounting for about 70% of the total area planted to cereals (0.8 to 1.1 million ha). Yields are limited primarily by variable rainfall, poor cultivation practices, low soil fertility and no fertilizer use, diseases and pests (principally downy mildew, smut and the head worm *Raghuva*) and poor markets with a narrow range of end-uses.

Opportunities

There is a long history of agronomic research in Senegal on problems of soil fertility, cultivation, animal traction, residue management, fertilizers, pest and diseases and crop breeding which form an excellent basis for collaborative research. Because of soil degradation due to the increased frequency of cropping and removal of all crop residues, research into 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.

Research Progress

Because of strict adaptation requirements, both physical and biological, genetic material introduced from outside West Africa is unlikely to be successful in the normal rainfed conditions in Senegal. Accordingly, crosses were planned and made in 1988 and early 1989 between INTSORMIL pearl millet and sorghum stocks and Senegalese and other West African parents. The F_1's and F_2's will be grown for selection in Senegal in 1989.

Michigan State University is the lead institution for implementing the Senegal Agricultural Support Project II funded by U.S.A.I.D./Dakar (#685-0957) which terminates in June 1990. For cereals, this project, in accordance with the existing Senegalese government plan, focuses on diversifying cropping in the Senegal River Valley where a very large expansion in the irrigated area is planned. "Decrue" sorghum (a low input, low production system dependent on river flooding) will no longer exist, but irrigation will provide other opportunities for more productive cropping.

To plan the research, Mr. Fofana first visited the University of Nebraska sorghum and pearl millet improvement projects in October 1988. This was followed by a visit in December by Mr. Andrews to meet Drs. L. Cisse, Demba M'Baye, Claude Luce of ISRA, and Dr. Ouedraogo of Michigan State University. A tentative plan was drawn up where support was given to CNRA Bambey for the increase of sorghum and pearl millet materials in the 1988/89 off-season and to conduct funded tests in the Flueve Senegal, in both the following wet and dry seasons, at a total cost of about U.S. $50,000. Further material was sent directly for these tests from several INTSORMIL projects (NU-115, -116, -118, TAM-121 and 122).

Networking and the Future

Pearl millet varieties from ICRISAT Sahelian Centre, and other West African countries were incorporated into the testing program. Depending on future funding and research orientation, sorghum material will similarly be obtained, especially from the INTSORMIL/Niger project. The current involvement of INTSORMIL in Senegal will hopefully be expanded when the third phase of the Senegal Agricultural Research project is funded, which will enable more emphasis to be placed on the agronomy of rainfed crop production and training.

South America (Colombia/CIAT)

Lynn M. Gourley
Mississippi State University

Country Coordinators

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Dr. Manuel Torregroza, ICA Director of Annual Crops, Apartado Aereo 151123, Bogota, Colombia. (Host Country Coordinator)

Collaborative Program

Memorandums of Understanding

The collaborative research site of Colombia operates under three formal and several informal agreements. In 1981, a Memorandum of Intention was signed by the Directors of INTSORMIL, ICRISAT, and CIAT. Research started in 1982 was formalized by a Memorandum of Agreement between the National Program of Colombia (ICA), INTSORMIL, and CIAT which was signed in 1988. In 1989, a Memorandum of Agreement between INTSORMIL and the El Alcaravan Foundation, a consortium of petroleum companies in Colombia managed by Oxidental, was signed. Informal agreements and linkages have been establish with FENALCE, a production and extension oriented organization, and with three national universities in Colombia. The INTSORMIL collaborative research site project, MSU-111, is managed through the Office of International Programs at Mississippi State University, Dr. Ron Brown, Director. Dr. Guillermo Munoz was named MSU-111 PI July 1, 1988. Dr. Lynn Gourley was appointed Colombia Country Coordinator by Mississippi State University and Dr. Manuel Torregroza Host Country Coordinator by ICA.

Interdisciplinary Research

This collaborative research site was originally established to conduct germplasm enhancement research on problems relating to acid soil production constraints of sorghum and pearl millet. Plant breeders at all INTSORMIL institutions have had germplasm evaluated at this site through germplasm exchange. Specific long-range research goals in Colombia now include pearl millet (NU-118 and KSU-101), drought tolerance (TAM-122), pathology (TAM-124), physiology (NU-114), and grain quality (TAM-126 and PRF-103B) investigations. Some entomology input was provided by MSU-105.

Interdisciplinary research activities are enhanced by ICA, CIAT, FENALCE, and three national universities staff members. During Year 10, undergraduate thesis research was conducted by 14 Colombian students in several areas of sorghum production and utilization.

Financial Inputs and Management

Colombia does not have a U.S.A.I.D. Mission, only a representative. Year 10 funding of MSU-111 was $70,000. The El Alcaravan Foundation has supplied equipment for ICA and approximately $90,000 to support INTSORMIL collaborative research in the territory of Arauca. FENALCE is funding some of the drought tolerance research on the Atlantic Coast for researchers at Texas A & M University. Additional support of land, equipment, and other facilities by El Alcaravan, ICA, and CIAT provide an effective 2:1 leveraging of INTSORMIL funding. Base funding to support an INTSORMIL scientist is essential since the outside funds cannot be used to supplant funds for the INTSORMIL PI.

Operational funds for MSU-111 are transferred to CIAT from Mississippi State University and are accounted for as an outside funded project. CIAT also manages the El Alcaravan account for INTSORMIL.

The genetic variability for acid soil tolerance and this additional funding has allowed the establishment of regional sorghum trials in the Llanos where no sorghum grew previously. Research has progressed to the extent that ICA is considering the commercialization of the products of this collaborative effort and expansion of sorghum production in the acid soils areas. Drought tolerant germplasm from Texas A & M University has encouraged ICA to conduct research in the Atlantic coast area. Currently, 14 students from Colombian National Universities are doing their thesis problems on sorghum in collaboration with INTSORMIL. Another activity being explored by ICA, in cooperation with INTSORMIL, is the use of sorghum flour to extend wheat flour. Germplasm has been distributed from this site and Mississippi to many countries around the world.

Collaboration with International Centers

The MSU-111 collaborative site project is headquartered at the International Center, CIAT. Collaboration with ICRISAT Center and ICRISAT's outreach programs in Mexico and Zimbabwe continues to be excellent. INTSORMIL's sorghum and millet research has high visibility due to CIAT's student training and outreach programs throughout Latin America, Africa and Asia.

The Planning Process

Specific long-range goals have been developed jointly with ICA for the Colombian program. Annual planning meetings are being formally held in Colombia. Specific experiments, organization, funding and individuals responsible for conducting the research are discussed at these meetings.

Sorghum/Millet Constraints Researched

Major constraints to sorghum production are the lack of improved varieties and hybrids for regions with specific ecological problems, such as infertile acid soils, drought, diseases, insects, and other related agronomic problems. Aluminum toxicity and acid soils are major constraints to sorghum production in the large potential zone called the Llanos Orientales. Farmers throughout the acid soil areas in Latin America require low-input sustainable agricultural technology to increase the sorghum production area. Drought stress is also a major constraint in the sorghum areas located in the states of Atlantico, Magdalena, Bolivar, Guajira, and Cesar. Marketing grain sorghum is a problem in the Caqueta and Uraba regions which are potential zones of production.

Research Methods

Sorghum breeding lines, and sorghum and pearl millet yield trails are grown on acid soil field plots in which purchased inputs have been added in low quantities. This results in the severe stunting or killing of Al-susceptible genotypes. This stress-breeding technique is being employed by INTSORMIL and ICA breeders and has proven effective in selecting acid soil tolerant genotypes.

Evaluation of INTSORMIL breeding lines and hybrids for tolerance to drought has been conducted in collaboration with ICA Experiment Stations at Motilonia and Nataima.

Research Progress

Results of grain sorghum yield trials conducted by ICA Sorghum Breeder Cesar Ruiz are presented in Table 1. These photoperiod sensitive varieties are the highest yielding entries in regional trials conducted in Colombia using low-input production techniques. Grain yields of about 2000 kg ha^{-1}, 72% Al saturation, appear to be the upper yield potential for varieties in the Llanos environment.

Aluminum-tolerant hybrids using these varieties as pollen parents could possibly increase the grain yield potential and tolerance to higher levels of Al saturation. Results from a genetic study conducted by Dr. Guillermo Munoz at Quilichao, Colombia are presented in Table 2. Some of the highest yielding hybrid combinations in the low and high-Al environments were those produced with Wheatland and these varieties as pollinators. The hybrid combination Wheatland x MN 4508 produced almost twice the grain yield of the Al-tolerant parent (MN 4508)

Table 1. Field evaluation of Al-tolerant sorghum genotypes at 48 and 72% Al saturation, La Libertad Experiment Station, Villavicencio, Colombia.

	48% Al saturation			72% Al saturation		
Genotype	Days to bloom	Plant height cm	Grain Yield kg ha^{-1}	Days to bloom	Plant height cm	Grain yield kg ha^{-1}
IS 8931	67	160	2593	65	168	2267
IS 9084	62	162	2741	64	163	2102
IS 2765	66	162	2907	68	153	2063
IS 8933	64	160	2852	69	160	1880
MN 4508	64	158	3092	68	168	1826
IS 8959	61	155	3149	65	168	1311
IS 3522	59	151	2185	64	156	1741
IS 8577	61	152	2963	57	161	1643
IS 7132	65	148	2280	65	148	1587
IS 7151	61	168	2092	64	175	1578
IS 3071	64	152	3796	68	159	1563

From Cesar Ruiz, ICA Sorghum Breeder, La Libertad Station, Villavicencio, Colombia.

Table 2. Yield and agronomic characteristics of parents and their hybrids grown at 26 and 77% Al saturation in field trials at Quilichao, Colombia.

Code genotype	26% Al saturation			77% Al saturation		
	Days to bloom	Height cm	Grain yield kg ha^{-1}	Days to bloom	Height cm	Grain yield kg ha^{-1}
Females						
1 B-Yel Pl	71	93	417	0	0	0
2 Tx 623	69	112	604	0	0	0
3 Martin	65	90	354	74	12	125
4 Wheatland	65	85	625	78	27	156
5 Wheatland Der	69	83	687	0	0	0
6 IS 12539C	68	125	667	74	45	187
7 IS 12685C	69	115	437	74	73	250
Males						
8 IS 3071	69	136	3687	74	124	2625
9 IS 3522	67	157	3831	74	120	1667
10 IS6944	70	133	3875	78	123	1167
11 IS 8577	68	137	3958	76	85	1417
12 IS 8931	70	142	2792	76	118	2146
13 MN 4508	69	123	3905	77	118	1208
Hybrids						
1 x 8	62	183	3729	73	146	1708
1 x 9	57	188	4500	71	152	1583
1 x 10	60	198	3854	72	160	1500
1 x 11	65	187	3000	71	102	1417
1 x 12	59	203	3104	72	154	1812
1 x 13	57	186	4333	73	156	2271
2 x 8	63	197	4562	77	134	750
2 x 9	66	172	1958	76	148	875
2 x 10	58	175	3729	76	132	1023
2 x 11	63	170	1646	72	129	1167
2 x 12	63	162	1833	72	122	917
2 x 13	60	157	2354	71	126	1625
3 x 8	58	155	2269	70	120	1396
3 x 9	58	170	2312	76	133	1458
3 x 10	56	167	3292	70	132	1542
3 x 11	57	182	3583	71	116	1375
3 x 12	58	168	3208	71	123	1500
3 x 13	58	197	2750	71	127	1250
4 x 8	61	180	3792	72	148	2083
4 x 9	60	187	4104	69	153	1708
4 x 10	62	177	3021	73	142	1979
4 x 11	61	185	4708	73	138	2812
4 x 12	56	182	4812	74	153	1896
4 x 13	59	188	7354	72	141	3042
5 x 8	64	175	5187	77	125	1500
5 x 9	63	198	5625	72	155	2979
5 x 10	65	167	4354	75	112	2229
5 x 11	68	178	2604	76	131	1437
5 x 12	63	158	3375	77	125	1417
5 x 13	69	163	3354	70	135	1687
6 x 8	58	243	2417	72	148	1062
6 x 9	60	208	1354	71	173	1021
6 x 10	63	262	1708	72	167	1375
6 x 11	59	222	2458	71	153	1146
6 x 12	60	230	2042	71	171	1521
6 x 13	63	223	1979	70	164	937
7 x 8	56	227	2021	74	152	1187
7 x 9	60	238	2104	71	182	1562
7 x 10	58	233	1521	70	167	1000
7 x 11	59	250	2271	71	163	1312
7 x 12	64	208	1146	70	170	1396
7 x 13	64	250	5208	77	191	1292

Adapted from dissertation of Dr. Guillermo Munoz, Inheritance of Aluminum Tolerance in Sorghum Under Field Conditions in Colombia, Mississippi State University in the low-Al environment and 150% more in the high-Al environment. Mechanized harvest of these photoperiod sensitive varieties and hybrids is limited to acid soil areas near the equator. Shorter photoperiod insensitive hybrids and/or varieties will be required in acid soil regions at higher latitudes.

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, Africa and Asia. Identification of genes which produce stress-tolerant hybrids will also benefit the agricultural industry in the U.S.

Institution Building

Research support funds provided to ICA have been limited due to a constrained operational budget. Host country capabilities have been strengthened through equipment, literature, trained staff, seed storage facilities, sorghum and millet germplasm, and travel for ICA staff professional improvement.

Dr. Guillermo Munoz (Ph.D.-MSU), a resident of Colombia, was appointed INTSORMIL PI for MSU-111 (Colombia) in July 1988. He coordinates research and training activities with collaborating organizations in Colombia and with INTSORMIL projects in the U.S. Mr. Cesar Ruiz (M.S.-MSU) is the principal sorghum breeder at ICA's main acid soil research station at La Libertad, Villavicencio, Colombia.

Dr. Dorance Munoz, Colombian Director of Annual Crops and INTSORMIL Colombian Coordinator; Dr. Guillermo Munoz, INTSORMIL MSU-111 PI; and Dr. Luis de Angulo, Director of the El Alcaravan Project traveled to Scottsdale, AZ to participate in the INTSORMIL CRSP Conference, 3-5 January 1989. Dr. Lynn M. Gourley coordinated EMBRAPA-INTSORMIL collaboration in Brazil, 7-18 April 1989, and ICA-INTSORMIL collaboration in Colombia 19 April-4 May 1989.

Fourteen B.S. degree students from the National University of Palmira, and the Universities of Tolima and Los Llanos are working on their thesis research in collaboration with INTSORMIL. The University of Magdalena has contacted the MSU-111 PI for future collaboration. At the advanced degree level, three Colombian students are pursuing degree programs at INTSORMIL universities. Desired training goals include 22 students trained in areas of INTSORMIL research. This leaves a net training need of 19 students.

Networking.

Colombia is the only collaborative site in which the universities, private sector, National Research Institution (ICA), extension oriented farmer funded organization (FENALCE) and an International Center (CIAT) are collaborating with INTSORMIL to further the accomplishment of research and training goals. Networking linkages have been established with other Latin American National Programs. CIAT has aided INTSORMIL in the dissemination of sorghum and millet research results to farmers and scientists throughout the region.

Research Accomplishments

Research conducted by INTSORMIL in collaboration with ICA and other organizations in Colombia has attracted private sector funds to further long-term research goals in Colombia. The El Alcaravan Foundation has provided substantial operation and training funds for research conducted in the Territory of Arauca.

First generation Al-tolerant sorghum hybrids from Projects MSU-111 and MSU-104 are being evaluated for grain yield and agronomic desirability in Colombia, Niger, and the U.S. Additional R-lines and A/B-lines developed for the humid tropics at this collaborative site are being evaluated in Colombia, Brazil, Niger, Kenya, and in the SADCC region of Africa.

Three universities in Colombia, the National University of Palmira, University of Tolima, and University of Los Llanos have teaching staff collaborating with INTSORMIL on sorghum and millet research through student thesis research. This assists INTSORMIL and ICA to conduct research projects at a very reasonable cost and has the additional benefit of identifying students for graduate programs in INTSORMIL Universities.

Sudan

Allen W. Kirleis
Purdue University

Country Coordinator

Allen W. Kirleis, Country Coordinator, Purdue University, West Lafayette, IN 47907
Katy G. Ibrahim, Administrative Assistant, Purdue University, West Lafayette, IN 47907
Omer El Hilu, Host Country Coordinator, Agricultural Research Corporation, Gezira Research Station, Wad Medani, Sudan

Collaborative Program

Organization

The INTSORMIL/U.S. principal investigators develop their scope of work jointly with ARC scientists. These workplans are reviewed and approved by Dr. Osman Gameel, ARC Director General; Dr. Omer El Hilu, ARC/INTSORMIL coordinator and Dr. Allen Kirleis, 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. Kirleis 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 non-existent, the U.S.A.I.D. Mission has provided excellent logistic support to relay communications to the ARC at the Wad Medani and El Obeid research stations.

Research Disciplines

Cooperative Breeding and Genetic Evaluation of Sorghum - Abdel Latif Mubarek Nour, ARC; Darrell Rosenow and Gebisa Ejeta, INTSORMIL.

Cooperative Sorghum Breeding - Osman I. Obeid Ibrahim, ARC; Gebisa Ejeta, Darrell Rosenow and Allen Kirleis, INTSORMIL.

Cooperative Millet Breeding - El Haj Abu El Gasim, ARC; David Andrews, INTSORMIL.

Agronomy and Water Management Program - S. M. Farah, ARC; and Jerry Eastin, INTSORMIL.

Plant Pathology Program - El Hilu Omer, ARC; Richard Frederiksen and Darrell Rosenow, INTSORMIL.

Striga and Weed Control - H. M. Hamdoun and A. G. T. Babiker, ARC; Larry Butler and Gebisa Ejeta, INTSORMIL.

Entomology Program - N. Sharaf Eldin, ARC; and Henry Pitre, INTSORMIL.

Food Quality Program - S. M. Badi, ARC; and Allen Kirleis, INTSORMIL.

Economic Program - Hamid Faki, ARC; and 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
U.S.A.I.D./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 underway in Sudan to incorporate drought tolerance with higher than average yield potential in sorghum are limited by the lack of a rapid field screening procedure and the lack of knowledge on sources of sorghum germplasm with useful traits. The insect pests known to attack sorghum, especially in the rainfed areas of Sudan, include stem borers, American bollworm, and central shoot fly. The major fungal diseases on 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

Striga

The parasitic weed *Striga* (witchweed) is a beautiful but deadly menace to production of sorghum, millet and maize in Africa. *Striga* attaches to the roots of the host plant, diverting nutrients and moisture to itself and greatly diminishing the productivity of the susceptible host. The shift away from traditional cropping patterns utilizing polycultures and fallowing to continuous cereal monocropping has exacerbated the *Striga* problem. Some fields have developed such high *Striga* populations that grain production has become impossible, and they have been abandoned. Drs. G. Ejeta and L. Butler of Purdue University and their Sudanese collaborator, Dr. A. G. Babiker, are using genetics and biochemistry in a multidisciplinary attack on this problem. Much of this work cannot be carried out in the U.S. because of restrictions aimed at preventing the escape of *Striga*. A sorghum cultivar (SRN 39) with superior *Striga* resistance has been identified and found to possess two or more mechanisms by which it resists attack by *Striga*. The roots of SRN 39 produce unusually low amounts of *Striga* germination stimulant. Unless stimulated by chemical signals from host roots, *Striga* seeds will not germinate. In addition, *Striga* parasitism has relatively little effect on grain yield of SRN 39. In *Striga*-infested fields, SRN 39 responds well to improved cultural practices for *Striga* management. Genes responsible for the *Striga* resistance of SRN 39 are being transferred to other sorghum cultivars and are being characterized for possible transfer to other cereals. A unique reactive chemical, sorgoleone, has been found in sorghum root exudate and shown to trigger germination of *Striga* seeds. This is the first *Striga* germination stimulant to be identified from a host crop. Identification of this chemical which controls the initial stage of *Striga* development may provide a key to *Striga* management. Interception or disruption of the signal governing the first developmental stage could prevent *Striga* germination; supplying a synthetic signal in the absence of the host plant could trigger suicidal germination. This interdisciplinary approach combining biotechnology with conventional plant breeding is providing hope that the *Striga* problem can be solved.

Techniques for Long Smut Inoculation in Sorghum

The results obtained from inoculation tests conducted in 1989 have revealed that sporidial inoculum has recorded the highest percent infection compared to teliospore inocula. Moreover, irrespective of inoculum source, the early boot stage has been found to be the best receptive stage for infection. On the other hand, delayed bloom of sorghum panicles favors production of high infection level. Thus, the longer the association of inoculum with boot, the higher the incidence of the disease. Inoculation tests have also shown that wild sorghum spp. "Adars" may play an important role in increasing inoculum potential. Both types of "Adars" under test were found to be susceptible to the disease. The study has also indicated that long smut sori tend to occur at any part of the panicle regardless of the site of inoculum injection and not confined to a certain part.

The investigation revealed that long smut disease prevails in the country. This is particularly manifested in the survey conducted in the seed propagation area (irrigated Gezira). Heavy incidence of the disease occurred in this area where the parental lines of the outyielding cultivar HD-1 had been cultivated for seed multiplication purposes. Disease incidence stresses the need for considering breeding for disease resistance before the release of new cultivars.

The present study deals with spore germination tests and the role of possible environmental conditions affecting spore germination. Comparison of spore germination of the three smut pathogens prevailing on sorghum, has clearly shown that spores of *Tolyposporium ehrenbergii* have lower percent germination than the two other smut incitants (*Sphacelotheca sorghi* and *S. cruenta*). Root exudates stimulate germination of spore balls, but the stimulatory effect is less pronounced when teliospores are separated. The developing inflorescence exudates have no promotive effect on spore germination.

The present study has revealed that teliospores tolerate elevated temperatures, whereas sporidia are sensitive to both high temperature and desiccation. Moreover, sporidia stay viable in sterilized distilled water for at least 20 days without any appreciable change in their germination capacity. Spore balls of the fungus retain their viability for two years.

Anatomical and histological studies have conclusively established that penetration of the fungus is only achieved through the stylar region of the developing florets. Furthermore, the development of the pathogen in the infected kernels takes place from the upper part of the ovary and the upper ovary sides then progresses downward and to the center of the infected ovaries. This is confirmed by the production of mature spore balls situated at the upper portion of the ovary and at the upper ovary sides, and spore balls in the phase of formation and reorganization located at the bottom part of the ovaries. Sections of early smutted grains also show a nonsmutted region present under the immature spore balls.

Instant Weaning Food

The Food Research Centre (FRC) has an ongoing effort to promote the use of locally grown sorghum and millet. One of the traditional uses for these grains is a fermented preparation sometimes used as a weaning food called "nasha".

Work that was started at Purdue University by Dr. Laila Monawar led to the development of a weaning food called "instant Nasha" by the FRC. The instant nasha is a drum dried product which can be reconstituted to make a ready-to-eat gruel by adding water. However, the drum drying process for manufacturing instant nasha is very energy intensive and consequently expensive. If the drum drying process were used to commercially produce instant nasha, the product cost would probably limit its market. Accordingly, the possibility of producing an instant nasha like product using a potentially less expensive heat extrusion process was examined.

Dr. Monawar worked at Colorado State University to determine the feasibility of using sorghum and peanut blends for making the heat-extruded instant weaning food. After extrusion the products were supplemented with non-fat dry milk, vitamins, and minerals to meet recommended daily intake requirements. *In vitro* protein digestibilities of the heat-extruded products were examined at Purdue University and found to be highly digestible.

Based on these findings, the FRC plans a production run of the heat-extruded sorghum/peanut instant weaning food so the product can be evaluated for consumer acceptability in Sudan and to conduct additional nutritional quality testing on the product. If positive results are obtained, plans are underway to produce and distribute the instant weaning food in Sudan.

Institution Building

Research Support

The INTSORMIL/Sudan program has continued to increase the direct allocation of funds to the Agricultural Research Corporation. Research support funds for the host country were as follows:

Sorghum breeding	$18,000
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

An IBM system 2 computer, along with other agronomic and physiological equipment and supplies, was 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

August 12-September 27, 1988 Osman El Obeid Ibrahim, ARC sorghum breeder, traveled to the U.S. Dr. Ibrahim attended the International Conference on Dry Land Farming in Amarillo, TX and visited INTSORMIL sorghum breeding programs at Texas A&M University, University of Nebraska, and Purdue University.

October 21-November 1, 1988 Omer El Hilu, ARC plant pathologist, traveled to Niger to collaborate with Richard Frederiksen, Texas A&M University, to conduct long-smut infection screening with INRAN sorghum scientists.

INTSORMIL Scientist Travel to Sudan

May 15-July 15, 1989 Mohamed Habach, Purdue University, agricultural economic graduate assistant, traveled to Sudan to conduct his Ph.D. thesis research on the evaluation of the potential impact of HD-1 and other new technologies there.

June 12-June 23, 1989 Gebisa Ejeta, Purdue University, sorghum breeder, traveled to Sudan to finalize plans for the Sudan Workshop scheduled for October 29-November 2, 1989.

Networking

Networking activities involving information and technology exchanges are developing through efforts of the ARC/INTSORMIL collaborators in Sudan and other parts of Africa. Research methodologies on drought tolerance screening are shared across countries and zones. Techniques used to screen sorghums for long smut resistance were transferred to scientists in Niger in 1987, 1988, and 1989. Plans are being made to develop a uniform nursery that can be grown in both locations so smut reactions can be compared between Sudan and Niger. The reason is that although these locations have similar environments, the disease patterns are distinctly different. In addition, experiences and information from releasing the hybrid sorghum in Sudan have been shared in the region and in other African zones.

Global-2000, an on-form testing and demonstration program designed to develop a simple technological package which can be extended to farmers in the traditional sector in Africa, began the Sudan operation in 1986. Global's Sudan program works primarily on sorghum (using HD-1 as a standard for comparison), millet, and wheat. Their expatriate staff work in close association with research and extension programs in the Sudan. Many of the ARC/INTSORMIL program collaborating scientists are involved in Global's program. Thus this provides an excellent link for transferring beneficial research findings to the farmers in Sudan.

Plans for a major Sudan Sorghum and Millet Workshop are underway. The workshop will be held at the ARC Headquarters in Wad Medani on October 29-November 2, 1990. The workshop program will focus on ARC/INTSORMIL research progress during the last nine years. The workshop will be jointly sponsored by ARC, INTSORMIL, and U.S.A.I.D./Khartoum.

General Comments

The U.S.A.I.D. Mission in Khartoum has all along supported ARC/INTSORMIL collaborative research efforts. That is probably why the INTSORMIL CRSP effort in Sudan may be one of the strongest and most successful programs. As a result of such Mission efforts and the excellent cadre of well trained Sudanese agricultural scientists, the INTSORMIL/ARC association exemplifies the essence of CRSP programs.

In order to maintain and strengthen the ARC/INTSORMIL Program in Sudan, continual dialogue between INTSORMIL and ARC scientists should continue in all research areas. Joint research planning among scientists, and visits in both the host country and the U.S. are essential.

Sorghum and pearl millet are the most important cereal crops produced in the Sudan. These crops are grown under both rainfed and irrigated conditions in Sudan. In addition, Sudan is a vast country having a diversity of ecological zones with varying climates. There is also a strong base of interest and scientific expertise in Sudan that INTSORMIL has activated. Thus, technology developed in Sudan through the collaborative ARC/INTSORMIL program in the areas of sorghum and millet breeding, physiology, pathology, entomology, agronomy, and food quality is relevant to the entire East African Zone.

On June 1, 1989 Gebisa Ejeta, Purdue University, assumed the INTSORMIL Sudan Country Coordinator position. With his past work experience in Sudan with ICRISAT and his involvement with the cooperative ARC/INTSORMIL program, he is well prepared to handle this responsibility.

Research Accomplishments

INTSORMIL activities in Sudan began in November 1980, with the signing of a memorandum of understanding with the Agricultural Research Corporation (ARC) and the University of Khartoum faculty of agriculture. This agreement led to the placement of Edward B. Reeves and Timothy Frankenberger (University of Kentucky economic anthropologist) in El Obeid from July 1981 through August 1982. These social scientists carried out farming and marketing system studies in 15 villages located within 50 km of El Obeid to collect baseline data for the western Sudan Agriculture Research Project, Kordofan Regional Ministry of Agriculture, and INTSORMIL. Among other things they found that the farmers of the region are producing millet and sorghum for home consumption and sesame and ground nuts for sale. They identified wind erosion, pests and diseases, low soil fertility and inadequate rainfall as the most important natural constraints limiting crop production. To combat inadequate rainfall, they recommended the introduction of early maturing drought-resistant varieties of present crops as well as new drought-resistant crops.

In March 1982, scientists and research administrators associated with ARC were interviewed and documentary data on research plans were collected by Larry Bush and William Lacy (University of Kentucky). They found that the ARC scientific community is well trained. The reserch conducted by ARC scientists is generally of an applied nature. They also found that while ARC scientists consider financial support and operating supplies and material the most important resources for their work, these same resources were also generally regarded either as the least adequate or often inadequate. Many of the findings from this study were used to develop the ARC/INTSORMIL cooperative scientist to scientist research program.

During the 1982 through 1984 cropping seasons Tareke Berhe (Kansas State University) carried out agronomic research in the El Obeid area of North Kordofan. This agronomic work targeted many of the natural constraints identified by Reeves and Frankenberger. Major accomplishments of the research work included (1) identification of an early maturing millet variety (Ugandi, developed by ICRISAT/Sudan program) having good yield potential with limited rainfall, and bristles rendering protection from the birds, mice and grasshoppers, and (2) establishment of an on-farm sorghum/millet testing program in cooperation with the Kordofan Regional Ministry of Agriculture. This on-farm testing program continues to be used by the Regional Ministry today as a measure of introducing new crop varieties and technologies to farmers.

In collaboration with scientists at ARC and INTSORMIL, ICRISAT's/Sudan cooperative breeding program released the first sorghum hybrid (Hageen Dura-1) in January 1983. Hageen Dura-1 (HD-1) is a superior hybrid with yields of over 150% of those of improved local varieties under irrigated and rainfed conditions. HD-1 possesses several important attributes including high yields, drought tolerance, and good grain quality characteristics that helped its rapid spread and wise acceptance by farmers.

The Food Research Centre has demonstrated that HD-1 grain is easily decorticated. Thus, it produces a high yield of white sorghum flour suitable for making good quality bread with a composite flour containing up to 40% HD-1 decorticated flour. INTSORMIL sponsored a workshop on hybrid sorghum seed at Wad Medani in November 1983. Detailed discussions at the workshop, involving scientists, administrators, policy makers and interested private entrepreneurs, focused on effective marketing and government policy considerations that would encourage seed industry development in the Sudan. Concrete recommendations for developing a seed industry were submitted to the Government of Sudan.

A study of the communication of agricultural information in Sudanese villages was done by C. Milton Coughenour (University of Kentucky) and Saadi M. Nazhat (graduate student) around El Obeid in 1984. They found that INTSORMIL's farm trials conducted by Tareke Berhe provided an excellent means of informing farmers about the characteristics of new sorghum/millet varieties. They also learned that information about an innovation spreads among Sudanese farmers much like that found in more developed communities (an S-shaped growth curve over time).

The ARC/INTSORMIL research program at the Gezira Research Station has been designed to strengthen ARC sorghum/millet research and training activities. These have been combined to facilitate attainment of the long-term ARC objectives. Although the program started in 1980, INTSORMIL funds were not transferred to ARC until 1984. The primary disciplines involved in ARC/INTSORMIL collaboration are breeding, stress physiology, plant pathology, entomology, *Striga*, cereal quality and agricultural economics. Some of the major accomplishments from the ARC/INTSORMIL program are listed below.

Cooperative ARC/INTSORMIL crop physiology and breeding work on drought tolerance of sorghum has led to a better understanding of crop adaptation to stress. Sorghum lines with preflowering stress tolerance were found to accumulate a significantly higher concentration of certain metabolic osmolytes than drought susceptible cultivars. Sudan is an excellent location for screening for drought stress. Some of the best new sources of drought tolerance for use in the ARC and U.S. sorghum improvement programs have come from screening INTSORMIL germplasm in Sudan.

In 1981/82 over 40 Sudan sorghum varieties were collected in the Kadugli and El Obeid area and introduced in the U.S. for conversion and breeding lines. In addition, a number of elite Sudanese breeding lines have been selected and transported to the U.S. for the same purpose. These lines should be very useful in broadening the sorghum germplasm base available in the U.S. and as sources of desirable grain quality traits.

An inoculation technique for long smut has been developed in Sudan. This long smut inoculation technique provides sorghum improvement programs with a method of evaluating germplasm for host resistance and is the first of its kind in the world. The inoculation technology was extended to Niger during the 1987 crop year. Work in Sudan on the histology of the infection has shown that long smut is not a seed born pathogen and can only infect sorghum flowers.

Work on the food quality of sorghum by ARC/INTSORMIL has shown that a fermentation process, commonly used to prepare most Sudanese sorghum foods, improves the protein digestibility of cooked sorghum products. This work has led to a better understanding of the factors that influence sorghum protein digestibility and work is now in progress to apply this new knowledge to improve the digestibility of sorghum when used as an animal feed in the U.S.

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, or being very closely related to it. During the year covered by this report, 121 students (97 international and 24 U.S.) were studying at INTSORMIL institutions. Twenty four of the students were female and 97 male. The number of students receiving 100% funding by INTSORMIL totaled 23 (15 international and 8 U.S.). There were an additional 19 students receiving partial funding from INTSORMIL (13 international and 6 U.S.). The remaining 79 students are funded from other sources but are working on INTSORMIL projects. One hundred one students were advised by INTSORMIL principal investigators and twenty students were studying sorghum/millet technologies under non-INTSORMIL graduate advisors at INTSORMIL institutions. The international students came from 33 different countries.

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. One young Host Country scientist was trained in this fashion during the fiscal 1988/89 year.

Total student numbers increased by 17.5% during 1988/89 as compared to 1987/88. However, INTSORMIL funded students has decreased by 17.65%. This represents a decrease of 40.43% decrease in INTSORMIL funded students as compared to 1986/87. 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 four years.

INTSORMIL is also cooperating 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 nine member States of SADCC, 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 U.S.A.I.D., 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 network exist.

The agreement for the second five year phase of the SADCC/ICRISAT/INTSORMIL program has been signed and will run through December 31, 1994. The activity extension calls for the training of an additional 60 scientists from the SADCC region to the M.S. and Ph.D. degree level. As of June 30, 1989 INTSORMIL has processed a total of 40 SADCC students encompassing all nine SADCC countries.

The following table is a compilation of all INTSORMIL training activities for the period covered by this report, July 1, 1988 through June 30, 1989.

Year 10 INTSORMIL Training Participants

Name	Country	University	Discipline	Advisor	Degree	Gender	Funding*
Coulibaly, Adama	Mali	KSU	Agronomy	Vanderlip	MSC	M	I
Kabambe, Vernon	Malawi	KSU	Agronomy	Vanderlip	MSC	M	S
M'Khaitir, Yahya O.	Mauritania	KSU	Agronomy	Vanderlip	MSC	M	O
Klinkebiel, David	US	UNL	Agronomy	Clegg	PHD	M	I
Maliro, Charles	Malawi	UNL	Agronomy	Clegg	PHD	M	S
Mohamed, Mirghani	Sudan	UNL	Agronomy	Clegg	PHD	M	P
Sebolai, Boingotlo	Botswana	UNL	Agronomy	Clegg	MSC	F	S
Bagayoko, Minamba	Mali	UNL	Agronomy	Mason	MSC	M	O
Kasalu, Helen	Zambia	UNL	Agronomy	Mason	MSC	F	S
Toure, Abdoul	Mali	UNL	Agronomy	Maranville	MSC	M	O
Adamou, Moussa	Niger	MSU	Breeding	Gourley	PHD	M	O
Chintu, Edmund	Malawi	MSU	Breeding	Gourley	MSC	M	S
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
Yakub, Muhammad J.	Indonesia	MSU	Breeding	Gourley	PHD	M	O
Mushonga, Joseph	Zimbabwe	PRF	Breeding	Axtell	PHD	M	S
Botorou, Ouendeba	Niger	PRF	Breeding	Ejeta	PHD	M	O
Hess, Dale	US	PRF	Breeding	Ejeta	PHD	M	O
Kapran, Issoufou	Niger	PRF	Breeding	Ejeta	MSC	M	O
Klingler, John	US	PRF	Breeding	Ejeta	MSC	M	I
Monyo, Emmanuel	Zimbabwe	PRF	Breeding	Ejeta	PHD	M	I
Dahlberg, Jeffrey	US	TAM	Breeding	Miller	PHD	M	P
de Franca, Geraldo	Brazil	TAM	Breeding	Miller	PHD	M	O
Kanyenji, Ben M.	Kenya	TAM	Breeding	Miller	MSC	M	O
Kenga, Richard	West Africa	TAM	Breeding	Miller	MSC	M	O
Khizzah, Bill W.	Uganda	TAM	Breeding	Miller	PHD	M	O
Nukal, Balaji	India	TAM	Breeding	Miller	PHD	M	O
Romo, Enrique	Mexico	TAM	Breeding	Miller	PHD	M	O
Nunes, Maria Eugenia	Mozambique	TAM	Breeding	Miller	MSC	F	S
Tenkouano, Abdou	Burkina Faso	TAM	Breeding	Miller	MSC	M	O
Toure, Aboubacar	Mali	TAM	Breeding	Miller	PHD	M	O
Wanous, Michael K.	US	TAM	Breeding	Miller	MSC	M	O
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
Jorgenson, Julie	US	TAM	Breeding	Rosenow	PHD	F	P
Walulu, Richard	Kenya	TAM	Breeding	Rosenow	MSC	M	P
Doumbia, Mamadou	Mali	TAM	Breeding	Peterson	MSC	M	O
Payne, Bill	US	TAM	Breeding	Peterson	PHD	M	O
Sow, Abdoul	Mali	TAM	Breeding	Peterson	MSC	M	O
Mazhani, Louis	Botswana	UNL	Breeding	Andrews	PHD	M	S
Chirwa, Rowland	Malawi	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
Lopez-Pereira, Miguel	Honduras	PRF	Economics	Baker	PHD	M	I
Ahmed, Mohamed	Sudan	PRF	Economics	Sanders	MSC	M	O
Habash, Mohamed	Syria	PRF	Economics	Sanders	PHD	M	I
Nichola, Tennassie	Ethiopia	PRF	Economics	Sanders	PHD	M	I

Name	Country	University	Discipline	Advisor	Degree	Gender	Funding*
Ramaswamy, Sunder	India	PRF	Economics	Sanders	PHD	M	I
Shapiro, Barry	US	PRF	Economics	Sanders	PHD	M	O
Castro, Marco	Honduras	MSU	Entomology	Pitre	PHD	M	I
Lopez, Julio	Honduras	MSU	Entomology	Pitre	MSC	M	I
Portillo, Hector	Honduras	MSU	Entomology	Pitre	MSC	M	I
Lastres, Lorena	Peru	TAM	Entomology	Gilstrap	MSC	F	I
Edwards, Jeff	US	TAM	Entomology	Teetes	MSC	M	O
Manthe, Chris	Botswana	TAM	Entomology	Teetes	PHD	M	P
Merchant, Michael	US	TAM	Entomology	Teetes	PHD	M	I
Pendleton, Bonnie	US	TAM	Entomology	Teetes	PHD	F	O
Rojas, Edgar	Costa Rica	TAM	Entomology	Teetes	MSC	M	O
Thindwa, Harriet	Malawi	TAM	Entomology	Teetes	PHD	F	S
Youm, Ousmane	Senegal	TAM	Entomology	Teetes	PHD	M	I
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, Helbert	Mexico	TAM	Food Quality/Util	Rooney	PHD	M	P
Bello, Tony	Nigeria	TAM	Food Quality/Util	Rooney	PHD	M	I
Clegg, Chally	US	TAM	Food Quality/Util	Rooney	MSC	M	I
Gomez, Marta	Argentina	TAM	Food Quality/Util	Rooney	PHD	F	P
Gous, Frans	South Africa	TAM	Food Quality/Util	Rooney	PHD	M	O
Jackson, David	US	TAM	Food Quality/Util	Rooney	PHD	M	P
Ramirez, B.	Mexico	TAM	Food Quality/Util	Rooney	PHD	M	O
Sikorski, Susan	US	TAM	Food Quality/Util	Rooney	MSC	F	O
Torres, P.	Mexico	TAM	Food Quality/Util	Rooney	MSC	F	P
Vivas-Valdez, N.	Mexico	TAM	Food Quality/Util	Rooney	PHD	F	P
Young, Robert	South Africa	TAM	Food Quality/Util	Rooney	PHD	M	O
Zake, Vincent	Uganda	TAM	Food Quality/Util	Rooney	PHD	M	P
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
Zvoutete, Petros	Zimbabwe	KSU	Pathology	Claflin	MSC	M	S
Alexander, John	US	TAM	Pathology	Frederiksen	PHD	M	P
Casela, Carlos	Brazil	TAM	Patholgy	Frederiksen	PHD	M	P
Esele, Peter	Uganda	TAM	Pathology	Frederiksen	PHD	M	P
Guthrie, Phil	Great Britain	TAM	Pathology	Frederiksen	PHD	M	I
Mansuetus, Anaclet	Tanzania	TAM	Pathology	Frederiksen	MSC	M	S
McClelan, Eddie	US	TAM	Pathology	Frederiksen	PHD	M	I
Naidoo, Gnanambal	South Africa	TAM	Pathology	Frederiksen	PHD	F	P
Rodriguez, Oscar	Mexico	TAM	Pathology	Frederiksen	PHD	M	I
Kunene, Innocentia	Swaziland	TAM	Pathology	Odvody	PHD	F	S
Mahuka, George	Zimbabwe	TAM	Pathology	Toler	MSC	M	S
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	O
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

Year 10 SADCC/ICRISAT Training Participants

Name	Country	University	Discipline	Advisor	Degree	Gender
Mushonga, Joseph	Zimbabwe	PRF	Breeding	Axtell	PHD	M
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
Marake, Makoala	Lesotho	UNL	Agronomy	Walters	MSC	M
Mofolo, Moea	Lesotho	UNL	Agronomy	Sorensen	BSC	M
Mothokho, Neo	Lesotho	UNL	Agronomy	Lewis	BSC	M
Moletsane, Nyakallo	Lesotho	PRF	Economics	Farris	MSC	F
Matli, Musi	Lesotho	UNL	Extension	Horner	PHD	M
Chobela, Molapo	Lesotho	KSU	Pathology	Claflin	PHD	M
Kabambe, Vernon	Malawi	KSU	Agronomy	Vanderlip	MSC	M
Maliro, Charles	Malawi	UNL	Agronomy	Clegg	PHD	M
Msiska, Felix	Malawi	MSU	Agronomy	Hodges	MSC	M
Chintu, Edmund	Malawi	MSU	Breeding	Gourley	MSC	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
Nunes, Maria E.	Mozambique	TAM	Breeding	Miller	MSC	F
Nxumalo, Edgar	Swaziland	TAM	Agronomy	Hons	MSC	M
Kunene, Innocentia	Swaziland	TAM, Pathology	Frederiksen	PHD	F	
Felix, Joel	Tanzania	PRF	Agronomy	Vorst	BSC	M
Mgema, William	Tanzania	UNL	Agronomy	Clark	MSC	M
Mndolwa, Samuel	Tanzania	KSU	Agronomy	Mosier	BSC	M
Chambo, Habel	Tanzania	KSU	Breeding	Brammel-Cox	MSC	M
Saadan, Hamis	Tanzania	MSU	Breeding	Gourley	PHD	M
Guutazi, Athman	Tanzania	KSU	Entomology	Wilde	MSC	M
Mansuetus, Anaclet	Tanzanaia	TAM	Pathology	Fredriksen	MSC	M
Chungu, Chibwe	Zambia	UNL	Agronomy	Mason	BSC	F
Hikeezi, Doreen	Zambia	KSU	Agronomy	Kropf	BSC	F
Kasalu, Helen	Zambia	UNL	Agronomy	Mason	MSC	F
Muuka, Ferdinand	Zambia	UNL	Breeding	Andrews	MSC	M
Sikabbubba, Ruth	Zambia	KSU	Food Science	Klopfenstein	MSC	F
Kaula, Godwin	Zambia	TAM	Pathology	Odvody	SPT	M
Muza, Figuhr	Zimbabwe	MSU	Breeding	Gourley	MSC	M
Mahuka, George	Zimbabwe	TAM	Pathology	Toler	MSC	M
Zvoutete, Petros	Zimbabwe	KSU	Pathology	Claflin	MSC	M

* I = Completely funded by INTSORMIL
P = Partially funded by INTSORMIL
S = SADCC/ICRISAT funded
O = Other source

ACRONYMS

AAA/SFAA	American Anthropological Association/Society for Applied Anthropology
AALSN	All Africa Long Smut Disease Nursery
ABA	Abscisic Acid
ADC's	Advanced Developing Countries
ADIN	Nursery for Disease and Insect Resistance
ADRA	Adventist Development and Relief Agency
A.I.D	Agency for International Development
A.I.D./ES	Agency for International Development/El Salvador
A.I.D./H	Agency for International Development/Honduras
APHIS	Animal and Plant Health Inspection Service, U.S.
ARC	Agricultural Research Corporation, Sudan
ARS	Agricultural Research Service
ARS-Sebele	Agricultural Research Station, Sebele, Botswana
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	Departement du Centre de Coopèration Internationale en Recherche Agronomique pour le Dèveloppement
CLAIS	Consejo Latin Americana dc Investigadores en Sorgho
CM	Las Playitas Experiment Station, Comayagua, Honduras
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
DAR	Division of Agronomic Research, Mali
DECOR	Ministry of Rural Economy, Niger
DOA	Department of Agriculture, Botswana
DR	Dominican Republic
EAP	Escuela Agricola Pan Americana, Zamorano, Honduras
EARAT	East African Regional Adaptation Trial
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
FONAIAP	Fondo Nacional de Investigacion Agropecuaria
FRC	Food Research Center, ARC, Sudan
FSR	Farming Systems Research
FSR/E	Farming Systems Research/Extension
FSSP	Farming Systems Support Project
FSU	Farming Systems Unit, Burkina Faso
GASGA	Group for Assistance on Systems Relating to Grain after Harvest
GOB	Government of Botswana
GRA	Graduate Research Assistant
GTZ	German Agency for Technical Cooperation
IAC	International Agriculture Center
IAN	Institute Agronomia Nacional, Paraguay
IANR	Institute of Agriculture and Natural Resources
IBM	International Business Machines
IBRAZ	Institut Burkinahe de Recherache Agronomique et Zoologique
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
IDIN	International Nursery for Plant Disease and Insects
IDRC	International Development Research Center
IER	Institute of Rural Economy, Mali
IFPRI	International Food Policy Research Institute
IFSAT	International Food Sorghum Adaptation Trial
IFTST	International Food Type Sorghum Trial
IHAH	Instituto Hondureno de Antropologia e Historia
IICA	Instituto Interamericano de Ciencias Agricolas de la OEA
IIMYT	International Improved Maicillo Yield Trial
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
INTA	National Agricultural Technology Institute
INTSORMIL	International Sorghum/Millet, Collaborative Research Support Program (CRSP)
IPA	Instituto de Pesquisas Agronomicas, Brazil
IPB	Institute of Plant Breeding, Philippines
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
ISA	Instituto Superior Agricola
ISAVN	International Sorghum Anthracnose Virulence Nursery
ISC	ICRISAT Sahelien Center
ISDMN	International Sorghum Downy Mildew Nursery, ICRISAT
ISFAHT	International Sorghum Food and Adaptation Hybrid Test
ISRA	Institute of Agricultural Research, Senegal
ISTAT	International Sorghum Tropical Adaptation Test
ISVAB	International Sorghum Virus Antiserum Bank
ISVN	International Sorghum Virus Nursery
ITA	Institut de Technologie Alimentaire, Senegal
ITAT	International Tropical Adaptation Test
JCARD	Joint Committee on Agricultural Research and Development
KARI	Kenya Agriculture Research Institute

KIRDI	Kenya Industrial Research and Development Institute
KSU	Kansas State University
LA	Las Acacias Experiment Station, El Paraíso, Honduras
LDC's	Less Developed Countries
LIFE	League for International Food Education
LL	La Lujosa Experiment Station, Choluteca, Honduras
MAFES	Mississippi Agricultural and Forestry Experiment Station
MAG	Ministry of Agriculture, Paraguay
MC	Maicillo Criollo
ME	Management Entity
MFC	Mechanized Farming Corporation, Sudan
MIAC	MidAmerica International Agricultural Consortium
MIPH	Integrated Pest Management Project, EAP, Honduras
MNR	Ministry of Natural Resources, Honduras
MOA	Memoranda of Agreement
MOA	Ministry of Agriculture, Botswana
MOALD	Ministry of Agriculture and Livestock Development, Kenya
MOTAD	Type of mathematical programming incorporating risk utilizing standard linear programming techniques
MOU	Memorandum of Understanding
MRN	Ministerio de Recursos Naturales, Honduras
MSU	Mississippi State University
NAAR	Niger Applied Agricultural Research
NBDMP	Nebraska Dwarf Millet Population
NCRP	Niger Cereals Research Project
NDFRS	National Dryland Farming Research Station, Kenya
NSA	National Seed Administration, Sudan
NSF	National Science Foundation
NU	University of Nebraska
OAU	Organization of African Unity
PAGE	Polyacrylamide Gel Electrophoresis
PCARRD	Philippine Council for Agriculture and Resources Research Development
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

SAFGRAD	Semi-Arid Food Grains Research and Development Project
SAFGRAD/IDRC	SAFGRAD/Canadian International Development Research Center
SAT	Semi-Arid Tropics
SCP	Santa Cruz Porrillos Experiment Station, El Salvador
SDMVN	Sorghum Downy Mildew Virulence Nursery
SEPON	Sorghum Elite Performance Observation Nursery
SICNA	Sorghum Improvement Conference of North America
SIDA	Swedish International Development Agency
SMARC/UPSOM	Southern Mindinao Agricultural Research Center/University of the Philippines, Southern Mindinao
SRCVO	Section of Food Crops Research, Mali
SRN	Secretaria de Recursos Naturales, Honduras
TAT	Tropical Adapted Trial
TAES	Texas Agricultural Experiment Station
TAM	Texas A&M University
TARO	Tanzania Agricultural Research Organization
TC	Technical Committee
TCCP	Tissue Culture Crops Project, Colorado State University
TROPSOILS	Tropical Soils Collaborative Research Program, CRSP
TRPSS	Texas Reduced Phenoyl Sorghum Synthetic
UAM	Universidad Autonoma Metropolitana, Xochimilco, Mexico
UANL	Universidad Autonoma de Nuevo Leon, Mexico
UES	University of El Salvador, San Salvador, El Salvador
UHSN	Uniform Head Smut Nursery
UK	University of Kentucky
UNISON	University of Sonora, Mexico
UNL	University of Nebraska - Lincoln
UPLB	University of the Philippines, Los Banos
U.S.	United States
U.S.A.I.D.	United States Agency for International Development
USDA	United States Department of Agriculture
USM	University of Southern Mindanao, Philippines
VAM	Vesicular Arbuscular Mycorrhizae
WARS	Western Agricultural Research Station, Kenya
WASAT	West African Semi-Arid Tropics
WASIP	West Africa Sorghum Improvement Program
WSARP	Western Sudan Agricultural Research Project