INTSORMIL
Five Year EEP Review

Years 12 - 13 - 14
1990 - 1993 Activities

Mission Statement

INTSORMIL is a community of Host Country National Agricultural Research Systems (NARS) and U.S. scientists collaborating together in developing sorghum and millet research capabilities and in increasing sorghum and millet productivity and utilization that can alleviate hunger while conserving and sustaining the value and diversity of natural resources.

Respectfully Submitted by the External Evaluation Panel

Dr. Bruce Maunder, Chairman
Dr. Fran Bidinger
Dr. Lawrence Busch
Dr. Joseph Hulse
Dr. Merle Shepard

INTSORMIL

The Sorghum/Millet Collaborative Research Support Program (CRSP) is an initiative of the Agency for International Development, Grant No. DAN-1254-G-00-0021-00, Title XII and the Board for International Food and Agricultural Development and Economic Cooperation (BIFADEC), the participating U.S. Universities and other collaborating institutions

Contents

Introduction

Following a U.S. Principal Investigator (PI) review in February of 1992, the External Evaluation Panel (EEP) of INTSORMIL conducted a comprehensive review of both U.S. and Ecogeographic Zone locations beginning in December of 1992 and finishing in October of 1993. The panel evaluated 26 U.S. projects plus four country programs which included multiple scientists. These 50 or more scientists worldwide determine the productivity of the CRSP which is now in its 15th year as an original component of the Title XII Program. Members of the review team throughout the eleven months of activity and their respective visit activity are as follows:

- Dr. Bruce Maunder, Chair
  DEKALB Genetics Corporation
  Plant Breeding

- Dr. Fran Bidinger
  ICRISAT
  Agronomy

- Dr. Lawrence Busch
  Michigan State University
  Sociology/Economics

- Dr. Joseph Hulse
  Ottawa, Canada
  Food Technology

- Dr. Merle Shepard
  Clemson University
  Plant Protection

In addition to the EEP, Dr. John Yohe of the Management Entity and members of the Board of Directors actively participated in this review. The EEP gave particular credit to the ME and staff for the exceedingly useful documentation provided prior to domestic and international site visits. Likewise, the individual review locations were well positioned to assist the team with the necessary information to make for an efficient and worthwhile use of the allocated time. Of particular note was the excellent timing in relation to the stage of crop development both domestic and overseas.

Whereas, the 1992 review illustrated some 13 significant accomplishments and 17 opportunities, the greatest significance to this report lies in the linkage of U.S. scientists to ongoing research in the six ecogeographic zones. (Unfortunately, a detailed review of Colombia and Sudan was not possible due to travel restrictions under USAID guidelines.) Prior to 1993, the major emphasis and readily measured accomplishments related to the training of some 700 students, most of whom came from the six ecogeographic zones. This included a special agreement for 100 SADC students funded from USAID, GTZ and CIDA through ICRISAT to INTSORMIL. This training continues at somewhat lower levels but still is very necessary. There were 155 students in degree programs during the review period of 1990-93 (Years 12, 13, and 14). Budgeting during this same time frame from USAID for INTSORMIL (both U.S. PI and host-country) funds was:

	Year	Total Funds*
12	1990-91	$ 2,700,000
13	1991-92	3,240,000
14	1992-93	2,930,000

*the current Year 15 is $2,700,000

Administrative overhead approximating 50% as well as allocations to international projects of a similar magnitude obviously reduces the effective funding available within each of the specific PI projects. At the same time outside grant monies, while available, tend to flow

	Maunder	Busch	Shepard	Hulse	Bidinger
Honduras 12/92	X	X	X		
Botswana 3/93				X	X
Texas A&M 7/93	X		X	X	
Mississippi State 7/93	X		X		
Nebraska 9/93	X				X
Kansas State 9/93	X		X		X
Texas A&M 9/93	X				X
Purdue 9/93	X	X		X	
Mali 10/93	X	X	X	X	X
Niger 10/93	X	X	X	X	X

towards biotech and environmental constraints whereas INTSORMIL must obviously be more applied with a mission to increase the quality and productivity of sorghum and millet.

Evolution of the CRSP

The early years of the CRSP emphasized a solid team of highly respected U.S. sorghum scientists who were less than familiar with the global constraints of sorghum/millet production. Thus, these first years were heavily involved in training future collaborators and more directly benefitting U.S. sorghum producers. The PIs were often questioned as to their linkages when in fact none were available until after a training period and even then positions of administration often discovered these more highly trained scientists once they returned to their respective countries. Successes early on related more to agronomic practices than improved cultivars. Germplasm did move freely and this in turn allowed the plant protection people an opportunity for effective screening and classification of sources of resistance. Early on, those working with grain quality and utilization found opportunities to contribute regarding processing as did the social scientists looking at farming practices as well as utilization and preference of food sources.

Accomplishments began to increase geometrically within the past five years as the CRSP now had collaborators in place for most all disciplines; the PI's better understood their new environments; and sufficient time had elapsed for the development and testing of improved practices and cultivars. We must stress that agricultural research often takes time. Project planning and participation in meetings/symposia has moved more heavily to the overseas collaborator with representations now on the Technical and Ecogeographical Committees. Consideration began to be given to looking at the return on research investment. The issue of sustainability, always a factor, now took on new importance within the CRSP. Whereas U.S. scientists had early on been an integral part of programs in Colombia, Honduras, Niger, and Botswana, while host country collaborators were in training, these people have now returned home and the collaboration from overseas proved more than adequate. As an example, when the EEP suggested phasing out the U.S. PI, who had made a major contribution in Honduras, and he did leave fairly soon thereafter, a rather glowing account of the condition of the project, now under F. Gomez, was received from the PIs following their recent visit.

Not only is this CRSP evolving from the ongoing support of USAID funding but so have U.S. farmers continued to benefit significantly from the public research sector. Germplasm, pest resistance, e.g., for greenbugs; utilization with the potential of food sorghum for our feed and export industry; all have been affected by INTSORMIL scientists. But much has yet to be done, such as the *Striga* work of Ejeta and Butler and their former student Dr. Dale Hess, now in Niger, plus collaborators in Mali, Niger, and Sudan. This project alone has potential to pay back the investment in all the CRSPs many times over. The discovery and strategy, as proposed in the accompanying bulletin on their work, combines both basic and applied research to solving a loss estimated at 845,100 MT per year in Sub-Sahelian Africa alone. The severe droughts in Sudan suggest germplasm exists within the program to not only produce crops where none could have survived but also to provide yield stability for U.S. farmers as well. The millets, so famous for their productivity under the harshest of conditions, may someday be a principal grain source in the more arid western U.S. The opportunities for this CRSP literally abound but a firm strategy will be needed to point everyone in the most productive direction.

Future Opportunity

This CRSP, with outstanding authorities in the fields of millet and sorghum improvement, relates to a large amount of the underfed, undernourished third world, and has made remarkable progress during its first 14 years. Several improvements, changes, and additions are needed, however, to see the measurable progress expected. First, with improved varieties or hybrids, how does the CRSP get these into farmers' hands? Can we be sure of quality control, trueness-to-type and adequate germination? Is there an infrastructure to handle extension, seed increase, and distribution in the countries who need it so badly? With only 34% of the world's crop area using the new, high yielding varieties, much gain in productivity can be expected. Incentives and interest must be generated for a private sector involvement and INTSORMIL, including the in-country scientists, realize and want this. Establishment of 35 small mills in Botswana, as an example, has reversed the practice of importing maize meal from South Africa and stimulated local sorghum production. Following the Mali/Niger visit the following paper so applicable to the above was developed:

National / International Seed Enterprises

An obvious need of developing country agriculture is technology transfer, such as with improved planting seed, from national or international research improvement programs to the producer, both subsistence as well as the large operator. To encourage development of the private seed industry, governments should first survey the state of agriculture, by crop and by socioeconomic region, to determine which crops and parts of their country can benefit from a private seed industry. For any crop the existence of dependable markets, relatively large areas of cultivation, and a desire on the farmers' part to increase yields through cultural and varietal changes could be signs that farmers might benefit from the presence of private seed firms. Additionally, profit to farmers should be great enough that they can afford to pay a higher price for good quality seed. Lack of a substantive knowledge of a viable seed business or industry will likely require input from those experienced in seed enterprises which should be readily available. We see three principal advantages and likely reasons for success: (1) dependable supply, (2) acceptable quality/purity, and (3) hopefully, but not necessarily, an improved level of performance. Any of these advantages would provide an answer for profit to farmers. In brief, commercial seeds are best suited to profitable crops in favorable farming regions.

To attract the development of seed firms, governments should be politically stable and the nations' infrastructure, particularly transportation, should be adequate for the delivery of goods and services to the farming community. To attract seed firms, an opportunity for a reasonable return on investment without government restriction, is essential since capital risk will be required. Private, but indigenous seed enterprises may be a logical first-step but their inability to cope with monetary fluctuations and lack of sufficient funds for research investment often has put them at a serious disadvantage to multinationals—Argentina being a good example. These entrepreneurial indigenous companies will likely require outside training and perhaps some subsidy early on but every country possesses the type of individuals capable of such activity. A supply of trained indigenous agriculturists will be indispensable in operating the seed firms. There should also be evidence that markets for the crop are relatively stable, without undue interference from either government regulations or private-market manipulators.

The presence of public plant breeding research will be an asset to private seed firms. Farmers will have become accustomed to the introduction of improved varieties and to learning new ways of growing them. Small, indigenous seed firms, in particular, will depend on public plant research institutions for advanced breeding materials or even new varieties, as well as for knowledge of new agronomic techniques applied to the new varieties. All seed firms will benefit from germplasm enhancement efforts of the public plant research institutions. A strong public plant breeding research program is necessary for long-range success of the private seed industry. By the same reasoning, public plant breeding researchers must accept the need for, and presence of, the private sector since in most third world scenarios this will be the only way their efforts will affect the agricultural, and subsequently, country economy. The private sector accomplishes what the extension and public foundation seed organization is not currently doing. Fortunately, in recent years USAID, in appreciation of this approach, has been encouraging more commercial involvement in developing countries.

National encouragement of a full line of improved agricultural practices (from seed conditioning, agronomic practices, harvest/storage of product, to efficient marketing) will set the stage for entrepreneurial indigenous seed companies to add their product to the mix of increasingly sophisticated practices in the commercial farming community. Only by this new kind of sophistication can commercial agriculture affect the much needed "after the farm gate" impact so badly needed with increasing urbanization.

Intellectual property laws are not a first requirement for building a commercial seed industry in a country. Seed firms often start out by handling hybrid crops, with built-in property protection, because the seeds must be purchased for each subsequent planting or they may provide much better seed quality or purity which again satisfies the lack of a need for intellectual property laws early on. The latter advantages relate most frequently to seeds of public varieties of self-and open-pollinating crops, where quality, purity, and trueness-to-type becomes value-added. Following this step, seed companies may wish to sell their own proprietary varieties. At this point, farmers and seed companies alike may be able to benefit from the introduction of carefully written and well administered intellectual property laws applied to plants.

To attract and assist in the development of seed companies, governments could set up a national consultative group on agricultural research, composed of representatives of farmers and both public and private institutions. For example, the first hybrid sorghum released in Sahelian Africa, Hageen-Dura 1, was "kicked-off" with a symposium at which representatives of farmers and both public and private institutions attended and participated.

A similar call could be made for germplasm storage and maintenance. Large amounts of capital have gone into vehicles, computers, and travel expense for collaborating countries but where is the funding for germplasm maintenance which makes all the other costs necessary? A small investment in cold storage or dehumidifiers will preserve the genetic treasure so badly needed by generations to come. To reincrease landraces, because they quickly go out of condition without proper storage, causes this activity to be the research investment rather than the much needed varietal improvement. Also, are we willing to allow the likely genetic drift to influence the description of future crops?

INTSORMIL and the Environment

It is useful to think of the INTSORMIL CRSP as an environmental management program. Of course, agriculture, in general, is a way of managing the environment so as to optimize the production of useful plants and animals for human use. However, beyond that, in the semi-arid tropics, INTSORMIL also plays the important role of developing productivity-enhancing technologies that, if widely adopted, will slow or even reverse environmental degradation. For example, one of the major problems in the Sahelian countries is that as population grows, farmers are tilling the soil in more and more northerly (and hence fragile) areas. As long as the technologies in use are largely static, farmers have little choice but to till areas normally left in pasture and to till more frequently rather than to let land lay fallow. Only by the introduction of productivity-enhancing technologies are farmers likely to till less land more intensively and, hence, engage in practices that are more friendly towards the environment. Indeed, no projects or programs specifically aimed at the environment will be successful in the Sahel as long as agricultural productivity issues are ignored.

However, farmers will only adopt productivity-enhancing technologies if they can sell the surplus they produce as a result of the use of those technologies and buy something else in return. Thus, it is essential that the entire agricultural system be upgraded. This requires research that transcends disciplinary boundaries and that aims at improving the overall situation rather than solving discrete problems in serial fashion. Such research must consider the full range of issues from seed production to consumption of the final product. INTSORMIL has been moving in this direction over the last five years (and, in fairness to the PIs, this type of research must be invented as little of it has been done to date anywhere). Such research must also be strategic, guided more by the situation than by the needs of disciplinary science.

In short, environmental issues are intimately coupled with productivity and income issues. Failure to recognize and support that connection will result in the failure of environmental programs. Indeed, people who are hungry and poor are not likely to be concerned about the niceties of biodiversity and soil erosion. Those who are well-nourished and comfortable are likely to be able to afford to reflect on the importance of environmental sustainability to long term human welfare.

Is INTSORMIL a Closed Club?

The EEP sees the TC and the EZC becoming less institution oriented in its deliberations and decision making on future strategy and budgeting for which they deserve much credit; an example is the movement of funds from an already heavy breeding component to other disciplines. A more drastic approach would lead to competitive bidding. That is while INTSORMIL scientists are among world leaders with respect to the quality of their research, the program is open to the criticism that it is a closed club in which a small group of scientists have received funds year after year. To counter this argument, as well as to recruit new scientists with new ideas to join the program, INTSORMIL needs to base its upcoming program on new projects rather than merely continuing the old ones. This can be done by setting priorities for the next five years and issuing a Request for Proposals (RFP) to all interested scientists, at both current INTSORMIL institutions as well as elsewhere. Proposals received should be subject to a rigorous review for (1) scientific quality, (2) relevance to collaborative programs, and (3) congruence with research priorities. Proposals received should be reviewed by ad hoc reviewers at other U.S. universities, USAID, and by scientists in countries with INTSORMIL collaborative agreements. Only proposals that meet all three requirements should be accepted for future funding. Reviewers should be expected to show how a project does or does not meet each of the funding criteria.

It should be noted that failure to open the process of project selection and funding will ultimately be damaging or fatal to the INTSORMIL programs. USAID/Washington staff will view it more and more as a pork barrel project and less as a contribution to USAID's development portfolio. In contrast, by opening the process, INTSORMIL will demonstrate its capacity for self-renewal as well as its continuing search for the best scientific talent available.

While such renewal is both desirable and necessary, new projects should be funded over long enough periods (3-5 years) and at levels of funding high enough to make a significant impact while maintaining continuity especially in relationships with developing nations. For maximum progress and efficiency, one must also wonder about the governing board being composed of one representative of each institution. In this time of budget constraints can this board function without institutional bias? Probably looking back to the days of developing the various CRSPs the ME should have related to a Board of more neutral composition.

Other Suggestions from the EEP

Other suggestions from the EEP following this comprehensive review would be:

> INTSORMIL may have made a mistake in the past in stating that its objectives were to increase production of sorghum and millet in areas where they are important cereals. What INTSORMIL is/should really be doing is strengthening the national research systems in such countries up to the point where they (the NARS) can take advantage of the well-demonstrated high rates of return to investment in agricultural research. This focuses on INTSORMIL's training, support and basic research capabilities, and will mean that INTSORMIL will be judged on how well it performs these functions, and on improvements in NARS capabilities and programs, not on production statistics.

> INTSORMIL permits too much duplication of effort in the U.S. based projects, with the system of allowing individual PI's to propose more than one project in the same area. It would be preferable if the INTSORMIL Board defined the priority areas for research (which should include applied, country collaborative projects, as well as more fundamental U.S.-based theme or constraint based projects), and call for groups of interested scientists to propose collaborative, broad-based projects to address the priorities. For example, a proposal for research on traits related to drought tolerance might include a breeder, a physiologist and a soil scientist.

> INTSORMIL research projects should be required to establish clear and time-bound research targets or milestones by which progress can be judged. Currently, objectives are far too broad and general, effectively allowing the PI to do whatever interests him or her, and making the evaluation of progress very difficult and subjective. Specific objectives, such as determining the value of a trait or the inheritance of a type of resistance, incorporating a trait or resistance into specific genetic backgrounds, developing a screening technique, etc. would make the evaluation process more effective and probably make the research more productive.

> There appears to be too much of a tendency for PIs to decide what they or their collaborators should focus on in the collaborative research, without taking into account host country priorities and present programs, other collaborative research programs working with the national program, etc. This usually results in the PI proposing research which reflects his/her own scientific interest, breeding materials, etc. Country coordinators and the heads of NARS should have a much larger role in deciding priorities for collaborative research to assure that this research conforms to NARS priorities and will assist in strengthening weak areas in NARS' programs, etc.

> Collaborative NARS-INTSORMIL breeding programs should focus on transferring traits, not breeding materials, from INTSORMIL to national programs. Requirements for disease and pest resistance, plant type and grain quality, etc. differ greatly between U.S. and especially African sorghum growing areas. In many cases, the direct testing of U.S. materials in collaborating countries is as unproductive as is the direct testing of African landraces in U.S. breeding programs. Sources of resistance, etc., from U.S. programs will, of course, be tested in collaborating programs, but the emphasis should be on the incorporation of these sources, traits, etc. into elite breeding materials from the collaborating program for subsequent selection for resistance and adaptation to collaborating country conditions.

> Collaboration is evident among disciplines within a country and between the country and the U.S. collaborators, but there seems little evidence of such between African countries even within a particular discipline. Should consideration be given to affect collaboration or at least information exchange to regions rather than specific countries?

> To follow this line of discussion more cooperation is still in order between participating universities such as between breeders or physiologists at one institution with a breeder at another. TAM-121, as an example, with no in-state physiologist in the CRSP could benefit from a closer relation to this support from another institution.

> INTSORMIL must "blow its horn" to get attention to past accomplishments and its contribution to supporting the projected 10 billion people by 2050. Use of journalism students, the farm press, Washington politicians and donor agencies to develop or receive impact information is becoming more and more essential. The environmentalists/ecologists have been very effective in making their points with the media. INTSORMIL also needs to capitalize on the public concern for the environment by showing how food production can be made more environmentally sound and by emphasizing the environmental damage that will be done if food production is increased through extensive means rather than by increasing productivity.

> It may now be opportune for the EEP to devote less critical attention to experimental detail and to concentrate more on INTSORMIL's long-term future: to examine present priorities and activities in light of most urgent needs, and the resources available; to decide what are INTSORMIL's particular comparative strengths, advantages and opportunities; which components of the program are uniquely progressive and most likely to be beneficial; to recommend administrative and institutional means to ensure integration and complementarity among the U.S. universities, and among the participating countries, particularly in Africa; between INTSORMIL, other CRSPs and related research and development programs.

> Perhaps more emphasis on a particular crop loss, e.g., drought would be a reasonable approach for this CRSP. Certainly, if global warming proves a reality, the justification becomes more reasonable but even now almost every sorghum/millet area in the world faces some degree of abiotic stress.

> Despite the extraordinary effectiveness of the CRSPs, none of them have been funded at levels near optimum. INTSORMIL, despite an excellent track record, has been subject to significant budget cuts over the last several years. As a result, USAID has not gotten as much for its money as it might have.

> The current world recession has been particularly hard on those countries in which INTSORMIL works. As a result, all have experienced severe cuts in their research budgets. Despite that, in each case, host countries have been able to maintain some level of support to their researchers. Nevertheless, without INTSORMIL collaboration, it is likely that sorghum/millet research would have ceased to exist in these nations.

> The universities have, despite their own fiscal woes, upheld their part of the bargain. Indeed, U.S. scientists involved in INTSORMIL have done an extraordinary job of weaving it into their domestic research. Germplasm from exotic varieties has made its way into domestic lines in large part as a result of these efforts. Moreover, U.S. scientists have used INTSORMIL funds to leverage significant funds

from other sources to support both domestic and overseas activities. Furthermore, INTSORMIL has aided in helping to institutionalize international activities among sorghum/millet researchers on U.S. university campuses.

> Faculty now have a much greater recognition of the mutual benefits of international activities to both host countries and the U.S. This is reflected in the broader scope of their work and the strong collaborative relations that have built up over the length of the project. The long term nature of INTSORMIL funding has made it possible to plan for internationally oriented positions as well.

> In each case, where we had an opportunity for interaction with students, we found that they were successfully integrated into the overall collaborative research program. Most importantly, virtually all of the foreign students supported by the program are involved in research that is relevant to their home country. In most cases, they are, or will be, doing their dissertations overseas on issues of direct relevance to sorghum/millet production and consumption.

> The EEP suggests that whenever possible graduate trainees be given a short time experiencing the private sector before returning home. The USAID training programs such as seed technology make an effort to do this and the future direction of agriculture suggests such exposure to be of real value.

> Most of the well trained and productive scientists who return to their countries would benefit immensely by an opportunity for a refresher period at both an institution of their training as well as at locations where they can gain the most. Such updates on technology could also accommodate project planning as well as exposure to new learning experiences such as from the private sector.

> We commend the CRSP for continued efforts to upgrade the principal ecogeographic zones as conditioned by scientific, political, and humanitarian needs. Likewise, future strategy will need to better integrate individual country and institution activities.

The following PI reviews and country reports contain strengths and weaknesses. Actual contributions to the CRSP are often difficult to discern in a brief discussion. Obviously, each PI operates differently with some more likely contributing while overseas and others through their own research and teaching train many future collaborators. The EEP certainly offers its input to the ME, TC, and EZC whenever such can help strengthen the CRSP in future planning. We do recognize a great deal of dedication by the PIs and their collaborators and are convinced the objectives of the Title XII program have been instituted by INTSORMIL with much still to be done. Certainly, we strongly urge a continued investment in this most worthwhile endeavor.

Sustainable

Plant

Protection

Systems

PREVIOUS PAGE BLANK

Agroecology and Biotechnology of Stalk Rot Pathogens of Sorghum and Millet

Project KSU-108
Drs. L.E. Claflin and J. F. Leslie
Kansas State University

Research in Progress in Host Country and in U. S.

INTSORMIL Project KSU-108 is somewhat unique in that the focus includes millet as well as sorghum and there is a strong biotechnology component that complements a practical field-oriented thrust. Students associated with the project can major either in plant pathology or genetics.

One of the major constraints facing breeders and plant pathologists is the ability of plant pathogens to develop new "strains" or "races". Although this is a natural evolutionary consequence of planting near-uniform germplasm over relatively large areas, strategies must be devised to deal with this problem. The team of Leslie and Claflin have an excellent synergistic working relationship with Claflin handing the details of field plot work and field plant pathology while Leslie concentrates on identifying mating populations of pathogens that cause stalk rot. The research focuses on *Fusarium moniliforme* (sexual stage name *Gibberella Fujikuroi*) with model systems using *Neurospora crassa* needed to support the *Fusarium* research.

Research in Leslie's lab has identified at least biologically distinct groups of *G. fujikuroi* from what was previously thought to be one homogeneous group. Strains that have been identified have become the standard for identification within this group and ways to incorporate these groups into existing taxonomy was the subject of a recent international workshop. Strains are routinely provided to industrial and academic researchers throughout the world from a collection of over 5000 strains of *Fusarium*. Major attention is being given to developing more efficient ways of identifying strains that can be used by developing countries. Protocols for identifying vegetative compatibility groups also have been developed. These protocols allowed researchers to determine that asexual recombination within *Fusarium* is rare and, with this technique, studies have shown that variability within sorghum pathogen populations in the United States is relatively limited. Other work includes genetic contributions to studies of mycotoxins by characterizing and describing these toxins.

The genetics research being carried out at Kansas State University by Leslie is highly regarded by researchers all over the world and the large number of collaborators underlines the importance and interest in this work. A notable finding by the group is that a here-tofore relatively unknown disease, "pokkah boeng", was identified in Egypt and the most widely planted cultivar 'Giza 15' is susceptible to it. In addition, a previously unidentified *Fusarium* may be playing a major role in reducing stand establishment in Egypt.

KSU-108, strengthened by the buy-in of USAID in Cairo, is still underfunded based on the amount of work being carried out. The researchers have been aggressive in seeking outside funding through various private and national sources. The project is dispersed over several sites with no specific collaborating host country. Other INTSORMIL projects (notably those at Texas A&M) have benefited greatly from collaboration with this project.

Collaborators in Egypt are scheduled to participate in several events including the American Phytopathology Society meeting, the Bellagio workshop, and the 6th International Congress of Plant Pathology. The PIs make one or two trips abroad per year to Egypt and several more trips to other countries.

Institutional Development and Training

Overseas and domestic institutions have been strengthened due to the impressive number of graduate students trained under this project. We met two graduate students, Mr. Mamourou Diourte and Mr. Linus Muriithi, during our visit to the field plots of Dr. Larry Claflin. Numerous researchers have visited and worked in the laboratory.

The most important contributions that the PIs are making toward keeping collaborators enthusiastic about this project are their achievements in understanding the genetic variability within plant populations and providing techniques which allow identification of this variability.

Evidence of Interdisciplinary Integration

There is good evidence that integration with other biological sciences is taking place. This is particularly true for the integration of genetics, plant pathology, plant breeding, and agronomy. At this time there is no evidence of integration of social sciences into the project, but this has not been the major focus, and could not be carried out under the current level of funding.

Balance of Domestic vs. Overseas Activities

Given funding constraints and the fact that this project is not tied to a particular country, the balance between overseas and domestic activities has been extraordinary. One or both of the PIs have traveled to Egypt, Bulgaria, Kenya, Senegal, Colombia, South Africa, Germany, France, Italy, Canada, and several domestic sites.

Level of Collaboration between U. S. and Host Country Institutions and Personnel

Even though there is no primary host country, the level of collaboration/cooperation within the country and with developing countries has been exceptional. The biotechnology/genetics components of the project allow development of models of systems of plant-pest interactions. Using this information, breeders and plant pathologists can devise long-term management strategies.

The major workshops/conferences that are being planned provide an excellent forum for planning and discussing the roles of collaborating researchers.

Publications and Presentations

During this period (1990-93), Dr. Claflin published nine refereed journal articles and five abstracts, and made several presentations. Dr. Leslie's record is extraordinary. The 23 refereed journal articles, five book chapters and a large number of oral presentations and abstracts make him possibly the most prolific publisher associated with any of the INTSORMIL projects.

Overall Rating

Excellent. The general strength of the project lies in the strong biotechnology/genetics components that provide the basis for understanding genetic variability in pathogen populations.

Recommendations

It would be good to consider increasing funding for this project, even at the expense of others.

Low Input Ecologically-Defined Management Strategies for Insect Pests on Sorghum

Project MSU-105
Henry Pitre
Mississippi State University

Specific Research Performance

The PI has added to the overall understanding of the role of the lepidopterous pest complex in intercropped sorghum and corn on subsistence farms in Honduras. Four species of insect pests have been identified and the role of weeds in the pests' population dynamics is now more clearly understood. A management strategy to avoid insect damage by caterpillars is to plant early with open-headed varieties and manage weed in or near fields. Although diseases are not important in southern Honduras, the necessity for incorporating germplasm from the Honduran land race sorghums will continue to be pursued. Some sorghum genotypes with resistance to fall armyworm have been identified through participation with TAM-131, RN (in Honduras) and the USDA. Other aspects of fall armyworm biology have been identified.

Results from studies of crop and non-crop acceptance as hosts plants by important pest caterpillars will allow manipulation of weeds as a control tactic and studies of movements of adult moths from crop and non-crop habitats will continue to contribute to our overall understanding of how to develop a sustainable management system.

The PI is satisfied with accomplishments so far. However, one constraint is that there is no trained entomologist actively working on the project in Honduras. The absence of the PI's collaborator, Dan Meckenstock, may cause some problems relative to facilitating the work in Central America.

Technologies in Honduras that require cash expenditures (e. g., chemical insecticides) may limit applicability of tactics requiring these inputs.

A rank of the important contributions are as follows:

> Lepidopterous pest complex has been identified

> Identification of antibiosis in Honduran landrace sorghums

> Control procedures for soil-inhabiting insect pests

The PI believes that most of the research information is disseminated through on-farm research.

Institutional Development and Training

Institution building is progressing as evidenced by positive research programs by Honduran nationals. The most important aspect of training is through participation of graduate students as well as through collaboration with personnel in the Ministry of Natural Resources and the Pan American School of Agriculture.

Evidence of Interdisciplinary Integration

The PI has established a working relationship with scientists from Purdue University, the USDA, ARC (Malawi), and ARC (Sudan). Also, there is active collaboration with a breeder in the Ministry of Natural Resources in Honduras. There is no evidence of Social Sciences involvement at this time. WID issues are partially addressed via female graduate students.

Balance of Domestic vs. Overseas Activities

There appears to be a good balance in this regard. The PI lists about 80% of his time on overseas activities but this would include correspondence, graduate student advising, etc., carried out in the U. S.

Level of Collaboration between U. S. and Host Country Institutions and Personnel

The research planning and budget preparation is done mainly by the PI. Publications carry joint authorship and the PI and collaborators have been very active in publishing their findings with over 12 papers either published or submitted during the 1990-93 period.

Overall Rating

Good.

Other Comments

It might be beneficial for the PI to integrate the MSU-105 projects with TAM-125 and 125B. Particularly the latter as both PIs are working in Honduras and biological control fits well into management strategies involving host plant resistant. It also may be appropriate to start putting the insect management tactics developed under this and other projects into a "pilot" IPM program and test this under farmer conditions and with constraints that face the farmer.

Chemical and Physical Aspects of Food and Nutritional Quality of Sorghum

Project PRF-103B and PRF-112
Allen W. Kirleis and Bruce R. Hamaker
Purdue University

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

Project PRF-104B
Larry G. Butler
Purdue University

The Purdue Program

As stated in the report of the EEP visit to Purdue in 1992, the objectives of PRF-103B, 104B and the new project PRF-112 are so interrelated and interdependent it is easier to address them collectively than as discrete entities. In all instances, the research reported is entirely consistent with the stated objectives. The techniques used are modern, the Purdue scientists are clearly *au courant* with state-of-the-art methodologies; the quality and quantity of the results reported are more than satisfactory; interdisciplinary coordination and integration is evident in the planning, implementation and internal evaluation.

All of the reported activities are relevant to the objectives of identifying, developing and evaluating sorghum lines of superior nutritional quality and adaptable functional properties; with stable yield potential, tolerance to drought and *Striga*. If, as was indicated, one senior and exceptionally productive staff member is firm in his decision to seek early retirement, it is immediately necessary for the Purdue faculty to decide whether or not all present activities should be continued into the long term, or whether some modifications to the program should be planned. These considerations will bear upon the qualifications and scientific interests to be sought in any future appointments.

Research on the biochemistry and physiology of drought resistance, at the genetic and molecular levels, should continue as a high priority given the exceptional interdisciplinary competence that has been brought together. The Faculty is to be commended on the breadth, depth and scope of the drought resistance program; on its studies of genetic determinants and its well deserved grant from the McKnight Foundation; the development of an RFLP map and the concomitant cDNA libraries of constitutive and drought inducible genes; on the unique drought resistant mutants generated. The interdisciplinary graduate training and research program is particularly noteworthy. It should inculcate a sense of the interdependence of specializations and counteract the all too frequent compartmentalization of scientific activities.

Purdue's concerns for nutritional quality are important bearing in mind that acceptance of triticale as a food crop was hindered and adversely influenced by unfavorable, albeit inaccurate, reports of its nutritional quality. Similarly, the commercial acceptance of rape/canola was not realized until breeders and biochemists developed genotypes relatively free from erucic acid and glucosinalates. The research on the components that depress digestibility is of special importance to the utilization of sorghum as an industrial food grain.

Dr. Hamaker is clearly a valuable addition to the Purdue team. He is a sound scientist with a pragmatic sharply-focused intellect. It is extremely difficult in a university laboratory to study African traditional food processes and acceptability of their products, which in their native environments vary widely among communities and individual cooks. Consumer attitudes and reactions can be studied only in real life locations. Dr. Hamaker is encouragingly aware that research in the U.S. should center on fundamental biophysical and biochemical properties, how they relate to technologically important functional attributes, how they vary among genotypes, and how they may be modified by physical and biochemical processes. Much time and effort has been wasted in empirical engineering and mechanics. Reliable milling technologies require systematic studies of grain structure and composition to determine the most efficient methods by which components can be fractionated and refined.

The literature on composite flours is dominantly empirical, little systematic effort having been devoted to determining compatibility between wheat flours and sorghum flours from various genotypes in composites intended for different baked or extruded products. Without a sound fundamental understanding of critical properties involved, little reliable technological progress can be accepted. Dr. Hamaker's concepts promise cooperative progress with the Africans who hope to develop commercial cereal products from locally milled composite flours.

Nutritional Qualities

The research on the relative digestibility of sorghum kafirins, their synthesis at different stages of crop maturity, the probable causes of indigestibility, the physical and chemical processes which aggravate or reduce indigestibility, is uniquely valuable and should continue as a high priority. Is it known what function, essential to the biological development of sorghum plants, is served by the kafirins and the HMW protein identified; what might be the agronomic consequences of their being eliminated by genetic modification? Is it important to find out? Is there an, as yet, unexplored role for molecular biology in the study of sorghum protein digestibility? The wheat gluten working group of the International Society of Cereal Chemists is studying protein structure and modification and, since this also implicates S-S bonding, it might be of interest to the Purdue research. The Chairman of the gluten group is Dr. Walter Bushuk, Professor of Food Science at the University of Manitoba.

Dr. Butler's research on sorghum polyphenols is outstanding by any standard of judgement. The shear volume of publications is remarkable. One wonders if it has received the international recognition it merits. The work is so singularly unique that any critical comment from an external observer would be impertinent. Other EEP members will judge the issues relevant to pest, parasite and pathogen protection. In terms of human and animal nutrition, Dr. Butler's research has brought to light valuable information on isolation, identification and chemical nature of the polyphenols in sorghum; on inhibitory mechanisms of nutrient metabolism by various polyphenols synthesized in different sorghum genotypes. Identification of sorghum genotypes relatively free of tannins, yet which display significant resistance to bird damage, is an important recent discovery. Equally interesting is the revised opinion of the possible systemic effects of tannins and low molecular weight polyphenols, and the hypothesis that some polyphenols, as they occur naturally in the sorghum seed, behave differently than chemically extracted polyphenols that are added back to diets otherwise PP free. EEP will share Dr. Butler's hope that the tannin-associated component responsible for antinutritional effects can be specifically assayed to make possible subsequent breeding of sorghums which combine pest resistance with superior nutritional qualities.

Some PPs present in high tannin sorghums are chemically similar to the hop antiseptics lupulon and humulon, which inhibit acid-forming bacteria in the brewing of beer. Several African communities prefer high-tannin sorghums for traditional beers, and African beer bananas are reported to be relatively high in tannins. With the rising demand for high diastase sorghums by African brewers, is it possible that the need for imported hops might be reduced by exploiting the antiseptic properties of sorghum tannins?

Special Initiative for Identification of Active Resistance Components in Sorghum and its Parasite, Striga

PRF-104C
Larry G. Butler
Purdue University

Although this project receives comments under PRF-107 of Dr. Gebisa Ejeta and also under PRF-104B specifically on the polyphenols, much credit for the significant gain in our understanding of the *Striga* life cycle and potential control of this parasitic weed comes from the laboratory of Dr. Butler. The EEP submits as evidence of accomplishment by INTSORMIL scientists, Purdue Publication RB-991, "New Approaches to the Control of *Striga*" published in 1993 and presented at the International Crop Science Congress. By locating stages in the life cycle related to parasitism work of Butler and Ejeta will allow breeding for genetic resistance in the host to the parasite at each stage or multiple stages to maximize resistance.

Disease Control Strategies for Sustainable Agricultural Systems

Project TAM-124
R.A. Frederiksen and R. Toler
Texas A&M University

Specific Research Performance

Specific research progress during the 1990-93 period has been very impressive and several research "outputs" can be cited. Within the overall objective of development of disease control strategies for sustainable agricultural systems, the PIs have not only identified resistant lines but the research tools and techniques that have been developed will ensure that disease control systems will continue to be improved. Establishment of disease nurseries where specific diseases are important is essential for continued screening. The joint ICRISAT/INTSORMIL International Sorghum Anthracnose Virulence Nursery is an example of this since it was established where the disease is endemic. The PIs have made nursery materials available to all interested parties on a worldwide basis.

As plant-disease systems are continually evolving systems, the approach that the PIs have taken by focusing on characterizing isolates of diseases is very appropriate. This approach, using the latest molecular techniques, serves as a model for less developed countries. Techniques that come from this project, in my opinion, are as important as identification of resistant plant materials. Isolation and culturing of the causal agent of long smut and inoculation at the boot stage allows screening of isolates that could take months or even years if it were necessary to rely upon natural disease epizootics. Plant material with potential head smut resistance are tested in field nurseries and using artificial inoculation at the seedling stage. Other researchers, working under the guidance of the PIs', found that some isolates of *Sporisorium reilianum* favor maize while other attack sorghum more vigorously. Thus, maize disease management could be improved as a result of research supported by INTSORMIL. This could be a very positive spin-off.

The PIs are to be commended on their work toward developing a system for classifying pathotypes. This will be extremely important in development of long term disease control strategies. Particularly noteworthy is the work on identification of different Anthracnose isolates by comparing their DNA using RAPD markers.

The International Sorghum Virus Nursery will continue to play an essential role in identification of germplasm with resistances to Sorghum Yellow Banding Virus and Maize Dwarf Virus. Advanced techniques such as the double antibody sandwich method of ELISA and field inoculations using a pressure gun are significant contributions to the total program domestically and internationally.

The promotion of the use of the chemical Apron® as a seed treatment should be approached cautiously. These is little doubt that this material can improve stand establishment. In developing countries, however, the extension infrastructure is inadequate to carry out training in the proper use of chemical pesticides thus, the environmental and human exposure consequences can often be unpredictable.

Institutional Development and Training

There is a large and impressive number of scientists from developing countries listed as collaborators on this project. This is one of the most efficient ways of promoting institutional development. In addition, several graduate students have added significantly to the overall training effort. It would be good to organize and carry out a workshop on techniques for screening for diseases of sorghum and help to support participants from collaborating countries. This should be targeted for scientists and technicians who actually do the work. This could be held at a central location (perhaps at an international center) or even at Texas A&M University. If the compound, Apron® Plus is to be suggested as a management tactic for stand establishment, it would be appropriate to carry out workshops or training sessions, in conjunction with local extensionists, on the proper handling of this material.

Evidence of Interdisciplinary Integration

There is an excellent level of integration of the biological sciences within this project. The interdisciplinary team works well together but it may be advisable to obtain entomological input since no one from this discipline is listed as a collaborating scientist. It is realized that the project's focus is disease management but the nurseries may afford a good opportunity for identifying material with differential susceptibility to insects.

There are no specific objectives that address social science or gender issues but there is interaction with both male and female students and collaborative scientists. It may be that during later stages of this project, a social scientist could be consulted to determine how the new varieties that are being developed are accepted by the farmer and farm family and how they fit into the farming system.

Balance of Domestic vs. Overseas Activities

In addition to designated collaborating institutions, the PIs also collaborate with personnel from several other international institutions. There is adequate balance between domestic and overseas activities.

Level of Collaboration between U.S. and Host Country Institutions and Personnel

Research planning is carried out with input from overseas collaborators but the leadership is clearly from the domestic side, as it should be given the high level of expertise and experience of the senior PIs.

Publications and Presentations

The outstanding list of publications and presentations reflect participation by host country counterparts, especially by host country students.

Overall Rating

Outstanding. This project should serve as a model for other CRSP projects.

Plant Pathogen RFLP Mapping

Project TAM-124A
R.A. Frederiksen
Texas A&M University

Specific Research Performance

This is a relatively small biotechnology project that supports Project TAM-124. The focus of the work is on downy mildew and head smut. The research objectives of mapping the relative location of each resistance-gene-linked RAPD marker by using it as a restriction fragment length polymorphism probe on the F2 mapping population has not yet been achieved. But large numbers of RAPD primers have been screened. One hundred-thirty RAPD primers have been screened with extracted DNA from the parental lines and 80 polymorphic loci have been located between susceptible and resistant parents. Linked markers will assist in locating genes for resistance and this work should continue because a breakthrough here could greatly expedite identification of resistant material.

The variability of the head smut organism, *Sporisorium reilianum*, underlines the importance of developing an RFLP map for characterizing resistance. The PI is also using maize as a model for detecting polymorphisms in two out of ten genomic cones. To date, none of these have been linked to sorghum head smut resistance genes but continued screening of RFLP markers should uncover these.

Institutional Development and Training

Several developing country and domestic institutions are involved in this effort while the major work is conducted at Texas A&M. These techniques will be valuable for host country collaborating scientists and the PI is involving host country personnel, very effectively, in this project.

Evidence of Interdisciplinary Integration

This project does not lend itself to integration of biological or social sciences, although the PI is collaborating with personnel from the Soil and Crop Sciences and Biochemistry and Biophysics Departments at Texas A&M.

Balance of Domestic vs. Overseas Activities

Isolates from other parts of the world are providing materials that are being used in screening for the two plant pathogens and host country scientists are involved in the project.

Level of Collaboration between U.S. and Host Country Institutions and Personnel

The level of collaboration between U.S. and host country institutions and personnel is appropriate at this time. It is expected that this effort would be expanded when research outputs and methods are further developed to identify genes for resistance.

Overall Rating

Good. Given the small amount of resources for this project, good progress is being made. It would not be advisable, however, to increase funding for this project by diverting funds from the PI's other INTSORMIL projects.

Integrated Insect Pest Management Strategies for Sustainable Agricultural Systems

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

Specific Research Performance

This project is now separate from Project TAM-125B that addresses biological control of insects but the two projects compliment each other. The current project is focused mostly on development of plant resistance as a control tactic. The collaborator in Mali has carried out trials, planned jointly with the PI, using techniques that evaluate panicle-feeding bugs (*Eurystylus marginatus*) to identify new sources of resistance to this pest. Fifty-one genotypes were screened and 21 had lower damage ratings than susceptible lines. In addition, 32 had encouraging ratings for head mold. Additional screening in Mali using genotypes from ICRISAT and Texas A&M identified eight lines plus Malisor 84-7 for further testing. The relationship between head bug damage and mold infection is being investigated and preliminary findings suggest that there is a correlation between bug damage and mold but this is not consistent across field trials. The PI is to be commended on development of field techniques that allow genotypes to be screened in the field using pollination bags and insecticides to manipulate bug population density. This procedure should also be useful for breeders in evaluating materials under pressure from panicle-feeding insects. Several publications and presentations have resulted for work carried out under this project.

Confirmation of a new biotype of greenbug has focused efforts to find resistant germplasm. Exotic lines from several countries were screened and two lines (P1550610 and P1550607) were highly resistant to the greenbug biotype. Likewise, germplasm with resistance to sorghum midge continues to be identified and evaluated and new genotypes with midge resistance will be released soon.

Seed has been sent to several developing country scientists for testing in their program by Gary Peterson, who is collaborating on this project.

Institutional Development and Training

Student training is a major part of this project. In addition, their contributions are adding to the growing body of knowledge about sorghum-insect interactions. In addition, 10 scientists from abroad visited the sorghum entomology program at Texas A&M. A description of the collaborative program in Mali will be provided as the review panel visits that country.

Evidence of Interdisciplinary Integration

While there are no specific objectives that address social science issues, the PI is aware of the importance of gender issues and through colleagues, collaborators and graduate students touches on this area. There is excellent integration of this program with other disciplines, plant breeding being the most important.

Balance of Domestic vs. Overseas Activities

There is good balance between domestic and overseas activities. The PI not only collaborates, in a meaningful way, with Mali but also has networked with other developing countries and international research centers.

Level of Collaboration between U.S. and Host Country Institutions and Personnel

As mentioned earlier, the PI has hosted 10 scientists from developing countries. In addition, he has advised several international graduate students. Networks have been forged with the cereals entomologist at ICRISAT and with the entomologist at SADC/ICRISAT in Bulawayo, Zimbabwe.

Overall Rating

Excellent.

Biological Control Tactics for Sustainable Production of Sorghum and Millet

Project TAM-125B
Frank E. Gilstrap
Texas A&M University

Specific Research Performance

One of the cornerstones of a sustainable IPM program is biological control. Not necessarily the importation of exotic predators and parasites but understanding the impact of indigenous beneficial arthropods. The PI has made excellent progress in identifying major indigenous biological control agents in millet and sorghum. The methodology for evaluating these natural enemies will be useful in understanding how predators and parasites fit into an insect management program. The toxicity of several insecticides to target pests as well as their natural enemies has been determined.

This is one of the few INTSORMIL projects that focuses on millet and methods for assessing the role of the millet stalk borer and head girdler and will be useful throughout West Africa and in other parts of the world where these pests or their ecological homologues are present. Likewise, similar methods for measuring the impact of indigenous biological control agents on the greenbug should add to our understanding of these natural enemies and how they fit into a management program. The PI has identified the major predators and parasites of greenbug in Texas and has linked his program with that of Dr. James Smith at Texas A&M in order to continue the stem borer research on millet. Tests to determine the relative merits of insecticides in natural enemy assessment should greatly improve natural enemy evaluation techniques.

Perhaps the most noteworthy aspect of the PI's results is the training of applied ecologists and biological control experts to work in their home countries.

Institutional Development and Training

The most important aspect of institutional development is well-trained personnel. The PI has an exceptionally active program of training graduate students (10 M.S. and 8 Ph.D.s) from a wide range of countries including Sri Lanka, Senegal, Nicaragua, Burma, Mexico, Honduras, Costa Rica and Niger. In addition, his collaborative activities with the Pan American School of Agriculture in Honduras, INRAN, and ICRISAT at Sadore (Niger).

Evidence of Interdisciplinary Integration

The PI has integrated his program very well into the other plant protection disciplines, especially with the host plant resistance and breeding programs. It may not be appropriate to attempt to integrate this program into the social sciences at this time. This should come later when systems for managing various insect pests are nearing completion and are ready to be tested.

Balance of Domestic vs. Overseas Activities

The PI has achieved a good balance between domestic and overseas activities. Besides training foreign students, he is working closely with INRAN and ICRISAT. In addition, his work with EAP in Honduras has been fruitful and will continue when a contact to replace Meckenstock can be found.

Level of Collaboration between U.S. and Host Country Institutions and Personnel

As mentioned above, the PI has established a good working relationship with several host country institutions including INRAN in Niger, the EAP in Honduras, and ICRISAT. All Honduran students that he trained were associated with the EAP. He also interacts actively with U.S. institutions in the area of biological control and he has an international reputation in this area. The PI has an excellent record of publications. Decisions regarding planning and budgets are carried out jointly with his collaborators.

Overall Rating

Excellent.

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

Project TAM-128
Gary N. Odvody
Texas A&M University

Specific Research Performance

Although the major collaborating country is Botswana, other SADC countries are involved and benefit from this research. The semiarid region near the Texas A&M Research and Extension Center offers a nearly ideal setting for carrying out research designed to fulfill the objectives of this project.

The PI has made good progress in characterizing *Macrophomia phaseolina* grown in field plots at Corpus Christi. Also, collections of charcoal rot tissue specimens from several hosts in Botswana should further assist in identifying host preferences of this pathogen. Emphasis is placed on identification of genetic materials that are adapted to the semiarid regions of Southern Africa. Isolates of *Fusarium* spp. from sorghum in Tanzania should be extremely helpful in characterizing other *Fusarium* isolates to aid in understanding how changes in these populations come about and how breeding strategies can address these changes.

The PI reported that Anthracnose (*Colletotrichum graminicola*) is important in Zambia and genetic relatedness of several isolates was determined using RAPD markers. It is noteworthy that no pathotype specific RAPD banding patterns have been found. This kind of technique, along with others such as the pathotype rating system, and methods for screening Anthracnose, will become increasingly important tools for use in the U.S. and the Host Country in selecting sorghum and millet germplasm.

There has been good exchange of germplasm (about 40-50 improved cultivars adapted to the SADC region) between the PI's program and those of the host country. Unfortunately, many times, proper credit is not given to the PI for materials that are introduced into another country. Simple crosses may be made and the material is often disseminated to other areas without acknowledging the source of the germplasm. Thus, the impact of this kind of activity is nearly impossible to assess.

Institutional Development and Training

There have been some changes in the overall objectives since 1989-90, but in general, they have remained the same. Collaboration with host country scientists have been good but the PI mentioned that communications could be improved. Progress, in general, has been satisfactory given the relatively small budget.

The impact of a program such as this one is not easily assessed. Results come forth slowly in small increments. The prospect for implementing findings by host country scientists are good but often hampered by lack of appropriate extension infrastructure. In addition, trained personnel often return to the host country and take positions unrelated to their training.

Many publications have resulted from this work and slide sets, useful for researchers and extensionists in many parts of the world, will soon be available.

Evidence of Interdisciplinary Integration

There is good integration between plant pathologists and breeders. The project may benefit from interaction with entomologists. No social scientists are involved because of budgetary restrictions but WID issues are addressed in that the PI involves women collaborators/cooperators and students whenever possible.

Balance of Domestic vs. Overseas Activities

The host countries are the major focus of the research but much of the work is carried out in the U.S. and will directly benefit U.S. agriculture. This is particularly true for techniques developed and germplasm identified for resistance to diseases. In general, there is a good balance between these activities.

Level of Collaboration between U.S. and Host Country Institutions and Personnel

In so much as possible, there is a high level of collaboration between the host country and U.S. personnel. Identification of materials that can be used in the host countries breeding program is an example of results from this collaboration. Also, identification of susceptible cultivars for use as comparison, are particularly important in Botswana, Zambia, and Zimbabwe.

Planning is carried out primarily by the U.S. PI with some input from U.S. and Host Country collaborators.

The PI indicated that a major strength of his program was the networking activities. Weaknesses identified include communication problems, poor host country extension infrastructure to disseminate information, political problems and trained personnel that assume jobs in areas other than what they were trained to do.

Overall Rating

The overall rating is good. The PI is a member of a highly motivated and dynamic team that are making significant contributions to U.S. and Host Country agriculture.

General weakness and strengths are pointed out above under the various headings.

Sustainable

Production

Systems

PREVIOUS PAGE BLANK

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

Project PRF-105
John H. Sanders
Purdue University

Specific Research Performance

Research in Process

A major obstacle to developing a collaborative research program in the socioeconomic area was the lack of suitable collaborators in the INTSORMIL targeted countries. Hence, the initial emphasis of this project was correctly focused on training in several countries.

Research under the project has focused largely on diffusion studies. These studies appear to be of excellent quality and relate directly to technologies developed by biological scientists connected to the CRSP. Moreover, the research is innovative from the standpoint of methodology. Quantitative impact assessments are often difficult to accomplish as (1) the data available in quantitative form is often inappropriate while (2) the qualitative data available does not suit itself to quantification. This research project has resulted in relatively straightforward analyses that address important impact issues of concern to INTSORMIL PIs and management, as well as USAID and the respective NARS.

Sanders is to be congratulated for forming an Impact Committee made up of technical scientists, although he is concerned that the committee is not as effective as he would like it to be. Improving the effectiveness of this committee will not be an easy task. On the one hand, biological scientists are likely to be uncomfortable if they view the project as an evaluation of the effectiveness and efficiency of their own research programs. On the other hand, providing the project with that kind of clout would be inadvisable. Ultimately, biological scientists need to understand the need for and effectiveness of interdisciplinary approaches to resolving the problems associated with sorghum and millet production. As long as they focus only on experimental results, they are not likely to appreciate the need for socioeconomic studies. However, the situation could be improved by striking a better balance between the social and biological sciences in INTSORMIL. Despite the high quality of Sanders' work, it only addresses a small fraction of the issues that need to be addressed by the CRSP.

Sanders also notes the long delays in identifying students, satisfying admissions requirements, and finding travel funds. In those areas of research where little or no indigenous capacity exists, such as the socioeconomics area, such delays are particularly frustrating. USAID could do more to see that such requests are expedited.

Research Results Disseminated

Technical Papers

Sanders and his colleagues/students have published nine journal articles, six proceedings, and six theses. A book is in progress. In addition, 12 presentations were made during the period covered by this review.

Impact of Studies

Impact studies themselves may have an impact on NARS as well as future INTSORMIL funding. However, as many other factors enter into decisions as to funding for agricultural research (e.g., national budgetary demands, the state of the national and international economy), it is impossible to attribute any specific impact of these studies on research funding.

Major Accomplishments

Perhaps the key finding of Sanders' studies is that the availability of a market for the disposal of a surplus is an essential factor influencing adoption rates. This should send a signal to INTSORMIL as well as to other donors that research and action on market development will be essential if success in disseminating the new cultivars is to be achieved.

Other Research Related Results

Over the course of this project, the PI has developed and tested a theory of technological change using quantitative data collected with collaborators and students in Burkina Faso, Niger, and Sudan. A number of papers have been published with these data (as noted above) and a book is currently expected to be published in 1994. In addition, 10 Ph.Ds have been produced by the project, of whom three are now working in IARCs and one in a national government. Most current trainees are Africans and they are increasingly from INTSORMIL priority countries. Given the relatively low level of funding for this project, and the critical shortage of economists at NARS, this is an accomplishment of considerable importance. Moreover, Sanders and his collaborators and students have presented their results to USAID's Africa Bureau, the World Bank, the American Agricultural Economics Association, and a conference of agricultural scientists.

Institutional Development and Training

As noted above, this project has contributed significantly to building research capacity in NARS where sorghum and millet are significant crops. Given the increased demand for impact studies by both donor agencies and NARS, this is an important and worthwhile institution building task. It will also help to enhance the credibility of social science research in NARS.

The PI feels (correctly) that credibility has been established. He expects to develop strong collaborative programs in Mali and Senegal in the next several years. In Mali the research involves an impact assessment of a new fungicide, water retention/soil fertility technology combinations, and the economic impacts of the regional concentration of sorghum research. In Senegal, research focuses on the impact of the cereals research program. While these two countries are expected to be the main foci of collaborative research and training, he would also like to renew activities in the Sudan should the political situation improve. Focusing on these nations, however, will involve a reduction in funds for long-term training. Given the current situation within INTSORMIL, this appears an appropriate strategy. However, the choice of Senegal over Niger as a country with significant collaborative efforts seems puzzling given the strong INTSORMIL presence in Niger in other disciplines and the availability of competent counterparts in Niger.

It is also worth noting that the economics project furnished computer software and extensively interacted with economists at the Sudan ARC during field visits. In the fall of 1992, Taha Ahmed interviewed farmers with Tennassie Nichola.

Evidence of Interdisciplinary Integration

Sanders has been actively involved in attempts to integrate his work into that of the INTSORMIL project as a whole as well as into other CRSPS and NARS. Specifically, he spent a month with SAFGRAD evaluating the impact of their research networks on maize, sorghum/millet, and cowpeas across Africa. His report documented the impact of these networks for USAID. Results were reported to approximately 20 Director Generals (DGs) from the NARS of West and Central Africa. In addition, he presented a paper to the INTSORMIL agronomists at a conference on stress in 1993. Furthermore, he participated in a Bean/Cowpea CRSP meeting at Purdue, reporting on results of research on impacts of cowpea research in Burkina Faso and Mali.

Sanders has also discussed collaboration and exchanged ideas with Maranville, Eastin, and Andrews. His graduate students have drawn frequently on agronomy graduate students for help in economic modeling.

Moreover, while no formal joint planning has been conducted, Sanders has been responsive to requests from other PIs for impact evaluation. Examples include various studies of HD-1, increasing involvement in the economics of the seed industry with Joao Carlos Garcia (from EMBRAPA), and work on diffusion of HD-1 in Sudan by Tennassie Nichola, which has emphasized the importance of shortages of seeds and fertilizers.

Sanders' work is particularly important in explaining why so little sorghum/millet technology has reached farmers. It has attempted to analyze constraints to the introduction of new technologies in semiarid regions, to develop explanations for the lack of this diffusion, and to recommend strategies for overcoming these constraints.

Finally, Sanders and his collaborators have been working with both large and small farmers in both various African nations and Honduras to identify barriers to adoption of new technologies.

Balance of Domestic vs. Overseas Activities

All of Sanders' work under this project has been international in character.

Level of Collaboration between U.S. and Host Country Institutions and Personnel

Research Planning

There has been some interaction with the ARC and with the IER, but it has been inadequate due to lack of travel money. To date, the budget has been invested in training students. Their is substantial interaction with graduate students from the NARS in the planning of their theses.

Interaction

This area definitely needs more attention now that more resources are available and there are more demands from potential collaborators in the NARS. As noted above, Sanders will be stressing the development of collaborative activities in Mali, Senegal, and, if political conditions improve, Sudan.

Relationships

Relationships with host country collaborators are currently in the incipient stages, whereas the project has excellent ties with former and current students. In the relatively near future, relationships should improve markedly as (1) former students are employed by the NARS, and (2) funds are shifted to collaborative efforts.

Overall Rating

General Strengths

Sanders has built up what is surely the most comprehensive impact evaluation program within the CRSPs. Moreover, Sanders' work and that of his students and colleagues is imaginative, creative, and well-executed. Within his field of Agricultural Economics, his work is widely read and respected. In addition, Sanders' work should have a significant impact on INTSORMIL's agenda as it documents the constraints to the adoption of technologies produced by INTSORMIL investigators. Finally, Sanders' work is respected within USAID as offering the agency new approaches to evaluating certain of its activities.

General Weaknesses

There are two sorts of weaknesses to Sanders' project, although neither one of them is directly under the control and direction of him or his colleagues.

First, Sanders' work has not been taken as seriously as it might be in the planning and direction of INTSORMIL activities. While some INTSORMIL scientists appreciate his work and have even asked for his help in evaluating new technologies, INTSORMIL has not developed a method for institutionalizing impact studies by using them to plan for future research and action. On the one hand, the research program has not adequately reflected the constraints identified by this project. On the other hand, INTSORMIL has not used its leverage as an institution to attempt to reduce or eliminate some of the constraints identified.

Second, Sanders' work stands out by virtue of its isolation from other socioeconomic work. While impact analysis is an essential component of CRSP activities, it is not a complete socioeconomic research portfolio. Especially given the nearness to release of many INTSORMIL technologies, INTSORMIL sorely needs a balanced socioeconomics program that includes economists, but also anthropologists, sociologists, and even political scientists. No one can fault Sanders for not engaging in these other research tasks (e.g., identification of means for overcoming constraints at the post-harvest and input levels, analysis of subsector strengths and weaknesses for sorghum and millet producing nations, etc.). However, their absence has left INTSORMIL less able to insure that its technologies are translated into practice.

Recommendations

This research is moving along at the speed expected and in the right direction. More overseas collaborations should be developed and we have every reason to expect that they will be shortly. Sanders's work should be encouraged and better integrated into overall CRSP activities.

This research project has been extraordinarily productive and should continue to be funded at present levels. Any additional socioeconomic research should be undertaken using other funds (and, all other things being equal, probably should be done at another institution).

Resource Efficient Crop Production Systems

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

Research Progress

General Approach

The basic approach of long term experiences in the U.S. which address the basic sustainable cropping systems objectives of the project (albeit conducted under different environmental and economic conditions) combined with applied research projects with collaborating National Programs, is sound. The U.S. long term projects provide a laboratory for training students in principles of cropping systems research, a model system for developing techniques and conducting initial research on basic principles equally applicable to developing country and U.S. agricultural research needs. The success of this approach however, depends on the linkages that can be established in developing country NARS, through which knowledge and techniques learned at UNL can be applied to designing resource efficient cropping systems for these countries. Such linkages appear to now be in place with the Institut d'Economie Rurale (IER) in Mali, but only in Mali. While this is not always an easy task, it appears that the project has not been as effective in pursuing such linkages as it might have been, and that, perhaps as a consequence, its research activities are more ad hoc and short term (individual student theses) than they should be.

Specific Research Projects

Rotation Effects

Focus of research in the U.S. has shifted from simply documentation of rotation effects to understanding the basis of yield increases due to rotation. This needs to be pursued vigorously to develop research methods and test hypotheses for use in collaborative research projects on rotation effects in developing countries. One priority area would certainly be the relationship of rotation effects to indigenous soil fertility levels and crop available moisture patterns. Exploitation of rotation effects are the most likely short term way of increasing cereal yields in developing countries; improving the targeting and effectiveness of rotation research in national programs is the probable major contribution of UNL-113 to production increases in the next decade. It is recommended that the PI consider seeking more funding for student thesis research in this area.

An apparently very effective collaborative program on rotation research has been establish in Mali, by exploiting linkages with former INTSORMIL students. This is presently in the phase of documenting the magnitude of rotation effects and their interactions with various crop management practices. Such research should lead to recommendation for on-farm testing in the near future, particularly if inputs used (especially fertilizer levels) are scaled down to more realistic levels for Malian agricultural conditions. Rotation research can then gradually shift to more focused experiments to maximize the beneficial effects documented in the initial round of experiments. The continued support of the project PI's in interpretation of results, planning of experiments, and personal and financial support for more detailed measurements and analysis will be essential in this phase of the research.

Water Use/Conservation

The project has correctly identified improvement of water use efficiency (through weed control, residue management, plant stand establishment, etc.) as the second priority for agronomic research in sorghum, particularly in areas where soil fertility is not a severe limiting factor. One Ph.D. thesis, completed during the period, indicated some of the potential research problems. This area would also lend itself very well to a combination of strategic research in Nebraska (perhaps centering on the development of simulation modeling techniques) and more applied research in national programs where such research is appropriate. Again, this depends on the opportunity to establish strong collaborative research projects with appropriate national programs.

Stand Establishment Research

The development of the *in vitro* method for assessing ability to emerge from crusted soils, and the demonstration of the heritability of this capability is promising work, but its relevance to the specific objectives of UNL-113 (which is not concerned with physiological-genetic research) is questionable. If the PI wishes to pursue this research further with INTSORMIL support, it should be done collaboratively with one of the INTSORMIL funded sorghum breeding projects, where the technique can be properly exploited.

Physiological Studies of Cropping Systems

UNL-113 also has the opportunity to support research on selected aspects of cropping systems, on which the project itself may not be conducting research. Current Ph.D. research on the shade tolerance of the maicillo criollos is a good example of this. Provided that the specific project has a genuine priority, UNL should continue to support such work.

Impact of the Project

The primary impact of the project over the review period has been in the assistance it has given to IER in Mali to develop a sound program of cropping systems research. The experiments in Mali were well planned and exceptionally well executed.

Research conducted by UNL-113 in the U.S. has helped to document the magnitude of rotation effects on cereal yield, under both low and high input agricultural systems (see especially Clegg, M. D. 1992. Predictability of grain sorghum and maize yield grown after soybeans over a range of environments. Agricultural Systems 39:25-31).

UNL-113 has provided graduate training to 25 scientists since its inception. A number of these are now in key positions in national research programs in developing countries.

Publications and Presentations

The project's rate of formal publication could be better, as work from the 80's is still in preparation. The record of presentation of results in workshops, annual meetings, etc., appears to be good. However, the long term data base from the sorghum rotation experiment at UNL could probably be more effectively exploited to test hypothesis on rotation effects, and their interactions with soil moisture and fertility. The PI should also encourage and assist his Nigerien and Malian collaborators to publish results of their research.

Organizational and Institutional Aspects

Institutional Development and Collaboration with National Research Programs

The major justification for INTSORMIL investment in long term cropping systems research in the U.S. is the supporting role of such research for training and collaborative research in developing countries. The effectiveness of UNL-113's collaborative research programs is therefore an essential part of the overall project's effectiveness.

UNL-113 has a good relationship with the national program in Mali, based on personal relationships between the PI and several former post graduate students now responsible for agronomic research in the country. The PI appears to have made a serious effort to develop these relationships and to provide assistance to the young Malian scientists involved. The research program has been adapted to the Malian national priorities for agronomic research, and the PI visited Mali for a joint planning session before the 1993 season. The technical and financial (U.S.$12,000 in 1993) support provided by UNL-113 from agronomic research is highly appreciated.

Unfortunately, Mali appears to be the only country where this has been possible. Earlier collaboration with INRAN in Niger was based on the assignment of U.S.-based scientists to INRAN, with apparently very little involvement/commitment by the national program. Collaboration effectively ended with the return of the expatriate scientists. More effort needs to put into developing collaborative research projects in countries in which there is a potential for this. There should be an excellent opportunity in Sudan, if the political conditions allow, as there is both a need for dryland cropping systems research and trained people with whom to collaborate. A serious effort should be made to resume collaboration in Niger, either with INRAN alone, if this organization can solve its own staffing problems, or in a three-way arrangement with INRAN and ICRISAT Sahelian Center. In addition, there should be opportunities in one or more southern African countries, where a number of young scientists have been trained by INTSORMIL Universities under USAID funding.

There are clearly a number of prerequisites for successful collaborative programs of this type, which are not under the control of the project PIs, but the initiative must come from the INTSORMIL side, particularly with increasing donor emphasis on the documentation of impact on developing country cereal production.

Evidence of Interdisciplinary Integration

There has been some interdisciplinary research on the cropping systems experiments at UNL (economic analysis and soil biology) but little evidence of linkages to other INTSORMIL projects. This has perhaps been less important in the past, but with progress in other INTSORMIL projects, there is strong logic for evaluation of genetic material with improved nutrient-use efficiency, drought tolerance, pest resistance, etc. from other INTSORMIL projects in appropriate cropping systems where such traits should have their greatest value. This includes both reduced input systems in the U.S. and low input systems in developing countries.

Overall Rating

The strengths of UNL-113 lie in its unique combination of long term rotational experiments in the U.S. for training and basic hypothesis testing, and of specific collaborative cropping systems and crop management research in developing countries, based on the needs of those countries and accumulated knowledge from the long term U.S. experiments. However, the inability to development sufficient long-term collaborative research linkages with developing countries has limited the effectiveness of the project. Considerably more effort needs to be devoted to building such linkages. It may be necessary to seek long-term special funding, particularly for graduate training, to develop the manpower base for such linkages with selected National Programs. Present donor emphasis on natural resource management and national agricultural research system development should assist the PI's or UNL to obtain such funding.

Nutrient Use Efficiency in Sorghum and Pearl Millet

Project UNL-114
Jerry W. Maranville
University of Nebraska

Research Progress

General Approach

The project combines basic research on genetic differences in nutrient use efficiency and mechanisms of nutrient use efficiency, using both controlled environmental and field conditions, with more applied research on nutrient management and environmental factors affecting nutrient response, both in the U.S. (masters thesis research) and in Mali (collaborative research). This approach is basically sound and should be productive; the main concern of the external review team is with the quality of some of the field experiments reported in past annual reports and seen in the field.

Specific Research Activities

Genetic Differences in Nitrogen Use Efficiency

Research early in the review period documented considerable genetic differences in N uptake (in low soil N levels) and in N use efficiency for both biomass and grain production (primarily at higher soil N levels). Current experiments are evaluating selected lines with a high nitrogen use efficiency under a range of soil N levels.

The experiments in Nebraska have been plagued by stand establishment problems, adjustment for which is a problem in experiments involving nutrient uptake. In addition, genotypes vary widely in adaption to Nebraska environmental conditions, such that differences in adaption may have unknown confounding effects on results. Ultimately, the case for exploiting N use efficiency in breeding will have to be made using populations bred for the purpose from crosses of selected parents; the PI should begin developing such populations now, preferably in collaboration with one of the INTSORMIL breeding projects, which are the targets of the research.

The experiments in Mali in 1991-92 which attempted to compare N use efficiency of local and "improved" varieties, encountered similar problems of poor adaptation in the improved varieties. These yielded well below the local varieties, due to poor stand establishment and susceptibility to grain mold.

It may be preferable to concentrate on demonstrating that there are sufficiently large heritable differences in N use efficiency in breeding populations in the U.S.-based research before too much effort is spent in attempting the same work in collaborative projects in Mali, where the conduct of such research is more difficult than in the U.S., and where there are probably higher priorities in nutrient management research than genetic differences in nutrient use efficiency.

Physiology of Nutrient Use Efficiency

This is a new area of work designed to determine how differences in the ability to efficiently extract N from the soil and maximize its use in crop growth are expressed on a tissue biochemical level. The experiments in the field seem well designed, but appear to suffer from the same limitations as those on genetic differences in N use efficiency.

The project research also includes studies on genetic differences in root morphology and their consequences for nutrient uptake. This is interesting and original, but difficult work; the PI is to be commended for his willingness to undertake it.

Applied Research on Nitrogen Management

The PI has guided two masters theses in Nebraska on aspects of nitrogen management in pearl millet, including differences in genotype response, and environmental interactions with N response, under both controlled environment and field conditions. Treatments used and data obtained from the controlled environments experiments looked reasonable, but there were problems in the field experiments which should not have occurred. The sites chosen for the experiment (a very high soil nitrogen level, limiting response to applied N), and very high levels of experimental variation, making interpretation of results all but impossible. If research done in Nebraska on aspects of nutrient management is to be relevant to collaborative research in Africa, field sites will have to be found and/or developed.

Collaborative experiments in Mali on nitrogen management in sorghum employ nitrogen rates that are unrealistically high for both the environmental and economic conditions in the country (as high as 160 kg N Ha^{-1}, in contrast to a range of 0 to 50 kg N ha^{-1} in IER experiments). There are also legitimate questions as to whether applied experiments designed to measure yield response to applied nitrogen (as opposed to more basic experiments on N physiology) should be done on research stations at all, as these inevitably differ in base soil fertility from farmers' fields.

The IER itself has commenced experiments on the response to nitrogen in relationship to previous crop in the rotation, to plant population, and to rainfall. It would be logical for UNL-114 to assist in and support this research, rather than continuing with the present on-station experiments.

Collaborative experiments between INRAN and UNL-114 on effects on N rate (1989-91) and P rate (1992-93) on water use and yield in millet have been conducted at Tarna Station. Apparently the results have never been analyzed or written up. A visit to the 1992 experiment indicated a limited P response, probably due to a high base soil fertility level on the Tarna Station. The UNL PI and a former student, now returned to INRAN, have proposed two experiments on N and plant population effects on sorghum yield. However, the scientist involved has been assigned to other responsibilities and the experiment seems, in any case, to duplicate work already under way in the INRAN program.

Publications and Presentations

Publication of results of UNL-114's research has been satisfactory. Work in progress has been reported to various conferences and meetings and has produced five journal articles; work plans include plans for formal publication of completed work.

Impact of the Project Research

The basic work on nitrogen use efficiency has effectively demonstrated the existence of genetic variation in various aspects of this complex trait and demonstrated a useful analytical approach to genetic differences (see Youngquist and Maranville. 1992. Journal of Plant Nutrition 15:445-456). This approach is now being used in collaborative research on N use efficiency in Mali.

The project has trained several students who are now responsible for nutrient agronomy work in their own countries, and with whom the PI has an active collaboration. These linkages should lead to a much improved opportunity for UNL-114 to apply concepts and methods developed in U.S.-based research to problems of nutrient availability/use in developing country agriculture.

Institutional and Organizational Aspects

Institutional Development

UNL-114 has an active role in agronomic research in Mali. The project is providing approximately $35,000 dollars a year in support of IER research and has collaborative linkages with six Malian scientists (in both physiology and agronomy), many of whom have been trained at UNL. The PI has recently helped an IER scientist to plan a comprehensive interdisciplinary program of agronomic research involving nutrient management, cropping systems, physiological basis of responses, and economic analysis of the results. This joint planning exercise represents a genuine step forward in enhancing the capability of the IER to conceive and manage their own research programs.

Collaboration with National Programs

UNL-114 is an active collaborator in agronomic research in Mali, and has helped organize and support an active program of research on fertilizer use on sorghum. This collaboration is expected to grow with the initiation of a more ambitious, multidisciplinary program of agronomic research in IER (see above).

UNL-113 collaboration with INRAN in Niger, in contrast, seems to have declined during the review period. Data generated in the one remaining collaborative experiment seems not to have been analyzed, financial support for collaborative research has ceased and the PI did not visit in 1993. The proposed resumption of activity with the return of Mr. Seyni Sirifi from UNL appears to be impossible as Mr. Sirifi has been assigned to another program.

The PI has also participated with UNL-116 in assisting the Egyptian national program in research on water x nutrient interactions and in studying physiological processes associated with stress tolerance.

Evidence of Interdisciplinary Integration

UNL-114 does not appear to have strong interdisciplinary linkages either within the INTSORMIL system or with other institutions at present. Participation of other INTSORMIL investigators appears to be limited to advice on cultivar choice and the provision of seed for research, apart from some collaboration on the work on genetic aspects of nitrogen use efficiency.

Ultimately genetic differences in nutrient uptake or use efficiency will need to be able to be manipulated in breeding programs, if research on them is to make a contribution to improving crop production, either in the U.S. or in developing countries. It is strongly recommended that UNL develop collaboration with one or more INTSORMIL breeding projects to begin now to develop the populations in which selection for efficiency can be carried out and the magnitude of gains from such selection determined.

Overall Rating

The general strengths of the project lie in its combination of both basic and applied research on problems on improving nutrient use efficiency and its potentially very effective role in assisting multidisciplinary research in Mali on applications of nutrient management research.

The project needs to devote more effort to improving the quality of its field research; developing more appropriate field facilities for research on nutrient use at low soil nutrient levels, improving the quality of plant stands and field data, and controlling experimental variability. In addition, applied research directed to developing country problems should focus better on (1) the more efficient usage of the small inputs of chemical or organic fertilizers that farmers are likely to be able to justify economically in poor soil/harsh climate environments in which sorghum and millet are the staples, and (2) the use of applied nutrients within common rotation/intercropping systems used by farmers.

Future work on genetic variation in both nutrient use efficiency and mechanisms involved should be carried out in collaboration with a plant breeder, and with especially created populations (based on combinations of sources of nutrient use efficiency x adapted lines) in which questions such as heritability of mechanisms and response to selection can be properly studied.

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

Project UNL-116
Jerry D. Eastin
University of Nebraska

Research Progress

General Approach

The general object of the project is to utilize physiological knowledge of crop response to temperature and water stress to improve both crop management methods and the effectiveness of varietal selection for stress environments. While the simultaneous consideration of both genetic and management approaches gives the project an unusual dimension, it appears to have resulted in the program attempting too many different studies at the cost of focus and accomplishment. For example, the PI appears not to have had the time or resources to finish one of the most important areas of his research - the screening methodology for tolerance to mid-season drought stress. The review panel appreciates the scope of the PI's interests, but not at the cost of insufficient time or resources to complete research projects. This is most especially true in the genetic work, given the amount of effort required to properly test a physiological trait as a selection criterion in a breeding program.

Specific Research Activities

Screening Methodology for Mid-Season Stress Resistance.

Research initiated during the 1980's on the stability of grain number under mid-season stress as a measure of mid-season stress tolerance resulted in the development of a putative mid-season stress tolerance population (NES$_3$R). Unfortunately, the project did not compare lines from the original and new populations to provide a conclusive demonstration that the selection method used is effective in producing higher yielding/more stable lines under mid-season stress. This would (and should) have been an important contribution to the methodology of breeding for tolerance, and thus to one of INTSORMIL's more difficult objectives. It is still important that this be done.

Physiological Studies of Stress Tolerance Mechanisms

Research was initiated during the period of this review on (1) heat shock protein (HSP) synthesis as a general mechanism of high temperature tolerance and (2) on panicle respiration rate as an index of grain filling rate. The first area is still in the exploratory stage of comparing the synthesis patterns of known high temperature tolerant and susceptible hybrids. The research will hopefully provide information on the potential for the use of the synthesis of specific HSP's as a selection criterion for heat tolerance. This is a useful area of basic research, but the experiments need to be carefully planned so as to assure that they produce conclusive results.

The work on panicle respiration rate is intended to test the hypotheses that respiration rate is related to rate/length of grain filling and can be used to manipulate either of these in a breeding program. The first hypothesis can be readily tested; exploiting the second hypothesis offers a number of possibilities. The present thinking that selection for a low respiration rate might be used to increase grain filling period and hence seed size to compensate for preflowering stress reduction in seed number is only one of the possible alternatives; a more important alternative might be that an increase in grain filling rate could provide a mechanism of terminal stress escape/tolerance.

A broad project of collaborative research on physiology of and breeding for stress resistance has been initiated in Egypt with USAID support. The actual commitment of the UNL-116 PI to this project is not clear, but it does not appear to be a small one.

Physiological Studies on Water Use efficiency (WUE)

Work done during the previous review period on WUE in alternative millet/cowpea intercropping systems in Niger has not been continued (largely for reasons of the lack of a cooperator in the Niger national program). The research station results indicated a substantial yield response for the cowpea in a management system designed to maximize WUE. INRAN has supposedly tested the system under farm level conditions, but no data are available.

The project is supporting a Ph.D. thesis project on stress resistance, WUE and nitrogen fixation in various legume species in the Sudan, with the long term objective of improving legume species for rotation with sorghum in dryland cropping area in which N deficiency is a major limitation on WUE and grain yield.

Both of these research areas are useful examples of the physiological analyses in decomposing both problems and results into more basic terms of water or nutrient use and/or use efficiency by crops or systems. Such analyses can contribute considerably to the understanding of species differences and management treatment effects. However, future work in both areas needs to be justified in terms of the research priorities of the host countries.

Publications and Presentations

The project has a good record of presentation of its work at professional meetings, workshops, etc. In contrast, the record of formal publication in refereed journals appears to be less productive. This may be partly a function of fact that much of the research done in 1990-93 has not been completed. However, work plans have projected the publication of results from the Niger project, and from the HSP and stress screening work which have not yet appeared. The PI is an effective proponent of mission oriented research in crop physiology.

Impact of Research

UNL-116 has contributed a great deal to the knowledge of temperature and water stress effects on sorghum, and has suggested/tested innovative ways of utilizing this knowledge in both breeding and crop management, in the years since its inception. Concepts researched by UNL-116 have influenced sorghum research programs worldwide. The PI has been an active spokesman for the utilization of physiological knowledge of the crop in applied research programs.

Despite this, the project has probably missed opportunities to see a more direct impact from certain of its projects, such as the mid-season stress resistance screening technology, by failing to fully quantify and document the gains in yield/stability possible through deliberate selection for tolerance. It should be noted, however, that lines from the population produced in developing the method have been used by a number of public and private breeders in the U.S.

Institutional and Organizational Aspects

Institutional Development

UNL-116 does not appear to have strong linkages to national programs overseas, apart possibly from Egypt, which the EEP did not have the opportunity to evaluate. The involvement in Niger in the late 1980s was dependent on the assignment of an INTSORMIL staff member to Niger; the collaboration appeared to have ceased with the departure of that staff member. Other linkages appear to involve only the thesis research of students from various countries. The more basic nature of the research done in UNL-116 certainly accounts for a part of this; realistically, countries such as Egypt or India (where the PI is involved in non-INTSORMIL collaborative research) are more likely to be able to use the techniques and concepts researched by UNL-116 than are countries presently targeted by INTSORMIL, such as Niger. It may be useful for the PI to attempt to target his training funds to one or two countries which have the capability to conduct the type of research in which UNL-116 specializes, and not to spread these as widely as in the past.

Collaboration with National Programs

UNL's only apparently active collaboration with a national program at present is with Egypt, apart from the support of the Ph.D. thesis of a Sudanese scientist. It is hoped that this latter relationship will develop into a collaborative project, but this is yet to be established. Prospects for restarting collaborative work in Niger do not appear to be good, as the scientist identified for the project has been transferred to another crop. As noted below, however, UNL-116's main target for its research findings should probably be other INTSORMIL projects, rather than developing countries directly.

Evidence of Interdisciplinary Integration

Much of the work of UNL-116 is targeted to the improvement of the efficiency of plant breeding and crop management research for stress conditions. The project's major impact should be indirect, through collaborative research with applied breeding/agronomy projects. As such, UNL-116 would be expected to have closer linkages to other INTSORMIL projects than it appears to have. The project has either not sought collaborative linkages with other scientists, or has failed to convince them of the applicability of its findings to their own programs (failure to finish work, such as the midseason drought screening technique, contributes to a lack of credibility). This lack of collaborative, interdisciplinary research appears to be the major weakness of UNL-116, which will ultimately affect the impact of its research.

Overall Rating

The strengths of UNL-116 lie in PI's knowledge of the physiology and management of the sorghum crop in stress conditions, plus his evident enthusiasm for his research. Projects such as UNL-116, which analyze problems and attempt solutions from a more basic biological level are needed to bring new concepts and methods into the large number of more applied research projects supported by INTSORMIL. The present project structure of INTSORMIL is not effective in generating collaborative research among INTSORMIL projects, and UNL-116 does not appear to have been able or effective in developing such linkages on its own initiative. In the future, the research currently done in UNL-116 should be packaged into joint projects with one or more plant breeders for the genetic improvement work, and with one or more agronomy programs for the management work. This should assure that the concepts/methods developed by UNL-116 are thoroughly tested in collaboration with the potential users of them.

The lack of strong overseas collaborative linkages is of less concern in the case of UNL-116, because of the more basic nature of its work. Where opportunities exist, as there apparently does with the national program in Egypt, they should be pursued; but it is more likely that the research done by UNL-116 will have its impact overseas through collaboration with the more applied breeding and management projects in INTSORMIL.

Germplasm

Enhancement

and

Conservation

Pearl Millet Germplasm Enhancement for Semiarid Regions

Project: KSU-101
W. D. Stegmeier
Kansas State University

Specific Research Performance

KSU-101 is currently in its 15th year with principal research objectives:

Mali

To determine the efficacy of alternate cycles of selection in western U.S. and Mali affecting stand establishment, drought tolerance, and wide adaptation.

Niger and Zimbabwe

Exchange of germplasm.

ICRISAT/India

Continue enhancement of materials by cycling between projects followed by crossing and selection in India and Kansas.

U.S.

To continue development of materials affecting productivity with hybrids for the U.S. grain market and to determine mode of inheritance of seed, seedling, and plant characteristics affecting productivity.

A 1992 review of U.S. millet programs by Dr. K. N. Rai suggested that this program, having been in effect longer than UNL-118, has generated a much wider range of variability and more productive materials than the Lincoln program. Still Professor Stegmeier feels greater progress can be made by selecting for deep rooting, longer coleoptile length, and access to a quarantine location, e.g., St. Croix for introducing African and Asian material to his program. Certainly there also appears real need for a plot combine. He also currently shares time with sunflower and canola research. Quality technician help could greatly strengthen the PI efforts and allow for more overseas activity.

In addition to several publications the past three years, the PI's greatest accomplishments perhaps relate to his released finish lines. AKM2068 shows excellent combining ability and is successfully being used as parental material by ICRISAT at Hyderabad. One hybrid using AKM2068 has already been released and commercialized in India. BKM1163 has been found highly resistant to downy mildew in India. This source of resistance in an elite line is being re-selected and backcrossed in India. A third significant development would be 0083, a restorer of proven heterotic potential. This program is then close to having the parents ready for an alternative crop on the sandy soils of Kansas.

As for germplasm exchange see Table 1 for accessions received and Table 2 for germplasm distributed internationally. Some 317 items have been distributed domestically.

Credit is also due this project for looking at management and utilization practices to make a launch of new crops successful. Cattle feeding

Table 1. Pearl millet germplasm accessions acquired, 1990-93.

	ICRISAT			
	Zimbabwe	India	Mali	UNL-118
1990	29	—	—	32
1991	—	11	14	—
1992	—	20	13	39
1993	—	145	—	51

Total tropical accessions received and in storage: 943

Table 2. Fort Hays Experiment Station pearl millet germplasm distributed internationally.

	ICRISAT			
	India	Niger	Mali	Other
1990	—	—	—	—
1991	—	—	56	2
1992	60	38	23	10
1993	200	12	100	6

trials show millet has 3-4% higher net energy than sorghum. It has also been found that the superiority of millet over sorghum in body weight gain is more related to protein than energy. Professor Stegmeier additionally is looking at herbicide response for this crop. He hopes for wide adaptation, improved standability to harvest, materials which tolerate low temperatures during meiosis (e.g., low 50's) and of critical need, a long mesocotyl for stand establishment especially for eco-fallow needs. A projected impact for hybrid pearl millet, assuming 500,000 acres in Kansas 10 years after release would be an additional $8,500,000 net gain for farm income.

Institutional Development and Training

KSU-101, being at a branch station, still is able to take visiting scientists on study leave such as Mr. A. S. Rao, an ICRISAT technician who accompanied us in the field. His Malian collaborator, Karim Traore, could no doubt benefit visiting the program. Also, A. Kumar of Niger ICRISAT exchanges materials and it would be expected that Ouendeba of INRAN would also take part. Dr. K. Rai of ICRISAT, who visited Hays in September of 1992 is the principal person with whom he exchanges material and with whom there is a joint effort to upgrade material for both. The PI visited Mali in October and has previously worked with the Sudan program.

Evidence of Interdisciplinary Integration

The PI appears to have a good relationship with Dr. Glenn Burton, especially in relation to breeding approaches and shared populations. He obviously collaborates with UNL-118, as he should. In fact his current list of collaborators totals some 17, with 5 overseas.

Balance of Domestic vs. Overseas Activities

The Year 15 budget suggests 37% allocated to U.S. activities with Mali, Senegal, Niger, and India the overseas recipients.

Level of Collaboration between U.S. and Host Country Institutions and Personnel

Annual planning sessions appear to occur. Some indication exists that communication with Mali is not the best and may reflect the move of Niangado to administration with K. Traore rather new. A recent visit hopefully corrected this situation.

Publications and Presentations

Some five publications have been noted for 1990-92. As hybrids become a reality in the U.S. the PI will likely become more extension active.

General Strengths

Professor Stegmeier appears to have a true breeder's ability to be able to select for the right traits. The program shows a nice diversity of germplasm as well as breeding methodology. His geographic location is a likely asset and of course being at Hays has the advantage of less distractions. Materials at Hays seemed much farther advanced than those we saw the day before at Mead and, in general, looked to be better adapted.

General Weaknesses

The program is larger and includes canola and sunflower, also. Funding and lack of adequate harvest equipment affect technician support and the equipment needed to make hybrid grain millet successful. Pressures on the PI for U.S. activities, e.g., other crops no doubt restrict overseas time. Also, stronger collaboration, e.g., with Mali and Niger will be beneficial.

Recommendations

Breeding approaches and productivity are well documented. Hopefully, adequate support from other disciplines can allow the grain millets to overcome specific breeding challenges and become a reality. One might question, also, if the potential at this point of research, might not suggest the PI give more time to millet and less to sunflower and canola.

A strong winter nursery and more test sites especially to the south would seem appropriate. Certainly, the St. Croix opportunity to growout materials in quarantine must be evaluated. A close association with the private sector will soon become a reality as hybrids become commercialized.

If more support can be given, then the PI, with more time, can be of real value working with overseas collaborators who can benefit greatly from his successes and hybrid experience.

Breeding Sorghum for Tolerance to Infertile Acid Soils

Project MSU-104
Drs. Lynn Gourley, Susana Goggi and Brian Baldwin
Mississippi State University

Specific Research Performance

MSU-104 is currently in its 15th year with major research objectives as follows:

Colombia

Screen and evaluate sorghum and pearl millet, in the laboratory and field, for sources of tolerance to infertile soils, low soil phosphorous content and availability, and aluminum and manganese toxicity.

Kenya

Enhancement of elite U.S. and LDC sorghum germplasm with sources of tolerance to infertile soils and with yield stability to low production inputs.

U.S.

To determine genetic variability for phosphorous uptake and use efficiency; and for aluminum and manganese toxicities. To characterize these and *bmr* genes using random amplified polymorphic DNA (RAPD) analysis among closely related lines. To induce acid soil tolerant mutants in elite and *bmr* susceptible sorghum lines using tissue culture techniques.

Three investigators, Gourley, Goggi, and Baldwin participate in MSU-104 with this time allocation:

	Percent INTSORMIL research time	
Investigators	1985-1989	1990-1993
Lynn Gourley	40	100*
Susana Goggi	0	50
Brian Baldwin	0	10
Total S/Y	0.4	1.6

*Through MIAC buyin.

Research progress in Colombia and Kenya has been rated satisfactory with obvious frustrations because of funding constraints by National Program staff and their slow-track approach to germplasm/variety/hybrid release. Dr. Gourley is particularly concerned with his lack of soil scientist support and the need for soil testing laboratories, not a problem in the U.S. but certainly in LDC's.

During the past three years, two INTSORMIL produced varieties, Sorghica 40 and Sorghica 60, have been released by ICA in

Research activity		% INTSORMIL time 1993
Colombia		
Lynn Gourley -	Breeding	5
Susana Goggi -	Biotechnology	10
Brian Baldwin -	Breeding	10
Kenya		
Lynn Gourley	Germplasm evaluation	90
Susana Goggi	Coordination MSU-104, 111 with Kenya	10
U.S.		
Lynn Gourley	Training/germplasm exchange	5
Susana Goggi	Biotechnology	30

Colombia. Additionally, workshops, publications, methods, systems, and germplasm have been widely distributed from this country program. The project under Gourley's direction lists these items as the principal contributions to date:

> A field screening method for acid soil tolerance and evidence that about 8% of the sorghum world collection selected from acid soil areas in Africa is tolerant to 65% Al saturation.

> Release of sorghum varieties and germplasm for acid soil areas.

> Publications and papers have stimulated sorghum-acid soils research as evidenced by ICRISAT listing acid soils research on their priority list.

Additional research results include ready movements of world collection materials going to breeders in the U.S. with one of these accessions currently being used in a commercial hybrid in this country and in southern Africa. Seed and pedigree lists have been sent to ICRISAT, Brazil, Zambia, Zimbabwe, Niger, and Kenya.

Whereas the review team saw increases of Sorghica 60 in 1991 no one seems to know the distribution or acceptance of this release. An objective for the CRSP should be a closer follow-up on acceptance/use of released material. ICA-INTSORMIL recommendations of fertilizer and other cultural practices have been distributed to Colombian farmers, a necessary total package. Increased grain production in northern South America with acid soil varieties will be used in animal feed (corn for humans) which improves the human diet in meat, milk, eggs, and other products. Previously, sorghum could only be grown with large quantities of lime.

Institutional Development and Training

While training has been a significant part of this project, with the PI overseas the past three years, less of this activity has been possible. He cites decreasing funds as another factor affecting training. As for on-going activities Dr. Gourley encourages joint publications and presentations.

Evidence of Interdisciplinary Integration

The workshop in Cali, Colombia in 1991 illustrates the collaboration between INTSORMIL and ICRISAT as well as the host institution, CIAT. This meeting brought in scientists (200+) from all over Latin America plus the U.S. Within the CRSP, MSU-111 is the in-country collaborator with ICA as well as UNL-114 and UNL-118. In 1992, Dr. Goggi participated in a successful seed technology short course in Kenya. She additionally has given a short course in Argentina plus consulted there and in the U.S. with DEKALB Genetics Corporation.

Frequent phone calls plus fax have kept up communication between Dr. Gourley and both Dr. Baldwin as well as Dr. Goggi. She in turn has coordinated activities between MSU-104 and MSU-111. In Kenya, planning of nearly all breeding and agronomic research is joint with disciplines. In Colombia and Kenya, the National Programs have allowed for interdisciplinary integration of biological and social sciences.

As to subsistence farming vs. after the "farm gate", Dr. Gourley questions the capability of small farmers to add to the food supply but certainly they deplete it in time of drought. He feels pressure to improve the productivity of the group but in turn would like to see his efforts affect the total food supply.

Balance of Domestic vs. Overseas Activities

MSU estimates a 50% domestic to 50% overseas annual budgeting with the FY/94 year's $70,000 also approximating that ratio and Colombia and Kenya are about equally divided.

Level of Collaboration between U.S. and Host Country Institutions and Personnel

Research planning for Colombia has, of necessity, had to take place in the U.S. because of travel restrictions. Both ICA and MSU-111 staff have participated at Starkville. In Kenya an annual meeting which includes ICRISAT and INTSORMIL plans research. Budgets in both countries depend heavily on in-kind support. Project funding has not allowed for assistantships but other sources, e.g., ICRISAT and IDRC continue to support students. Communication takes place through MSU International

Programs. Contact between Kenya and other locations appears to be at least weekly.

Publications and Presentations

Numerous papers and presentations have been given by MSU-104 and its collaborators. The Latin American conference was a much recognized event. In Dr. Gourley's absence Dr. Goggi has done an admirable job of giving papers and poster presentations at the ASA/CSSA annual meetings and the International Seed Technology meetings, e.g., in Buenos Aires.

General Strengths

This project has done considerable training of a hands-on nature with a modern philosophy of international agriculture—one that seeks joint cooperation between both the public and private sectors. The MSU-104 PI has willingly gone out of the country, e.g., Colombia and Kenya for extended periods of time to get the job done. Certainly the discovery of a screening technique and germplasm tolerant to low pH soils in Colombia along with their release has received much deserved recognition. Dr. Gourley has a deep sense of strengthening through teaching which he does very well. Now the project is developing a biotech approach to better understanding the plant/soil relationship. Also, this approach will be used as a more effective screening tool. Thus, Dr. Goggi is adding this component of expertise along with her seed technology and breeding input. Dr. Baldwin handles the field program but other responsibilities seem to limit him from the size project he would like. The location of Starkville should be considered a strength in that sorghum responses from the Delta tend to resemble Colombia, for example. The project deserves credit for bringing together soils and crops, an interaction that has been overlooked all too long.

General Weaknesses

Naturally the extended absences of the principal PI from the project have made training and overseas collaboration less effective and certainly more difficult. The lack of good soil/tissue test facilities is also a limitation for this type project although CIAT was able to provide the necessary support in Colombia. The input from Dr. Goggi on seed technology should be given further consideration as a necessary component of the CRSP. Certainly this aspect, if not handled properly, could result in lack of useful material moving from INTSORMIL to producers.

The EEP was somewhat surprised to learn that even with only two on-campus projects, there was no collaboration. Germplasm from MSU-104 should be of help to Dr. Pitre's entomology efforts with MSU-105. Cultural practices with the very limited field nursery should be upgraded to give sorghum a good image on the agronomy farm. No doubt as Dr. Baldwin becomes more familiar with the project the U.S. component will expand or perhaps Dr. Gourley will have returned to Starkville.

With interests expressed for food types, more effort should perhaps be given to including more millet in the project. Currently there is indication of 10% millet. The program could be strengthened considerably by a closer association with a TAM breeding project, e.g., TAM-121. This could be especially valuable to Dr. Baldwin but could help all involved become more familiar with world collection activities.

Recommendations

More nursery activity at MSU as project must supply collaboration, e.g., Colombia/Kenya as much as possible.

Additional support to Colombia in relation to their breeding effort.

Emphasize biotech/seed tech component as additional strength to project.

Increase activity within and between CRSP disciplines.

Continue as much training as buy-ins etc. can fund.

Encourage germplasm/variety/hybrid release by collaborators.

Breeding Sorghum for Increased Nutritional Value

Project PRF-103
Dr. John Axtell
Purdue University

Specific Research Performance

This project continues to keep the CRSP on the cutting edge of molecular genetics/biotechnology with the recent and significant accomplishment by Dr. Axtell, et al., to develop transgenic sorghum plants, an exciting first. The accomplishment itself, because of involving herbicide resistance, raises some real questions and in fact the entire experiment was isolated in the horticulture greenhouses. The significance lies in the methodology using microprojectile bombardment on miniature zygotic embryos. With the system applicable to future activity, possibilities of real significance exist which could solve heretofore challenges, e.g., *Striga* or the plant to strengthen its current levels, e.g., drought tolerance, insect resistance, and nutritional quality. Additionally, real success is evident in the field in the development of a transposon tagging system which will be useful for identifying and cloning specific and significant genes in sorghum. Also, Axtell, et al., have developed an RFLP genetic map to begin to screen recombinant inbred families for RFLP's which are associated with specific drought resistant/susceptibility traits.

Good sources of modified quality protein sorghums have been identified and are comparable to the quality protein maize as developed by CIMMYT. The high lysine gene, P-721 opaque, has been combined with sources of vitreous endosperm to give the QPS (quality protein sorghum). Also, 38 independently occurring mutants in the epicuticular wax genetic system have been identified and are being used to investigate the biochemistry and genetics of this wax. Also, the research hopes to characterize the contribution of the waxy "bloom" trait not only to drought resistance, but also resistance to fungal pathogens.

Research on cold tolerance with improved seedling vigor will have use in both temperate areas as well as higher elevations in eastern Africa. Materials from northern China continue to be excellent sources of this trait. Another significant research result would be the identification of an exotic plant introduction which has a reduced cross-kafirin fraction and shows very good digestibility results—results not commonly associated with cross-linked kafirin.

Dr. Axtell suggests that of recent accomplishments he still gives high ranking to the use of enhanced germplasm in Niger allowing for production of the hybrid, NAD-1. Promotion and success of this singlecross benefits INRAN, the people of Niger, and reflects well on INTSORMIL. He also lists the collaboration with McKnight, Pioneer, the Horticulture Department and many capable scientists on the leadership in the transformation of sorghum. His third most significant accomplishment relates to the transposon system located with the "candy stripe" variety.

This program has been cooperative to both the public and private sectors as regards to germplasm movement, e.g., ideal sources of Chinese cold tolerance. Significant releases from Purdue include Sepon 82, NAD-1, and the SRN-39 *Striga* resistant variety already released in Sudan. Materials are readily moved to Niger to support that sorghum effort.

Institutional Development and Training

Dr. Axtell, as country coordinator, has a major position in the success of INTSORMIL in Niger. His enthusiasm for the CRSP allowing both basic and applied research tends to rub off on all involved, especially the collaborators in LDC's. In Niger, where Ouendeba Botorou is host country coordinator, there is a positive relationship which is strengthened by the less than favorable relationship with the in-country ICRISAT program. Axtell is very pleased that Professor Andrews is developing an INTSORMIL millet program in Niger to further strengthen the program. The bilateral agreement with Purdue (non-INTSORMIL) has terminated.

Evidence of and Interdisciplinary Integration

The listing of collaborators does not seem relevant here as the numbers are great and collaboration really is a method of operation in the Purdue program and its success has moved to the McKnight foundation where their newest granting will be based on collaboration with third world scientists. Also, Axtell sees some real interest in the biotech people at Texas A&M getting more involved with Purdue scientists.

Balance of Domestic vs. Overseas Activities

Budgeting is somewhat over 50% for the U.S. but of the five countries getting an allocation, Niger approaches 30%. Others are Sudan, Zimbabwe, Kenya, and India. Fortunately, a primary sorghum breeder for Niger, Issoufou Kapran, is currently at Purdue finishing a Ph.D. so communication is very good and he frequently travels to and from Niger. Ouendeba, as country coordinator and on the EZC, also suggests that the situation should be good.

Level of Collaboration between U.S. and Host Country Institutions and Personnel

With Niger, Hamaker, Butler, Ejeta, and Axtell all have collaboration so even though schedules may get tight for the country coordinator one of the others will be somehow involved. Research planning is done jointly with Ouendeba having full input on budget and control of its allocation.

Publications and Presentations

Some 10 publications are listed for PRF-103. Numerous presentations are also made by the PI.

Strengths

This project is led by a PI who can get just as enthused with a good hybrid, e.g., NAD-1 as with being part of a team to first accomplish transgenic sorghum. His wide breadth of knowledge and interests makes for a strong program as has so often been recognized. Much recognition has come to Axtell and his co-worker, Ejeta, and deservedly so. His area of research tends to give a total capability to the CRSP and this includes other co-workers, e.g., Butler and Hamaker. Certainly student training must not be overlooked as that is a significant aspect of the whole Purdue involvement. A long list (49) of mostly practicing plant breeders has come through the Purdue sorghum program. Dr. Axtell would like to see even more students as this program offers so many opportunities. PRF-103 exemplified what collaborative research can achieve, if funded properly, and INTSORMIL plus outside grants, e.g., the McKnight money, have done this.

Weaknesses

Location in a non-sorghum area but this has some positives. Certainly the appearance of the 1993 nurseries did not indicate this to be limiting compared, for example, to Nebraska sorghum. Time competition is no doubt a real challenge considering the varied activities for which the PI also has responsibility. Hopefully time would allow periodic visits to other public and private programs.

Recommendations

With the unique activities and capabilities at Purdue perhaps some system of communication to better include other out-of-state but interested workers could be developed. Many former students could benefit from some sort of updating on research and training activities which might suggest a 1-3 day type session, for example, in the fall of 1994. Overseas collaborators, trained in the U.S., also ask for a similar opportunity. Dr. Axtell, with his many contacts, could also help to analyze the development of an effective in-country seed industry where there is no outside activity, e.g., from multinationals. Hopefully, USAID will recognize the shortcomings of the CRSP if products to improve the food supply are only carried as far as the experiment station. Both extension and seed multiplication are vital to changing to improved cultivars.

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

Project PRF-107 and PRF-107A
Dr. Gebisa Ejeta
Purdue University

Specific Research Performance

PRF-107 involves the development and enhancement of sorghum germplasm with tolerance to drought *Striga*, and grain mold whereas PRF-107B deals with RFLP mapping of genes for *Striga* resistance in sorghum and is relatively new to the CRSP. Constraints addressed by this research would be (1) drought, (2) *Striga*, and (3) grain mold with the program focus being: (1) germplasm development, (2) research, and (3) training.

Activities affecting germplasm development center around the exploitation and enhancement of existing variability; the induction of new variability; identification of gene sources; and the incorporation of these gene sources. Research activities stress the characterization of trials; the evaluation of the mode of inheritance; assessing the mechanism of trait expression; developing reliable assays; and developing appropriate breeding strategies. Training activities would be graduate education, working with host-country scientists, and organizing/participating in international workshops.

Even with the above overview the PI sees barriers to progress with seed increase and distribution in LDCs a specific example. His experience in African research gives Dr. Ejeta an ability to better understand the economic, social and political implications which must be overcome to see real increases in production of quality grain at the farm level.

Principal contributions from PRF-107 and 107B would be (1) technical assistance, (2) training, (3) germplasm development, (4) institutional collaboration, (5) interdisciplinary collaboration, and (6) workshops/conferences. To do the above, the PI made 2-3 trips/year to Africa to support his work in Sudan and Niger.

All three problems with which this project deals have traditionally been among the most difficult in the improvement of sorghum. All three are similar in that resistance/tolerance involves a number of partial resistance/tolerance mechanisms, which are probably additive in the expression of field resistance. There is generally insufficient knowledge of the expression, usefulness, and genetics of individual mechanisms to use these as direct selection criteria. Field resistance/tolerance as a selection criterion has been equally difficult because of the multiplicity of traits involved, the high degree of g x e in the expression of individual mechanisms and hence of field resistance/tolerance, and the large degree of escape conditioned by differences in phenology in the cases of drought and grain mold. Thus, the approach followed in PRF-107 in dealing with these problems, although long term, is very appropriate for the INTSORMIL mandate: the isolation of individual components to resistance/tolerance, the evaluation of their contribution to field performance, and the identification of molecular markers for them. This is a very costly approach, and probably not realistically possible without the extensive external funding available to PRF-107, but the knowledge produced by the research, if successful, should have very large multiplier effects.

Striga Resistance

The collaboration between Drs. Ejeta and Butler designed to understand the control points in the complicated process of *Striga* germination, infection, growth, and suppression of the host plant appears to be producing promising results. The stimulant signal has been known for a long time, but the hypothesis (an accompanying evidence) that there are additional chemical signals controlling both haustorial formation and parasite growth, and additional evidence that *Striga* affects host plant growth via toxin production will, when fully documented, be major advances.

The major advantage in the collaboration, however, lies in the use of this basic information on parasite-host biology to identify specific molecular markers for host genes controlling the expression of the individual components of host plant resistance. A set of RI lines from a cross of parents with and without the ability to produce the germination stimulant chemical has already been evaluated for stimulant production, and the genetic control of this trait determined, and the mapping work is underway. The same set of lines is under field evaluation to attempt to map field resistance as well, although this effort is likely to be less successful, unless the individual lines also carry a random assortment of genes for the other mechanisms involved in field resistance. It might be more useful to concentrate in using the marker(s) as they become available to put the individual tolerance mechanisms into a wider range of genetic material better adapted to the countries to which the project is targeted.

Drought tolerance

The approach used in this work is similar to that of the *Striga* resistance work: the evaluation of individual mechanisms of tolerance/resistance and the identification of molecular markers for improving the effectiveness of selection. In this case however, PRF-107 appears to lack the strong collaboration with specialist scientists at the mechanism level, which is the key to the *Striga* work. The drought literature is full of promising traits, most of which are untested as selection criteria, and many of which have not even been properly physiologically evaluated. Thus, a very careful choice of putative traits for evaluation/mapping is essential. As Purdue is not located in an area where field studies on drought mechanisms are possible, the PI should seek to develop linkages with U.S. scientists who have strong, but applied, programs in stress physiology.

Two traits presently under evaluation, the nonsenescence or "stay green" character, and glycinebetaine synthesis. The former is a logical choice, and is supported by considerable research/breeding work in other U.S. institutions/crops. The latter trait is much more speculative. It possesses the theoretical advantage of being a basic biochemical pathway, and, therefore, easy to analyze and map, but the linkages between such very basic biochemical processes and field resistance have been historically more difficult to prove than have the same linkages for so called "whole plant" traits, which represent possible evolutionary complexes of basic mechanisms and are more closely tied to a favorable plant response to stress. As PRF-107's strength is in the genetics/plant breeding area, and not in physiology, the project should concentrate on appropriate whole plant responses to stress which are as strongly linked to field performance as possible.

Institutional Development and Training

Training has involved five Ph.D. and two M.S. degrees from LDCs plus three visiting scientists. Germplasm developed following his success with Hageen Dura-1 include SRN-39 (first *Striga* release) and 10 pollinators known for drought tolerance and food quality. Also, many informal releases have come from his program and been invaluable to both the public and private sectors.

Evidence of Interdisciplinary Integration

Dr. Ejeta frequently collaborates not only with other institutions but also between disciplines at his home institution, Purdue. Examples would be:

ICRISAT, Hyderabad	Grain mold
Pioneer Hi-Bred	Grain mold
ISC, Niger	*Striga*
SAFGRAD	Short courses
SADC/ICRISAT	TAP
Univ. of Wisconsin	SIAAR
Rockefeller Foundation	ADIA
USAID Missions	Khartoum, Niamey
Bean/Cowpea CRSP	Training

At Purdue he has projects with Butler (*Striga*) in biochemistry, Nyquist in quantitative genetics, and Bennetzen and Goldsbrough in molecular biology.

The PI is to be highly commended for both the investment of considerable time and resources in his collaboration with the national programs of Niger and Sudan and the effectiveness of this collaboration. He correctly emphasizes not only the technical side of such collaboration, but also the important psychological side of helping national program scientists demonstrate to themselves and to their governments that a well planned and conducted agricultural research program can make a significant contribution to increasing agricultural production.

A visit to the INRAN breeding program in Maradi underlined both of these points. The program was extensive and technically well run, the plant breeder and his senior technician had clear objectives for the material in the nurseries and knew its strengths/weaknesses, the relationships with the PI appeared excellent, and there was clearly a positive, enthusiastic attitude toward the program on everyone's part.

Workshops and conferences he has organized include the Hybrid Sorghum Seed Workshop at Wad Medani in 1983, the Niger and Sudan Sorghum and Millet Workshops in 1985, 1989, the International Conference on Sorghum Quality in 1990, and the INTSORMIL CRSP Conference in 1991. Other research activity with which he collaborated would be bird tolerance, aluminum tolerance, cold tolerance, food-quality, quantitative genetics, and food grain female development.

Balance of Domestic vs. Overseas Activities

As one might expect, the project appears to be 2/3 international to 1/3 domestic. This seems appropriate when one looks at the potential but outside funding seems essential to accomplish all the domestic activities.

Level of Collaboration between U.S. and Host Country Institutions and Personnel

This topic has already been discussed in part, however, it should be pointed out that the PI with his travel schedule does have opportunity for effective research planning and discussion of budgets. The PI has a unique ability to stimulate scientists through his own expertise and enthusiasm which impacts on host country collaborators.

Publications and Presentations

Some 22 publications are listed in the 1991 and 1992 annual reports not including Year 14.

Strengths

Research progress has been possible with grain mold. Resistant sources have been accumulated; breeding and testing strategies developed; a relationship to phenols shown; studies with physical/chemical traits; and genetic, microbial, and molecular studies are underway.

Work with *Striga* can best be illustrated through Purdue publication, RB-991, which updates the status of this critical research estimated at 845,000 MT of loss per year in sub-Sahelian Africa alone. Ejeta, Butler, and Hess have experienced host-root produced signals to stimulate *Striga* germination and developed a method to screen host genotypes. They are also involved in the molecular characterization of the genes conferring *Striga* resistance. Now more emphasis will be placed on haustorial initiation signal production, host influence on attachment/penetration, host derived signals controlling *Striga* differentiation as well as antibiosis factor, and possible *Striga*-derived factors which seem to control host growth. Past research has emphasized sorghum but future efforts will also include other crops. In fact they have already found the maize inbred, B-37, to be a low stimulant producer. Their first *Striga* resistant release, SRN-39, seems to have multiple mechanisms of resistance.

Drought work, much of it done away from Lafayette, has allowed for the identification of drought tolerance genes; led to evaluating the role of an osmoregulatory compound; caused the study of the genetic control of glycinebetaine; has involved looking at elite or exotic germplasm; and the testing for stability of drought tolerant lines. (Also see page 5.)

The team approach at Purdue and successful grant activities, e.g., the McKnight renewal, all are positive strengths, although people still make the difference.

Weaknesses

Previous suggestions have been accepted but one would be remiss to not encourage as much support staff as possible to maintain the quantity and quality so well illustrated.

Recommendations

Few seem necessary except perhaps to encourage the PI to continue to seek solutions to commonly observed problems in sub-Sahelian Africa, e.g., need for adequate seed storage and private sector entrepreneurial approach to seed increase and distribution. Scientists active and well respected in the CRSP must continue to lobby for their perceptions of the best approach to improve the food supply.

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

Project TAM-121
Dr. F. R. Miller
Texas A&M University

Specific Research Peformance

TAM-121 is currently in its 15th year with primary emphasis on the enhancement of sorghum germplasm for stability, productivity, and utilization. This project has inherently been the leader in developing public germplasm of benefit to both the seed industry as well as other public researchers both domestic and abroad. Therefore, such improved genetic material finds its way into the programs of INTSORMIL collaborators either directly or indirectly. The success of the program relates to both the PI as well as to the mutual or joint/team effort by many Texas A&M scientists representing disciplines such as pathology, entomology, physiology (non-INTSORMIL), nutrition, and genetics and plant breeding. The very nature of the project suggests an incremental accomplishment which when assimilated by third world scientists should result in opportunity for measurable gains in crop production. Every ecogeographic opportunity in the INTSORMIL program is affected by TAM-121 through graduate training germplasm distribution, host country collaboration, and institutional development.

Some seven areas of program emphasis include the six INTSORMIL ecogeographic areas plus China, Kenya, Argentina, Mexico, Nigeria, Ghana, and Brazil. These activities center around graduate student training and germplasm transfer. In regard to the latter, the FAO undertaking would be well advised to note the north-south transfer of germplasm from TAM-121. As an example, the female of Sudan's Hageen Dura-1 hybrid comes from TAM-121, utilizing and introgressing Ethiopian material, whereas, the male is a yellow endosperm line no doubt of Korgi or Sudan origin selected by Karper of the TAM system at Lubbock.

Currently, four graduate students function in the project (two U.S. — two foreign) whereas nine were involved during the 1991-1992 period. These students are provided a unique opportunity in that few institutions continue to provide hands-on plant breeding experience of a Mendelian or conventional nature.

Principal accomplishments of this project are numerous with these of recent significance:

> The inbred (female) Tx622 is currently involved in Chinese hybrids affecting 10,000,000 ha.

> Up to 100,000 acres in Paraguay—mostly forage sorghums—rely on hybrids from this program, e.g., Chaco-1 and Freddy with feed supply no longer a limitation. The grain hybrid, ms629xTx434, will be significant for poultry. In summary, this large Mennonite area is now a major exporter to the rest of Paraguay for milk and poultry.

> Hageen Dura-1 in Sudan—the first successfully produced Sahelian hybrid grain sorghum—depends on a female from TAM-121 and will likely be upgraded with new parental materials from the same project.

> Cristiani, a Guatemalan seed producer will be providing an anthracnose resistant hybrid for Honduras by using R8503 onto Tx626.

> Mexican programs at the Guadalajara and Nuevo Leon locations use TAM-121 material to find specific adaptation.

> African projects have benefitted from Tx623 and have found Tx631 to be particularly useful in Mali/Niger for foliar resistance. This same female has recently received strong praise for its drought resistance in Brazil.

> A collaborative release policy with Argentina has made Arg-1 available for food sorghums as it possesses tan plant and waxy endosperm. Tx635, also newly released will be of value for its unique resistance to head smut. Tx436 will likely also have significant implications because of its food properties and combining ability.

Germplasm moves often and in quantity from this project. In the 1991-92 time frame, some 72 and 92 requests for seed were received from international and domestic sources, respectively, which resulted in the sending of 1599 accessions overseas and 969 to domestic programs. The international shipments went to 24 countries. To reciprocate, the PI makes an effort to always bring back seed to the U.S. during his travels.

This PI coordinates the (1) International Food Sorghum Adaptation Trial, (2) International Adaptation Test, and (3) the International Sorghum Virus Nursery. Dr. Miller estimates only a 50% return on materials/tests/experiments sent to collaborators, a common problem experienced with PI's. From a measurable impact standpoint, he believes the Paraguay program to be a good candidate.

Institutional Development and Training

Dr. Miller is an outstanding teacher. He attempts to take his students to two commercial seed companies each year to allow them to understand the complete seed industry picture. He expresses a real concern for less students going into plant breeding each year and has a real basis for this having had some 55 students. Where will we go for breeders in the future? "Perhaps as with the medical profession, foreign students trained here will need to replace a lack of domestic breeders in this country."

Evidence of Interdisciplinary Integration

TAM-121 supplies germplasm and consults with essentially all the U.S. PIs. Materials from this program, for example, are much more likely to adapt to subtropical and tropical environments than will those coming from more temperate programs, e.g., in Nebraska as was clearly pointed out to the EEP in the regional performance trial.

Balance of Domestic vs. Overseas Activities

The PI, Dr. Miller, estimates about 50% of his activity relates to overseas. His $80,000 budget shows $25,000 going to six countries and $16,000+ to overhead. Some 55% of his funding is for germplasm enhancement with crop utilization getting another 25%. A buyin from the Rockefeller Foundation of $18,724 occurred in 1992.

Level of Collaboration between U.S. and Host Country Institutions and Personnel

His primary collaboration appears to be with Paraguay where planning and project reviews occur regularly. The PI has been a part of some 500+ publications and presentations with worldwide respect for his knowledge of the genetics of sorghum and plant breeding. In that regard, this program has provided many valuable descriptors such as with the sorghum conversion program—a project closely related to TAM-121 input and which has received much acclaim in both the public and private scientific community. TAM-121, by taking advantage of "biological accidents", is the acknowledged leader in germplasm enhancement and introgression with both U.S. producers as well as third world countries the benefactors. Improvement now seems possible for yield in the third world with trained scientists and appropriate germplasm having the scientific collaboration of INTSORMIL PIs to serve as a catalyst. Continued support, however, will be essential from both sides to make the system work.

Obviously, this PI is spread extremely thin but now with fewer graduate students can hopefully be more involved with overseas collaborators in addition to Paraguay. This strengthening of the program will require increased budget for travel expenses.

The EEP notes his efforts to incorporate physiology by using non-INTSORMIL assistance. They also recognize his followup to past suggestions concerning how to use the world collection with a very significant thesis study underway on combining ability and heterotic patterns between the various taxonomic classes. Future use of this program, besides the overseas increase in linkages, will allow more progress from the other disciplines and thus greater efficiency of CRSP funds. As in past reviews, the EEP remains highly supportive of the past contributions of TAM-121 and sees even greater opportunities ahead.

Germplasm Enhancement for Resistance to Pathogens and Drought and Increased Genetic Diversity

Project TAM-122
Darrell Rosenow and L. E. Clark
Texas A&M University

Specific Research Performance

TAM-122 represents a primary strength of the CRSP with a productive U.S. program, graduate training, country coordinator responsibilities in Mali, and collaboration in three ecogeographic zones of the CRSP. Major research objectives would be:

U.S., Honduras, Mali

To develop agronomically improved cultivars and breeding lines with genetically enhanced resistance to important diseases with emphasis on downy mildew, charcoal rot, grain mold/weathering, anthracnose, head smut, head blight, and foliage diseases. Develop new breeding germplasm containing resistance to head bug and *Striga* for distribution and use in Mali and Niger.

U.S., Sudan, and Mali

To develop agronomically desirable, high yielding breeding lines and cultivars with high levels, or with a superior combination of pre- and post-flowering drought tolerance for use in enhanced sustainable production systems.

U.S., Mali, Sudan, and Honduras

Enhance germplasm base with new genetic diversity and new sources of disease and drought resistance and other desirable traits through collection, introduction if appropriate, evaluation, and distribution of new and basic germplasm lines.

In addition to the above, selected germplasm will be developed and distributed for use and evaluation in Niger (head bugs and drought), Kenya (sugarcane aphid and drought), Botswana (drought and charcoal rot), Colombia (drought) and Zimbabwe (anthracnose and head blight).

During this time frame, some 110 additional converted lines have been released with 250 partially converted bulks soon to be available. Also, selected new exotics have been entered into the conversion program annually. Numerous papers, presentations, and articles continue to be given by the PI worldwide. Specific accomplishments of impact would be:

> A_1 hybrids in Sudan replacing Tx623 to increase yield 5% and improve standability.

> New cultivars in Mali, e.g., Malisor 84-7 with head bug tolerance could increase production by 10%.

> New stay-green female in U.S. could increase yield by 5%.

> Strengthening Malian National Sorghum Program.

> New germplasm releases to provide elite sources for private companies affecting the U.S. and Latin America.

Research results include 10 food types released jointly by Dr. Ejeta and Rosenow with drought tolerance a primary component. Many new crosses were generated for use in both the U.S. and host countries. Inbred stay-green lines were developed for use in RFLP and RAPD genome analysis of the stay-green and other drought traits. Dr. Rosenow was active in getting the Sudan collection of over 3100 items grown-out and classified in 1991. Through much effort, it has been introduced for backup storage at NSSL but is currently growing in quarantine in St. Croix. Sureño, the food sorghum released in Honduras, is now being grown by a large number of small farmers in southern Honduras, perhaps on 15% of the area. It has been quickly accepted because the grain makes excellent tortillas, and its stover makes good livestock feed.

Institutional Development and Training

One only has to look at the travel schedule of Dr. Rosenow to appreciate his impact as a respected sorghum scientist. For example, in

Year 13 he had five overseas trips plus five INTSORMIL related domestic trips. These generally involved presentations and direct contact with collaborating scientists from host countries. As evidence of his relationship to Mali, where he is country coordinator, Dr. Rosenow and Acar Toure put together an excellent week of activities for the EEP in October of 1993. The program is illustrated by the handout provided all attending—see Mali report. Before Mali, Rosenow successfully coordinated the Honduras program.

Evidence of Interdisciplinary Integration

Dr. Rosenow, in his 1992 annual report, lists some 22 scientists as collaborators. Of these, only three are at or with Texas A&M. Some 13 are in overseas locations and the remaining six are at other U.S. institutions. When working in various LDCs the PI exhibits such enthusiasm and interest that there is likely a spin-off of enthusiasm to his collaborators.

Balance of Domestic vs. Overseas Activities

As might be expected, less than 50% of his budget goes for U.S. activity. Interestingly, the remainder is allocated between Honduras, Mali, Sudan, Niger, SADC region, and Colombia-Senegal, with Mali the principal recipient followed by Sudan and Honduras. The majority of the Year 15 budget is allocated to germplasm enhancement and conservation.

Level of Collaboration between U.S. and Host Country Institutions and Personnel

Dr. Rosenow takes a serious interest in research and budget planning in those countries where he has activity. He realizes the role of INTSORMIL should be to help NARS to develop new techniques and materials to increase production significantly and with more stability at the farmers' level.

Publications and Presentations

The Year 13 annual report lists 23 publications and three presentations. Certainly, he remains a much sought-after speaker or writer in reference to drought and germplasm issues.

General Strengths

This is a long term and well established program which has worldwide respect for its research on drought, a primary constraint, and its efforts at germplasm enhancement through the conversion program. Not to be overlooked would be the successful collaboration with TAM-124 in the search for new sources of disease resistance. Collaboration with host countries and successful country collaborator positions in Honduras and Mali deserve recognition. Overseas, he relates well with host country scientists who welcome his input. Besides international activity, the PI conducts a large program in both South Texas (9456 plots) plus at his home base at Lubbock. Dr. Rosenow deserves considerable credit for the successes of this CRSP.

Weaknesses

Whereas location is limiting in respect to graduate student training, the environmental factors allow for a fairly consistent level of stress. Foliar disease work, however, is nearly impossible in West Texas. While drought x genotype interaction takes a majority of his research input, this study is at a stage needing additional input such as from physiologists for a better explanation of stay-green and pre-bloom and post-bloom stress, i.e., GS-2 vs. GS-3. Certainly, the new relationship with the TAM biotechnology group is encouraging with prospects for not only better understanding the genetic components but hopefully being able to move or increase their level through transformation.

Recommendations

We see the program at a stage where some serious planning is in order. Should the conversion program continue in its current fashion? Can physiology collaborate either within the TAM system or between INTSORMIL institutions? With heavy travel demands should more trained technician support be added to maintain the program size and quality? We encourage the PI to continue his strong leadership capabilities in this CRSP.

Germplasm Enhancement through Genetic Manipulation for Increasing Resistance to Insects and Improving Efficient Nutrient Use in Genotypes Adapted to Sustainable Production Systems

Project TAM-123
G. C. Peterson and A. B. Onken
Texas A&M University

Specific Research Performance

This project, with breeding and a soil scientist, is somewhat unconventional in relation to the others but the components are very essential to a strong CRSP on sorghum and millet. Perhaps a look at current objectives may help to clarify TAM-123.

Mali and U.S.

Refine methodology of determining efficient nutrient use or tolerance to soil toxicity problems. Find genetic sources of above and utilize to develop agronomically superior germplasm. Determine effects of efficient nutrient use on efficient water use in sorghum.

Honduras and U.S.

Evaluate sorghum germplasm for resistance to selected LDC sorghum pests.

U.S.

Obtain and evaluate exotic sorghum germplasm for resistance to selected LDC sorghum pests. Determine resistance traits and their inheritance. Develop and release high yielding ecologically fit germplasm resistant to selected insects and additional stress factors and responsive to LDC and U.S. production systems.

A separate attachment provided by Dr. Onken further defines objectives from a soils perspective and discusses original concepts vs. results to date. Research relates to Global Plan constraints on biotic stress and germplasm and genetic diversity. Peterson has these activities underway or completed.

> Identified five lines of 127 conversions for midge resistance.

> Identified four potentially useful restorer breeding lines. Lines developed to study resistance to midge using RFLP's.

> Progress with both biotype E and I of greenbug by introgression. Also selections made to study resistance to E and I using RFLP's.

> Sugarcane aphid research with Dr. Manthe mostly completed. Chinese scientist visiting to learn methodology of breeding/screening for resistance to insects. Resistance transferred to F_4 is in short, early genotype.

Onken is involved with research being conducted in Mali in cooperation with TropSoils to address soil toxicity, low nutrient status, and low available water. Additionally, nutrient x genotype studies continue at Lubbock.

The program in Mali is small due to funding limitations and the lack of laboratory support at Cinzana. Peterson is mostly satisfied regarding status of U.S. research as increased funding three years ago made a significant improvement in his research capability. He provided midge resistant materials recently to both Mali and Niger. Dr. Peterson's latest germplasm releases were in 1989 and he expects both midge and E greenbug materials to be released next. He cooperated on the release of 110 converted exotic sorghums. He also participated in the identification and description of the Sudan sorghum collection. Besides official releases, he has distributed germplasm to Honduras, Colombia, Mali, Niger, Uruguay, India, Senegal, South Africa, Botswana, Puerto Rico, China, Japan, Mexico, Australia, England, Spain, Venezuela, Taiwan, Nigeria, Peru and Korea.

Peterson cites as his three most significant accomplishments:

> Identification of A-lines (females) resistant to sorghum midge and with excellent yield potential.

> Development of commercially useful R-lines to biotype E greenbug.

> Identification/utilization of additional germplasm lines with resistance to insects.

Dr. Onken cites several research results:

> Test method of paired plots coupled with covariance analysis is being used in soil toxicity study.

> Concepts of nutrient and WUE relative to genotype x nutrient level x water level interactions being incorporated in breeding programs.

> IER soils and crop breeding scientists working together.

> Must screen breeding materials on soils where they will be used.

> Even small increases in yield due to soil fertility result in corresponding increases in WUE.

> Soil fertility affects transpirational WUE.

For the project in general, regarding soils, he summarizes the three primary contributions to date as:

> IER soil and crop scientists conducting interdisciplinary research.

> Determining soil effects on WUE and establishing genotype interactive effects which resulted in redefining of concepts important to crop breeding.

> Showing necessity for characterizing soil along with other environmental factors and doing breeding under crop conditions for which the crop is expected to perform.

Dr. Onken has furnished IER collaborators with a computer, software, and printer. He has obtained an agreement with the Director General of IER to allow a soil and plant analytical lab to be established at Cinzana when funds become available.

Institutional Development and Training

Dr. Peterson has served on 10 graduate committees over the life of the project with seven students at Texas A&M and three at Texas Tech. All were from LDCs. He is also the country coordinator for Honduras where he works closely with Dr. Francisco Gomez in planning the many interactive disciplines there.

Dr. Onken expects to have two Malian Ph.D. students back in-country soon, both having received support from INTSORMIL and TropSoils. Whereas agreement for an analytical lab at Cinzana has been accomplished and a prioritized list of equipment is being compiled, funding has not been identified. He also plans annual travel to Mali to review the project and develop new work plans and budget.

Evidence of Interdisciplinary Integration

Dr. Onken has the collaborative project in Mali with TropSoils. His program is closely tied to sorghum breeding. Bill Payne, plant physiologist at the ICRISAT center in Niger, conducted his research at Lubbock with support from both INTSORMIL and TropSoils. Onken indicates the urban population increases occurring ahead of food production are detrimental to food production because of political policies to maintain cheap food in cities.

For Peterson his collaboration of most significance would be with Dr. Teetes of TAM-125 plus those PIs working in Honduras where he serves as country coordinator. He is active with TAM-121, TAM-122, TAM-124, TAM-125 and collaborates to a lesser extent with TAM-126 and TAM-128 but has joint nurseries with all projects listed. He also has collaboration with ICRISAT and TropSoils.

Balance of Domestic vs. Overseas Activities

The funds are used pretty equally between domestic and overseas. Mali gets the majority of the overseas money. Research, however, is slanted toward overseas activity, e.g., midge, sugarcane aphid, and water/nutrient problems.

Level of Collaborationbetween U.S. and Host Country Institutions and personnel

The project proposal for Inter-CRSP research in Mali is written jointly by three PIs. The preparation of work plans and budgets are a joint effort of the PIs. There appears to be an obvious need for people trained in soils with appreciation for need to collaborate, in part, with scientists in other disciplines. All presentations in national or international meetings and publications are approved by each scientist involved. Communication appears to take place primarily on an as-needed basis.

Publications and Presentations

The 1991 and 1992 annual report lists eight papers and five presentations for 1990 to 1992.

General Strengths

TAM-123 affects two critical constraints of third world agriculture: soil and insects. Midge are a worldwide limitation to productivity in sub-tropical and tropical environments. A coordinated effort with TropSoils in Mali is essential considering this constraint to production. The possibility of a soils lab at Cinzana, when funds surface, would be a major accomplishment. Efforts to control the yellow sugarcane aphid in the U.S. would be a significant impact economically.

Weaknesses

Limited progress has been possible in Mali after some 14 years of soil toxicity research. U.S. research in 1993 was adversely affected by drift of a genotype x desiccant interaction. Midge results were not achieved in Niger due to lack of or low frequency of the insect. The PI, as suggested previously, can only increase odds of success by number of locations. The location of Peterson at Lubbock and chief collaborator at College Station undoubtedly results in some inefficiencies and reduced communication. Also, efforts on biotype I greenbug was somewhat delayed and may not be substantial.

Recommendations

Significance of soil/crop breeders working together, plus TropSoils involvement, suggests soils PI spend considerably more time on site in Mali, such as a 6-12 month sabbatical leave. Also, U.S. nutrient studies need to be enlarged and more applicable to current cultivars especially hybrids. With a PI change in Honduras, Peterson needs to give extra input to that ecogeographic zone. Also, an alternate midge location needs to be found due to the bird problems at the Lubbock experiment station. Alternate sites at little or no cost might be possible in commercial fields in the Panhandle or additional sites in South or Central Texas. Industry could provide support in-season or off-season. A greater effort on yellow sugarcane aphid compared to biotype I greenbug will likely be more helpful to the U.S. sorghum industry. Midge losses worldwide should be examined closely to determine where TAM-123 can make the greatest impact, even if not a primary site. Peterson is to be commended for his efforts at developing useful software. When possible this information should be circulated within this CRSP.

TAM-123
(Research of Dr. A. B. Onken only)

Research Progress

General Approach

The stated objectives of the project are develop/refine methodology to determine genetic differences in nutrient use efficiency and to use these methodologies in the breeding of more water and nutrient use efficient germplasm. This in theory, like many INTSORMIL projects, lends itself well to a combination of basic research on principles and methods in the U.S. and the application of these in applied research programs in developing areas where the problems are most severe. As noted below, however, the project has concentrated almost entirely on water and nitrogen relationships in Lubbock, and has not initiated work on either the genetic component or in the target developing areas.

Specific Research Activities

<u>Basic Research on Water and Nitrogen Use Efficiency</u>

Several detailed experiments were conducted (beginning during the last review period) in mini-lysimeters and under field conditions to evaluate the effects of varying nitrogen and water supply on water and nitrogen use efficiency and on the relationships be-tween the two. It is somewhat difficult to assess this work as the external review panel did not have access to full reports of methodology and results. The following observations are based on the presentation made by the PI.

> The work has provided additional support/data for existing concepts of effects of a varying supply of N and water on crop transpiration and soil evaporation, on crop yield, and on the relationship among N, grain yield and water use efficiency.

> A model developed for the assessment of grain nitrogen use efficiency (NUE), differs from conventional NUE models in that it confounds carbon use efficiency (harvest index) with biological nitrogen use efficiency (biomass/unit crop N). These two components have very different implications for plant breeding, and should be separated.

> The research done at Lubbock is useful for establishing principles, future work in this area, should probably be shifted to Mali if this is at all feasible, as (1) genotype differences in NUE are primarily important at low soil N levels, far below those available for research at Lubbock, and (2) if the work is to provide a basis for designing management or breeding approaches for developing areas, it needs to be demonstrated, under appropriate conditions and with appropriate genotypes, that it will provide a more useful approach than what is being presently used. This appears to be provided for in the new collaborative INTSORMIL\TropSoils project, in which case, work at Lubbock should probably be limited to support of this effort in Mali.

Identification and Use of Sources of Greater N and Water Use Efficiency in Breeding

Apart from one report of a comparison of genotype differences in grain yield at two fertility levels, there is no evidence that the project has attempted to identify sources of nitrogen or water use efficiency and/or use them in even an exploratory breeding program.

Collaborative Research with TropSoils on Soil Toxicity Problems in Mali

This work is being done entirely in Mali and is attempting to determine reasons for poor performance of sorghum on areas of acid sandy soils, and to search for genetic variability for tolerance of whatever the specific problem(s) is. Present work is in the initial stages.

Publications and Presentations

The reporting of results from the nutrient efficiency work has been poor during the period under review. Research done in the U.S. is poorly documented in the INTSORMIL Annual Reports, and the PI has published no papers on the work in refereed journals during the review period. A number of presentations were made to the annual meetings of the American Society of Agronomy, but these are available only as one paragraph abstracts.

Impact of Research

A contribution to the basic understanding of the relative limitations of nitrogen and water in semiarid sorghum environments, and the effects of each on the efficiency of use of the other. The project does not appear to have designed/evaluated improved management/ breeding methodologies which could make an impact on sorghum production.

Institutional and Organizational Aspects

Institutional Development

The PI spoke of having attempted to establish a soils laboratory at Cinzana, but this has yet to be done.

Collaboration with National Programs

The PI is working with the Malian National Program in a new collaborative project with TropSoils on problems of acid toxic soils. This is a relatively new effort (since 1992 ?), which is attempting to diagnose the problem(s) associated with poor sorghum growth on these soils and identify genetic differences in adaptation to these soils. Previous research in TAM-123 appears to have been largely conducted in Texas.

Evidence of Interdisciplinary Integration

The project has an inbuilt collaboration of geneticist/plant breeder and soil scientist, but to date little joint work seems to have been carried out. TAM-123 also seems to have little collaboration with INTSORMIL agronomy/physiology projects at Nebraska, one of which has similar objectives.

Overall Rating

It is difficult to appreciate the progress made in this project or its likely future contribution, because of the lack of any published synthesis of results of the work or any indication that the PI is or will move from the methodology stage to tackling its stated objectives of "developing agronomically superior germplasm with increased efficiency in nutrient and water utilization capability ...." The PI has a unique chance to address this objective in that he shares the responsibility for TAM-123 with a plant breeder, but does not appear to have taken advantage of it as yet. The probability that the project will make a future contribution in its stated objectives does not seem high, based on the apparent limited progress to date.

Breeding Sorghums for Stability of Performance using Tropical Germplasm

Project UNL-115
David Andrews
University of Nebraska

Specific Research Performance

UNL-115 is currently in its 15th year with these objectives:

Basic research

For low-resource agriculture

> generation of sources of high parental worth

> use elite material to generate custom segregating populations

> methodology to determine combining ability

> examine potential for using seedling vigor

For U.S. agriculture

> variability for lodging resistance

> combining ability for yield

> improved feed value

> bio-I greenbug resistance

Applied Research

> For low-resource agriculture

- populations involving UNL-115 by other germplasm as appropriate to specific NARS objectives for Senegal/Botswana
- consult on breeding strategy/procedures
- research efficient selection for combining ability

For U.S. Agriculture

> breed adapted, lodging resistant inbreds of high combining ability and high parental worth: principally with cream/white hard endosperm "food type" grain. Collaborate on feeding trials. Identify chinch bug and greenbug I resistance in adapted backgrounds.

Activity in Developing Countries

> Senegal

- germplasm exchange
- segregating material and testing

- evaluating UNL and Texas hybrids and parents

> Botswana

- germplasm exchange
- segregating material and testing
- seed parent selection
- off-season nursery in Zimbabwe

> Other countries

- Germplasm exchange with Mexico, Sudan, Niger, Nigeria, Egypt, Soviet Union, Dominican Republic, South Africa, ICRISAT.

> Projects in U.S.

- Inbred line development/evaluation
- Genetic studies
- Pest and disease resistance
- Nutritional value

> Germplasm Releases

- Three seed parents
- Thirty-six germplasms
- Two sources of chinch bug resistance

Of the above releases N-122 performs exceptionally well with Tx430 and is currently in commercial production.

Professor Andrews has worked closely with Dr. Mazhani and Setimele in Botswana; Gilles Trouche in Senegal; and Tunde Obilana in Zimbabwe. U.S. collaboration has primarily been with Nordquist, Baltensperger, Pedersen, and Maranville of the University of Nebraska and Bramel-Cox of Kansas State University. Topics in the U.S. involved seed parents, early maturity, feed quality, N-use efficiency, and greenbug I selection.

The PI indicates need for more in-country visits per year and also the introduction of more equipment. His collaborator, Mazhani, was promoted out of breeding, and the lack of a winter nursery early on slowed down developmental work. In Senegal, fiscal matters and a lack of cooperation between the breeder and pathologist were detrimental. Even so, the project showed that excellent yield levels were in fact possible. This suggests a possible economic impact study. Botswana now has an excellent nursery of drought tolerant material.

The three largest contributions to date would be yield of food sorghum in Senegal; drought tolerant seed parents, plus winter nursery for Botswana; and the release and use by U.S. companies of seed parents, e.g., N-122. His contributions of significance also include the screening and release of insect resistant germplasm, i.e., chinch bug and most recently bio-I material jointly with Bramel-Cox. He serves on the Sorghum Crop Advisory Committee to NPGS and also was on the SADC Advisory Committee until 1992.

Institutional Development and Training

This project has in recent years trained four sorghum breeders and two are currently studying with Andrews. Also, some four visiting scientists have benefitted from the program. Andrews encourages his students to maintain ASA membership; encourages phones to be available; suggest a Newsletter to keep collaborators current and enthused. He also encourages return visits by former students.

Evidence of Interdisciplinary Integration

Collaborators have been listed previously but special mention should be made of his close work with Maranville, UNL-124; Pedersen, and Bramel-Cox. Andrews points out need for a market system and an infrastructure system for improving food production for urban use. His years of international experience obviously help him to see opportunities and limitations.

Balance of Domestic vs. Overseas Activities

The budget allocations suggest 35-40% domestic which points out the rather heavy overseas component of the program.

Level of Collaboration between U.S. and Host Country Institutions and Personnel

Annual research planning takes place with these programs. Also, a regular dialogue takes place.

Publications and Presentations

Since 1990 there have been six sorghum publications from this project. The project, besides Oregon State funds for Senegal work, is currently being funded by the Nebraska Grain Sorghum Board in his developmental work on male and female parents.

General Strengths

This project benefits from the experience and breeding knowledge of Professor Andrews. Training and in-country collaboration are excellent. The movement of germplasm and knowledge of adaptation have allowed the program to be effective even when the Nebraska environment fails to relate to the African countries involved. Creativity is obvious as is the willingness of Andrews to share materials. A productive off-season program has been developed in Mexico for the U.S. and Zimbabwe for Botswana.

General Weaknesses

Location of program in the north, without the ability to screen for drought and disease as readily as needed, plus time and fiscal constraints on the PI must be considered. With Senegal outside the normal INTSORMIL activity, the PI has been associated with Botswana, a country which has need for INTSORMIL activity, but for several reasons is currently being phased out or seeing reduced activity.

Recommendations

The EEP appreciates the concern by the TC for the heavy breeding component on sorghum with the increasingly tight funding. With six breeding projects, this half time program must be questioned not for its accomplishment but rather to prioritize funds to best use. Should sorghum breeding continue to be funded at UNL by INTSORMIL, the EEP would urge a closer on campus team approach using the climatic challenges of the area to better direct research activity. Life cycle requirements suggest a greater input on cold germination and seedling vigor, the relationship with GDD (growing degree days) and earlier maturity germplasm, and certainly the effect of cool temperatures on GS-3 and the genetic variability for this trait. Perhaps more use could also be made of other locations for screening materials. Hopefully, a greater effort on livestock utilization might be possible in a state like Nebraska. Finally, the EEP encourages visits by the PI and students to other programs, both public and private.

Breeding Pearl Millet for Stability of Performance Using Tropical Germplasm

Project UNL-118
David Andrews
University of Nebraska

Specific Research Performance

UNL-118 has completed eight years through Year 14 of the CRSP with funding of $100,000. Research objectives and projects are well defined by the PI:

Basic Research

> For Low-resource Agriculture

- methodology to develop variety synthetics
- study effect of female selfs on protogyny hybrids
- use of A_4 cms cytoplasm: merit and development of restorer germplasm stocks
- ergot related to A_1 and A_4 hybrids
- radiation mutants on finger millet
- develop segregating populations

> For U.S. agriculture

- lodging resistance
- stability of A_1 and A_4 for sterility and restoration
- genetic resistance to chinch bugs

Applied Research

> Low-resource agriculture

- collaborate in acquisition, manipulation and utilization of UNL-118 and other germplasm as appropriate to specific NARS research objectives.
- provide planning assistance with breeding strategies/procedures

> U.S. Agriculture

- develop dwarf, early, lodging, resistant germplasm
- develop segregating populations for developing countries
- Use parental stocks for population and hybrid development, both on A_1 and A_4 systems.
- elect for herbicide tolerance
- coordinate pearl millet regional grain trials

Research Projects

Developing countries

Senegal

> generation of variability and *in situ* selection

> testing UNL + KS varieties

> proto-hybrid use

> A_4 development

> germplasm exchange

Niger

> generation of variability for *in situ* selection

> proto-hybrid use

Mali

> generation of variability for *in situ* selection

> germplasm exchange

Sudan

> program planning

> germplasm exchange

Botswana

> variety development

> proto-hybrid use

ICRISAT

> A_1 and A_4 stability

> downy mildew screening and resistance transfer

> germplasm exchange

Other countries

> Germplasm exchange: Colombia, China, Kenya, Korea, Malawi, Mexico, Yemen, ICRISAT/SADC, Zambia, Zimbabwe

U.S.

> Population improvement

> Inbred line development and evaluation

- A_1 parents
- A_4 parents
- proto-hybrid research

> Genetic studies

> Regional grain nursery

> Releases: NPM1, NPM2 (A_1 dwarf restorer populations) 1993, NPM-3 (A_4 dwarf restorer population)

Collaborators exist in Botswana, Colombia, India, Niger, Senegal, Sudan, and the U.S. Both Burton and Hanna at Tifton are mentioned. Currently Andrews is developing a project with Dr. Ouendeba of INRAN in Niger. The Sudan situation is now questionable for future work and all pearl millet germplasm may be lost. The PI lists the largest contributions to date as (1) improved yield levels of dwarf pearl millet in Senegal, (2) the possibility of producing hybrids with protogyny—using a topcross with variety as male, and (3) the A_4 cytoplasmic system.

Institutional Development and Training

Three M.S. students and two Ph.D. students have been trained by Professor Andrews. He served on three other advisory committees and has worked/hosted three visiting scientists. Several comments on sorghum UNL-115 relate also to pearl millet.

Evidence of Interdisciplinary Integration

The wide range of collaborators representing many disciplines suggests somewhat of a team effort.

Balance of Domestic vs. Overseas Activities

The budget for Year 15 suggests 54% domestic or roughly 50-50 domestic to overseas.

Level of Collaboration between U.S. and Host Country Institutions and Personnel

Annual planning sessions and on-site visits take place. Joint decisions are encouraged regarding research plans and necessary training. The KSU-101 project has many of the same objectives and geography permits a rather easy exchange of visits.

Publications and Presentations

Some 16 papers have been developed during this period. Two of particular note relate to the use of protogyny to make hybrids and pearl millet as a new feed grain crop for the U.S.

General Strengths

The PI is well versed in the subject and exhibits considerable enthusiasm. The Nebraska location offers real opportunity for a drought tolerant crop in the western part of the state and south while the range of collaborators allows for sharing/exchanging of germplasm. INTSORMIL needs this program, especially overseas. As with sorghum, the performance of millet hybrids in Senegal is very impressive, e.g., in the 5-6 ton range. The proto-hybrid research as well as the A_4 cyto system breaks new ground, opening up real possibilities for improvement. Certainly the three released populations are a real reflection of progress. Coordination of regional millet trials in the U.S. is essential to the development of this commodity. Overseas, improved varieties and higher yields are much in demand. Pro-hybrids will raise yields, reduce ergot problems, and allow for quicker development.

General Weaknesses

The project again is in a very temperate environment to relate effectively to much of the millet area worldwide. The attempt, however, to establish a working relationship with Ouendeba in Niger is significant to the future impact of this project. A breeding effort alone cannot develop a new crop and its market. Probably there is more chance for success if a demand exists before the crop is available; therefore, much economic and extension input is essential. Nebraska germplasm may not be suited for the southern U.S. because of maturity and disease susceptibility.

Recommendations

The EEP very much appreciates the opportunities for this program and commends the PI for a wide collaborator base. Every effort, however, must be made to make UNL-118 affect areas which are extremely dependent on millet. The PI, with his many contacts with NARS and ICRISAT scientists, will be in a position to make both short and long term gains with millet. Whereas the KSU-101 project is perhaps a little better situated for U.S. impact west, this program and its PI can likely make a greater impact worldwide and must do so. Since funds haven't allowed for Wayne Hanna's inclusion in the CRSP, regular visits to Tifton seem in order. Also, this project, time permitting, must focus on such limitations in less developed programs as seed storage and seed multiplication and distribution. No doubt, when hybrid grain millet becomes a commercial reality in the west, many of the same principles can apply to hybrid increase and distribution in Africa.

Crop Utilization

and

Marketing

Chemical and Physical Aspects of Food and Nutritional Quality of Sorghum

Project PRF-103B and PRF-112
Allen W. Kirleis and Bruce R. Hamaker
Purdue University

The Purdue Program

As stated in the report of the EEP visit to Purdue in 1992, the objectives of PRF-103B, 104B and the new project PRF-112 are so interrelated and interdependent it is easier to address them collectively than as discrete entities. In all instances, the research reported is entirely consistent with the stated objectives. The techniques used are modern, the Purdue scientists are clearly *au courant* with state-of-the-art methodologies; the quality and quantity of the results reported are more than satisfactory; interdisciplinary coordination and integration is evident in the planning, implementation and internal evaluation.

All of the reported activities are relevant to the objectives of identifying, developing and evaluating sorghum lines of superior nutritional quality and adaptable functional properties; with stable yield potential, tolerance to drought and *Striga*. If, as was indicated, one senior and exceptionally productive staff member is firm in his decision to seek early retirement, it is immediately necessary for the Purdue faculty to decide whether or not all present activities should be continued into the long term, or whether some modifications to the program should be planned. These considerations will bear upon the qualifications and scientific interests to be sought in any future appointments.

Purdue's concerns for nutritional quality are important bearing in mind that acceptance of triticale as a food crop was hindered and adversely influenced by unfavorable, albeit inaccurate, reports of its nutritional quality. Similarly, the commercial acceptance of rape/canola was not realized until breeders and biochemists developed genotypes relatively free from erucic acid and glucosinalates. The research on the components that depress digestibility is of special importance to the utilization of sorghum as an industrial food grain.

Dr. Hamaker is clearly a valuable addition to the Purdue team. He is a sound scientist with a pragmatic sharply-focused intellect. It is extremely difficult in a university laboratory to study African traditional food processes and acceptability of their products, which in their native environments vary widely among communities and individual cooks. Consumer attitudes and reactions can be studied only in real life locations. Dr. Hamaker is encouragingly aware that research in the U.S. should center on fundamental biophysical and biochemical properties, how they relate to technologically important functional attributes, how they vary among genotypes, and how they may be modified by physical and biochemical processes. Much time and effort has been wasted in empirical engineering and mechanics. Reliable milling technologies require systematic studies of grain structure and composition to determine the most efficient methods by which components can be fractionated and refined.

The literature on composite flours is dominantly empirical, little systematic effort having been devoted to determining compatibility between wheat flours and sorghum flours from various genotypes in composites intended for different baked or extruded products. Without a sound fundamental understanding of critical properties involved, little reliable technological progress can be accepted. Dr. Hamaker's concepts promise cooperative progress with the Africans who hope to develop commercial cereal products from locally milled composite flours.

Nutritional Qualities

The research on the relative digestibility of sorghum kafirins, their synthesis at different stages of crop maturity, the probable causes of indigestibility, the physical and chemical processes which aggravate or reduce indigestibility, is uniquely valuable and should continue as a high priority. Is it known what function, essential to the biological development of sorghum plants, is served by the kafirins and the HMW protein identified; what might be the agronomic consequences of their being eliminated by genetic modification? Is it important to find out? Is there an, as yet, unexplored role for molecular biology in the study of sorghum protein digestibility? The wheat gluten working group of the International Society of Cereal Chemists is studying protein structure and modification and, since this also implicates S-S bonding, it might be of interest to the Purdue research. The Chairman of the gluten group is Dr. Walter Bushuk, Professor of Food Science at the University of Manitoba.

Cooperation with Zimbabwe Cereal Industries

During the time at Purdue a proposal whereby Purdue, TAM and KSU milling school would combine to cooperate with a Zimbabwe association of cereal industries was formulated, sent to USAID Zimbabwe, copies to the EEP and the universities involved. If accepted, it would break new ground for INTSORMIL in cooperating with African agro-industries.

Texas A&M - Purdue - Kansas State Cooperative Proposal

Grain Quality and Utilization Program - Matopos, Zimbabwe

Background

The Zimbabwe industrial association of grain millers, bakers, and cereal processors have established a fund amounting to several hundred thousand Zimbabwe dollars to establish and maintain a cereals research, technology, and training center.

As ICRISAT/SACCAR have decided to cease their work on grain quality and utilization at Matopos the Zimbabwe cereal industries have applied for access to the facilities at Matopos formerly used by ICRISAT/SACCAR for grain quality research.

The Zimbabwe industrial group is well organized under their president Mr. E.G. Cross and have members who are transnational (international) corporations and locally owned companies.

They are relatively weak technologically and scientifically and it is applied research, technology development, and adaption that they need and, seed assistance. The necessary expertise to provide guidance and cooperative support exists at Kansas State University in the milling and cereals department, at Purdue in Food Science, and at Texas A & M under Professor Rooney.

It is strongly recommended that a firm offer of cooperation be channeled via INTSORMIL and USAID in Zimbabwe to the Zimbabwe cereals industries.

It is envisaged that technical cooperation consist of the following components:

Grain Quality

Assistance in developing standards for cereal flours and products for different processed products and applications; e.g., as composites for bread, biscuits (cookies), pastas, breakfast, and infant foods.

Grain Milling Efficiency

The industries include 1) large wheat and maize mills employing technologies similar to those used in the American mills, 2) a vast assortment of small-scale sorghum and maize mills which operate with varying degrees of efficiency. The large mills could afford to pay for technical advice: Most urgent need is for a systematic study and evaluation of existing of small-scale sorghum and maize mills.

The sorghum mills consist of two main components: a decorticator constructed of either carborundum or resinoid abrasive disks which rotate on a horizontal drive shaft; and a hammer-mill to reduce the decorticated endosperm to flour or semolina.

Maize mills are various designs of plate or hammer mills. Studies of milling efficiency need to take account of genetic variability among the grains available; what biophysical and biochemical factors influence milling grind-out yields; engineering design and operation; pre-processing (e.g., tempering).

Cereal Products

Zimbabwe is not self-sufficient in wheat and the wheats grown are not of superior breadmaking quality. There is no systematic record of Zimbabwe wheat quality as it relates to various end-uses, or of the compatability of other cereal grains (e.g., different sorghums, maize, millets) for incorporation in composite flours.

Very little work seems to have been done to determine the variability of important functional properties (e.g., water activity, gelatinization characters) among the varieties and cultivars grown.

The fast food outlets are growing rapidly with substantial sales of hamburgers, meat patties, sausages, and other comminuted meat products. There are significant opportunities for meat extenders produced by extrusion of cereal, oilseed, and legume derivatives.

Malting for brewing and infant foods is widely used and could be improved by competent technical assistance.

The above are simply illustrative of the many opportunities and needs for R & D and technology improvement for cereal and other food grains.

With some additional equipment, all of which could be supplied by the U.S. (e.g., National Manufacturing Co., Lincoln, NE). The present facilities at Matopos could adequately serve the Zimbabwe cereal industries needs. In addition, the hostel at Matopos could provide accommodation for trainees.

Training

The greatest need is for training of technologists and technicians already employed, or to be employed, by the existing cereal industries. In addition, some M.S. and Ph.D. students will need to be trained to assume senior positions in scientific research and technical management.

Recommendations

INTSORMIL make a specific offer of assistance through the USAID mission in Harare.

A small INTSORMIL team visit Matopos for 2-3 weeks to develop, in consultation with Zimbabwe industry and scientific community, a phased program of cooperation in 1) technology development and improvement, 2) grain quality and utilization, 3) training. As stated above some additional technical equipment will be required and need to be identified by the visiting team.

Utilization and Quality of Sorghum and Millet

Project TAM-126
Lloyd W. Rooney and Ralph D. Waniska
Texas A&M University

Brief Description of 1992 Activities (Country Activity)

Objective 1 - Refine, use, and continue to develop simple tests to predict food quality in plant breeding programs and to determine which characteristics of sorghum and millet limit food and nutritional quality.

Determined the variation in dry milling properties of sorghum from several nurseries including the IFSAT, hybrid trials and many others. The information is used to provide additional information on quality for sorghum improvement by the plant breeders. Simple milling techniques and physical properties are most useful.

Determined the tortilla quality of sorghums grown in Honduras in the advanced Maicillo Criollo breeding project. The information is used by Dr. Gomez and Meckenstock to elect for sorghums with good quality. Some samples from on farm trials have been evaluated in large tortilla making trials.

Determined the quality and processing properties of sorghum from head bug trials conducted in Mali by IER and ICRISAT.

Continued to determine the kernel and plant characteristics of sorghum that affect grain quality. For example, a tan plant color sorghum with red pericarp has been incorporated into advanced hybrid lines by Dr. Miller (TAM-121).

Small scale procedures for determining the malting quality of sorghum have been developed. Methods for determination of alpha and beta-amylase activities in sorghum malt were adapted from barley malt procedures.

Objective 2 - Determine physical chemical and structural factors that affect food and nutritional quality of sorghum and millet.

Scanning and light microscopy showed that head bugs severely damaged the endosperm of sorghum kernels and caused decreased milling quality. The difference among varieties were highly significant. Some varieties with tolerance to head bug attack had the best milling properties and least endosperm disruption.

A procedure was developed to evaluate the steam flaking properties of sorghum with improved food characteristics using a pilot steam flaker at Texas Tech University in Lubbock. The waxy and heterowaxy sorghum samples gave greater diameter flakes with enhanced flake durability. The appearance of the flaked grain was vastly improved when food type sorghums were flaked.

Methods to characterize starch using aqueous extraction and high performance size exclusion liquid chromatography have been developed and applied to various processed sorghum products. The relationship between starch characteristics and food quality is critical.

Environmental scanning electron microscopy provides new information on changes in components during processing or maturation in the field. Changes during malting of sorghum have been documented.

Objective 3 - Develop methods to process sorghum into acceptable food products by combining processing methods with improved sorghum varieties.

Steam flaked and micronized waxy and nonwaxy sorghums were used to develop sorghum granolas and ready to eat breakfast foods. The micronized waxy sorghum flakes had a light airy expanded texture that made excellent granola products. The steam flaked waxy and nonwaxy flakes had too firm a texture and had to be ground into flour and pressed into ready to eat flakes.

The fundamentals involved in gelatinization of starch to produce noodles from 100% sorghum flour were determined. The best noodles were made with white tan plant color sorghums that were milled to eliminate the black specs from the flour.

JOWAR Crunch: White food type sorghums were cooked in lime, allowed to dry, fried in hot oil and seasoned to produce an excellent crunchy snack of intermediate to low oil content. The dry kernels can be stored as pellets until they are fried. The procedure works well for food type sorghums especially those with tan plant color.

Parboiling processes were optimized and introduced into Mali and S. Africa with mixed success. The fundamental changes that occur in grain during parboiling and changes in nutritive value were documented. The economics depend upon the relative price of grain in the country and the availability of good quality grain for parboiling.

Millet and cowpea mixtures for weaning foods were developed and tested in Mali. Low technology processes for preparation of precooked weaning foods were evaluated. (Ms. Haidara - Mali)

JOWAR: The use of a term called JOWAR to refer to special high quality sorghum products was promoted to establish that grain of excellent quality would be of interest to food processors. Much interest was obtained. A positive image could be obtained by innovative merchandising of unique types of sorghum. This would apply in the U.S. and Africa.

Objective 4 - Determine factors affecting malting quality of sorghum and how to select for it.

Factors affecting the properties of sorghum varieties for malt were determined by two graduate students. Variety by environment interaction was significant. In general, steeping for 18 hours and germination for four days were optimum. The mean dry matter losses were around 15% and increased with greater germination times.

Waxy sorghum and corneous endosperm sorghums had very poor malting properties. Evaluation of malting studies conducted around the world suggest that intermediate to soft sorghum kernels have the best malting properties. However, the level of enzymes is not necessarily related to endosperm texture.

Objective 5 - Determine the factors that affect resistance to grain molds and field deterioration in sorghum and devise laboratory procedures to detect genotypes with resistance.

Work continues to develop a bioassay for determining the anti fungal activity of various components isolated from sorghum.

Anti-fungal proteins reported by Chandrasekar at the CFTRI in India are being investigated for prevention of grain molds in sorghum.

The effect of weathered sorghum on milling properties and nutritional value is being evaluated.

Research Results Disseminated

Many technical reports, presentations and proceedings summarizing the results of research were published to distribute the information.

White sorghum hybrids with tan secondary plant color, waxy and nonwaxy endosperm, and other desirable properties have been released by the TAES to commercial industry. Some of the hybrids are being grown and more will follow. This is the result of 20 years or more cooperation between the breeding and sorghum quality research projects. These sorghums have good yields and acceptable quality for food and foods. Greater improvements can be expected. Papers on sorghum products demonstrate their utility. The steam flaking properties are superior as well.

Parboiling to improve the processing properties of millet and sorghum and to produce a rice like product of acceptable quality has been introduced into Mali and S. Africa. A former student has conducted significant research to develop a mechanized process to produce parboiled sorghum. The major constraint to its use is the inadequate supply of white high quality sorghum.

The increased use of Sureño in Honduras by farmers who grow sorghum for tortilla has demonstrated that our research on sorghum tortilla quality is relevant and accurate. Some farmers have adapted planting systems to where they can use Sureño because it produces light color tortillas and has improved forage quality.

Malting quality studies have been useful to permit us to collaborate with various groups around the world working on malting quality of sorghum. They include The Institute of Brewing, Guiness, Inc., Heiniken, Inc., CSIR of S. Africa, Herriot-Watt University, and University of Louivan in Belgium. The Cooperation allows us to learn a significant amount about the quality characteristics of sorghum for malting at a minimum investment in actual research. In this way we can provide information to U.S. breeders and others.

Travel/Interactions

Traveled to Mali one or two times annually to conduct cooking trials/evaluate the progress made in Mali to produce sorghum/millet products by the public and private sectors, to encourage write-up and dissemination of results, and to plan research as part of the Malian INTSORMIL project.

Personnel from the project participated in annual meetings of the AACC, IFT and International Association for Cereal Science and Technology Conferences in Paris where L. W. Rooney became chairman of the ICC Working Group on Sorghum and Millet.

Lloyd Rooney participated in special ICC conferences in Australia and South Africa where special presentations on sorghum quality were made. In S. Africa, three half day sessions on sorghum were organized as part of a special symposium on sorghum. While in Australia and S. Africa, special presentations on sorghum quality were given to industrial and public research groups.

Mexico/Honduras special seminars were presented on sorghum in Monterrey, Mexico, ITSEM, Mexico City at the Pan American Food Science Congress and University of Sonora. Special projects to collaborate with Dr. H. Almeida Dominguez, Institute of Technology-Merida and Dr. Serna-Saldivar at ITSEM in Monterrey are underway. Interactions with EAP, Zamarano, Honduras regarding cereal processing is continuing.

L.W. Rooney reviewed the past harvest technology of sorghum and millet for EMBRAPA-CTA in Brazil to make recommendations for interaction between EMBRAPA breeding and food technology research.

Training

During 1990 to 1993, we have graduated three Ph.D. and three M.S. students (with four more M.S. to finish in 1993). Since 1979, the project has graduated 16 Ph.D. and 23 M.S. Food Technologists.

Institutional Development and Training

The project has had a major impact in Mali in helping to develop a laboratory for routine analysis of sorghum and millet quality as part of the crop improvement program. Various personnel have completed short training programs. Information on new products and processes, i.e., parboiling, dehulling, Tô testing, have been disseminated.

Internationally, the relationship between genetics of kernel characteristics and processing quality has contributed to efficiency in breeding and selection of sorghums for food and feed.

Interaction with Other INTSORMIL Projects

The millet research has been conducted with Mr. Stegmeier and Mr. Andrews projects. They have supplied appropriate samples and have developed some cultivars such as the white or yellow millets specifically for processing.

This project has collaborated effectively with all the Texas INTSORMIL projects plus some of the Purdue projects as needed. The release of the tan food type sorghums is the result of 20 years of close cooperation with TAMU plant breeders.

WID Issues

Food processing is of direct benefit to women. Development of new foods or food processes can directly help women earn income and provide for their families more efficiently. The weaning foods are of direct importance to women.

Utilization and Quality of Sorghum

This project was reviewed in February 1992 and no major changes in objectives and activities have been introduced. Some comments made in the 1992 EEP Report deserve repetition: "University and government laboratories can be well equipped to develop analytical tools and methods: to study the properties of natural biological materials and how these change during and after processing. Rarely are they equipped to develop products for commercial manufacture and marketing."

It was recommended that TAM in cooperation with KSU School of Grain Milling give particular attention to the decortication and milling of sorghum and millet, and to an examination of how grain structure and composition vary among genotypes and how these may relate to milling efficiency. It was also recommended that TAM concentrate its efforts on a systematic examination of how important biochemical/biophysical properties vary among the food sorghum collection and how these properties relate to functional utility. These recommendations still stand and are addressed later. A commendable feature of TAM-126 is the close working relation between the food science group and the plant breeders. It is hoped in the computer record, food sorghums will be systematically classified according to functional properties as well as agronomic characters.

Activities in 1992-93

The five stated objectives overlap and several activities are briefly described under more than one objective. What follows seeks to highlight activities of particular significance. Several ongoing activities were reviewed in the February 1992 EEP Report.

Of particular importance: White sorghum hybrids with tan secondary plant color, waxy and nonwaxy endosperms, the result of a 20 year breeding and selection program. Yields are good and the types include lines suitable for food and feed, some showing superior steam-flaking properties. These hybrids should be among the first included in the cooperative milling program proposed below.

Structural and compositional analysis of sorghums and millets from around the world is ongoing and it would be useful to disseminate annually results of particular functional significance.

Parboiling

Results related to 2-acetyl-1-pyrroline as the source of off-odor in millet flour was reported in the EEP report of 1992.

Sorghum Malting

Investments by brewing and food industries in Nigeria in production and use of high-diastatic sorghums in beer and malted food products resulted from a ban on barley imports. This, in turn, has stimulated a research network the main participant being the Herriot-Watt brewing research laboratories in Edinburgh, Scotland. A recent conference on sorghum in brewing and food, held in Harare, attracted 65 participants from interested industries.

TAM-126 is conducting malting trials, under varying conditions of steeping and germination, on cultivars grown in Texas. Analyses, which included dry matter loss, alpha- and beta-amylase, showed variations among varieties in rates of enzyme proliferation and dry matter loss. In general, the sorghum malts were significantly different from barley malts in structure [by SEM], composition and enzymatic activities, and in friability. The studies will continue to determine which types have properties best suited for malt extracts to be used in nonalcoholic and alcoholic beverages and infant foods.

Apart from American transnational seed companies, the results will likely benefit African and Latin American countries more than the U.S. In light of budgetary constraints, INTSORMIL and TAM may wish to decide how much time and effort can profitably be devoted to malting, and who will benefit most from the results.

One aspect as yet unexamined: The polyphenols in high-tannin sorghum types are chemically similar to the hop antiseptics lupulon and humulon. Could the high-tannin fractions from milled sorghum be used by African brewers to reduce dependence on imported hops?

Food Products

Work on tortilla quality, on pasta products and weaning foods was reported in the EEP report of 1992. Continued research on sorghum tortillas included physical properties and response to processing conditions of sorghum cultivars grown in Honduras. Variability among cultivars, in pericarp removal, dry matter loss during cooking, and tortilla color was reported. Sometime soon it would be interesting to discover reactions of tortilla producers in Texas and Honduras restaurants to tortillas made from the "best" sorghums.

Food quality sorghums were used in a JOWAR crunch snack made by alkali cooking, drying and frying in oil, and in a granola-type food. It is not clear which producers and markets these new products and bread from a cassava starch-sorghum flour bread are intended.

Cassava starch, distinct from whole cassava dried, ground meal is produced commercially in very few African countries. The high cost of production puts the price per kilo about double that of wheat flour.

From a modern industrial process: mechanical peeling, shredding, starch extraction, centrifugal separation, vacuum drying, mechanical milling and sizing, a starch yield of ca 25% is normal. From a labor intensive primitive operation common in rural Thailand, starch yields rarely exceed 15%. It is improbable that a process requiring one-third of the dry ingredients to be cooked before incorporation in the bread dough would find favor with bread bakers. Nor is there any evident advantage in diluting sorghum flour with cassava starch. More urgent in Africa and Asia is to dilute imported wheat flour with sorghum and other local grains.

Micronizing

Results of considerable potential value to food and feed industries have come from processing of waxy, heterowaxy and nonwaxy sorghums in a laboratory micronizer. Waxy types showed greater expansion rates.

Steam Flaking

TAM-126, in cooperation with Texas Tech University, has demonstrated variability among hybrids subjected to steam flaking. White food types were preferred because of superior color. Flakes, considered good and poor, were examined by light and scanning microscopy. Variations in starch gelatinization, critical to flake stability, were determined. A laboratory steam flaking method, suitable for a few kg of grain, produces flakes comparable to commercial samples. The objectives and methods of this project are exemplary and the results promise future benefit to feed industries in the U.S. and elsewhere.

Grain Mold

The methodology in this project is commendable. It seeks to identify and quantify bioactive compounds, naturally synthesized, that induce resistance to grain mold. With the urge to reduce pesticide use, novel transgenic techniques to transfer biochemical resistance from wild and weedy species into food quality cultivars are fast progressing. The TAM approach of identifying bioactive compounds and determining their effectiveness and potential human toxicity deserves extensive application.

International Food Sorghum Adaptation Trial

Accessions are distributed throughout the U.S. and to cooperating breeders around the world. Objectives are to determine adaptation and productivity among a broad selection of varieties and F1 hybrids with food quality traits. Critical examination is made of plant and glume characters, grain color, endosperm structure and composition. Results will be of particular interest to food processors. Consideration might be given to publication of a semi-annual newsletter to which food processors and others interested could subscribe.

Future Activities

Machines of various designs and capacities to decorticate and mill sorghum and other small grains are being installed throughout Africa. Several are being fabricated in Senegal, Botswana, Zimbabwe, Tanzania and other African countries. Most were designed by mechanics without close cooperation with scientists familiar with grain structure and characters critical to milling efficiency. The Zimbabwe Milling and Baking Association are in process of establishing a technology and training facility. They need technical assistance from scientists with competence resident within the INTSORMIL universities.

It is proposed that a meeting be held during the EEP review at Purdue in September, to be attended by TAM, KSU School of Milling, and Purdue, to discuss and formulate a program, systematically to examine the various African sorghum milling processes in relation to the food quality sorghums available. Cooperation of INTSORMIL with the cereal industries association in Zimbabwe would be consistent with USAIDs stated objective of encouragement for the private sector.

Host

Country

Program

Enhancement

PREVIOUS PAGE BLANK

Botswana - Project KSU-107

March 6-10, 1993

Review Team

Dr. Joseph Hulse, IDRC (retired)
Dr. Fran Bidinger, ICRISAT Cereals Program

Visiting Participants

Dr. Darrell Nelson, Board of Directors
Dr. John Yohe, Director, Management Entity
Dr. Max Clegg, University of Nebraska

Project Leaders

Dr. Max Clegg, INTSORMIL/Botswana Country Coordinator
Dr. Lucas Gakale, Botswana/INTSORMIL Country Coordinator

INTSORMIL's involvement in Botswana was initiated in July 1983 and staffed in April 1984 under the INTSORMIL/Kansas State University KSU-107 project. Dr. D.C. Carter held the position of Agronomist with KSU-107 from its inception until September 1990. In December 1987, Dr. N. Persaud was appointed the soil management specialist to support the activities of the USAID-funded bilateral Agricultural Technology Improvement Project (ATIP). When ATIP ended in September, 1990, INTSORMIL amended its Memorandum of Understanding with the Government of Botswana and USAID to continue the services of the soil management specialist until September, 1992. Funding for the KSU-107 project up to July 1992 was jointly shared by INTSORMIL, USAID/Botswana, and the Government of Botswana. The INTSORMIL contribution for KSU-107 is provided by the U.S. Government under the provisions in Grant DAN-1254-G-00-0021-00 to the University of Nebraska, Management Entity for INTSORMIL and by subgrant to Kansas State University. The plan of work attached to the Memorandum of Understanding between the Government of Botswana, USAID/Botswana, and the INTSORMIL ME describes the scope of work and the operational procedures for the KSU-107 project. The Department of Agricultural Research (DAR), provides all operational facilities for KSU-107. The technical objective of KSU-107 has been to continue and expand the on-farm and on-station research on tillage and fertilizer practices across the various rainfall and soil conditions in Botswana. The collaborative research relationships in pathology, entomology, sorghum and millet breeding have operated in conjunction with the KSU-107 project.

The Botswana program model has two related components; an INTSORMIL researcher stationed in the country and scientist to scientist collaboration in the areas of agronomy, plant pathology, plant breeding, entomology, and food science and technology. Various aspects of collaboration can be seen in other projects. Collaboration and/or contact with various scientists are detailed in individual projects.

USAID/Botswana and the Government of Botswana (GOB) inputs to the INTSORMIL/DAR collaborative research program have been about $100,000 per year. INTSORMIL, up until July, 1992, provided about $103,000 per year for operating, equipment, facilities, technical assistants and an in-country scientist. These resources allowed for the Botswana program to undertake comprehensive and collaborative research on dryland sorghum/millet production. With the termination of the long term soil scientist position in July 1992, the INTSORMIL budget has been reduced to about $30,000 per year pending review of the role of INTSORMIL in Botswana and the Southern Africa Development Conference (SADC) region. Future funding must be the most critical issue facing this exemplary endeavor.

Observations and Findings

Background

Though not the most widely or extensively cultivated crops in Southern Africa, sorghum, pearl and finger millet are the cereals best adapted to the semiarid tropic ecologies in general and to the SADC region in particular. Most farm land within SADC lies within areas of marginal and uncertain rainfall and is subject to recurrent drought. Drought occurred during five of the first seven years of the 1980s; the drought of 1991/92, the worst on record, inflicted immense suffering and economic disruption. Across all of Botswana and three-quarters of Zimbabwe, precipitation is unevenly distributed with a long-term mean of less than 600 mm per year. Sorghum and the millet, being comparatively resistant to water stress, are the most suitable cereals for cultivation in Botswana, Zimbabwe and most other SADC countries.

For various historical, technical and social reasons, throughout most of SADC, maize is planted more extensively than sorghum and millet and in years of adequate rains yields a larger harvest. Being sheathed in foliaceous bracts, maize is more resistant than sorghum to attack by birds. The whole grain, being generally lower in fibre than sorghum and millet, can be hand-pounded or hammer-milled, whereas sorghum needs to be first dehulled to remove the outer seed coats from the endosperm. Throughout the world, maize utilization has benefited from substantial long-term U.S. industrial investment in products and processes, and in Rhodesia/Zimbabwe from the development of high-yielding hybrids. No comparable investment to improve production or utilization has been given to sorghum and millets. Most sorghum research has been devoted to high tannin types for traditional opaque and European-type beers.

Maize was introduced into Africa, and probably to the SADC region by Portuguese traders in the 16th Century. Early in this century white settlers in the former British colonies so expanded maize cultivation that by the early 1920s maize covered over 90 percent of the farm land of what are now Zimbabwe, Zambia and Malawi. Maize was pressed upon the indigenous people as wage food by their colonial employers. Only since WWII has it become realized that sorghum and the millets are better suited ecologically. It is some conventional wisdom that Botswanan and Zimbabwean people prefer maize to sorghum. The results of two national market tests in Zimbabwe contest that assertion. In one test, 45% of the respondents preferred pearl millet, 31% sorghum, 6% maize while 18% were undecided. In a second market test, 51% preferred sorghum, 35% millet, and 10% maize. (This information was provided by Dr. S.C. Muchena when he held the position of Deputy Secretary in the Ministry of Agriculture).

Table 1 shows the estimated average yields (tons per hectare) and annual production levels ('000t) of sorghum and pearl millet in the southern African region since 1960. The data illustrates wide variability and shows little indication of progressive adoption of improved genotypes or production practices developed by the SADC/ICRISAT Sorghum/Millet Improvement Program (SMIP) and national programs.

That sorghum can out yield maize, particularly during low rainfall years, was demonstrated by ICRISAT/SMIP trials at 11 rainfed locations, the differences being most evident

Table 1. Estimated average yields (tons per hectare) and annual production levels ('000t) of sorghum and pearl millet in the southern African region 1960-1990.

	Sorghum		Millet	
Year	Yield	Production	Yield	Production
1960	0.6	350	0.5	250
1965	0.8	500	0.6	425
1970	0.65	550	0.5	350
1975	0.7	400	0.6	400
1980	0.55	395	0.5	350
1983	0.35	225	0.4	300
1985	0.55	350	0.55	350
1990	0.6	375	0.5	275

Table 2. Hybrid sorghum and maize yield trials conducted by ICRISAT/SMIP in Botswana, Zimbabwe and Zambia (1990-1992).

	Zimbabwe			Zambia			Botswana		
	90/91	91/92	Mean	90/91	91/92	Mean	90/91	91/92	Mean
Hybrid sorghum	3.3	1.4	2.35	5.0	3.1	4.1	4.7	2.4	3.6
Hybrid maize	2.0	0.0	1.00	3.9	0.0	2.0	2.1	0.0	1.1

Table 3. Area harvested and crop yields during the 1980s decade.

	Area harvested as % area planted			% Total crop area*	
	Highest	Lowest	10 Yr. Mean	Planted	Harvested
Sorghum	89 [1988]	40 [1983]	67	61	70
Maize	68 [1981]	6 [1984]	42	23	16
Millet	82 [1980]	25 [1982]	54	6.1	5.7
All crops	82 [1988]	29 [1983]	55	100	100
*10 Year average					
	Crop yields (kg/ha)			**Crop production**	
	Highest	Lowest	10 Yr. Mean	A*	B*
Sorghum	338 [1988]	40 [1983]	161	67	27
Maize	253 [1981]	10 [1984]	148	23	9
Millet	225 [1988]	26 [1987]	94	4	1.6

*A = 10 Yr mean % of total crop production
*B = 10 Yr mean annual production ['000t]

during the 1991/92 severe drought. The data cited in Table 2 are in tons/hectare.

Botswana

Sorghum is Botswana's most important grain, the area planted covering more than 70 percent of cultivated cropland. Only among the refugee settlements of the northwest is millet the main crop. The dominance of sorghum in Botswana's agricultural economy is illustrated by superior yields, the area planted and the ratio of hectares planted to hectares harvested, in all instances sorghum surpassing all other crops. Because of inadequate and variable precipitation, for all crops the hectarage harvested is invariably less than the hectarage planted. The data for the 1980s decade is shown in Table 3.

Table 4 gives the estimated average yields and production of sorghum in Botswana during the past 30 years.

Total grain production in Botswana is, on average, barely 40% of need. In 1989, Botswana imported 1.6Mt of maize and 14,000t of wheat. Mean annual consumption of sorghum is 60,000t. Since, in 1988 and 1989, respectively,

Table 4. Estimated average yields and production of sorghum in Botswana during the past 30 years.

Year	Yield (kg/ha)	Production ('000t)
1960	350	58
1965	350	10
1970	50	8
1975	40	40
1980	22	30
1985	10	15
1987	15	12
1988	34	94
1989	30	53

production reached 94,000 and 53,000t respectively, no sorghum was imported.

The Botswana Agricultural Marketing Board (BAMB) gives a guaranteed floor price for sorghum, maize, groundnut, sunflower and pulse crops, but since marketing of food grains is uncontrolled, only 20% of crops harvested pass through the BAMB, 80% are traded by the private sector.

Private traders are free to import grains and to negotiate prices with farmers. Floor prices offered by the BAMB, which is the buyer of last resort, vary according to grade and the distance of the producing region from Gaborone. Table 5 shows the maximum and minimum prices (Pula/t) for each grade that were in effect in March 1993.

Table 5. Maximum and minimum prices (Pula/t) for each grade in effect in March 1993 in Botswana.

Grade	Sorghum	Maize, white	Maize, yellow	Millet (No grade)
1	375-480	310-414	349-353	290
2	363-467	303-407	341-446	
3	279-382	265-370	337-441	

2 Pula = approximately $1.00 USD

Among the sorghum grades, highest price is for "sweet" low tannin. The BAMB holds the strategic reserve stocks for the country. Botswana being the wealthiest in terms of GNP/cap, and with the largest foreign exchange reserves, is generally least stressed of the SADC members when drought inflicts serious crop failure. In 1981, SADC began a regional Food Security Program, administered by Zimbabwe's Agriculture Ministry. The Program made provision for regular meetings of the member nations' marketing boards to develop grading and quality standards, and to exchange information on storage, grading and other matters relevant to regional food security. According to the BAMB Director, no such meetings have taken place.

[NB Since issues relevant to the utilization of sorghum are in large part common to Botswana, Zimbabwe and other SADC members, the subject will be addressed at the end of this report].

Zimbabwe

It is unfortunate that the new Director of SMIP refused permission to the INTSORMIL EEP to visit the Matopos research station. Both the EEP and SMIP would have benefited from a meeting, particularly since the future of SMIP and the Matopos facility is under review.

Added to historical influences cited above, maize production in Zimbabwe has benefited from research by the Department of Research and Special Services and by attractive prices set by the Grain Marketing Board (GMB). The maize harvest hit an all-time high of 2 Mt in 1982, a year of favorable weather when the sorghum crop produced barely 30,000 tons. [NB The data quoted are based on deliveries to the GMB and may not adequately account for grain retained by growers for auto-consumption]. Though maize has been processed for many years by large commercial and small rural enterprises, until recently sorghum has been commercially processed only for beer.

A significant boost to sorghum production came in 1984/85 when a new attractive pricing policy was introduced. Following severe droughts in the mid 1980s, the government raised sorghum prices to parity with maize (ca Z$180/ton) resulting in a sharp rise in production and sales to the GMB from large commercial and small communal growers. The price incentives stimulated production of high tannin types suitable for brewing. The proportion of white sorghum fell from 9.5% in 1984/85 to 1.9% in 86/87. The quantities ('000t) of maize and sorghum purchased annually by the GMB since 1970 are given in Table 6.

Until three years ago, all food grains that were traded were controlled by and sold to the GMB. Imposed by the economic structural adjustment program, several changes in grain marketing have come about. Food crops are now in three categories:

Controlled - Prices, standards and sales controlled by the GMB

Regulated - Crops can be freely traded with the GMB as purchaser of last resort.

Table 6. Quantities ('000t) of maize and sorghum purchased annually by the GMB 1970-1987.

Year	Maize	Sorghum	Year	Maize	Sorghum
70/71	611	3	87/88	403	4
75/76	1114	4	88/89	1197	14
81/82	2100	30	89/90	1166	9
85/86	1830	82	90/91	781	6
86/87	1595	703	91/92	615	1

Unregulated - Commodities entirely free of GMB control.

In the case of "Regulated crops", the Ministry may establish prices if a critical situation so demands. The change from "Controlled" to "Regulated" accounts in some degree for the low quantities of maize and sorghum cited above during the past three years since these state only the amounts purchased by the GMB. It is believed that the brewers are buying significantly under contracts with growers. The sorghum crop harvested in 1990/91 is estimated at 21,000t. The severe drought in the 91/92 crop year reduced sorghum off-take to about 2,600t.

In good years, Zimbabwe is a net exporter of cereals, mainly because of its maize exports, which between 1984 and 1992 ranged from 174,000 to 495,000 tons per annum. The country is not self-sufficient in wheat with imports during the past five years varying from 12 to 30% of total wheat consumption. The text on utilization which follows will suggest how wheat imports could be reduced by more efficient processing of sorghum.

Utilization of Sorghum and Millet

Production of sorghum and millet throughout SADC are far less than seems justified by their superior tolerance of drought stress. Various reasons have been suggested to explain the low rate of adoption of improved genotypes and production systems. It is this consultant's considered opinion that too little attention has been given to grain properties that influence commercial utility: properties that permit sorghum and millet to be converted to industrially processed foods of acceptable and consistent quality. "Industrially processed" covers a broad spectrum of technologies, from simple rural labor-intensive to large-scale mechanized systems. Whatever the processing system, raw materials consistent in desirable biophysical and biochemical nature and composition are essential.

When, in 1984/85, the Zimbabwe GMB raised sorghum prices to parity with maize, farmers responded with a bumper harvest. They grew what they knew; high tannin varieties, suitable for local beer but not for cereal foods. In consequence of low food industry acceptance, production in the following years fell to customary low levels. The grains were difficult to mill, being irregular in shape and size, and the high tannin outer seed coats resulted in flour low in yield, with poor color and flavor.

In 1988, Nigeria imposed an embargo on the importation of cereals, including malting barley. Nigerian breweries and food industries who use malt in infant foods launched intensive investigations to identify high diastase sorghum. Within four years sorghum has almost entirely replaced barley for malting and as a source of hydrolyzable and fermentable carbohydrate. ICRISAT holds over 28,000 sorghum genotypes. A great deal is known of their agronomic properties; little relative to their utility as food ingredients.

Traditionally, throughout the semiarid tropics (SAT) of Africa, sorghum and millet are used to make various stiff and thin porridge; some are bland in flavor, some entail lactic, others alcoholic fermentations, the latter being produced as opaque beers. In Botswana, stiff porridge is Bogobe, thin Motloge; in Zimbabwe stiff is Sadza (Shona), Isitshwala (Ndebele), thin; Bota (Shona) Ilambazi (Ndebele). The Zimbabwe lactic ferment is Mahewu (Shona), Amahewu (Ndebele). Opaque beer is Doro (Shona) or Utshwala (Ndebele).

The ground sorghum flours used in these various products are made traditionally by hand-pounding with a large pestle and mortar, the bran being removed by winnowing. During the early 1970s an IDRC-supported study discovered, in West Africa, that women spent up to five hours a day pounding sorghum or millet. To relieve them of this tedious chore, IDRC financed a series of studies that led to the establishment of a multi-purpose grain mill at Maiduguri in the northeast state of Nigeria. What began as a highly successful enterprise fell apart as a result of various political upheavals. In the meantime, the technology came to the attention of the Botswana Agricultural Marketing Board who sought and received IDRC assistance to develop and establish a sorghum mill at Kanye.

Because, throughout Africa, sorghum is poorly graded and grains are delivered in many shapes and sizes, the milling technology depended on abrasive dehulling, using carborundum discs rotating on a horizontal shaft enclosed in a rubber-lined metal case. After separation of the bran, the decorticated endosperm is pulverized in a hammer mill and the resultant flour screened to provide grits [semolina] and/or fine flour fractions.

The first BAMB mill was manufactured in Canada. The International Development Research Center (IDRC) then assisted the Rural

Industry Innovation Centre (RIIC) at Kanye to modify and improve the machines to suit varying Botswanan needs. RIIC began manufacture of dehullers and provided training in operation and maintenance to small-scale entrepreneurs. RIIC sold its dehullers to other African countries, some of which, including Zimbabwe and Senegal, now manufacture derived models. The most widely commercialized model is the RIIC Tshilo Mk II, more than 50 of which are operating throughout Botswana on a semi-commercial scale, providing service milling to women who bring their own grain, and/or producing a processed packaged sorghum flour known as Bopijwa Mabele.

In Zimbabwe, plans are in progress to establish about 60 sorghum dehullers integrated with hammer mills. One Zimbabwean manufacturer is experimenting with resinoid discs, light-weight thermoplastic resins, the surfaces impregnated with aluminum oxide to provide abrasion. These being lighter and stronger provide a larger working surface, they can rotate much faster, giving greater throughput, and are less susceptible to fracture than carborundum. The Zimbabwe company also intends to replace steel with cast aluminum casings. What began experimentally in Botswana has developed into hundreds of mills throughout west, east, and southern Africa, liberating many African women from a tedious chore. A sociological study in Botswana discovered that the time freed from pounding had been put to more profitable activities, including raising poultry and kitchen gardens, and more attention to child care.

Though some work on grain hardness and epicarp composition, relative to dehulling efficiency has been productive, overall, more attention has been given to engineering than to grain structure and composition, and to functional properties that influence milling and the quality of products processed from abrasively dehulled, hammer-milled sorghum and millet flour. Urgently needed is a systematic study of how desirable properties vary among the many genotypes available from the ICRISAT collection.

So far, no such studies have been undertaken by INTSORMIL partners in Botswana; neither the RIIC nor the Botswana Food Technology Centre (BFTC) are INTSORMIL collaborators. The RIIC continues its interest in design and manufacture and operates a commercial mill in cooperation with a private entrepreneur. BFTC in cooperation with a local food processor is pursuing development of a sorghum-based weaning food, an enriched sorghum flour, a malted breakfast food, and various mixes for lactic and alcoholic sorghum products.

Dr. Berhane K. Wahid at the Department of Agricultural Research (DAR) is conducting useful research on the utilization of sorghum and millet stover, other post-harvest byproducts in feeds supplemented with Dolichos lablab (Lablab purpureus). The DAR team, working with some 30 farmers, have determined dry-matter yields from post-harvest residues and the influence of various production systems on lablab yields and composition. Periods of lactation, milk yields, calf weights and variation among native and cross-breeds (Tswana compared with Simmental-Tswana) have been recorded. This is important work given that there are three times as many cattle as people in Botswana, and the sizable contribution made by cattle to Botswana's economy. There is no evidence that this work has been assisted by INTSORMIL.

There is no evident cooperation between DAR and RIIC or BFTC to study grain quality in relation to commercial utility. There appears to be an unexplored opportunity for a cooperative program involving DAR, RIIC and BFTC with Purdue (nutritional quality), Texas A&M (grain structure and composition) and Kansas State (properties that affect milling and composite flours for baked, extruded and blended cereal products). Priorities would include examinations of how important functional properties (e.g., water activity; gelatinization) vary with genetic diversity. Such studies would be of greater long-term benefit as thesis subjects than having African students devise food products in American university laboratories. The U.S. universities could give specific assistance in developing and formulating grading standards based upon characters that affect milling efficiency. These should not be confined solely to abrasive dehulling. It is conceivable that, given suitable morphology and uniformity, sorghum could be milled by modified break-and-reduction systems. It is also desirable to examine more intensively the properties of ICRISAT's cream-colored millets, some of which are being tested in southern Africa. It is possible these could be milled as whole grains without dehulling.

It is suggested that during the summer INTSORMIL review the U.S. universities, a meeting be convened to include appropriate scientists from Purdue, Texas A&M and Kansas State universities to formulate a collaborative program along the lines suggested. This is of pressing importance if, as seems probable, Dr. Gomez' work on sorghum and millet utilization is to come to an end at Matopos. The program should envisage and explore means and opportunities for collaboration with RIIC, BFTC and the newly created Scientific and Industrial Research and Development Centre in Zimbabwe.

Please Note

This report does not address the subject of the future of the Matopos station or in what manner the utilization research at Matopos should be continued. If and when requested, a specific proposal will be developed. It is important however that INTSORMIL be directly involved in the study proposed by SMIP/SACCAR to recommend on the Matopos station's future program.

Soil and Water Management Research

Soil and water management research, which was the subject of KSU-107, is now well integrated into two of the DAR's basic research programs, the Soil/Water Management and Agricultural Engineering Research Program and the Production Systems Research Program. Both of the programs appear to be adequately staffed and to have an extensive research agenda (based on the limited information available to the review team). In addition, there is a special Working Group on Tillage and Fertilizer Research composed of scientists from the DAR and the Arid Lands Development Program (ALDEP), with support from the UNDP/FAO Soil Mapping Service, which is charged with developing clear recommendations on tillage and fertilizer management practices for dryland crops in Botswana. (The soil physicist assigned to the DAR under KSU 107 was instrumental in organizing this group in 1988). Thus, the necessary components for a sustained national research program on soil and water management in Botswana seem to be in place, and a continued direct involvement in this area by INTSORMIL does not seem necessary. This, however, does not preclude support of research in this area by INTSORMIL scientists through linkages with Botswana scientists, if there is an interest in the DAR in such linkages. The Director of the DAR concurred in this recommendation.

Training and Human Resource Development

The most widely recognized and appreciated contribution of INTSORMIL to agriculture in Botswana is undoubtedly the post graduate training of Botswana scientists done under both INTSORMIL's own projects and under the USAID/CIDA/GTZ-financed regional Sorghum and Millets Improvement Project, which contracted with INTSORMIL for the training of nearly 100 scientists from SADC member countries. This training has provided a significant base of trained scientists to the DAR (cite numbers and specialties). The success of this training program has stimulated an interest in the DAR in maintaining access to INTSORMIL's technical expertise in sorghum and millet research to support its own research programs in this same area. There was a general consensus that this should take the form of what might be called "second generation" training/support activities, which could provide specifically tailored training, collaboration, and technical support to DAR research projects which could benefit from these. This is particularly the case with projects under the direction of young scientists who do not as yet have sufficient practical experience in research planning and research management, and who could thus benefit from a linkage with an INTSORMIL senior scientist. This type of support fits well with the concept of linkages between INTSORMIL U.S.-based staff and DAR scientists who have been trained by INTSORMIL Universities. Several such linkages have either been initiated or proposed in Botswana by INTSORMIL principal investigators (see section on Linkage Programs). These linkages, however, appear to have been developed in a very unplanned and unstructured fashion, and are consequently considered by the Director of the DAR to be of rather doubtful value to the DAR's own research effectiveness. (The review team was handicapped in trying to evaluate these linkages by a lack of documentation as to their purpose and activities, and by a lack of a presentation of their activities by DAR scientists, and consequently had no means of verifying this. The lack of any formal plans for these activities, however, suggests that the Director's observation is justified). Future linkages encompassing one or more of the types of support activities listed above must (1) be requested by the DAR in support of its own research priorities, (2) be thoroughly planned in meetings with the DAR program leaders and INTSORMIL PIs and (3) be clearly documented in Memorandum of Understandings (MOUs) between the two organizations. The present, apparently ad hoc arrangements, are not appropriate in the southern African context of research planning and implementation.

Linkages between DAR Scientists and INTSORMIL Projects

Institutional Arrangements

INTSORMIL annual reports list linkages between Botswana and a number of U.S.-based INTSORMIL research projects. These include TAM-122, 125, and 128 and UNL-113, 115, and 118. Almost all of these are apparently outgrowths of former student-professor relationships, often relating to the time when the Botswana student was conducting M.S. or Ph.D. thesis research in Botswana. The review panel could determine all of these arrangements are ad hoc at best and operate without any formal memoranda or work plans between INTSORMIL and the DAR. Both the USAID Agricultural Program Officer and the Director of the DAR were critical of the lack of any formal structure to the linkages.

The review team was provided no written information (apart from a hand written note on UNL-115 and 118) on the objectives or accomplishments of any of the linkages, nor any briefings from DAR scientists on their collaborative activities with INTSORMIL scientists. A check of INTSORMIL annual country reports for Botswana indicate that in most cases the research activity reported was the thesis work of the Batswana student. It appears that at present (1992/93 crop season) most of the linkages are nonfunctional, with the exception of UNL-115 and possibly UNL-118.

The level of interest in such collaborative linkages appeared to vary among DAR scientists, from enthusiastic to nil. The Director of the DAR was very guarded concerning the value of such linkages to his program. A part of his feeling was undoubtedly due to the comparison of linkages in Botswana with INTSORMIL collaborative research projects in other countries which are jointly planned and coordinated by host country and INTSORMIL scientists, and address host country priorities. Above and beyond this, however, it appeared that the present linkages had not contributed a great deal of value in the minds of a number of the DAR scientists.

Apart from the support provided to the major professors of Batswana students conducting thesis work in southern Africa, which can more properly be discussed under the formal training activity of INTSORMIL (and which are not included here), there is little to discuss under this topic for the linkages between INTSORMIL projects and the DAR.

Mode of operation

Clearly the mode of operation, without mutually agreed and formalized research plans has not been effective. Any future attempts at collaborative research in Botswana need to be planned and organized as is done for collaborative research, e.g., in Mali.

Benefits from collaborative research

There are a limited number of sorghum lines furnished by the UNL-115 PI in the Botswana breeding nurseries. These have not yet reached a stage where they can be evaluated as final products so it is not possible to determine their potential. UNL-118 also assisted in the improvement of millet variety Serere 6A, but the improved version has not demonstrated superiority to the original, and apparently has not been continued. The review panel does not have evidence of benefits from other collaborative research projects.

There is no evidence that collaborative research activities in Botswana have any regional impact.

Needs of Botswana scientists

Financial constraints do not seem important in the DAR: budgets are expanding by approximately 10% per year and there are no foreign exchange problems as the Pula is strong and fully convertible.

The major area in which INTSORMIL can provide assistance to the DAR is through assistance in problem analysis and research planning, and possibly through backup research on particular problems for which the DAR does not have the personnel/equipment to solve. Most DAR scientists are recent graduates and can definitely benefit from some backup from the more experienced INTSORMIL scientists. How this need can be met in the future is discussed in the section on Recommendations below.

Technical Aspects

Sorghum Breeding - UNL-115

A number of maintainer lines were selected from crosses between the Botswana variety Segaolane, which has outstanding stability in low yield environments, and a number of higher yielding lines from the UNL-115 breeding project. These are currently being converted to male sterile lines for hybrid production. This should provide the DAR with an excellent base of adapted parents for a hybrid breeding program. The male sterile lines could also have a considerable potential in other dry areas of southern Africa. Male sterile breeding is one of the more difficult aspects of sorghum breeding; assistance from UNL-115 in this area should be very useful to the Botswana Cereal Program.

Millet Breeding - UNL-118

The assistance provided by the PI of this project and the SMIP Millet Breeder to improve the adapted millet variety Serere 6A was logical, as the variety was badly contaminated. Why there was no associated yield improvement is not clear, although it may be due to the very variable test conditions during the improvement process. However, with only a reported 10,000 ha of pearl millet in the country, plus the large amounts of breeding material available to Botswana from the SMIP Millet Breeder, it is difficult to see Botswana as a priority for UNL-118.

Entomology - TAM-125

The Ph.D. thesis work of Dr. Chris Manthe on the sugar cane aphid identified specific biotypes of the aphid, sources of resistance to them, and information on the inheritance of resistance, which should provide the necessary information for the national breeding program to breed aphid-resistant sorghum varieties. The review panel is not aware, however, that TAM-125 has made an attempt to follow up on this thesis research to establish a collaborative research linkage with Dr. Manthe now that he has rejoined the DAR.

Pathology - TAM-128

Anthracnose resistance nurseries have been grown and some disease survey work done in Botswana, apparently as a part of a regional collaboration by the TAM-128 PI and the SMIP pathologist. Again, there is little evidence that this activity has developed into a specific research linkage between TAM-128 and the DAR.

Agronomy - KSU-106 and UNL-113

KSU-106 had some collaborative research with the ATIP farming systems research project prior to 1990; the project has not been active in Botswana since then. UNL-113 supplied a scientist to continue Dr. Lucas Gakale's research on cropping systems during his Ph.D. studies in Nebraska. After Dr. Gakale's return to Botswana, UNL-113 has not continued a collaborative program with the DAR.

SADC/ICRISAT Regional Activities

Several of the individual INTSORMIL PIs have collaborative activities with SMIP scientists. Such linkages can be an effective means for INTSORMIL to benefit from the existing sorghum and millet collaborative research efforts in the region to introduce and/or test genetic material, to study pathogen variability, disease or pest severity, etc. Such linkages do not usually involve any funding from INTSORMIL projects, other than travel expenses. The benefits of such regional activities to national programs are likely to be in the form of knowledge of problems and solutions, which can then be applied in collaborative linkages with individual country scientists.

Future Research Support

The review panel recommends that such research support to the DAR be established in the context of a SADC regional research support program, not on a bilateral basis. Such a regional program should be based on a general agreement between INTSORMIL, SACCAR, and an appropriate donor, and implemented through MOU's with individual countries. These MOU's should describe the objectives, work plans, and time frames of the specific support/training activities agreed on between individual INTSORMIL PIs and the national research organizations, as noted above. The possible model for future INTSORMIL training/support in sorghum and millet research at the regional level in southern Africa was discussed at length in a meeting with the Principle Program and Training Officers of SACCAR in Gaborone. A number of specific activities were identified under the general heading of "second generation research training/support," including the following:

> Short term training courses in specialized techniques conducted in the SADC region

> Specialized training for individual scientists in U.S. University or industrial laboratories.

> Consultancies by INTSORMIL scientists to SADC member institutions.

> Study leave/sabbatic support for U.S.-based scientists in SADC institutions and for SADC scientists in U.S. Universities .

> Joint research projects in areas of mutual interest.

> Supporting research in U.S. Universities on problems of importance to SADC institutions, which require basic research technologies not available in SADC institutions.

> Limited postgraduate degree training in specialized/new research areas not covered in previous INTSORMIL degree programs. The proposed budget for Phase III of the SADC Regional Sorghum and Millets Improvement Program (SMIP) to be provided by USAID, is likely to contain U.S.$ 100,000 per annum for training. The panel members were given to understand from both SACCAR and USAID representatives that this was intended to address specific training needs not covered in the larger scale degree training programs in Phases I and II, and as such, include much of what is described above as "second generation" training. U.S. Government regulations restrict the spending of such funds only to developing countries or the U.S.. This would appear to present an excellent opportunity for INTSORMIL to make a proposal to SACCAR to provide a range of "second generation" training services to the SMIP and its member countries. Such an arrangement, if accepted by SACCAR, would have a number of advantages for INTSORMIL:

- INTSORMIL would be assured that its efforts in the region would be clearly identified with regional and national research priorities;
- the individual linkages established between INTSORMIL scientists and their former students in the SADC region could be fully exploited, to mutual advantage;
- INTSORMIL could position itself favorably for a long term involvement in the southern African region; and,
- INTSORMIL could be assured of external funding for a period of ten years to supplement its own project funding for its work in southern Africa. The Phase III SMIP documents (proposals for funding) are currently under preparation, as Phase II ends in September, 1993. INTSORMIL, therefore, needs to move quickly if it wishes to take advantage of this opportunity for establishing a regional research training/support program. Given the favorable light in which INTSORMIL is held in the region, because of the success of its extensive training program for the SMIP project, the review panel members strongly recommend that INTSORMIL not miss this opportunity.

Summary and General Comments

The utilization of sorghum and millet has received very little attention in the INTSORMIL program in Botswana and Zimbabwe despite the evident need and opportunities that could be realized through the collaboration of Purdue, Texas A&M, and Kansas State. Markets for sorghum and millet are constrained by a lack of demand from food processors, caused by an absence of systematic information on useful functional properties.

DAR devotes no resources to food utilization nor does it appear to cooperate systematically with RIIC or BFTC. It is not clear where the food science graduate student now at Texas A&M will be employed when she returns.

Botswana is not poor, relative to its neighbors. Its need is for technical cooperation and advice rather than financial assistance. There is little evidence of integrated planning and management for agro-industrial development. INTSORMIL could make use of facilities at Mississippi State University for training in agro-industrial management. INTSORMIL's admirable record in the formation of specialist scientists needs to be complemented by training of men and women who will plan and manage integrated agricultural production and post-production systems.

It now seems timely to consider shifting the INTSORMIL program from a national to a regional orientation and emphasis. The needs of the SADC countries have many commonalities.

There is need for effective cooperation in research and training on fundamental issues, leaving those of purely national concern to the respective governments.

INTSORMIL can continue as an effective partner to SACCAR in bringing into being a well-integrated agro-industrial regional program from which all the member nations can benefit. To this end, it is very important that INTSORMIL be involved directly in the examination and consideration of the future of the Matopos Station.

The necessary components for a sustained national research program on soil and water management in Botswana seem to be in place, and a continued direct involvement in this area by INTSORMIL does not seem necessary. This, however, does not preclude support of research in this area by INTSORMIL scientists through linkages with Botswana scientists, if there is an interest in the DAR in such linkages. The Director of the DAR concurred in this recommendation.

There was a general consensus that a "second generation" training/support activities, which could provide specifically tailored training, collaboration, and technical support to DAR research projects should be initiated. Future linkages must (1) be requested by the DAR in support of its own research priorities, (2) be thoroughly planned in meetings with the DAR program leaders and INTSORMIL PIs and (3) be clearly documented in MOUs between the two organizations. The present, apparently ad hoc arrangements, are not appropriate in the southern African context of research planning and implementation.

The review panel recommends that such research support to the DAR be established in the context of a SADC regional research support program, not on a bilateral basis. Such a regional program should be based on a general agreement between INTSORMIL, SACCAR, and an appropriate donor, and implemented through MOUs with individual countries.

Recommendations for Future Collaboration with the DAR

Soil and water management research, which was the subject of KSU-107, is now well integrated into two of the DAR's basic research programs, the Soil/Water Management and Agricultural Engineering Research Program and the Production Systems Research Program. Both of the programs appear to be adequately staffed and to have an extensive research agenda (based on the limited information available to the review team). In addition, there is a special Working Group on Tillage and Fertilizer Research composed of scientists from the DAR and the Arid Lands Development Program (ALDEP), with support from the UNDP/FAO Soil Mapping Service, which is charged with developing clear recommendations on tillage and fertilizer management practices for dryland crops in Botswana. (The soil physicist assigned to the DAR under KSU 107 was instrumental in organizing this group in 1988). Thus, the necessary components for a sustained national research program on soil and water management in Botswana seem to be in place, and a continued direct involvement in this area by INTSORMIL does not seem necessary. This, however, does not preclude support of research in this area by INTSORMIL scientists through linkages with Botswana scientists, if there is an interest in the DAR in such linkages. The Director of the DAR concurred in this recommendation.

The most widely recognized and appreciated contribution of INTSORMIL to agriculture in Botswana is, undoubtedly, the post graduate training of Botswana scientists done under both INTSORMIL's own projects and under the USAID/CIDA/GTZ-financed regional Sorghum and Millets Improvement Project, which contracted with INTSORMIL for the training of nearly 100 scientists from SADC member countries. This training has provided a significant base of trained scientists to the DAR.

The success of this training program has stimulated an interest in the DAR in maintaining access to INTSORMIL's technical expertise in sorghum and millet research to support its own research programs in this same area. There was a general consensus that this should take the form of what might be called "second generation" training/support activities, which could provide specifically tailored training, collaboration, and technical support to DAR research projects which could benefit from these. This is particularly the case with projects under the direction of young scientists who do not as yet have sufficient practical experience in research planning and research management, and who could thus benefit from a linkage with an INTSORMIL senior scientist.

This type of support fits well with the concept of linkages between INTSORMIL U.S.-based staff and DAR scientists who have been trained by INTSORMIL Universities. Several such linkages have either been initiated or proposed in Botswana by INTSORMIL principal investigators (see section on Linkage Programs). These linkages, however, appear to have developed in an unplanned and unstructured fashion, and are consequently considered by the Director of the DAR to be of rather doubtful value to the DAR's own research effectiveness. (The review team was handicapped in trying to evaluate these linkages by a lack of documentation as to their purpose and activities, and by a lack of a presentation of their activities by DAR scientists, and consequently had no means of verifying this. The lack of any formal plans for these activities, however, suggests that the Director's observation is justified). Future linkages encompassing one of more of the types of support activities listed above must (1) be requested by the DAR in support of its own research priorities, (2) be thoroughly planned in meetings with the DAR program leaders and INTSORMIL PIs and (3) be clearly documented in MOUs between the two organizations. The present, apparently ad hoc arrangements, are not appropriate in the southern African context of research planning and implementation.

The review panel recommends that such research support to the DAR be established in the context of a SADC regional research support program, not on a bilateral basis. Such a regional program should be based on a general agreement between INTSORMIL, SACCAR, and an appropriate donor, and implemented through MOUs with individual countries. These MOUs should describe the objectives, work plans, and time frames of the specific support/training activities agreed on between individual INTSORMIL PIs and the national research organizations, as noted above. The possible model for future INTSORMIL training/support in sorghum and millet research at the regional level in southern Africa was discussed at length in a meeting with the Principle Program and Training Officers of SACCAR in Gaborone. A number of specific activities were identified under the general heading of "second generation research training/support," including the following:

> Short term training courses in specialized techniques conducted in the SADC region.

> Specialized training for individual scientists in U.S. University or industrial laboratories.

> Consultancies by INTSORMIL scientists to SADC member institutions.

> Study leave/sabbatic support for U.S.-based scientists in SADC institutions and for SADC scientists in U.S. Universities.

> Joint research projects in areas of mutual interest.

> Supporting research in U.S. Universities on problems of importance to SADC institutions, which require basic research technologies not available in SADC institutions.

> Limited postgraduate degree training in specialized/new research areas not covered in previous INTSORMIL degree programs.

The proposed budget for Phase III of the SADC Regional Sorghum and Millets Improvement Program (SMIP) to be provided by USAID, is likely to contain US$ 100,000 per annum for training. The panel members were given to understand from both SACCAR and USAID representatives that this was intended to address specific training needs not covered in the larger scale degree training programs in Phases I and II, and as such, include much of what is described above as "second generation" training. U.S. Government regulations restrict the spending of such funds only to developing countries or the U.S.. This would appear to present an excellent opportunity for INTSORMIL to make a proposal to SACCAR to provide a range of "second generation" training services to the SMIP and its member countries. Such an arrangement, if accepted by SACCAR, would have a number of advantages for INTSORMIL:

> INTSORMIL would be assured that its efforts in the region would be clearly identified with regional and national research priorities;

> the individual linkages established between INTSORMIL scientists and their former students in the SADC region could be fully exploited, to mutual advantage;

> INTSORMIL could position itself favorably for a long term involvement in the southern African region; and,

> INTSORMIL could be assured of external funding for a period of ten years to supplement its own project funding for its work

in southern Africa. The Phase III SMIP documents (proposals for funding) are currently under preparation, as Phase II ends in September, 1993. INTSORMIL therefore needs to move quickly if it wishes to take advantage of this opportunity for establishing a regional research training/support program.

Given the favorable light in which INTSORMIL is held in the region, because of the success of its extensive training program for the SMIP project, the review panel members strongly recommend that INTSORMIL not miss this opportunity.

Honduras - Project TAM-131

November 30 - December 4, 1992

Review Team

Dr. Lawrence Busch, Michigan State University
Dr. Merle Shepard, Clemson University
Dr. Bruce Maunder, DEKALB Plant Genetics

Visiting Participants

Dr. Bobby Eddleman, Board of Directors, Texas A&M Agricultural Experiment Station, Corpus Christi, TX
Dr. John Yohe, Director, Management Entity, University of Nebraska, Lincoln, NE
Dr. Gary Peterson, Country Coordinator, Texas A&M Agricultural Experiment Station, Lubbock, TX
Dr. Darrell Rosenow, Texas A&M Agricultural Experiment Station, Lubbock, TX
Dr. Richard Frederiksen, Texas A&M University, College Station, TX
Dr. Lloyd Rooney, Texas A&M University, College Station, TX

Project Leaders

Dr. Dan Meckenstock, Principal Investigator, TAM-131
Dr. Francisco Gomez, Honduras National Sorghum Coordinator

TAM-131, "Tropical Sorghum Conservation and Enhancement in Honduras and Central America," has functioned for 12 years out of Honduras with a stated objective, "to improve the quality of life of farm families in Honduras that produce sorghum." Since the last EEP review (December 1986) this project has become much more involved with inter-CRSPing; has become more involved with extension type activity, e.g., LUPE; and formulated a workable Memorandum of Understanding with the Panamerican Agricultural School (EAP). This latter arrangement provides office and laboratory space as well as administrative support for PL480 funds programmed to strengthen the national sorghum program. Also, recent research studies suggest that maicillos possess the unique attribute of shade tolerance, so significant to a sustainable agricultural system, and specifically here where sorghum is often grown under a maize canopy. TAM-131 technical emphasis stresses conservation of local landrace sorghum populations and their enhancement.

The EEP was particularly pleased with the type of advance planning, including reference material, made available prior to this review. Also, organized discussions with Dr. Keith Andrews, new Director of the EAP, in Miami prior to the review as well as his predecessor, Dr. Simon Malo were of significant value. Other such sessions throughout the week included:

USAID Mission Staff

- Mr. Dwight Steen
- Dr. Vince Cusumano

- Dr. Edgar Cabrera

Ministry of Natural Resources

- Ing. Roberto Toledo

Dept. of Agronomy, EAP

- Dr. Juan Rosas

Dept. of Animal Science, EAP

- Dr. Raul Santillan

Farm visit

- Dan Cupertino

LUPE

- David Leonard
- Peter Hughes
- Hector Sierra

The EEP, prior to specific observations and issues, would be remiss in not noting and complimenting Meckenstock and Gomez for their well organized and sizeable breeding project, an effort which is likely one of the largest of any host country program within INTSORMIL. The partnership between these two scientists has been complementary and synergistic to the overall benefit of the project. Meckenstock has done an extraordinary job of developing an in-country program and bringing in Honduran counterparts who are well trained and excited at the prospect of making a difference through research. This integrated program functions smoothly and involves large numbers of U.S. scientists who estimate some $100,638 of their INTSORMIL funds to be spent in or on behalf of Honduras. Additionally, this program, TAM-131, has shown leadership in the development of outside grants and contracts ($89,790 in 91-92) as well as inter-CRSPing activities. Finally, their strategies, short, mid, and long term, seem well thought out and reflect the high level of scientific expertise recognized by the EEP in this and previous reviews. Currently, future funding must be the most critical issue facing this exemplary endeavor.

Observations/Findings

Importance of Sorghum in the Honduran Agricultural Economy

Corn is the principal crop with sorghum and edible beans second or third, depending on the year, and rice fourth in importance. Whereas, corn yields run as much as 50% higher than sorghum, this crop is less able to tolerate the stresses found under small, resource poor, hillside farms. Approximately 350,000 ha of sorghum are grown annually in Central America with a 17% increase the past 10 years. Much of this is reported to be in the maicillo criollos which account for approximately 65% of the total acreage. An attempt to break-out current Honduran planted area suggested 60,000 ha in maicillos, 15,000 ha in short grain hybrids and 5,000 ha in Sureño for 25% improved seed. El Salvador, the largest country area-wise, plants 123,000 ha.

Sorghum is primarily for feed but may be a food crop for subsistence purposes. National policies affecting grain prices can significantly affect hybrid seed usage as we observed with farmers' use in 1992-93 of varieties rather than hybrids of corn and thus, a local seed company stocked with carry-over inventory. Since hybrid sorghum seed is an import commodity, supply can be controlled somewhat better.

With a birth rate said to be averaging 3.2% annually, demand for feed/food grain will increase especially to supply a rapidly increasing urban market. In contrast, steepland sorghum production is devastating for the Honduran environment with its growth no doubt due to (1) population growth, (2) lack of flat arable land, and (3) monopolization of the better land by larger landholders. Fortunately, INTSORMIL scientists realize the gravity of erosion from these hillside farms and are working closely with LUPE in this regard.

Of the 2/3's of the Central American sorghum currently in maicillos the heaviest concentration is in El Salvador and Honduras followed by Guatemala and Nicaragua. The apparent increase in these and the acceptance shown for Sureño would suggest TAM-131 inputs to be on target as the commercial seed activities remain involved with hybrids where their investment can be protected.

Honduras INTSORMIL Program: A Unique Institutional Arrangement

The transfer of the program to the EAP appears to be a very desirable move but the program in its current structure can only exist with funding outside the Honduran government and outside TAM-131 budgeting for that matter. The EAP has an outstanding reputation for its continuation of structured classes and hands-on experience with a highly successful alumni. Dr. Andrews, the new director, is likely to give more emphasis to research which is an objective yet to be realized by this institution. Recent linkages with LUPE, in addition to six other CRSPs, should further strengthen the presence of INTSORMIL in Honduras. Benefits are exemplified in the field demonstrations that the EEP team visited at Don Cupertino's farm at Los Espabeles where combinations of treatments, (e.g., seedlings treated with systemic insecticides to control the lepidopterous larvae complex, stone walls and *Teucaena leucocephala* to prevent erosion and interplantings of improved maicillos with corn). These linkages will enhance the long term sustainability of the INTSORMIL program in Honduras.

The national research system can continue to benefit without long term technical assistance provided that PL480 funds remain available as support for all versus a part of the program. The government does not currently have funds for such support or even to match PL480 money. Given that much of the research is for the subsistence sector, it is unlikely that the private sector can or will pick up this burden.

As the project matures, more counterparts exist for U.S. based PIs. From a plant protection perspective, more Honduran counterparts need to be trained. Plant protection specialists at EAP are, however, backstopping this part of the program. Dr. Gomez with his background in both breeding and grain nutritional quality makes a significant in-country contribution.

Relation of INTSORMIL to USAID Mission Country Strategy

The mission emphasized that INTSORMIL has been a very effective program that has had a major impact particularly with its interaction with the Ministry of Natural Resources and the EAP. Mission strategy is, however, currently unclear and may remain so until the new administration determines direction for the Agency. As mentioned, PL480 funds are becoming increasingly tight with requests to the Honduran government for matching money. Also, new strategies have been developed within the Ministry and USAID with the INTSORMIL program not necessarily a high priority. Their general goals of sustainability support agricultural production and export plus natural resource management which, in the latter case, favors TropSoils and SANREM (sustainable agriculture). Continued emphasis on sustainable hillside farming systems from an environmental/conservation perspective seems, however, to fit into mission objectives.

Funding

The most recent complete figures on budget are the 91-92 fiscal year with these inputs:

TAM-131	$ 135,000
PL480	88,700
Other	490
Total	$ 224,190

Also, INTSORMIL projects spent in or on behalf of Honduras totaled $111,116 for 1991-92 for a grand total of $335,306. Approximately $2,388,000 has gone through this program since its inception without including this "other project" allocation. Additional outside funds are currently being sought with support now coming from the PCCMCA, the private seed sector for evaluation of hybrids, and the EEC (strengthening grant for control of downy mildew). Some $15,000 of the budget goes to the EAP annually for overhead. Some teaching activity, e.g., by Dr. Gomez would likely offset part of this cost and bring a closer relationship between the EAP and INTSORMIL.

The level of commitment from the Mission for future years is uncertain at this time but every indication suggests a phasing out by the year 2000. Also, there is no clear indication of a source of Ministry support. Were long term technical assistance withdrawn it is likely that less work would be accomplished, however, this program in a narrower perspective could continue at a reasonably high level of productivity. Less time could be used for administrative purposes (now estimated at 50%) as well as inter-CRSPing or extension activities, all currently worthwhile endeavors.

Project Performance and Maturity

The INTSORMIL program in Honduras has been singularly effective, in large part due to the long term commitment of Dan Meckenstock and, for the past six years, Francisco Gomez along with the strong support of the AID mission. Two varieties, Sureño and Tortillero, and a hybrid, Catracho, have been selected/developed/evaluated by the project with Sureño by far the most successful. Also, three or four photoperiod sensitive shade tolerant hybrids are currently in advanced testing. Testing of commercial hybrids and the publication of data has apparently increased the national sorghum area by 20 percent or 10,000 ha. Certainly, LUPE is making use of INTSORMIL technology in their on-farm demonstrations. Currently, other CRSPs are in a holding pattern which limits inter-CRSP activity. Certainly stabilizing the fragile ecosystem should be a top priority and continued participation with LUPE is essential.

Economic benefits of the new technology have been studied by Gonzalez-Rey, et al., 1991. Over 40% of farmers in the target areas have adapted new cultivars developed by INTSORMIL and its collaborators. Whereas, the cultivars developed in Central America will not likely be relevant in Africa or Colombia, the technology developed in working with photoperiod sensitive germplasm as well as the shading studies would be applicable. Certainly the size and scope/dedication in this program are such that it would be an ideal training area for those involved with other collaborative sites.

The project has had and should have influence regionally but this could be considerably improved now that conditions in neighboring countries have changed. Budget constraints may be responsible for less inter-country activity. Germplasm has been circulated and undoubtedly has been of value. Apparently not much credit gets back to those involved in the development/circulation.

Training has certainly been a strength for these past 12 years and information provided suggests five students associated with TAM-131 have gone on for a Ph.D.; nine have gotten an M.S., and ten became Ing. Agronomos, for an average of two students each year. These numbers could very well increase if the EAP does in fact become more research oriented.

Some 13 journal publications have come from the project. Descriptions of varietal releases, e.g., Sureño and hybrid trial results are well done and have been well received. A future publication relating to all aspects of maicillo criollo management practices could make a significant impact regionally.

Technical Aspects

Breeding

The technical thrusts of TAM-131 emphasize conservation and enhancement. The former effort stresses the conservation of maicillo by *in situ* means although an effort has been made to collect a fair number of the landraces for ex situ conservation. Certainly breeders in other environments realize the existence and potential of many useful traits. Some enhancement of maicillos has taken place and is now being utilized on farms with the goal of increasing the diversity of this unique class of sorghum. This means that elite genes have been introgressed into primitive cultivars which is essentially the reverse of the sorghum conversion program which is designed to allow the introgression of genes from primitive cultivars into elite germplasm.

The short term goal of varietal release of food types was successful and involved insensitive types which included Sureño in 1985. The mid-term goal is to enhance available maicillos by (1) reducing plant height, (2) adding tan plant color, (3) increasing resistance to foliar disease, (4) incorporating resistance to downy mildew, (5) selecting for better exsertion/seed number, and (6) maintaining such critical traits as maturity, white testa-free grain, shade tolerance, and photoperiod sensitivity. These enhanced maicillos have been reported to yield up to 58% more grain than original parental material. The long term goal will be hybrid maicillos using complementary height genes to allow for easier seed production. Technology from this effort will be of value to tropical situations in other sorghum areas of the world.

We were particularly impressed by the large segregating nurseries with and without intercropping with corn. It seems appropriate that both photoperiod sensitive and insensitive materials be worked at La Lujosa. With needs projected in the range of a 50% yield increase over the next 25 years, much will need to come from the best farming situations where hybrids of a photoperiod insensitive nature are currently used. Also, much of this segregating germplasm will likely show marked improvement for the maicillos where yield increases have been more or less nonexistent (see appendix). Philosophy and activities in the breeding program look to be right on target with this program serving as an example for others in emphasizing that plant breeding is a numbers game and you can improve your odds by working a wide array of germplasm with large populations. The EEP certainly commends this research effort.

We were somewhat surprised to see such a large program, that appeared to be computer driven, still planting in the same fashion as was done since the early days of agriculture. Cost of a modern 2-row max-emerge planter with cones should not run over $10,000, less if used. This would result in much greater precision of stand establishment avoiding uneven emergence and allow for uniform application of fertilizer, herbicides, and insecticides. On-farm demonstrations would still be handled in a conventional way where subsistence farming is practical.

Entomology

The team was not able to observe fields with the "Langosta" complex (caterpillars that attack the seedling stage) but visits to a demonstration farm at Los Espabeles (Don Cupertino's farm) allowed us to see fields receiving earlier treatments with the systemic insecticide, Promid, that was used as a seed treatment. This carbamante insecticide has a lower mammalian toxicity than Furadan, the chemical previously evaluated. Earlier studies showed that some varieties had resistance to the armyworm complex but this was not enough to control the pest complex. It is good that entomologists are taking a more ecologically-oriented perspective. Planting date or habitat manipulation, combined with some plant resistance, could be more sustainable in the long term than the use of systemic insecticides. It was reported that attacks by the grass looper, *Metaponpneunata rogenhoferi*, can be avoided by late plantings.

We commend the biological control efforts. The role of ants and the earwig, *Doru*, should aid in understanding when or if pesticides are needed for control of caterpillar pests of seedlings. At present, however, systemic insecticides seem to be the only effective tactic. The use of these materials should be de-emphasized and more ecologically sound, less expensive and less hazardous approaches should be explored.

Our visit to the downy mildew nursery at Comayagua revealed differential plant responses to infestation of yellow sugarcane aphids. Entomologists should make closer observations of this along with the possible crop losses by stem borers and leaf-footed bugs.

Pathology

Pathotype 5 of downy mildew has been of concern for at least seven years and is especially common in the Comayagua region. TAM-131 recognized this new pathotype as reported in the 1986 review. Now they not only are incorporating resistance in the maicillos but are offering a screening service to the private sector which benefits industry, Honduras, and provides additional funds to the project. At least two multinational seed companies were taking advantage of this opportunity. A close cooperative effort with TAM-124, Dr. Frederiksen, provides useful technical assistance regarding mildew as well as the many foliar diseases.

Quality/Utilization

Dr. Gomez is trained in that aspect of breeding (TAM-126, Rooney). With his experience and expertise, naturally, breeding efforts will stress the high level of grain quality desirable for food purposes as well as the need to avoid damaging late season molds. Certainly one of the six categories of enhancement objectives stresses nutritional quality but the use of sorghum for food is currently limited to maicillos when the corn crop is lost or inadequate. Sureño also possesses acceptable food properties.

Physiology/Agronomy

UNL-113 - Agronomy, which involves the University of Nebraska, supports this aspect of the program which, for example, relates to the shading phenomenon. The PI's postulate that shade tolerance will be one of the most important discoveries in sorghum research in the 90s which will require a multidisciplinary effort to elucidate its causes and benefits. A position paper on shade tolerance is included in the appendix. Examples of differences shown the EEP at Zamorano (EAP) were certainly dramatic. The value of this trait to the temperate and short insensitive sorghums is yet to be determined. However, recent studies in this project suggest shade tolerance may be selected on the basis of yield. With that trait lower leaves in the canopy will make a greater contribution to production.

Socioeconomics

Given the very small investment in socioeconomic research in Honduras in recent years, accomplishments have been substantial. As Gonzales-Rey et al. (1991) have shown, the internal rate of return to sorghum research in Honduras is substantial. While the precise values that they put on the economic benefit may be arguable, there is little doubt that returns have been substantial.

However, there are other issues not addressed (presumably for lack of funds) that could be of direct benefit to INTSORMIL programs. Why has diffusion of the new steepland cultivars proceeded at so slow a pace, given the small area, dense population and widespread extension effort? How does the reorganization of the seed industry and the relative prices of various grains affect INTSORMIL's lowland sorghum program? What institutional barriers, if any, exist to the transfer of technologies developed in Honduras to surrounding nations? How might they be overcome? Are there indigenous practices of sorghum cultivation that might be of use to the INTSORMIL program? These and related questions beg further analysis.

Collaboration

Considerable comment has been made already, but to reemphasize, the PIs have strong linkages with the Ministry of Natural Resources, the EAP, other CRSP scientists, U.S. collaborating PIs (see appendix) and USAID staff. This became even more obvious as Dr. Vince Cusumano accompanied us to Comayagua to view the disease screening there.

Inter-CRSP Activities - Private Sector - Regional Activities

Inter-CRSP activities are beneficial and the PI's have taken a lead role with both having specific activities. The private sector in Honduras is weak and poorly organized. Moreover, it is hampered by poor infrastructure, the only partial money economy, and, arguably, by the constantly changing governmental legal framework within Honduras and as imposed by the international donor community. This is not likely to change in the near future.

Moreover, despite the privatization of much research, certain kinds of research are no less likely to be of priority to the private sector in Honduras than they are in the U.S.: germplasm enhancement, development of improved cultural practices and soil conservation measures, crops grown largely for subsistence, etc.

Furthermore, there is some confusion over what "private sector" means. In the case of the seed industry, it appears that some effort is being made to permit and encourage private companies to enter seed production. However, obtaining the necessary capital is not easy. In addition, certification procedures are bureaucratic and lengthy making this a risky enterprise.

The privatization of research is taking several paths. The EAP is a nonprofit school with an international board. It has a 50 year history of performance and is likely to continue to succeed. In contrast, the new foundation for research risks being accountable to no one at all; in any case, its need for funds will likely limit its role to export crops where growers can pay fees. Another aspect of the private sector is the Non-Government Organizations (NGOs) such as World Neighbors and World Vision. The organizations do cooperate with INTSORMIL, though we learned little about their effectiveness.

This means that INTSORMIL will have to pick and choose among private sector organizations, some of which will prove valuable and dynamic partners while others will soon fade from sight.

Regional activities have been reduced as already discussed, mostly because of available funds. Being located at the EAP, however, immediately results in a regional approach since it is the only Central American agricultural institution with emphasis on semiarid agriculture. CLAIS did not operate in 1992 because of a lack of funds on maicillos. The role of ICRISAT in Central America is currently changing, likely diminishing, and new strategies being developed. Locally, the Ministry is planning a major government revision which privatizes sorghum in as much as the responsibility for this crop is given to the EAP. Nothing, however, indicates funding to help support this reorganization. This project has been active with the PCCMA with Dr. Gomez past president. Dr. Gomez has also just completed a two year term as the elected president of the Council of Latin American Sorghum Researchers (CLAIS). In 1990, he was appointed as the EAP's representative to the National Council of PRIAG (i.e., Regional program to Strengthen Agronomical Research in Basic Grain in Central America) which is sponsored by the EEC. Dr. Meckenstock, as newly appointed team leader of the Inter-CRSP Council, has felt it necessary to shift more time and resources previously committed to sorghum networking in Central America to developing an Inter-CRSP program in Honduras.

Recommendations and Future Prospects

The EEP recognizes several issues which seem appropriate to address in this review:

> The Honduras program needs to be broadened to cover all of the sorghum growing areas in Central America. Until a few years ago, the various internal conditions in Central America made a regional program nearly impossible. However, the situation has improved markedly which will allow INTSORMIL to take the lead in establishing a sorghum research program for the region. This should involve both the establishment of formal cooperative relations and multilocational testing in these countries as well as student training. As ICRISAT reduces their support, more networking activities by INTSORMIL need to be initiated. It seems especially important, with the limited area planted in sorghum in each Central American nation, that activities in Honduras affect neighboring countries.

> After some 12 years of significant input and assuming budgeting will continue to be a limiting factor, a phasing out strategy for Dr. Meckenstock needs to be considered by the parties involved. Several reasons for this exist, e.g., several Hondurans are well-trained and could take over leadership of the national program—Dr. Francisco Gomez being the most logical example. The current structure between these two, though not readily apparent in the interviews, must create certain inhibitions. Third, the total sorghum acreage in Honduras hardly seems to justify a full time INTSORMIL employee in country. Indeed, it would perhaps be appropriate to put a person in the field in another nation (perhaps Africa) at this time. A phaseout date should be established by the technical committee and phaseout accomplished within the next several years.

> INTSORMIL should continue to explore the possibility of inter-CRSPing based in Honduras. Indeed, one way in which Meckenstock might be phased out of the INTSORMIL program would be to have him serve as coordinator for several CRSPs working in the area. This seems reasonable in that many of the gains made by improved sorghum cultivars on the Honduran hillsides will be wiped out unless better soil conservation techniques are developed and put into wide-spread practice. Similarly, pond fisheries are unlikely to succeed if farm runoff causes rapid silting. Finally, sorghum production needs to be incorporated into larger sustainable systems, thus collaboration with the sustainable agriculture CRSP, SANREM, is desirable.

> The EAP has indicated a desire to utilize Dr. Gomez more in a teaching capacity, a position for which he would be well qualified. Should this be possible, then part of his wage could reasonably come from the EAP which along with INTSORMIL support could sustain the project in the absence or significant reduction in PL480 or Ministry funds.

> Given the successes of the Honduran program, we recommend the next PI meeting be held there. It has the advantage of being close to the U.S., thereby keeping travel costs down, and would permit PIs a first hand look at the multiple activities of TAM-131. It should also bolster support for the Hondurans' own programs.

> Should matching funds not be forthcoming from the Ministry, and a subsequent halving of the current PL480 money, one approach might be to attempt to reduce administrative time spent by both Meckenstock and Gomez which currently equates to nearly one PI. Certainly, benefits of research versus administrative gains would need to be considered.

> A general comment or two about the review seems appropriate. The EEP found it necessary to request more time for in-depth discussion with the principal investigators. We realize they like to show as many aspects of their program as possible but visiting every field site with 11 or more people often becomes less than productive and relatively uninformative. Also, perhaps the numbers present for the review were too large. We would, however, suggest that in the future more time be devoted to informal discussions with the PIs and local counterparts so that the EEP can focus on key issues of concern to all. To avoid misunderstanding, the review in our estimation was highly successful and we came away with a much better appreciation for TAM-131 and its highly successful program in Honduras.

Mali

October 11-16, 1993

Review Team

Dr. Fran Bidinger, Principal Scientist, ICRISAT, India (Agronomist)
Dr. Lawrence Busch, Professor, Michigan State University (Social Scientist)
Dr. Joseph Hulse, Consultant, Sciences-Hulse Int'l Developments Associates, (Grain Utilization Specialist)
Dr. Merle Shepard, Professor, Clemson University (Entomologist)
Dr. Bruce Maunder, EEP Chair, Senior V.P. DEKALB Genetics Corp. (Sorghum Breeder)

Collaborating Entities

IER (Institute of Rural Economy)
INTSORMIL CRSP
SPARC (Texas A&M University - Supporting Research Planning and Financial Organization)
WASIP (Sorghum Improvement Program in West Africa - ICRISAT)
TropSoils - CRSP
USAID - Catherine McIntyre, A.D.O.

Project Title

Sustainable Systems for Production, Utilization, and Marketing of Sorghum and Millet in Mali

Country Coordinators and Respective Collaborative Institutions

Dr. Aboubacar Toure, IER Republic of Mali
Dr. D. T. Rosenow, INTSORMIL, Texas A&M University

Major Research Objectives

Develop improved sorghum and millet cultivars adapted to Malian conditions with high yield potential, good levels of disease, insect, and drought tolerance, and acceptable food quality.

Develop an integrated approach to reduce disease problems of Mali, including *Striga*, through an interaction of pathology and breeding.

Identify cultivars and breeding lines with various types of stress resistance, study mechanisms giving resistance, and incorporate into improved types.

Relate the interaction of soil fertility, cropping systems, and toxicity on water use and grain production to breeding lines that combine drought tolerance with resistance to soil deficiencies or toxicities.

Define grain characteristics and other factors affecting food quality; evaluate the grain quality of new lines and cultivars; and develop new food products from sorghum and millet with increased utilization and marketing potential.

Coordinate marketing and economic studies with cropping systems and product development activities to achieve profitable systems of production, enhanced value-added processing, and enhance income and food availability for producers and consumers.

Current collaboration between INTSORMIL PI's and Malian scientists would be for:

Breeding of sorghum and millet

Aboubacar Toure - IER
Amadou Sy - IER

D. T. Rosenow - TAM-122
Karim Traore - IER
W. Stegmeier - KSU-101
F. R. Miller - TAM-121
G. Ejeta - PRF-107
G. C. Peterson - TAM-123

Sustainable Crop Protection Systems

Yacouba Doumbia - IER
Bourema Dembele - IER
G. L. Teetes - TAM-125
Kadiaton Toure - IER
R. A. Frederiksen - TAM-124
Marian Diarra - IER
Aboubacar Toure - IER

Sustainable Crop Production Systems

S. B. Coulibaly - IER
J. W. Maranville - UNL-114
Mamadou N'Diage - IER
Steve Mason - UNL-113
Abdoul W. Toure - IER
A. B. Onken - TAM-123/TropSoils
Minamba Bagayoko - IER
G. C. Peterson - TAM-123
Zoumana Kauyate - IER
M. Doumbia - IER/TropSoils
Aboubacar Toure - IER

Grain Utilization, Quality, and Marketing

Haidara Mariam Fofana - IER
L. W. Rooney - TAM-126
Ibrahim Goita - IER

Economics

O. N. Coulibaly - IER/Student
J. Sanders - PRF-105

Potential Impact

New processing techniques and new products could stimulate small businesses, enhance market demand, provide local foods with shelf stability, and enhance income to sorghum/millet producers.

New sorghum cultivars combining head bug resistance, grain quality and overall adaptation could begin to replace traditional cultivars.

The understanding of the soil/nutrient deficiency/water/genotype interactions would lead to proper research/methods/solutions to this serious problem of West Africa.

Funding

The annual budget allocation for this project is U.S. $100,000 with $58,500 available to IER and $41,500 being held by INTSORMIL for Mali purchases. Total funds expended on behalf of Mali for years 12-15 (July 1, 1990-June 30, 1994) would be:

Travel	$ 254,780
Equipment	157,400
Salaries/benefits	347,534
Host country contribution	580,000
Overhead	181,633
Institutional match	23,285
Other direct costs	240,271
Total	$1,784,903

The host country contribution may not be a realistic figure but is the best available. Additional funding results from SPARC funds passed through the USAID Mission to IER for one full-time person in the field as an advisor under a contract with Texas A&M University.

Importance of Sorghum and Millet to the Malian Agricultural Economy

The principal cereal crops, sorghum and millet, account for over 75% of Mali's total cereal production. Sorghum and millet are considered the staple cereals in the country. Together, both crops occupy about 75% of the total cultivated land area in the country and produce approximately 1.3 million tons of grain or 866 kg/ha. With consumption constant at 167 kg per person, a 3.5% increase in production annually will be needed to reach the 2.475t required by 2010. Although grown throughout Mali, about 60% of the cultivated area is in the south, which receives more than 800 mm of rain annually. Some 30% of the crop is produced in the central with 500-800 mm of rainfall. This leaves some 10% for the drier north.

The role of agriculture in the economy of Mali is crucial; it has contributed an average 48% to the gross domestic product (GDP) over the past five years. Some 75% of the population is in rural areas, of which 70% are directly employed in agriculture (52.5% of work force).

Sorghum is essentially a food crop in Mali but increased demands for protein through meat will generate increasing demands for the crop in poultry diets. This could be the most likely acceptance of hybrids, e.g., in the southern cotton area under irrigation. The leaves and stalks serve as livestock feed and the stalks alone frequently serve as building materials, e.g., for fences, housing and storage. Millet will basically have a similar utilization.

Institutional Arrangement

The effectiveness of INTSORMIL collaborative research programs in developing countries depends largely on the interest, organization and leadership of the national programs themselves. The INTSORMIL/Mali project continues to gain momentum because the IER has developed into a well led and effective organization, which is able to productively use materials and scientific input from INTSORMIL. Malian personnel trained in sorghum and millet research by INTSORMIL form the backbone of the IER's research program on these crops, and provide a large pool of ideal collaborators for US-based INTSORMIL scientists. Collaboration over several disciplines is making a significant contribution to the IER program.

Less than a decade ago, there was relatively little scientific capacity for sorghum or millet research in Mali. Hence, while the program was collaborative, it was also driven heavily by INTSORMIL scientists' understanding of the host country problems and prospects. Today, in large part, as a result of INTSORMIL participation and collaboration, Mali has a dynamic, ongoing sorghum/millet research program run largely by Malian scientists trained at INTSORMIL institutions. At present, some 37+ projects are underway with various donors. The INTSORMIL program is unique in that it has been long term and ongoing, and has focused on building an effective agricultural research capacity that will remain in place long after INTSORMIL has left the scene. The program is truly collaborative. Materials, trials, ideas, and breeding strategies, are developed through mutual collaboration and dialogue. Moreover, Malian scientists are now able to identify constraints, develop programs, and identify key areas for collaboration.

In large part, as a result of the growth and development of the IER, Mali now finds itself at the beginning of what may be a period of enormous growth and productivity in research capacity and performance. USAID has recently approved and initiated a large program, SPARC, designed to upgrade agricultural research and financial management in Mali. The World Bank is considering a similar project which will also extend beyond research to other institution building activities. Together, these projects and programs should take IER to full maturity as a NARS. Continued INTSORMIL participation will be vital to insuring that IER research reaches the point where it is delivered more rapidly and successfully to farmers and other users.

However, there is some concern with respect to IER's ability to respond to the conflicting needs and demands of two major donors: USAID and the World Bank. At the time of our visit, we were pleased to find that USAID was helping IER to develop an up-to-date accounting and financial system. However, the Bank was insisting that it also provide technical assistance in financial management as part of its loan to the Malian government. This has caused some apparently heated discussions between the USAID mission and the Bank but is unresolved at present. Moreover, the Bank was pushing quite strongly for the privatization of IER and the separation of its staff from the government service. If this project goes ahead as planned, it is likely that IER will become a creature of the World Bank for the duration of the loan, as the Bank will be essentially the sole funder. This approach seems ill-advised. It is highly unlikely that IER will become self-supporting at any time in the foreseeable future, given the lack of significant cash cropping in Mali. (Indeed, no developed nation has been able to completely abandon public support for agricultural research.) Thus, if the Bank goes ahead with its plan, in the long run INTSORMIL may lose its collaborators.

Little collaboration was noted between INTSORMIL and WASIP. The IER has strong collaborative research with ICRISAT in millet, but it is not clear that INTSORMIL participates in this. Their center has expertise in breeding both millet and sorghum as well as in physiology and entomology. INTSORMIL should make an effort to participate in the regional sorghum and millet networks, as they are an ideal way of disseminating results of collaborative research, meeting scientists from other countries, and perhaps developing or sharing in collaborative research.

There should be a good opportunity for joint activities among the sorghum/millet, peanut and cowpea CRSPs in the area of cropping systems research, as much of the IER's agronomy research involves these crops in either rotation or intercropping combination. Any future inter-CRSP program should attempt to aid IER agronomists in gaining more advantage from their present program, and not attempt to initiate a new research program(s). INTSORMIL and TropSoils initiated a collaborative project in 1992 on soil acidity/toxicity, which could exploit a potential synergism of considering the problem in terms of both soil and plant simultaneously.

Collaborating scientists exist for all disciplines. Some 19 IER scientists collaborate with 12 U.S. INTSORMIL PIs. Besides staff training and research transfer, INTSORMIL has built and equipped an Agro-physiology Laboratory at the Cinzana Agricultural Experiment Station; three vehicles have been purchased; equipment for the Food Technology Lab was provided, and INTSORMIL has provided computer systems/word processors for CGNET and software to IER scientists.

Discussions with Catherine McIntyre, USAID, ADO, suggest the mission views with favor the input from INTSORMIL as it relates to future country strategy. The establishment of SPARC to support IER research reorganization and handling of finances should make the fit between all parties even better.

Project Performance and Maturity

Some of the primary constraints to improved productivity in Mali should, perhaps, be listed first.

> Producers preference and reliance almost entirely on a specific class of sorghum, the Guineense, has severely restricted outside infusion of cultivars having specific improved traits.

> Lack of head bug resistance in most other sorghums.

> Lack of toxic soil tolerant cultivars and improved nutrient use efficiency.

> Diseases such as charcoal rot, long smut, grain mold, sooty stripe, and anthracnose in sorghum and certainly downy mildew in millet.

> Grain quality for better urban acceptance of Guineense, e.g., with tan plant and white seed.

> Later maturing, photoperiod sensitive types, e.g., the Malisor 84s to avoid the rainy season.

> Absence of food or feed sorghum hybrids which reflects the lack of an improved seed production and distribution infrastructure. (See Introduction for discussion of National/International Seed Enterprises.

> Variability in rainfall, low soil fertility.

> *Striga*.

> Lack of market stability/incentives.

> Cold storage facilities to maintain germplasm over years, especially landraces.

> Technology transfer from current research capability to subsistence farmers who lack equipment and look for better life through rural exodus.

The collaborative mode of operation has been effective in developing the research program by first assessing training needs of the government research program (IER) and then matching returning scientists with the most appropriate U.S. PIs as listed previously. At this stage of the collaborative process, the frequency of joint planning and discussion could determine the success of the specific projects.

A change in the mode of operation would likely only be beneficial if considerably more funding existed. This would allow scientist exchange for three months to one year for a closer level of collaboration. The proposed new organizational structure of the IER will make research more, rather than less, dependent on operational funding from outside. The present balance appears to be good: INTSORMIL, for example, provides 20% of the operational funding for research at the Cinzana station, any less would affect the quality of research, and too much more would make the station too dependent on a single donor.

Some 14 Malian scientists have been trained by INTSORMIL PIs during the period of joint involvement. During this period, INTSORMIL has been wholly or partly responsible for the quality lab at Sotuba, the physiology lab and computer lab at Cinzana, and the vehicles already mentioned. Obviously financial support along with technical support have been instrumental in making this the project it now is.

The quality of the research program appeared good with the number of experiments impressive. The quality of the field work at

Cinzana was particularly impressive. Care must be taken in all disciplines to avoid projects of too basic a nature but instead more effort needs to be placed on applied research and on adapting proven relationships, traits, etc. to Malian conditions.

At this point, the technology developed in the projects is primarily providing a base for the next accomplishments which hopefully will be producer related. Much of the cropping systems work, however, is focused on understanding/refining existing cropping systems, particularly at Cinzana, where the agronomist has close links with local farmers. Refinements, if they meet farmers' objectives and increase production, should be readily accepted. However, fertilizer rates used in collaborative fertility experiments are less likely to be used by farmers under present and likely future economic conditions. Nutritional work found the combination of cowpea and millet flour (1:3) significantly improved the nutritional status of young children. This technology has been transferred to many villages, especially on the Cinzana areas.

While new cultivars have been developed and disseminated, there is little more than anecdotal data on their use in the countryside. Some observers have suggested that the improved cultivars do only marginally better than traditional cultivars under current conditions. This may be due to the selection of closed headed cultivars which are easier to breed but are susceptible to head bug infestations. Moreover, IER lacks a strategy to control release of new cultivars and no social scientist has been involved in studying diffusion of the new cultivars.

The soil toxicity work in Mali should also relate to TropSoils activity in Niger. Also, the cropping systems research should have a wide applicability in Sahelian/Sudanian West Africa, as there are similar soils, climates, and crops across the whole region. INTSORMIL could provide technical backup/collaboration to the current Millet Network and the planned Sorghum Network which is planned to be based in Mali.

The Niger/Mali INTSORMIL sites have enough similarity in research methodology, if not always germplasm, to suggest joint visitations by both PIs as well as local scientists to each country annually, funds permitting. This additional opportunity for exchange could be of real significance. The Mali project was not intended to have more than a national focus but through networks as mentioned above could affect neighboring countries. Some movement of germplasm, e.g., 84-7 to Niger, has taken place and is being worked.

Some six Ph.D. and eight M.S. participants from Mali have been trained and now form the framework of sorghum and millet research in the country. Apparently there are no slots currently available for additional advanced degree training and the long term outlook is uncertain. Much more could be done in the way of shorter term (1-6 month) scientist exchange, to target specific needs such as statistical analysis/computer skills, soil analysis lab management, etc. Both INTSORMIL scientists need to spend time working in the IER program as well as IER scientists working in U.S. universities.

Some 100 demonstration plots of selected improved cultivars were planted as on-farm demonstrations in 1993. Agronomic research has just reached the point where the question of dissemination of results arises. This is an area where the PIs can have an important role as they will have had much more experience in analyzing, writing, and disseminating research results. Again, the West African networks offer an excellent vehicle for this.

Technical Evaluation of Collaborative Research

Breeding

Dr. Niangado, until recently chief millet breeder, and now Director General of IER successfully selected/re-purified improved millet varieties from the better landraces and these are grown on a significant area. His position has been taken by a skilled millet/sorghum breeder, Mr. K. Traore, located at Cinzana. Dr. A. Toure heads up the sorghum breeding effort which is responsible for the Malisor 84-1 to 7 releases. These seven lines show real promise and have been successfully evaluated in on-farm demonstrations. Three local photosensitive cultivars have been improved and grown by farmers on a significant area, CSM388, CSM219, and CSM63.

Breeding objectives with sorghum center around head bug resistance with drought tolerance also of real significance. Malisor 84-7 has been identified to have the most resistance to head bugs and work is underway to move these genes into genotypes with more favorable agronomic traits. Entomologists at IER and Texas

A&M have developed an improved head bug field screening method that should greatly expedite this. A wide range of germplasm is being tested in field plots using this method at Sotuba and at the WASIP at Samanko.

Except in the north, the Guineense sorghum type predominates and essentially limits or sets boundaries on introgression of diverse germplasm. Nevertheless, a wide range of diverse materials from the U.S. program and ICRISAT are being used to raise the yield level of the Guineense, incorporate the tan plant characteristic, and improve grain mold resistance. Since the landraces of both millet and sorghum tend to show less disease and insect problems, having evolved over thousands of years under these particular environmental constraints, including soil and weathering, introgression will likely require several backcrosses to the local cultivars. A unique opportunity exists for the conversion program where BC_1 to BC_4 or BC_5 of Guineense can be grown out in Mali to observe the number of backcrosses essential for adaptation. The same principle must be considered by U.S. programs sending in germplasm which may have favorable yield genes but is totally unadapted to the Malian environment. Should the introgression take place before or after transfer of germplasm becomes significant. Certainly BC_1 materials which would segregate in F_2s as theoretically 75% Guineense types for selection purposes, seems to be a starting point.

With the association of Stegmeier and Traore on millet and Rosenow, Miller, Peterson, and Ejeta working with Toure and Sy on sorghum, plus the opportunity for collaboration with ICRISAT at Samanko, a very strong breeding team is in place with a clear understanding of priorities which relate to on-farm needs. The plot work and evidence of well-structured programs was equally well apparent at Sotuba, Samanko, and Cinzana. Some 584 F_3s of sorghum were being screened at Sotuba for disease, insect, grain weathering, and lodging. The evaluation team was surprised to learn that no cold storage/low humidity room was available at either Sotuba or Samanko which therefore requires re-increasing the landrace varieties every two years to maintain adequate quality. With sorghum this is not such a challenge but for millet, with its need to cross-pollinate, their landraces require considerable space and isolation for maintenance. More than likely they are experiencing far too much genetic drift from one increase to the next. Where possible, new collections at the village level would be appropriate.

Entomology

Considerable discussion on the significance of a collaborative program between breeders and entomologists has already been covered in the preceding section. Dr. Y. Doumbia along with G. Teetes and Ratnadass of WASIP have a strong program on head bugs which are definitely a greater problem on the introduced sorghums as opposed to the local varieties; the same scenario being true with the head girdler of millet. This effort needs to continue its relationship with food quality tests. The INTSORMIL collaborative sorghum entomology research program in Mali has discovered a source of genetic resistance to head bug which has been a major constraint to the quality of grain sorghum in Mali. Inheritance of head bug resistance is quantitative and primarily recessive.

Pathology

INTSORMIL collaborative research has shown that grain yield increases of 20% can be obtained by treating seed with Apron® plus. Besides controlling downy mildew, this seed treatment resulted in improved early vigor similar to that of a starter fertilizer. Plans are currently underway to evaluate the use of this chemical in other West African national programs where there are pearl millet stand establishment and downy mildew problems. Also, protection from head bugs will be a requirement for evaluation of grain mold resistance. The diseases, long smut and anthracnose are severe in Mali while leaf spot is not as serious in southern Mali as other diseases. An excellent screening program for mildew in millet was underway at Cinzana making use of misting (M. N'Diaye).

Development of resistance to *Striga* has been given a high priority with Dr. B. Dembile collaborating with G. Ejeta on this major challenge. There could be real value in having a WASIP *Striga* scientist, also, with their *Striga* effort centered in Niger. SRN-39 has the most resistance to this parasitic weed and an active screening program at Cinzana, which has heavy infestations of *Striga* in the research plots, has been helpful for identifying materials with resistance. Of the 25 entries in one trial, one local variety "Sequetana" was identified with possible resistance and Malisor 84 may have some tolerance. Other tests included hand pulling, herbicide, and crop rotations.

Quality / Utilization

Sorghum and millet are important food crops particularly in the areas of low rainfall. In southern regions, with annual precipitation above 1000mm during about 140 days, maize is the preferred food crop.

Though there may be a potential for industrial utilization, this has not been realized or pursued. The IER food quality laboratory has concentrated upon rural domestic use and the food industry group that visited perceived little that IER was doing to be of immediate commercial interest. Though commercially milled maize products are available in the markets, we did not find locally commercially produced sorghum or millet products.

Studies on feeds for farm animals seem to have progressed further in the south where the more prosperous farmers use animal power in producing cotton, maize and various other crops. As the demand by the oil mills for cottonseed rose, its use in animal feed became uneconomic and IER carried out studies on feeds using maize stover and other crop residues. IER studies on crop residues in animal feeds do not seem to have progressed in the regions where sorghum and millet are the main crops of subsistence, nor does Mali seem to have had significant involvement in ILCA's program of crop residue and by-product use.

The IER food quality laboratory has produced interesting results on grain quality related to the use of sorghum and millet in such traditional products as Tô and couscous. To improve the protein quality, Tô, couscous and bouille (a thick broth fed to infants and also served to adults) have been formulated from mixtures of sorghum or millet and cowpea flour. These have been publicized through brochures and village demonstrations but no clear data was obtained on levels of acceptance or adaptation. While improving the nutritional quality, additions of 25% cowpea flour tended to increase the viscosity of the cooked products.

IER also has examined parboiling and composite mixtures of wheat with millet or sorghum flours for bread and other baked products, and millet/sorghum plus cowpea for infant foods. There is no evidence that any have excited commercial interest. The IER technology-push approach is typical of many food technology institutions, based upon the wholly fallacious "better mouse-trap theory". If industrial development and exploitation is the objective, the industry must be directly involved from the outset in planning the nature, composition and style of the product to be developed and in determining the market for which it is intended. These are essential principles of which IER seems unaware.

The suggestion that IER give more emphasis to research on grain storage indicates little awareness of what is already well-known in terms of basic principles and in practices demonstrably effective in West Africa. IER clearly needs to decide its priorities in matters relating to grain quality and utilization. It would also benefit from a greater awareness of what others in the region are doing and what they have already achieved.

This is not to denigrate the earlier good work which IER, with considerable help from Dr. Rooney's department, has realized. There does now, however, seem to be a state of uncertainty and lack of clear program focus and objectives in the IER grain quality and utilization program. The quality lab, due to personnel changes, no longer ties closely with agronomic needs.

Physiology / Agronomy

Drought tolerance research

This area of research is presently in limbo, with the termination of UNL-123, which was the collaborating INTSORMIL project, and the promotion of Dr. Moussa Traore, the IER collaborator to the Ministry. Areas of research had included the role of abscisic acid, exogenous and endogenous, on seedling drought tolerance and proline accumulation as a mechanism/indicator of genetic drought tolerance. Both of these are fairly speculative/basic areas of research, which do not as yet have a demonstrated role in the breeding of sorghum varieties for improved tolerance. Therefore, they are not likely to have a short or even medium term impact on sorghum improvement in Mali. It would be preferable that future collaboration in drought physiology research be targeted to shorter term inputs into the breeding program, emphasizing fairly simple technologies that are applicable in West African national programs: field screening techniques, simple morphological/ developmental indices of stress tolerance, etc.

Seedling Heat/Drought Screening

A technique for screening seedlings for post emergence heat/drought tolerance was adapted for use in Mali a number of years ago. It is presently used in a very limited way to screen advanced varieties in the sorghum and millet breeding trials (36 entries of each crop each year). Apparently, no further research has been done on this technique or on the general problem of seedling tolerance. It would seem to be worth investigating whether this technique could be used in actual selection for tolerance in segregating generations of the breeding program, for segregating populations of crosses targeted to areas where seedling mortality is a major problem.

Soil Toxicity Research (Collaborative with TropSoils).

The inter-CRSP research began formally in 1992, but is based on a number of years of earlier work at Cinzana on spatial variability of sorghum growth and its relationship to soil fertility and soil chemical characteristics. The research is attempting to determine the reasons for field toxicity effects and to identify tolerant germplasm. The field screening site visited should be useful for associating stand variability with soil variability, but was far too variable for effective germplasm screening. If the latter is a genuine priority (both cowpea and pearl millet are tolerant of these soils and are used by farmers to crop them) then a laboratory/glasshouse screening system will probably be needed which accurately predicts field behavior. An understanding of the chemical nature of the problem should allow the development of such a technique.

Cropping Systems Research

UNL-113 is collaborating with the IER in two long term experiments designed to measure rotation effects on soil fertility, crop yield, and nitrogen requirement. The experiments are well designed to answer the questions they address, and were well conducted on the Cinzana and Sotuba stations. They are presently in their fourth year; it would be useful for the collaborators to summarize the data available to date and decide if there is a case for continuing at least some of the treatments for an additional five years, (the next phase of INTSORMIL funding). Another five years could result in a sufficient data base for an attempt to model rainfall, initial soil nitrogen, etc., effects on both rotation and continuous cropping system performance. If successful, this could allow the results to be extrapolated to a long term series of real or generated weather data, the results of which would be a unique and very valuable piece of work.

Nitrogen Response and Nitrogen Use Efficiency

IER has collaborated with UNL-114 in a set experiments to evaluate the sorghum nitrogen response and nitrogen use efficiency in relation to rainfall, soil, and cultivar. These have been suspended with the departure of the scientist involved to the U.S. for Ph.D. training. Nitrogen levels used appeared unrealistically high for present and likely future economic conditions in Mali, and all experiments were conducted on experiment stations, which characteristically have a much higher base level of soil fertility than the farmers' fields to which the research is supposedly targeted. The results that have been reported have been mixed, as there have been problems with the poor adaptation of "improved" varieties used in comparison to local ones, and the latter have often outyielded the former. The work needs to be summarized and a decision made if there is justification for continuing it. In general, the applied (N response) part of the research is probably better done by the extension serviced on farmers' fields; the more basic part (nitrogen use efficiency) needs to be done with adapted cultivars or breeding lines only, so that apparent differences in nitrogen use efficiency can be related to nitrogen physiology and not to disease susceptibility, etc.

Socioeconomics

As the relatively successful cotton production projects in Mali demonstrate, major increases in commodity production, beyond what is needed for self-provisioning, demand (1) clearly defined commodity subsectors that function as a whole even while involving multiple actors, (e.g., seed producers, farmers, transporters, grain handlers, processors, and retailers), (2) standardized products that can be traded easily because their qualities, while not necessarily the very highest, are widely known and consistent, and (3) products that reduce the food preparation time investments of urban consumers while remaining affordable given current urban wages. The creation of more efficient and effective subsectors will provide new income streams to farmers that will permit them to purchase productivity-enhancing inputs as well as to participate more fully in the national economy. It will also demand new kinds of research that is coordinated with activities that go far beyond the research process. Unlike the current research program, which is largely supply driven due to the lack of effective client demand, more effective subsectors would generate and articulate and clear demand for research to eliminate or reduce subsector constraints.

Inter-CRSP Activities

The TropSoils inter-CRSP project currently being structured is a logical and necessary step to bring together and understand the genotype x soils interaction. As for the suggested close relationship with INTSORMIL, the IER, and ICRISAT in the scope of work, we must question this as the INTSORMIL annual report does not list WASIP staff among its collaborators in 1992 and there was no mention of any collaborative research between the two organizations during the site visit except possibly with head bugs. The IER does have strong collaboration with ICRISAT in millet, but it was not clear that INTSORMIL participates in this.

INTSORMIL should make an effort to participate in the regional sorghum and millet networks. These networks are without doubt the best vehicle for extending INTSORMIL's influence across the region.

Unfortunately, the private sector in relation to seed is essentially nonexistent. A special paper in this report, however, points out the need and opportunity for such activity. Seed treatment research with Ciba-Geigy as mentioned is of significance for pathogen control and improved stand establishment. In food processing there is somewhat of an opportunity as pointed out in the quality section.

Future Prospects and Recommendations

Mali is a showcase for the CRSP program with INTSORMIL PIs and the in-country Malian scientists planning projects covering all disciplines. The Program has interacted not only with IER but also with TropSoils, Ciba-Geigy, ICRISAT-WASIP and has been supported by USAID/MALI over the years. Some specific observations follow:

> Returning, well trained scientists, form the basis for a strong in-country program.

> With former INTSORMIL leaders, Dr. Moussa Traore and Dr. O. Niangado now in high administrative positions with the Ministry and IER, respectively, the Malian researchers can better feel a close relation to their leadership which gives a great deal of encouragement/moral support.

> It will be essential, however, for U.S. collaborators to make an extra effort at communication with a real question often posed as to whether the annual visit is adequate. Probably not.

> Return visits by Malian scientists for continuing education would provide a solution as their outlook is no doubt broader as well as their scientific contacts. Longer visits by U.S. counterparts will, in some situations, be appropriate, also.

> Somehow computers and vehicles have successfully made their way into locations where even telephones don't exist. Why then should there not be a major effort to provide at least one useable cold storage facility to maintain critical sources of germplasm—diversity that could otherwise be lost forever? This must be a high priority with requests to every potential source of funds.

> In a similar fashion, a serious effort needs to be made to bring the Malian sorghum collection (500 lines) back from France, grow it under at least two environments to not only increase seed but also to gain necessary descriptors. This seed could then be stored at ICRISAT, Hyderabad, as a backup collection. Perhaps Dr. J. C. Chantereau of WASIP can arrange for returning a viable sample of this material.

> Hopefully the infusion of SPARC will allow for some of the problem solving in addition to experiment station reorganization and financial management. Perhaps consideration, along with the USAID ADO, could be given to the establishment of a viable national seed industry. (See the discussion in the Introduction).

> As a follow up to the above, the on-farm plots provide a great first step to bring practices and materials in front of the farming community. Increasing varieties to sufficient quantity and quality plus their distribution can and is, however,

somewhat overwhelming for a government agency.

> This brings up the place of hybrids which have received little mention in the report. They do and can have a place, perhaps first in the more productive south, but their advantages for drought, pathogens, and yield cannot be overlooked countrywide. Somewhat of an evolution to these crosses will take time but cannot be ignored.

> The current concerns on the objectives and strategy of the quality lab need to be discussed openly between all parties as this aspect affects the acceptance and, hence, utilization of both millet and sorghum.

> Because of the time lag in placing trained collaborators, this is still a young program making it essential for continued INTSORMIL strengthening—research is long term.

> Mali can be a showplace for CRSP accomplishments with a regional and even world impact.

> A multi-institutional collaboration and approach exists with a restructured IER, SPARC, WASIP, ICRISAT, and INTSORMIL. This opportunity for INTSORMIL appears cost effective and carries real opportunity for success in increasing both quality and productivity of millet and sorghum.

> Success of the program, to date, will require that INTSORMIL make new investment in Mali while maintaining older, established projects. It will also require that INTSORMIL leverage other organizations to insure that the entire sorghum and millet subsectors are reorganized and directed more toward the growing urban population.

> Evidence from Mali and other Sahelian countries suggests that sorghum and millet are losing ground in the urban markets to imported grains. In Bamako, fully 70% of the urban cereal market consists of rice and wheat. These grains have the major advantage of requiring considerably less preparation time for urban consumers. They are easily available in partially prepared form, as dehulled rice and flour, respectively. Moreover, quality of these two cereals is consistent. In contrast, sorghum and millet (1) are not usually available in partially processed form, and (2) are often of poor quality and/or contaminated with weed seeds and dirt particles. This puts them at a severe disadvantage with respect to other grains available in urban markets.

- Much of the rice and all of the wheat is imported. This is both costly to Mali in terms of foreign exchange and problematic for farmers as they have little or no incentive to either grow or sell a surplus on the national market. Ironically, liberalizing the cereal market has not resulted in greater opportunities for farmers but has fragmented the cereals subsectors instead. The result is that farmers are likely to be further marginalized rather than integrated into a growing national economy. Hence, we recommend that INTSORMIL engage in socioeconomic research on the sorghum and millet subsectors in Mali with the express aim of identifying blockages and constraints to increased consumption in urban areas. Such research needs to identify the major actors in the subsectors, the constraints to increased utilization of the products at each stage of the production process, and the potential avenues for ameliorating the situation.

> INTSORMIL needs to help IER become more demand-responsive in its research strategies. Currently, IER's research is focused almost entirely on increasing sorghum production as is evidenced by its sorghum and millet research objectives in the strategic plan (Ministere de l'Agriculture, de l'Elevage, et de l'Environnement, 1992). Yet, merely developing technologies that increase production/yields will not contribute to national development because such technologies may not be used as a result of high costs of inputs or use, indivisibility, length of the learning curve, or post harvest qualities (as food, feed and fodder or in storage). Put differently, while there is little doubt that yields must be raised to feed an increasing population on a fixed amount of land, IER's approach tends heavily toward focusing on the supply of research products rather than the demands of clients*. This is due in part to the fact that client demand is not well articulated either through the market or through other channels, (e.g., through extension, farmer groups, etc.) INTSORMIL

can help the IER become more demand oriented by encouraging more on-farm research and development of farmer advisory groups. This is likely to lead to greater concern for farmer incomes and consumer preferences than is evident in the current program.

> To the extent that IER becomes more demand oriented in its research strategies, and to the extent that demands and constraints are addressable by research, INTSORMIL needs to devote considerable resources to developing new collaborative arrangements to overcome them. This may involve the establishment of joint IER/INTSORMIL economic analysis of the potential for new food products for use in urban areas. Such products might include prepackaged flour for couscous products, or wholly new extruded snack products. It might also include industrial production of sorghum beer as is already commonplace in southern Africa. In addition, the use of sorghum and millet as animal feed needs to be more fully explored.

- To date animal research in Mali has focused on disease prevention rather than animal nutrition. Yet, pasture is being rapidly converted to cropland as population growth pushes the margins of agriculture. Maintaining or expanding animal production must involve developing alternative feed sources. Sorghum and millet (as well as maize) are logical sources of such feed. Finally, the potential for export of sorghum and millet to Senegal using existing rail lines exists. However, taking advantage of this potential will also require the establishment and maintenance of quality standards.
- Of central importance here is that research on the technical constraints to the production of such food and feed products will be insufficient. Indeed, for the most part, the basic dimensions of such products have already been defined. In Mali, as well as other sorghum and millet producing nations, food scientists have developed laboratory prototypes of new food products that are either made entirely of sorghum/millet or that involve blended flour (usually including wheat). What is needed in addition to the technical research is socioeconomic research to establish the potential market size for such products as well as the potential profitability of small scale, labor-intensive enterprises to produce such products.

> If the socioeconomic analysis indicates that such activities would be profitable, then some combination of local and foreign capital will be needed to establish small-scale production of standardized products that will inspire urban consumer confidence. USAID and/or foundation money may be necessary to partially underwrite and reduce the risk in developing such production facilities.

> INTSORMIL needs to examine the input side of the sorghum and millet subsectors, giving special attention to the provision of credit. Currently, farmers in areas where export crops are not grown are unable to obtain credit for cereal production. This is largely due to the reticence of lending institutions to provide loans for which there is essentially no collateral. It is highly likely that only village level credit unions would be able to exert the necessary social pressure to insure that loans are repaid. Establishment of such lending institutions might be undertaken by NGOs.

> INTSORMIL scientists should give greater attention to seeing to it that collaborators get their names on refereed journal articles. Given the senior status of most INTSORMIL scientists, this should pose little problem and respond to genuine concerns of Malian scientists.

> In short, INTSORMIL, perhaps through its management entity office, needs to play the role of catalyst in promoting and organizing the necessary players likely to be interested in investing in developing the

---

* In our discussion with IER's sorghum researchers it became apparent that they are well aware of this shortcoming in their research program and are anxious to overcome it. Their strategic plan does include the formation of a user group to advise researchers.

sorghum and millet subsectors. To clarify our position, we realize that as a research organization, INTSORMIL cannot and should not engage in non-research activities. However, INTSORMIL can and should leverage other organizations to insure that its research is used to its fullest extent as well as to insure that its research responds to client demands. To fail to do so will mean that INTSORMIL will not have realized its full potential as an organization dedicated to producing science that contributes to socioeconomic development.

Special thanks are extended from the EEP to Dr. Aboubacar Toure for his very professional coordination of the review including a most helpful handout summarizing the program (see attached). Also, our appreciation goes to Dr. Niangado and the many IER staff, including Dr. Tim Schilling of SPARC, who provided information and took time from their activities to make this a productive visit. Finally, the team appreciated the advance information and in-country support given by Dr. Darrell Rosenow, country coordinator, as well as accompanying PIs from the U.S.

Niger

October 16-23, 1993

Review Team

Dr. Bruce Maunder, EEP Chair, Senior Vice President, Sorghum and Tropical Maize Research, DeKalb Plant Genetics
Dr. Merle Shepard, Professor, Clemson University (Entomologist)
Dr. Larry Busch, Professor, Michigan State University, (Social Scientist)
Dr. Joe Hulse, Consultant, Siemens-Hulse International Development Associates, Inc. (Grain Utilization Specialist)
Dr. Fran Bidinger, Principal Scientist, (ICRISAT, India, Agronomist)

Collaborating Entities

INRAN
ICRISAT Sahelian Center
INTSORMIL
USAID
Other USAID projects/CRSPs
USAID Mission Staff: Unable to Meet

Persons Interviewed

Tahirou Abdoulaye, Economist, INRAN
Moussa Adamou, INRAN
Cherif Ari Oumerou, INRAN
Ly Samba, Economist, INRAN

Importance of Sorghum/Millet in the Nigerien Agricultural Economy

Determine the importance of sorghum and millet in Niger through review of National Research Plans and government interviews.

Niger harvests more millet than does any other African country, although yields are among the lowest and have remained so for the last 20 years. Area harvested has continued to increase from about 1.4 million ha in 1960 to about 3.5 million in 1990. Only the southern part of the country is arable with an annual rainfall of about 350mm that is highly variable. Soils are infertile and mostly sandy. As with Mali, the population growth rate is nearly 3%. Cereals occupy 90% of the cultivated areas and pearl millet represents about 75% of the cereals grown. Groundnut and cowpea are the cash crops. Major agricultural constraints are much the same as in Mali: heat stress, drought, poor and infertile soils, lack of markets for cereals and lack of a seed industry. Biological constraints include head bugs, grain molds, midge, millet head girdler, *Striga*, plant pathogens (mainly long smut) and lack of an effective extension infrastructure. In addition, there are economic and sociological constraints discussed below.

How does sorghum rank in terms of country commodity priorities?

Sorghum is second to millet in terms of areas planted and harvested. More emphasis is placed on sorghum at the Konni station but at the major experiment station at Maradi, millet is receiving much emphasis, especially as an intercrop with cowpea. Discussions with the director of the Maradi station revealed that millet should be emphasized more but not necessarily through breeding. Much work needs to be done with *Raghuva*, the millet head miner and with agronomic practices such as interplanting cowpea with millet.

What are the major uses and markets for sorghum in Niger? Are there increased demands for sorghum as a feed and/or for industrial utilization?

Because of the high variability in climatic conditions, prices of sorghum vary widely. Also, the lack of state intervention to control the market adds uncertainty to sorghum marketability. Clearly, however, markets should be found before greater expansion of the sorghum market could be expected over subsistence levels. If markets as human food, animal feed, and industrial uses could be found, demands would surely increase. The main uses for sorghum in Niger are porridge, drinks, couscous and pancakes. Some farmers use sorghum for brewing traditional beer. Also, stalks, leaves and bran are used for animal feed. Stalks are used for fuel and building materials. Some farmers recognize the importance of plant residues for prevention of soil erosion.

Determine the importance of pearl millet in Niger through review of national research plans and government interviews.

Given the large amount of millet harvested (about 3.48 million hectares) and utilized as human food, this crop is given high priority by the government. Unfortunately, little progress has been made in improving production in the last 20 years. Even if seeds were available, many farmers could not afford to buy them. Most farmers buy "mixtures" of seeds from the local market. There is a need for better information relative to the production, uses and potential markets for millet in the country. Demands for millet are likely to remain high given the increases in population density and the adaptability of the crop to the region.

How does millet rank in terms of country commodity priorities?

We were told by Mr. Hamma Hassane, Director of the Experiment Station at Maradi, that the research emphasis at his station is heavily oriented toward millet. However, there was an active sorghum breeding project being carried out at Konni and Kollo. It is recognized that millet research needs more emphasis but we were told that the emphasis here should not be on breeding.

What are the major uses and markets for millet in Niger?

Most millet products go to satisfy human needs. In addition to food, the fodder is used for animal feed and the stalks are utilized for fuel and building materials. Given the limited time and contacts, we were not able to clearly ascertain the real or potential millet markets. This should be determined by socioeconomic studies.

The program has had a unique institutional arrangement with INTSORMIL. The collaborative program has included collaboration with INRAN and the ICRISAT Sahelian Center.

Assess the effectiveness of the program under these collaborative arrangements.

The collaboration between INTSORMIL-funded scientists and INRAN personnel has been good. Many Nigerien counterparts have been trained but several areas still need strengthening through training. This is particularly true for entomology and to a lesser extent plant pathology. Even so, good progress has been made within INRAN but more attention should be given to forging stronger relations with scientists at the ICRISAT Sahelian Center. In the plant protection area, (plant pathology, *Striga* research and entomology), there was not much evidence of strong collaboration. Particular attention should be paid to this with INRAN and the U.S. based scientist finding ways to strengthen this collaboration.

The collaborative INTSORMIL/INRAN program in the agronomy/physiology area of research has not been very effective during the review period. INRAN does not appear to value this area of its collaboration with INTSORMIL very highly, and has not given it priority in the assignment of staff returning from degree training in the U.S. (see below). Since the withdrawal of INTSORMIL staff assigned to INRAN, the volume of collaborative research has declined markedly; in 1993 it consists of a single experiment, apparently conducted at a single location.

The sorgum breeding collaboration between Drs. Gebisa Ejeta and Issoufou Kapran is exemplary and very productive. There are several reasons for this: Issoufou Kapran is a very able and interested scientist and research project manager, with excellent technical help at Tarna, the personal relationship between Gebisa and Issoufou is very good, and extends well beyond the student-professor relationship they also have, and finally, Gebisa clearly identifies closely with the Niger program, knows well the needs of the program, and directs a significant amount of his own work in Purdue towards the Niger program. The breeding program at Tarna, consequently, represents a good balance of local Niger materials crossed to exotic sources of yield, quality, and resistance from the Sudan, ICRISAT, etc., identified in the Purdue program.

Determine to what extent the national research system can accommodate and benefit opportunities which may arise from an inter-CRSP project.

It is likely that benefits could arise from collaboration between the Bean/Cowpea CRSP and the INTSORMIL CRSP in Niger. Other obvious CRSPs that could provide opportunities are the SANREM, Peanut, TropSoils and IPM CRSPs. However, INRAN already has its own research program, as well as an active collaborative research program with the West African Millet Network (ROCAFREMI), in the management of millet/legume systems; any inter-CRSP program would have to complement this program. It is also not clear that INRAN would be interested/able to put more scientific resources into this area of research.

Do Nigerien counterparts exist for all INTSORMIL U.S. based PIs working in Niger?

We were told that there was a good working relationship between Issoufou Kollo and the U.S. based scientist, Dr. R. Frederiksen. There was some complaints by the station manager at Maradi that U.S. scientists rarely come to the station. The entomology program at INRAN could benefit from closer collaboration with the two entomologists at the ICRISAT Sahelian Center. There are counterparts for all INTSORMIL U.S.-based PIs working in Niger.

There is only a single INRAN scientist, Cherif Ari Oumarou, a Purdue graduate, working in the millet agronomy/physiology area at present, who is collaborating with UNL-114 in the single joint experiment in 1993. An INRAN scientist, Seyni Sirifi, recently returned from degree programs in agronomy/physiology in the U.S. and another INRAN agronomist, Mamane Nouri, who collaborated with INTSORMIL from 1987 to 1989 have been assigned by INRAN to other areas of research.

How does the INTSORMIL program fit into the USAID Mission current and future country strategy. How does the Mission view the interface of agriculture/sustainable agriculture in the environment/natural resources management program area?

The EEP team was not able to discuss this with USAID Mission personnel in Niger.

Funding

PRF-109
Other INTSORMIL projects
INRAN
USAID

Assess the level of commitment of each organization for the near-term (1-2 years) and long-term (2-5 years).

It was not clear as to the level of commitment by INRAN but clearly the activities being carried out are priority areas for them. Almost without exception, the INTSORMIL projects are underfunded and scientists from both U.S. and host country institutions are to be commended for judicious use of funds. Most U.S. researchers are being supported by a number of sources other than INTSORMIL. In general, all entities involved are committed for the near and long term to the extent that funding will allow.

The commitment of both organizations to the collaborative sorghum breeding program appears to be very good, although its effectiveness is very much dependent on the two scientists involved. Sorghum breeding is one of the INRAN research programs where there are results to show. For Purdue, the collaboration is excellent and presents an opportunity to claim a genuine success from this mode of assistance, and a very important opportunity to demonstrate the results of its McKnight Foundation basic research program.

Are there any opportunities for Mission Support for Agricultural Research in INRAN?

There may be short term training funds that move scientists in either direction. In the past, these have been used to bring scientists like Dr. Wayne Hanna from Georgia to Niger. Because millet needs more emphasis, it would be good to invite Hanna to work with INRAN scientists on a short term consultancy. In view of the recent history of the USAID local support for agricultural research in Niger, U.S. funds for sorghum breeding research are probably much better channeled through the INTSORMIL program at present.

Project Performance and Maturity

Assess project performance and maturity, taking into consideration INTSORMIL, INRAN, and USAID support and activities. Has the collaborative mode of operation been effective in developing the research program?

Yes, overall there has been significant collaboration. However, in the agronomy/physiology area, the present collaboration between INRAN and INTSORMIL is virtually non-existent. Niger is felt by many INTSORMIL PIs to be a very difficult country with which to establish collaboration, and INRAN appears to have a much lower level of interest in collaboration with INTSORMIL in the agronomy/physiology area than in, for example, the sorghum breeding area. Whatever the reasons, these feelings result in a mutual lack of interest/confidence in the collaborative mode of research.

Would the performance of the sorghum / millet program change, become more or less effective, if the mode of operation were changed?

The mode of operation seems to be working as well as can be expected given the geographical and communication constraints. The program may benefit by more exchanges of personnel from the host country and U.S. (both directions) but decisions would have to be made regarding priorities for budgeting. Also, it has been suggested that an electronic mail (computer) network between host country and U.S. investigators would be of tremendous benefit for facilitating communications. INTSORMIL should attempt to build its collaborative research effort as a supporting effort for INRAN's research priorities/present program, rather than as an independent program focusing on the interests/priorities of the INTSORMIL PI involved, if it is to effectively compete for INRAN staff/resources for collaborative research. In addition, additional training of INRAN agronomists/physiologists is clearly necessary, if the program is to be pursued in the future.

Is technology developed in this project being used by producers?

The program has several promising genotypes of sorghum in various stages that may have widespread impact. A new hybrid, NAD-1, is being tested in several locations in farmers' fields and the *Striga*-resistant SRN-39 is reported to be working well in field trials. Several varieties and hybrids from the program are now in on-farm trials in the favorable/irrigated Birni N'Konni area. Their productivity under favorable conditions is very good, and they should spread rapidly in this area. Unfortunately, this area represents a negligible part of the Niger sorghum area: the new varieties need to be extensively tested on-farm in the typical dryland, sandy soil sorghum growing area in the Maradi district. However, there are several major constraints to the use of these cultivars including:

- the lack of an established seed industry. Niger desperately needs a seed industry that can multiply sorghum and millet seeds of improved cultivars in sufficient quantity and with sufficient quality to meet farmers' needs. Numerous informants told us of the inability of the existing seed industry to meet quantity and quality standards.
- the lack of a market for surplus grain. Evidence suggests that Nigerien farmers are willing and able to grow more than needed to meet their own needs. However, for them to do this there must be an established market for surplus grain. Currently, urban residents, especially in Niamey, are more likely to eat (sometimes imported) rice and imported wheat, rather than sorghum or millet. Often, that rice and, especially the wheat are imported at below market prices as a result of heavy subsidies to producers. No import fees or comparable subsidies for Nigerien farmers exist. Moreover, farm to market roads are often in poor condition. Prices are often

extremely low at harvest time and on-farm storage is limited. Police and army roadblocks are common and appear to slow the speed and raise the prices of grain shipped from the villages. Finally, rice and wheat are available in semi- or fully processed form whereas sorghum and millet are largely available as whole grain. Given the difference in preparation time and the existence of more lucrative employment sources in the cities, housewives prefer rice and wheat over sorghum and millet.

- inadequate post-harvest processing facilities. Despite the existence of well-established technologies for milling and processing sorghum and millet, there has been little or no post-harvest technology transfer in Niger. Wheat milling is controlled largely by Grands Moulins de Paris. While the use of composite flour (i.e., including a significant percentage of sorghum and/or millet in wheat flour) has become commonplace in Senegal and Sudan over the last decade, no similar change has occurred in Niger. This is both costly in terms of foreign exchange and reduces the market potential for indigenous sorghum/millet producers. Similarly, although beer is produced industrially in Niamey, the ingredients are imported. Numerous other African nations, including Nigeria, have been successful in producing western style beers from sorghum as well as in producing sorghum beers industrially. Niger needs to borrow this well-established technology. In addition, although there is a significant urban population that could serve as a market for grain-fed chicken, no such industry exists. Again, this is a well-established set of technologies that need to be put into place so as to create new and expanding markets for sorghum and millet. Finally, although simple mills for milling small quantities of sorghum/millet were developed years ago by IDRC and are currently being manufactured in Senegal, they are unavailable in Niger. Such mills would reduce the amount of time that women spend pounding grain, freeing that time for more productive pursuits. In addition, it would make sorghum and millet more competitive with rice and wheat in urban areas.
- poor extension infrastructure will limit dissemination of other technology.

At this time, technology has not been developed that is being used by very many producers but good progress has been made. For example, Ouendeba Botorou reported collecting several hundred samples of millet from different regions of Niger. Several varieties have been "improved" but these are not in farmers' fields. Work on a modified millet/cowpea intercropping system (UNL-116) was supposed to have reached the on-farm testing stage, but there are no reports of the results. In contrast, Ouendeba and associates are taking the material to the farmers themselves and claim success in using this approach. Ouendeba is doing research with the West African Network. About 60 farmers cooperated in trials around the Kollo area this year. Lack of a seed industry continues to be a major drawback. There is a need to gather baseline information on current practices and priorities of Nigerien farmers within their own cropping system context.

Is technology developed in this project of use or being used in other development projects, i.e., TropSoils Watershed Project, other CRSPs, regional projects?

We are not aware of technology generated by this project that is being used in other development projects. However, if the new varieties/hybrids prove to be also well adapted to the dryland areas, they should be a very valuable part of any future extension/development package.

Have the economic benefits of this/these technology(s) been or being studied?

No socioeconomic studies of the new technologies or the constraints to their adoption have been conducted in Niger. INRAN has a socioeconomics unit (DECOR) but it is not adequately integrated into the overall research organization. INRAN officials are aware of this problem, and are trying to correct it. The unit has engaged in some studies of prices and markets in the Niamey area but it remains a relatively weak unit.

Are there any implications for these benefits to other INTSORMIL collaborative sites? If not, recommend activities to enhance influence.

As benefits become available, they can be shared by several countries, particularly those in West Africa with similar climatic and edaphic conditions.

Has the project had a positive influence regionally?

The EEP were not able to determine the regional influence, but we believe it to be somewhat limited. However, the work done on both millet/cowpea intercropping and on crop rotation has contributed to the knowledge base of these two areas, and is reflected in treatments used in present studies by INRAN and regional collaborative studies funded by the West African Millet network.

For example, how has INTSORMIL assisted other West African countries through the Niger program: How many requests/year for germplasm have other countries made during the past five years.

In principle, material developed in the Niger program should have a broad adaptation across the drier sorghum growing areas of West Africa, either for direct introduction or as parental material. (The Nigerien hybrid NAD-1, for example, has performed well in West African Regional Trials). If not already done, the newer Nigerien varieties should be entered into the regional sorghum trials. There are a number of genotypes from Niger that have been shipped to the U.S. and to other countries for testing. Indigenous germplasm with heat, drought and acid soil tolerance are particularly noteworthy. One major strength of the program regionally is exchange/sharing of information and germplasm.

List level of training for students and/or short-term scientist visits. Is the level appropriate for the 1) past, 2) present, and 3) future?

About 10 students have been or are being trained under the program. Nine of the thirty Nigerien students trained in the U.S. from 1980 to 1990 are listed as having been trained in agronomy, which should have been sufficient to build a collaborative research base. However, only one of these is still with INRAN, and is not working on INTSORMIL collaborative research. This is largely out of the control of the collaborating INTSORMIL PIs, and has been a major source of frustration. If INTSORMIL wishes to build an effective collaborative agronomy/physiology research program, additional degree training will be necessary, as will more frequent short-term scientist visits. Furthermore, there is a need for the entomologist to receive graduate training. This may be the weakest part of the program at this time. Other short-term training (workshops, etc.) would be beneficial to those with higher levels of training and it would be good to work out an arrangement with the ISC to have closer collaboration between ISC and INRAN plant protection specialists.

INTSORMIL has also trained/is training two Ph.D. level sorghum breeders; one is now in an administrative position, the other heads the breeding program. This is probably adequate in view of the need in Niger. The INTSORMIL PI spends several weeks a year in Niger, working with the national breeder, which is probably enough, given the degree of organization of the project evident during the field visit to Tarna.

Has the project adequately disseminated results of research and participated in outreach activities? List releases, on-farm demonstrations/workshops, networking publications and other suitable activities.

Yes. Project results have been disseminated among the research community. As noted above, the program has initiated a good set of on-farm demonstrations in one area, and has prepared descriptive information for the new varieties. The demonstration program needs to be extended to the main dryland sorghum-growing areas around Maradi.

Hess, D.E., G. Ejeta, and L.G. Butler. 1991. Research into germination of *Striga* seed by sorghum root exudates. Pages 217-222 in Proceedings of the Fifth International Symposium of Parasitic Weeds. Nairobi: Centro Internacional de Mejoramiento de Maiz y Trigo (CP 619).

Bayoun, I., F. Gilstrap, and O. Youm. 1993. Collaborative research on the biological control of the millet head miner *Heliocheilus* (=*Raghuva*) *albipunctella*. Internal Publication, Oct. 20, 1993.

Clark, J. W. and I. Kapran. 1990. "Sepon-82" a promising sorghum variety for production in Niger and other West African countries. Sorghum Newsletter, Vol. 36, p16.

Kadi, H. A. and F. Gilstrap. 1993. Panicle feeding insects and stem borers of sorghum. Internal Publication, INTSORMIL CRSP/ Texas A&M University.

Kollo, I. and R. Frederiksen. 1993. Diseases of Sorghum in Niger. Internal Publication, INTSORMIL CRSP/Texas A&M University.

International Consultative Workshop on Panicle Insect Pests of Sorghum and Pearl Millet 1993. ICRISAT Sahelian Center, Niamey, Niger. Oct. 4-7, 1993.

Technical Aspects

Evaluate the technical merits of the program in the context of projects / disciplines involved.

Disciplines involved in Niger include:

Breeding

The breeding effort is focused on development of varieties that are adapted to the various ecological zones in Niger; varieties that are well adapted, and have resistances/tolerances to major insect pests and diseases and with good food quality. The level of yield potential in the sorghum breeding program as Tarna is very good, with the use of introduced material from ICRISAT (e.g., Sepon 82, M lines, etc.), Purdue, the Sudan and elsewhere. The major task facing the program is to improve the adaptation of this material (drought tolerance, head bug, long smut and *Striga* resistance, etc.) to a level equal to that of indigenous Nigerien varieties. This will be slower, less exciting work than was the yield potential improvement work, but more important to the long term success of the program. The program seems to recognize that this is the priority and has a number of breeding programs, both pedigree and population, to tackle these problems. Some of these problems (stand establishment, drought tolerance) can be solved by crossing local landraces with the improved, high yielding lines in the program, others will require the use specific sources of resistance from outside (*Striga*, long smut). In both cases, however, the critical component will be the identification/development of selection sites/nurseries which place a heavy selective pressure for the target trait on the test material. This may, in some cases, such as long smut, require an artificial inoculation capability.

The Purdue PI is assisting the INRAN program effectively by developing specific populations for selection in Niger, by combining good adapted lines from the INRAN program with known sources of tolerance/resistance to specific problems. This activity should be expanded, and incorporate as much preselection in Purdue as is possible before sending the material to Niger. It is of little use to send U.S. combine height material to Niger, for example, or material without leaf disease resistance.

The question of hybrids vs. varieties for Niger deserves comment, as it appeared to the review panel that the INTSORMIL country coordinator is placing considerable emphasis on hybrid development for Niger. From a visit to the Losso seed farm, it appears that Niger does not have the capability to produce a reliable supply of hybrid seed at a reasonable price, despite a history of a large, USAID-funded seed production program. While it is clear that hybrids will outyield varieties in high input, irrigated environments, it is not necessarily true that this is also the case in low input, dryland environments and at yield levels typical of farmers' fields in Niger. In addition, there are greater difficulties with hybrids in resistance breeding programs, where resistance needs to be incorporated into both parents (e.g., *Striga*, grain mold, head bug). The Niger program urgently needs to compare its best hybrids and varieties on farmers' fields, with farmers' levels of inputs, in the typical dryland sorghum growing areas around Maradi to determine if hybrids offer advantages that good, high yielding varieties such as Sepon 82 do not, under these conditions. Only if the answer is unequivocally yes, should hybrids be emphasized in the program.

The breeding program is making good use of local sorghum germplasm. It is also making additional collections of its own, and has requested and evaluated the Niger collection held by ICRISAT.

It is clear that without the appropriate mechanism for seed production, dissemination of varieties will be severely restricted. It is recognized that a team approach, involving breeders, entomologists, pathologists, etc., should be involved in development of the material. The breeder, Dr. Ouendeba, suggests that they start out with bulk populations of 2,000 square meters and let these random mating populations develop into new potential varieties. This takes 4-8 years and then experiment station testing takes another 2 years and on farm testing another

After this, extension is supposed to increase seed but this is not happening so the process essentially stops. There is a real need for private involvement for seed production and distribution. At this time four varieties have been released and more than six more could be released. We were told that there was a network of about 6-7 African countries that are attempting to get out the best varieties. Major sources of materials are coming from: Hanna from

Georgia, an Indian genetic resource pool, and one called "Tift" with good genetic material in them. A major problem is that trips to Niger by plant protection specialists have been limited. Although Kollo and Frederiksen have a good working relationship, the station manager at Maradi indicated that U.S. investigators rarely visit the station there. The presence of Professor David Andrews, millet breeder from Nebraska indicated that an attempt was being made to increase emphasis on millet breeding. Mr. Hamma Hassane at Maradi feels strongly that while more work on millet is needed, it is not in the breeding area but more effort should be expended on agronomy (millet intercropping with cowpea, etc.). Much emphasis was being given to sorghum and millet at the Maradi station. We surveyed large numbers of plots of hybrids, long smut midge resistance trials. Unfortunately, the agronomist Mr. O. Cherif and the entomologist, Mr. Kadi Kadi were out of the station and, therefore, could not meet the EEP.

Entomology

The most important insect pests of sorghum are head bugs and midges. The "improved" genotypes with compact panicles are particularly susceptible to head bugs. The millet head miner, *Heliocheilus (Raghuva) albipunctella*, is by far the worst insect pest of millet although outbreaks of stalk borers can be a problem in both millet and sorghum. For all insect pests, breeding for resistance is the main approach for control. Work carried out at the Maradi station on identifying resistance to the sorghum midge has identified 10 genotypes (out of 31 tested) that may have resistance. The best local check resistance to midge was Sepon-82. Collaboration with ICRISAT helped to obtain four varieties that were incorporated into the screening trials. More field screening is needed. Additional field experiments for insect resistance are being conducted at Konni against head bugs and midges. A recent entomology workshop at the ISC identified the millet head miner as the major pest of millet. A new project is being started at the ICS by Mr. Imad Bayoun, Dr. Frank Gilstrap and Dr. Ousmane Youm to identify major biocontrol agents of the head miner and determine potential for use in a biocontrol program for this pest. The work at the Konni station involving the influence of maturity dates of sorghum and morphological characteristics on insect pests is commendable. We were told that the entomologist was supposed to work mainly on millet but he basically works on sorghum (midge, head bugs, stalk borers). There is a pressing need for the entomologist at INRAN to work closer with ICRISAT entomologists. The work on pheromone of stalk borers at the ISC may be particularly useful in a field monitoring program for this pest and closer collaboration with the entomologists at INRAN, IER and ISC in Mali and Niger could be highly beneficial. Additional training for the INRAN entomologist is strongly recommended.

Pathology

There is an active program in plant pathology to address major constraints due to pathogens. In sorghum, the major disease is long smut. This was noted in almost every field that we visited and major breeding efforts are underway to address this problem. It was mentioned that some varieties may be able to escape long smut because they flower early. Downy mildew can be especially important on millet but this varies widely depending on location. We noticed heavy infestations in some plots at the Konni station. Issoufou Kollo indicated that a major breakthrough in the long smut screening effort was development of a technique for inoculation that allows screening at least two times per year. Farmers plant early around the Konni station to "escape" infestations of long smut. Late maturing materials almost always suffer from smut infestations. Acromonium wilt is found more in hybrids but not at high levels in farmers' fields. Maturity dates, in order to escape long smut and grain molds, should be a major strategy for the breeding effort relative to disease control. We were told that, in general, sooty stripe was not very important. *Striga* is a major constraint and SRN-39 is the best *Striga*-resistant material. This variety is used widely in the Sudan. The addition of nitrogen has been found to suppress *Striga*, especially in SRN-39 but neither seeds nor fertilizer are available to the farmers. Rotation with other crops helps, e.g., cowpea or groundnut but this approach should be examined in the context of farmers' practices. Mr. Hammer Hasten has found two sources of *Striga* resistance: TN-121-80 and TN-93-80. These are derived from local landraces. Also, it has been found that where sorghum and millet are rotated, the *Striga* infestations are reduced. It appears that there are at least two strains of *Striga*, one that attacks sorghum and the other that attacks millet. Discussions with ISC scientists revealed that there was little collaborative work on *Striga* between INRAN and ICRISAT scientists although the ICRISAT Center has a strong research program that focused on this pest. There was some concern on the pathologist's part that INTSORMIL funds were not finding their way to his projects. It may be good to go over INRAN internal funding mechanisms and develop ways to help ensure that INTSORMIL projects at INRAN are receiving funds in the appropriate manner.

Quality/Utilization

The value of improved sorghums for their suitability for use as traditional foods and for their potential in new markets were recognized as high priorities.

Millet and sorghum are the most important food grains in Niger. About 4Mha are planted to millet, 2Mha to sorghum, the former area having doubled, the latter increased by ca 30% during the past ten years. While yields fluctuate significantly among crop years, a general downward trend is evident most noticeably in sorghum. This, probably is in part attributable to population growth [>50% during the past 10 years] farm incomes too low to permit maintenance of soil fertility, with consequent expansion onto marginal lands. Sorghum and millet are the principal sources of subsistence for the rural population which make up ca 90% of the total. There is little evidence of any industrial use of sorghum and millet though, as discussed later, some opportunities may exist.

INRAN and the Nigerien agricultural economy do not appear to have derived as much benefit as might be expected from ICRISAT's Sahelian Centre at nearby Sadore. In particular, the ILCA/ICRAF/ICRISAT project on crop residue utilization should be of greater practical interest to INRAN and Nigerien farmers than seems to be the case. The project and its purposes are discussed later. The economics program refers to studies of fodder utilization but it is not clear what, if any, progress has been made by INRAN as distinct from or in cooperation with the ILCA project.

Grain Quality and Utilization at INRAN

The budget for this work is small and, therefore, priorities need to be carefully chosen. Routine analyses of protein content is of dubious value. It was noted that 6.25 is used as N-to-protein conversion factor so that all results are inflated by at least 15%. This is not serious since it is doubtful the results are used for any practical purpose. [NB: It would be helpful to Africans who undertake graduate research in food science in the U.S., if they were made aware of a) variability in food grain composition and the factors that contribute thereto; b) sources of error in standard analytical methods; and c) for what practical purposes food analyses are necessary (other than keeping technicians occupied)]

The technological objectives of the INRAN laboratory are closely similar to those of IER and ITA. A proposal to undertake a project on composite flours for breadmaking was presented. Before starting, it would be wise to discuss the proposal with one or more local bakers. Since, during a visit to a large biscuit factory, it was learned that roughly 20 per cent of imported white maize flour is used mixed with wheat flour, it would seem more probable of success if INRAN were to cooperate with the biscuit maker to determine if flour milled from local sorghums or millets could, wholly or partially, replace the imported maize flour. Starting with grains light in color, they could explore the comparative performance of different endosperm characters. Such a project could be moved forward using the experience gained in Senegal by SISMAR and CNRA in decortication and milling. Composites of wheat flour and sorghum or millet are more readily adaptable to cakes, biscuits and pasta than to fermented bread where strong gluten is essential to ensure a stable uniform texture with good gas-retention properties.

The subject of composite flours, particularly for biscuit making, was raised with the management of Les Grands Moulins du Sahel, the flour milling company which, using modern Buhler equipment, processes ca 100t wheat per day. Most wheat (ca 80%) is imported from Europe, mainly from France, the rest from North America. The manager expressed interest in milling millet and/or sorghum if an economic outlet, such as to the biscuit factory, could be assured. If INRAN seeks to realize commercial acceptance of its efforts, it should work closely with local industry.

ARDETEC. A visit was made to an interesting parastatal company, ARDETEC, which designs, fabricates and sells agricultural machinery: water pumps and piping for irrigation, small conveyors, threshers and other machines for smallholders. The enterprise has been supported by the local USAID office and would be interested in manufacturing decorticators and hammer mills for sorghum and millet processing. Though in somewhat primitive facilities, it clearly has the capability to do so if given adequate incentive. If the proposed workshop in Senegal comes about, it is recommended that ARDETEC be invited to attend.

It was suggested that if ARDETEC becomes able to fabricate small decorticators, a mobile demonstration unit could be assembled on the back platform of a robust vehicle and taken to rural communities. If, for example, an International Harvester four-wheel drive was used, the vehicle engine could provide power to operate the demonstration mill. Herein lies a further opportunity for INRAN to cooperate with an interested industrial enterprise.

Most of the visits in Niger were made with Moussa Oumarou and Bruce Hamaker. The pragmatic good sense of these two men is impressive and if present linguistic difficulties can be overcome, they promise to become an effective mutually complementary partnership, with INRAN dealing with local practical issues, Purdue giving support and assistance in planning, methodologies and fundamental research relevant to grain utilization.

ILCA Program in Crop Residue Utilization.

There are five ILCA scientists specializing in agroecology, economics, animal nutrition, rangeland ecology and animal physiology. In addition, there are supporting scientists from ICRAF concerned with biomass from trees as fodder, and leaf litter in nutrient recycling; and post-docs working on nutrient recycling and sociological issues. The project is a component of an ILCA regional network on crop residue and by-product utilization and nutrient recycling. It recognizes the importance of large and small ruminants in Sahelian agriculture and seeks economic systems of using crop residues both as feed and for soil improvement.

The brown mid rib (BMR) gene types discovered by John Axtell's team are of particular interest. The leaves and upper stalk are low in lignin and, thus, more easily digestible; the lower stalk being higher in lignin takes longer to decompose, a character useful in mulching.

Briefly, the project is examining nutrient recycling both direct and through animals; the economics of collecting and using stover, other crop residues and plant materials in feeds. It is examining intercrops of millet with cowpea and pasture legumes and the physiological response in fistulated animals to different feeding regimens. There is cooperation with smallholders and with government ecologists, but less with INRANs agricultural scientists.

Question: Can INTSORMIL/USAID help to inspire a closer working relationship between ICRISAT/ILCA and INRAN or is INTSORMIL satisfied with the present state of affairs?

General Comment

Niger, Mali and Burkina Faso are among the poorest of the world's nations. It is commendable that USAID and INTSORMIL continue to support efforts to improve and use more efficiently their staple cereals. Since these three share many similar resources, needs and constraints with other African Sahelian nations: Senegal, Ethiopia, Sudan to mention three of particular interest, and since no one can conceivably address all of the relevant issues and difficulties, in its future phases, could not INTSORMIL/USAID take a more active role in encouraging complementary cooperation rather than the isolated independence that now prevails?

Physiology/Agronomy

During the previous review period (when both Purdue university and UNL-116 had staff stationed in Niger) the effects of cowpea/millet intercropping on millet yields (UNL-113), effect of nitrogen fertilizer on millet growth and water use (UNL-114), management and resource use of alternative millet/cowpea systems (UNL-116), and crop residue utilization alternatives (UNL-116) were included. Only one (UNL-114) of these themes has been continued in the present period, despite efforts of the PIs involved, mainly due to the lack of local INRAN scientists with whom to collaborate due to either their being away for training or having been assigned to other responsibilities.

The UNL-114 collaborative research completed a three year study of the effects of nitrogen on millet growth and water use in 1991, and initiated a second, similar study on the effects of phosphorous on the same variables. The second year of the phosphorous study was seen on the Tarna Station during the review; it was well conducted, and there was an evident response to the higher levels of P. Results from neither study were available, however, so it was difficult to assess the quality of the data. The nitrogen study, which was completed in 1991, should certainly have been analyzed and written up by this time. The failure to do this was blamed on the INTSORMIL PI by INRAN staff (and cited as a negative factor in the present state of collaboration), but it was not clear whose responsibility the analysis and summary of the data actually was.

The basic objects of the studies appear to be sound, as fertility is probably the major factor limiting millet yields in Niger. Three years is not a sufficient period of time to sample the range of probable responses in an environment in which rainfall is as variable as it is in Niger.

The agronomy/physiology area is clearly weaker than at least some other areas of INTSORMIL collaborative research in Niger. INRAN's own internal problems are certainly partly responsible for this. But it also seems INTSORMIL has not succeeded in identifying agronomy/physiology research projects of major interest to INRAN and/or demonstrating that INTSORMIL collaboration is of significant value to INRAN. INRAN is in the process of preparing a new plan for agronomic research to be partly funded by the World Bank. There clearly should be a role for the assistance and support of experienced INTSORMIL researchers in carrying out that plan. The Niger country coordinator needs to determine how INTSORMIL can best support INRAN's agronomy/physiology research efforts on sorghum and millet, and to assure that collaborating INTSORMIL projects offer that support.

It is clear that more work is needed in the agronomy area, particularly since lack of moisture is the single most important constraint. An area that demands much attention is the role of interplanting cowpea with sorghum and millet for a more sustainable crop production system. Crop rotation in relation to *Striga* control also is an area that should be explored as a practical crop production practice. There should be opportunities for collaboration with the Bean/Cowpea CRSP in this area. More emphasis should be given to "on farm" trials in order to understand agronomic issues faced by farmers and how farmers try to overcome them.

Socioeconomics

This area is one of the weakest in the program. There was little that the review team could draw from regarding information relative to this area. It would be appropriate to try to understand the farmers' cropping system and the socioeconomic constraints. We did not understand what the actual or potential markets were and what increasing sorghum and millet production could mean. There was some work reported on sorghum by products that helped us to understand part of how the crops are utilized. As pointed out by previous EEP reports, not enough attention has been given to social science and economics.

INRAN has a Departement d'Economie Rural (DECOR) with about 12 researchers. The head of the department, Mr. Ly Samba, is a competent economist who has a sincere interest in the improvement of Niger's agriculture. However, several key points become apparent rapidly in talking with him and his staff.

> The staff are rather limited in both their experience and training. Many are from urban backgrounds and have little or no feel for life in the countryside. They have considerable depth in some areas but tend to lack breadth.

> The program is heavily oriented toward microeconomic issues, with particular emphasis on on-farm issues. There is a considerable need for research on marketing, urban demand for sorghum and millet products, potential for processing and milling, and economics of the input industry.

> Perhaps the most serious problem is the virtual disjuncture between socioeconomic research and technical research. DECOR staff feel and are isolated from their counterparts in technical departments. INRAN is aware of this problem and is reorganizing to correct it. This should be encouraged by INTSORMIL.

Currently, INTSORMIL has no socioeconomics program in Niger. Given where the overall program is, this is a serious oversight that should be corrected as soon as possible, even if other programs go unfunded.

Assess the strength/weakness of collaboration between NARS and U.S. Principal Investigators and among disciplines.

The major strength of the collaboration is the training program that has produced qualified scientists that return to the NARS to further improve the overall quality of the collaborative research. In addition, germplasm exchange and breeding are major strengths. There is still much to be done in the plant protection disciplines. Among them, entomology is perhaps the weakest with plant pathology next. Much of this has to do with lack of trained personnel, especially in entomology. Much could be gained in these areas by closer association with scientists at the ICRISAT Sahelian center where strong programs in these areas are being carried out. Given the budgetary constraints of the ISC, additional support for joint projects between ISC and INRAN scientists seems appropriate. In general, there seemed to be good collaboration between Issoufou Kollo and R. Frederiksen. Collaboration between Gilstrap and the INRAN entomologists was hampered by lack of a highly trained collaborator. Gilstrap does have a strong collaborative program with the entomologists at ISC.

Is the project concerned about bio-diversity and in situ germplasm conservation, sustainability, and natural resource conservation?

We were not made aware of concern about biodiversity although the PIs are cognizant of its importance. There was significant effort toward germplasm conservation although this was hampered by lack of an appropriate seed storage facility. Sustainability and natural resource conservation did not appear to be a high priority, however, opportunities may exist through cross-CRSPing buy-ins which are relative to these areas.

Inter-CRSP activities

Assess the role of this project and the national program in inter-CRSP activities being planned or conducted.

Inter-CRSP activities of this project could be improved. Logical CRSPs that could be involved include: Bean/Cowpea, Peanut, SANREM, TropSoils, IPM and Small Ruminants. It should be recognized, however, that expansion of efforts into new activities may take additional resources or rearrangement of priorities. Research thrusts would need to be more interdisciplinary in nature and address issues on a more regional basis. At this time, technology generated by this project is of limited use. However, there has been a good flow of germplasm into and out of Niger and several new research methodologies have been generated that are allowing faster progress toward fulfilling the objectives. It seems important at this time to try to determine ways that the technology and information being generated by the project will make its way to the end user—the Nigerien farmer.

Are there collaborative ties with the private sector in country and in the region?

We are not aware of collaborative ties with private sector organizations. There is collaboration between scientists at INRAN and the ISC but in several areas this collaboration could be improved. This is particularly true for the plant protection disciplines. Moreover, INTSORMIL does not appear to be collaborating with the West African Regional Millet Research Network, which does have an active agronomy trial program in Niger.

There appears to be limited contact between the INRAN sorghum breeding program and the ICRISAT West African Sorghum Program, possibly because of the present low level of activity of the latter due to funding problems, or possibly because of historical reasons. (ICRISAT has had problems developing with INRAN the type of close, productive relationship it has with the Mali program despite the fact that the ICRISAT Sahelian Center is located in Niger).

Future Prospects and Recommendations

Future prospects for the projects in Niger seem good. The numbers of trained personnel that have come from the program is one of the major contributions of the project. In addition, the quality of the mentors have insured that the program's strength is not compromised. There is an increasing awareness among host country scientists of the need to communicate with other African countries for information sharing and joint planning and project execution. This should lead to results that are applicable over a wider area where sorghum and millet are grown.

INRAN is in the process of a major reorganization, as part of a World Bank-financed program on agricultural research. This may result in a number of changes in the way in which INRAN conducts agronomic research: a regional rather than a crop focus in agronomic research, project based budgeting, etc. INTSORMIL PIs should study the results of this reorganization, identify areas in which they would be interested in joining with INRAN in a collaborative research effort, and making specific proposals for collaborative work in these areas. This is likely to be the only way in which INRAN will make a sufficient commitment to a collaborative program with INTSORMIL to assure useful results. Future training opportunities should also be based on collaborative research activities on INRAN priority research areas. Success in establishing future collaborative research projects may depend largely on INTSORMIL being able to convince INRAN that INTSORMIL is offering more interesting and productive opportunities than at present; INTSORMIL PIs may have to modify their own interests/priorities to achieve this.

Recommendations

> Projects need to be planned and carried out with interdisciplinary teams that address regional problems and mechanisms should be found to encourage joint planning, research and information-sharing among African countries with similar constraints. For example, closer collaboration with scientists at the ISC/WASIP and IER in Mali would greatly benefit the program in Niger.

> It is important to continue to expand "on farm" research in the context of the farmers' practices.

> There is a serious need to find ways to collaborate more closely with the ICRISAT Sahelian Center, particularly among plant protection disciplines.

> More emphasis should be placed on millet because of its importance in food production systems.

> It may be necessary to de-emphasize the breeding effort in favor of more agronomic research on intercropping (with cowpea, etc.), rotations (for soil fertility, conservation, pest control—especially *Striga*), nutrient use efficiency and nitrogen fixation.

> Mechanisms should be found to encourage joint planning, research and information sharing among African countries with similar constraints.

> Possible markets for sorghum and millet should be explored.

> There is a need for more socioeconomic studies. The EEP were not able to get a clear understanding of the current farming system practices by the Nigerien farmer and how "improved" varieties may fit into his or her crop production system. What would a yield increase of say 20% mean? Would demand go down?

> It would be good to have Wayne Hanna more closely involved with the project. His experience with millet would be extremely helpful.

> Because of the likelihood of decreasing INTSORMIL funds, it will become more important for INRAN scientist and those from the U.S. to seek support from other sources.

> The plant pathologist complained that INTSORMIL funding was not being appropriately dispersed after receipt by INRAN. This should be discussed with parties involved so as to find ways to try to alleviate this problem.

> Better communications between host country and U.S. scientists and among scientists in Africa would be highly beneficial. Perhaps ways could be found to network through an e-mail system.

> It is necessary for scientists and administrators at INRAN to develop ways to disseminate information/technology to farmers.

> The INTSORMIL PI devoting a greater proportion of his effort to tailoring material directly for Niger, as opposed to introducing materials from his own, U.S.-based breeding program. This is only a shift of emphasis, as this is being done to a significant degree already. It is intended to accelerate the process of incorporating resistances into the very good material already in the collaborative project.

> The question of hybrids for Niger should be reexamined, based on the likelihood that hybrid seed availability, and particularly cost, will be a major limitation to the spread of hybrids. It is necessary to prove that hybrids actually do have an advantage over varieties under the input conditions and yield levels of farmers' fields. Both varieties and hybrids represent equally new phenotypes and higher potential level for productivity, compared with existing local varieties. This should be more than adequate to interest farmers; the distinction between modern varieties and modern hybrids may be much more in the scientist's mind than in the farmer's.

In sum, the challenge for INTSORMIL is not merely to develop improved varieties but to establish modern agricultural commodity subsectors for sorghum and millet. In short, the seed producers, producers, processors, transporters, marketers, retailers, and consumers must all be aligned in such a way as to insure that increased production is matched with increased demand. Failure to enroll even one of these actors is likely to result in the failure of the overall project—even if no direct fault of INTSORMIL.

INTSORMIL scientists have now reached the stage where new varieties exist and are adapted to the Nigerien agronomic conditions. What is essential now is that the *non-agronomic* barriers to adoption and consumption be identified and addressed. In short, INTSORMIL and INRAN need to move from being supply oriented to being demand oriented. They need to become more proactive such that they identify and address the key constraints to sorghum and millet *consumption* (i.e., all of the constraints from research through to final consumption). While INTSORMIL itself cannot address all these issues, it can (1) use socioeconomic research to identify the barriers and suggest institutional, policy, and research alternatives, and (2) use its track record to leverage other actors so as to enroll them in the process of building the new and expanded subsectors.

References

Ministère de la Tutelle dese Etablissements Publics, Sociétés d''Etat et Sociétés d'Economie Mixte, Office des Produits Vivriers du Niger. 1993. Prix Moyens. (Monthly).

Tahirou, Abdoulaye. 1993. Rapport de Campagne de l'Enquête sur le Role des Sous-Produits dans la Production de Sorgho. Niamey: INRAN, DECOR/INTSORMIL.

Appendices

PREVIOUS PAGE BLANK

INTSORMIL Buy-Ins

University/ Project No.	Buy-In	Year	Life of Buy-In	Annual Amount	Total
KSU-106	Kansas Sorghum Board	1985	6 years	17,500	105,000
	Kansas Agric. Exp. Station	1989	3 years	19,000	57,000
	Kansas Agric. Exp. Station	1989	3 years	13,333	40,000
	Kansas Sorghum Board	1991	4 years	15,334	61,338
	Kansas Agric. Exp. Station	1990	3 years	19,000	57,000
	EPA/Univ. of Nebraska	1990	2 years	32,518	65,036
					$ 385,374
KSU-108	Kansas Sorghum Board	1985	9 years	18,482	166,338
	Kansas Corn Commission	1988	3 years	16,845	50,535
	Kansas Sorghum Commission	1989	1 year	7,166	7,166
	Kansas Sorghum Commission	1989	1 year	6,500	6,500
	EPA	1990	3 years	39,523	118,569
	Kansas Agric. Exp. Station	1991	3 years	19,000	57,000
	USDA/ARS	1992	1 year	14,400	14,400
					$ 420,508
MSU-104	MIAC/Kenya	1990	2 years	115,725	231,450
	MIAC/Kenya	1992	3.5 years	142,000	497,000
					$ 728,450
MSU-105	FAO	1992	3 years	2,245	**$ 6,735**
MSU-111	Fedearroz	1990	5 years	10,000	50,000
	El Alcaravan Foundation	1990	2 years	200,000	400,000
	Fenalce	1991	1 year	5,000	5,000
					$ 455,000
PRF-103A	AID/Program Support Grant	1988	2 years	7,500	15,000
	Agric. Exp. Station	1988	2 years	6,000	12,000
	Purdue Agronomy Dept.	1989	2 years	1,000	2,000
	McKnight Foundation	1989	3 years	250,000	750,000
	Corporation for Science & Tech.	1991	1 year	10,000	10,000
	Pioneer Hi-Bred Intern.	1992	3 years	33,900	101,693
	Purdue Agronomy Dept.	1992	1 year	1,000	1,000
	McKnight Foundation	1992	3 years	250,000	750,000
					$ 1,641,693
PRF-103B	USDA Training	1989	3 years	15,000	45,000
	AFGRAD Training	1989	4 years	9,000	36,000
	NAAR Project	1991	1 year	3,000	3,000
					$ 84,000
PRF-104B & 104C	USAID PSG	1989	2 years	7,500	15,000
	Rockefeller Foundation	1989	3 years	23,067	69,200
	USAID/PSTC	1990	4 years	37,450	150,000
	USAID PSG	1991	2 years	10,000	20,000
	Purdue Research Foundation	1991	1 year	2,800	2,800
	Pioneer Seed Co.	1991	3 years	40,000	120,000
	PSTC/USAID	1991	3 years	50,000	150,000
	Pioneer Seed Co.	1991	2 years	30,000	60,000
	NSF	1992	1.5 years	173,333	260,000
	Pioneer Seed Co.	1993	2 years	13,600	27,192
					$ 874,192
PRF-105	USAID PSG	1989	4 years	5,000	20,000
	USAID PSG	1989	3 years	5,000	15,000
	World Bank	1989	2.5 years	10,000	25,000
	World Bank/IDA	1989	1 year	4,500	4,500
	USAID/Bean-Cowpea CRSP	1990	1 year	27,000	27,000
	EMBRAPA	1992	1 year	10,000	10,000
	USAID/AFT/ARTS	1992	1 year	20,000	20,000
					$ 121,500

BEST AVAILABLE DOCUMENT

University/ Project No.	Buy-In	Year	Life of Buy-In	Annual Amount	Total
PRF-107	Purdue Agronomy Dept.	1988	1 year	1,500	1,500
	State of Indiana	1990	1 year	7,000	7,000
	McKnight Foundation	1990	3 years	20,632	61,896
	USAID PSG	1990	2 years	14,000	28,000
	McKnight Foundation	1990	3 years	22,000	66,000
	Pioneer Seed Co.	1991	2 years	30,000	60,000
	State of Indiana	1991	1 year	1,200	1,200
					$ 225,596
PRF-109	USDA Grant	1990	2 years	60,000	**$ 120,000**
TAM Joint	USAID/TAMU	1989	3 years	15,000	45,000
	USAID/TAMU	1991	3 years	15,000	45,000
					$ 90,000
TAM-122	State of Texas Grant	1989	2 years	20,000	40,000
	USAID/TAMU	1990	2 years	10,000	20,000
	USAID/TAMU	1990	3 years	13,000	39,000
	Texas Higher Coordinating Board	1991	2 years	27,000	54,000
	USDA	1991	2 years	7,500	15,000
	USAID/TAMU	1992	2 years	28,000	56,000
					$ 224,000
TAM-123	Texas Grain Sorghum Producers	1990	5 years	50,000	250,000
	USAID/TAMU	1990	1 year	17,000	17,000
	USAID/TAMU	1991	1 year	28,000	28,000
					$ 295,000
TAM-124	USDA	1989	3 years	10,000	30,000
	Texas Advanced Research	1989	1 year	75,000	75,000
	TAES/ERA	1989	2 years	32,000	64,000
	Texas Advanced Research	1990	3 years	15,000	45,000
	Rockefeller Foundation	1990	2 years	30,000	60,000
	Texas Advanced Research	1992	2 years	10,000	20,000
	Rockefeller Foundation	1992	2 years	7,000	14,000
					$ 308,000
TAM-125	TAMU/PSG	1989	2 years	45,000	90,000
	Industry Grant	1989	2 years	10,000	20,000
	USDA/CRSP	1989	1 year	15,000	15,000
	USDA/APHIS	1989	2 years	15,000	30,000
	USDA/APHIS	1989	1 year	14,000	14,000
	Texas Agric. Exp. Station	1990	2 years	7,000	14,000
	USDA/APHIS	1990	3 years	23,734	71,202
	USDA/CSRS	1990	2 years	59,819	119,638
	TAMU/Program Support Grant	1990	2 years	18,638	37,276
	TAMU/Program Support Grant	1990	2 years	30,000	60,000
	Texas Grain Sorghum Producers	1990	2 years	50,000	100,000
	USDA/APHIS	1991	1 year	13,200	13,200
	TAMU/Program Support Grant	1990	3 years	27,000	81,000
	Texas Grain Sorghum Producers	1993	5 years	25,000	125,000
					$ 790,316
TAM125-B	TAES	1993	2 years	29,000	58,000
	USDA/APHIS	1993	4 years	32,500	130,000
	USDA/CSRS-SR	1993	2 years	45,000	90,000
	USDA/APHIS	1993	4 years	15,000	60,000
					$ 338,000
TAM-126	Texas Center for Energy	1989	1 year	14,500	14,500
	TAMU/Program Support Grant	1989	3 years	10,000	30,000
	Texas Agr. Exp. Station	1989	5 years	50,000	250,000
	TAES/ERA	1990	2 years	25,000	50,000
	HATCH	1990	4 years	35,000	140,000
	Texas Sorghum Producers	1990	1 year	15,000	15,000

University/ Project No.	Buy-In	Year	Life of Buy-In	Annual Amount	Total
TAM-126	Grain Sorghum Producers	1991	3 years	10,300	30,900
(Cont.)	TAMU/Hatch	1992	5 years	31,184	155,920
	TAES/ERA	1990	2 years	19,000	38,000
	Grain Sorghum Producers	1992	2 years	20,000	40,000
					$ 764,320
TAM-131	USAID/Honduras PL480	1990	1 year	111,395	111,395
	USAID/Honduras PL480	1991	1 year	120,000	120,000
	USAID/Honduras PL480	1992	1 year	88,704	88,704
	USAID/Honduras PL480	1993	1 year	88,704	88,704
	Commercial Seed Co.	1992	1 year	7,000	7,000
	EEC/IICA/PRAIG	1992	3 years	9,260	27,780
	EEC/IICA/PRAIG	1993	3 years	10,975	32,920
					$ 476,508
UNL-113	Rockefeller Foundation	1988	3 years	8,333	25,000
	Ministry of Science (Leave)	1991	1 year	25,000	25,000
					$ 50,000
UNL-114	German Acad.Exchange Serv.	1993	2.5 years	11,000	**$ 27,500**
UNL-115	Michigan State/Senegal Agric.	1989	3 years	46,700	140,000
& 118	USAID/Dakar	1992	5 years	70,000	350,000
					$ 490,000
UNL-116	Elliott Grant	1986	4 years	17,250	69,000
	USDA/OICD	1989	3 years	14,667	44,000
	Nebraska Sorghum Board	1990	3 years	24,00	72,000
	USAID/OICD	1990	3 years	43,000	129,000
	USAID/OICD	1990	1 year	4,000	4,000
					$ 318,000
UNL-123	USAID/PSTC Grant	1989	3 years	50,000	150,000
	USDA/ARS	1986	5 years	22,669	113,345
	USDA/ARS	1991	5 years	24,356	121,780
					$ 271,750
M.E.	INTSORMIL/Egypt/NARP Nebraska/Kansas St.	1991	3 years	156,727	$ 470,183
	SADC/ICRISAT/INTSORMIL Training	1990	5 years	1,280,400	6,402,039
	AID/CROSS CRSP Activities	1990	1 year	100,000	100,000
	USAID/Botswana/DAR	1990	1 year	35,860	35,860
	USAID/Khartoum/ARC	1990	1 year	80,000	80,000
	Social Science Research Workshop	1991	1 year	31,600	31,600
	Adaptation of Plants to Soil Stress Workshop	1992	1 year	25,000	25,000
	Rockefeller Foundation-Conference	1993	1 year	6,500	6,500
					$ 7,151,182
Total Buy-Ins					**$ 16,770,969**

INTSORMIL Sponsored and Co-Sponsored Workshops 1979 - 1993

	Name	Where	When
1.	International Short Course in Host Plant Resistance	College Station, Texas	1979
2.	INTSORMIL PI Conference	Lincoln, Nebraska	1/80
3.	West Africa Farming Systems	West Lafayette, Indiana	5/80
4.	Sorghum Disease Short Course for Latin America	Mexico	3/81
5.	International Symposium on Sorghum Grain Quality	ICRISAT	10/81
6.	International Symposium on Food Quality	Hyderabad, India	10/81
7.	Agrimeteorology of Sorghum and Millet in the Semi-Arid Tropics	ICRISAT	1982
8.	Latin America Sorghum Quality Short Course	El Batan, Mexico	4/82
9.	Sorghum Food Quality Workshop	El Batan, Mexico	4/82
10.	Sorghum Downy Mildew Workshop	Corpus Christi, Texas	6/82
11.	Plant Pathology	CIMMYT	6/82
12.	Striga Workshop	Raleigh, North Carolina	8/82
13.	INTSORMIL PI Conference	Scottsdale, Arizona	1/83
14.	INTSORMIL-ICRISAT Plant Breeding Workshop	CIMMYT	4/83
15.	Hybrid Sorghum Seed Workshop	Wad Medani, Sudan	11/83
16.	Stalk and Root Rots	Bellagio, Italy	11/83
17.	Sorghum in the '80s	ICRISAT	1984
18.	Dominican Republic/Sorghum	Santo Domingo	1984
19.	Sorghum Production Systems in Latin America	CIMMYT	1984
20.	INTSORMIL PI Conference	Scottsdale, Arizona	1/84
21.	Primer Seminario National Sobre Produccion y Utilizacion del Sorgo	Santo Domingo, Dominican Republic	2/84
22.	Evaluating Sorghum for Al Toxicity in Tropical Soils of Latin America	Cali, Colombia	4/84
23.	First Consultative and Review on Sorghum Research in the Philippines	Los Banos, Philippines	6/84
24.	INTSORMIL Graduate Student Workshop and Tour	College Station, Texas	6/84
25.	International Sorghum Entomology Workshop	College Station, Texas	7/84
26.	INTSORMIL PI Conference	Lubbock, Texas	2/85
27.	Niger Prime Site Workshop	Niamey, Niger	10/85
28.	Sorghum Seed Production Workshop	CIMMYT	10/85
29.	International Millet Conference	ICRISAT	4/86
30.	Maicillos Criollos and Other Sorghum in Middle America Workshop	Tegucigalpa, Honduras	12/87
31.	INTSORMIL PI Conference	Kansas City, Missouri	1/87
32.	2nd Global Conference on Sorghum/Millet Diseases	Harare, Zimbabwe	3/88
33.	6th Annual CLAIS Meeting	San Salvador, El Salvador	12/88
34.	International INTSORMIL Research Conference	Scottsdale, Arizona	1/89
35.	INTSORMIL Graduate Student Workshop and Tour	College Station, Texas	7/89
36.	ARC/INTSORMIL Sorghum/Millet Workshop	Wad Medani, Sudan	11/89
37.	Workshop on Sorghum Nutritional Grain Quality	West Lafayette, Indiana	2/90
38.	Sorghum for the Future Workshop	Cali, Colombia	1/91
39.	INTSORMIL PI Conference	Corpus Christi, Texas	7/91
40.	Social Science Research and the CRSPs	Lexington, KY	6/92
41.	Workshop on Adaptation of Plants to Soil Stresses	Lincoln, NE	8/93

Acronyms

AAA/SFAA	American Anthropological Association/Society for Applied Anthropology
ABA	Abscisic Acid
ADC's	Advanced Developing Countries
ADIN	Nursery for Disease and Insect Resistance
ADRA	Adventist Development and Relief Agency
A.I.D	Agency for International Development
AID/H	Agency for International Development in Honduras
ALDEP	Arable Lands Development Program
APHIS	Animal and Plant Health Inspection Service, U.S.
ARC	Agricultural Research Corporation, Sudan
ARS	Agricultural Research Service
ASA	American Society of Agronomy
ATIP	Agricultural Technology Improvement Project
BAMB	Botswana Agricultural Marketing Board
BIFADEC	Board for International Food and Agricultural Development and Economic Cooperation
BFTC	Botswana Food Technology Centre
CARE	Cooperative for American Remittances to Europe, Inc.
CARS	Central Agricultural Research Station, Kenya
CATIE	Centro Agronómico Tropical de Investigación y Enseñanza, Costa Rica
CEDA	Centro de Enseñanza y Adiestramiento, SRN, Honduras
CEDIA	Agricultural Document and Information Center, Honduras
CENTA	Centro de Technologia de Agricola, El Salvador
CIAB	Agricultural Research Center of the Lowlands, Mexico
CIDA	Canadian International Development Agency
CIAT	International Center for Tropical Agriculture, Colombia
CILSS	Interstate Committee for Drought Control in the Sahel
CIMAR	Centro de Investigación en Ciencias del Mar y Limnologia, Costa Rica
CIMMYT	International Maize and Wheat Improvement Center
CIRAD	Centre de Coopèration Internationale en Recherche Agronomique pour le Dèveloppement
CLAIS	Consejo Latin Americana de Investigadores en Sorgho
CNPQ	Conselo Nacional de Desenvolvimento Cientifico e Tecnologico
CNRA	National Center for Agricultural Research, Senegal
CRSP	Collaborative Research Support Program
CSIR	Council for Scientific and Industrial Research
DAR	Department of Agricultural Research, Botswana
DR	Dominican Republic
DRI-Yoro	Integrated Rural Development Project, Honduras-Switzerland

EAP	Escuela Agricola Pan Americana, Zamorano, Honduras
EARSAM	East Africa Regional Sorghum and Millets
ECHO	Educational Concerns for Hunger Organization
EEC	European Economic Community
EEP	External Evaluation Panel
EIME	Ensayo Internacional de los Maicillos Enanos
ELISA	Enzyme-linked Immunosorbent Assay
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuaria, Brazil
EMBRAPA-CNPMS	EMBRAPA-Centro Nacional para Maize e Sorgo
ENA	National School of Agriculture, Honduras
ERS/IEC	Economic Research Service/International Economic Development
EZC	Ecogeographic Zone Council
FAO	Food and Agriculture Organization of the United States
FENALCE	Federacion Nacional de Cultivadores de Cereales
FHIA	Fundacion Hondurena de Investigacion Agricola, Honduras
FPX	Federation of Agricultural and Agro-Industrial Producers and Exporters
FSR	Farming Systems Research
FSR/E	Farming Systems Research/Extension
GASGA	Group for Assistance on Systems Relating to Grain after Harvest
GMB	Grain Marketing Board
GOB	Government of Botswana
GOH	Government of Honduras
GTZ	German Agency for Technical Cooperation
IAN	Institute Agronomia Nacional, Paraguay
IANR	Institute of Agriculture and Natural Resources
IARC	International Agriculture Research Center
IBM	International Business Machines
IBSNAT	International Benchmark Soils Network for Agrotechnology Transfer
ICA	Instituto Colombiano Agropecuario/Colombian Agricultural Institute
ICARDA	International Centre for Agricultural Research in the Dry Areas
ICC	International Association for Cereal Chemistry
ICRISAT	International Crops Research Institute for the Semiarid Tropics
ICTA	Instituto de Ciencias y Technologia Agricolas, Guatemala
IDIAP	Agricultural Research Institute of Panama
IDRC	International Development Research Center
IER	Institute of Rural Economy, Mali
IFPRI	International Food Policy Research Institute
IFSAT	International Food Sorghum Adaptation Trial
IHAH	Instituto Hondureno de Antropologia e Historia
IICA	Instituto Interamericano de Cooperación para la Agricultura

IIMYT	International Improved Maicillo Yield Trial
IITA	International Institute of Tropical Agriculture
ILCA	Instituto Interamericano de Cooperación para la Agricultura
INCAP	Instituto de Nutricion de Centro America y Panama
INFOP	National Institute for Professional Development
INIA	Instituto Nacional de Investigacions Agricola, Mexico
INIAP	National Agricultural Research Institute, Ecuador
INIPA	National Agricultural Research Institute, Peru
INRAN	Institute Nigerien du Recherche Agronomic, Niger
INTSORMIL	International Sorghum/Millet, Collaborative Research Support Program (CRSP)
IPA	Instituto de Pesquisas Agronomicas, Brazil
IPIA	International Programs in Agriculture, Purdue University
IPM	Integrated Pest Management
IRAT	Institute of Tropical Agriculture and Food Crop Research
IRRI	International Rice Research Institute, Philippines
ISC	ICRISAT Sahelian Center
ISRA	Institute of Agricultural Research, Senegal
ISVN	International Sorghum Virus Nursery
ITA	Institut de Technologie Alimentaire, Senegal
JCARD	Joint Committee on Agricultural Research and Development
KARI	Kenya Agriculture Research Institute
KIRDI	Kenya Industrial Research and Development Institute
KSU	Kansas State University
LDC	Less Developed Country
LIFE	League for International Food Education
LUPE	Land Use and Productivity Enhancement
LWMP	Land and Water Management Project
MAFES	Mississippi Agricultural and Forestry Experiment Station
MC	Maicillo Criollo
ME	Management Entity
MFC	Mechanized Farming Corporation, Sudan
MIAC	MidAmerica International Agricultural Consortium
MIPH	Honduran Integrated Pest Management Project
MNR	Ministry of Natural Resources, Honduras
MOA	Memorandum of Agreement
MOA	Ministry of Agriculture, Botswana
MOALD	Ministry of Agriculture and Livestock Development, Kenya
MOU	Memorandum of Understanding
MRN	Ministerio de Recursos Naturales, Honduras
MSU	Mississippi State University

NAARP	Niger Applied Agricultural Research Project
NARS	National Agricultural Research System
NGO	Non-Government Organization
NSF	National Science Foundation
NSP	National Sorghum Program
NSSL	National Seed Storage Laboratory
NU	University of Nebraska
OAU	Organization of African Unity
PCCMCA	Programa Cooperativo Centroamericano para el Mejoramiento de Cultivos Alimenticios
PI	Principal Investigator
PL480	Public Law No. 480
PRF	Purdue Research Foundation
PRIAG	Regional Program to Strengthen Agronomical Research on Basic Grains
PSTC	Program in Science & Technology Cooperation
PVO	Private Volunteer Organization
RFP	Request for Proposals
RIIC	Rural Industry Innovation Centre, Botswana
ROCAFREMI	Réseau Ouest et Centre Africain de Recherche sur le Mil, Niger
SACCAR	Southern African Centre for Cooperation in Agricultural Research
SADC	Southern Africa Development Conference
SADC/ICRISAT/SMIP	SADC/ICRISAT Sorghum and Millet Improvement Program
SAFGRAD	Semi-Arid Food Grains Research and Development Project
SANREM	Sustainable Agriculture and Natural Resource Management CRSP
SAT	Semi-Arid Tropics
SDM	Sorghum Downy Mildew
SICNA	Sorghum Improvement Conference of North America
SIDA	Swedish International Development Agency
SPARC	Strengthening Research Planning and Research on Commodities Project, Mali
SRCVO	Section of Food Crops Research, Mali
SRN	Secretaria de Recursos Naturales, Honduras
TAES	Texas Agricultural Experiment Station
TAMU	Texas A&M University
TARS	Tropical Agriculture Research Station
TC	Technical Committee
TropSoils	Tropical Soils Collaborative Research Program, CRSP
UNILLANOS	Universidad Technologica de los Llanos
UNL	University of Nebraska - Lincoln
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
WASAT	West African Semi-Arid Tropics

WASIP	West Africa Sorghum Improvement Program
WSARP	Western Sudan Agricultural Research Project

RB-991

NEW APPROACHES TO THE CONTROL OF *STRIGA*

Striga Research at Purdue University

G. Ejeta, Department of Agronomy, Purdue University, West Lafayette, IN 47907-1150;
L. Butler, Department of Biochemistry, Purdue University, West Lafayette, IN 47907-1153;
A.G.T.Babiker, Weed Science Program, Agricultural Research Corporation, Wad Medani, Sudan.

Agricultural Experiment Station • Purdue University • West Lafayette, IN

117

BEST AVAILABLE DOCUMENT

NEW APPROACHES TO THE CONTROL OF *STRIGA*

Striga Research at Purdue University

Gebisa Ejeta, Larry G. Butler, and
Abdel Gabbar Babiker

Introduction

To date, conventional research approaches to the control of *Striga* have not been very successful. Previous work on *Striga* in the National Agricultural Research Systems (NARS) and International Agricultural Research Centers (IARC) has been scattered and unfocused. Efforts and resources directed toward basic and fundamental understanding of the host-parasite interaction have been limited. We have developed, at Purdue University, an interdisciplinary research program and a research agenda based on a growing understanding of the basic biology of *Striga* and its association with its hosts. Our approach is based on exploiting the unique life cycle and parasitic traits of *Striga*, especially the chemical signals required for germination, differentiation, and establishment. Our emphasis is on identification, characterization, and manipulation of genetic resistance to *Striga* parasitism. Our goal is the development of crop cultivars with durable resistance to *Striga* and the integrated utilization of these cultivars with appropriate cultural practices. To this goal, we work with a network of cooperators in several national and international research programs both in Africa and the U.S.

We have been carrying out this interdisciplinary research with encouraging results. We believe that our modest success has been largely due to the research rationale and the unique approach to the problem which we have developed with our network of international cooperators. This bulletin[1] highlights these particular approaches to *Striga* control which we are finding to be productive, along with relevant background information about *Striga*.

---

[1] Adapted from: Ejeta, Gebisa, and Larry G. Butler. 1992. Host Plant Resistance to *Striga*. Paper presented at First International Crop Science Congress, Ames, Iowa, 14-22 July, 1992.

Background

Striga spp. are obligate parasitic weeds of tropical cereals and legumes. The common name "witchweed" ascribed to these weeds befits the debilitating and "bewitching" effect they inflict on host plants even before they emerge from the soil. Because witchweeds parasitize important food crops, they are economically important production constraints in much of Africa and Asia. Cereal and legume crops vulnerable to *Striga* are the major source of energy and protein in the diets of hundreds of millions of people in the semi-arid tropics.

Yield losses from damage by *Striga* are often significant. Recently Lagoke *et al.* (1991) estimated annual cereal grain losses associated with *Striga* damage at about 40% when averaged across Africa. In countries such as Ethiopia and Sudan, losses of 65-100% are common in heavily infested fields. In India, some 25,000 tons of sorghum grain is lost annually in the State of Andhra Pradesh alone (Doggett, 1988). *Striga* may have already become the greatest biological constraint on food production in Africa, a more serious problem than insects, birds, or plant diseases.

The impact of *Striga* is compounded by its predilection for attacking crops already under moisture and nutrient stress, conditions which prevail throughout the semi-arid tropics. Moreover, the available evidence strongly suggests that the problem is worsening. Infertile lands poorly managed by subsistence farmers, with limited input and resources, are heavily infested by *Striga*. Such farms are often abandoned, leading to forced migration into new land, which under similar practices will again be exposed to *Striga* infestation. There seems to be little doubt that the *Striga* problem has grown to be epidemic, presenting a desperate problem to small subsistence farmers.

In contrast to traditional cropping practices which kept *Striga* in check by crop rotations and long fallow periods, current practices such as continuous cropping worsen the problem. Eradication of *Striga* may not be a feasible goal, but with innovative and integrated farming practices the spread of *Striga* can be checked and the impact on crop losses can be minimized. Combining several approaches may be necessary. Cultural practices which conserve moisture and nutrients lessen the vulnerability of *Striga* hosts. Chemical inputs specifically directed to weaknesses of *Striga* may prove to be effective and feasible for African farmers. But host-plant resistance is central to an integrated approach to control of *Striga* and is the most practical and economically feasible means for reducing crop losses to *Striga*.

Biology of *Striga*

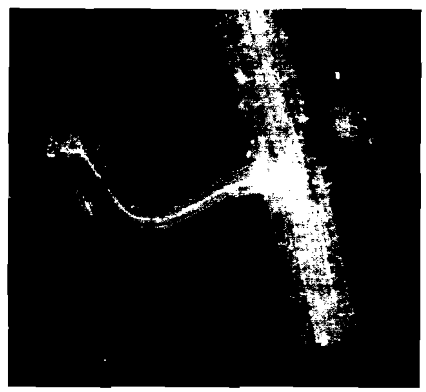
The genus *Striga* belongs to the family Scrophulariaceae. *Striga* plants are not unusual in appearance, having green leaves and brightly colored flowers. Botanically, the genus is characterized by opposite leaves, irregular flowers with a corolla divided into a tube and spreading lobes, herbaceous habit, small seeds, and parasitism (Musselman, 1987). *Striga* seeds are tiny, some 0.30 mm long and 0.15 mm wide. Each *Striga* plant produces at least 40,000 seeds, depending on the species and growth conditions.

Ecologically, *Striga* is native to the grasslands of the Old World tropics, reaching its greatest diversity in Sub-Saharan Africa. Although there are said to be 50-60 species of *Striga*, three obligate parasitic species are recognized as the most economically important because of their impact on crops. The species affecting cereal crops, *S. hermonthica* (Del.) Benth., and *S. asiatica* (L.) Kuntze, occur in Africa and Asia. *S. gesnerioides* (Willd.) Vatke is very serious on cowpeas and tobacco in both Africa and Asia. *S. gesnerioides* and *S. asiatica* are highly self-pollinating whereas *S. hermonthica* is believed to be an obligate outcrosser (Musselman and Hepper, 1986). These pollination mechanisms may result in host-specific races and have significant bearing on host plant resistance and even on potential adaptation of the parasite to new hosts (Parker and Reid, 1979).

Striga's unique characteristics arise from its adoption of a parasitic life-style and its adaptation to the conditions of the semi-arid tropics. Seeds are not only numerous (up to 500,000/plant) but can remain viable for as long as 20 years (Doggett, 1988). Seeds cannot germinate at the end of the crop season in which they were produced, but require a period of after-ripening. In fact germination appears to improve with long-term dry storage. Only after preconditioning in moist conditions for one to five weeks will *Striga* seeds germinate, and only in response to a stimulus from a host root (Patterson, 1987). Brief exposure to the stimulant from the host plant is sufficient to initiate germination, which is evident within 8-12 hours. The nature of the host-derived germination stimulant, which is active at extremely low concentrations, has attracted considerable interest. Preconditioned seeds not exposed to stimulant enter a period of "wet-dormancy" and revert to their original dormant condition when dry. This survival mechanism helps build a seed bank of *Striga* in tropical soils.

Upon germination, *Striga* rootlet close to a host root develop an organ of attachment, the haustorium, which forms a morphological and physiological bridge between the host and parasite. As in germination, the formation of haustoria has been found to be under the control of an external chemical signal produced by the host root (Edwards, 1979; Okonkwo, 1966; Lynn and Chang, 1990). The chemical signals for germination and haustorial initiation are different from each other. Simple compounds such as 2,6-dimethoxybenzoquinone (Lynn and Chang, 1990) are active as a haustorial initiation factor in *S. asiatica*, but the natural signal

Seeds of* Striga *(center) are very small contrasted here with those of sorghum and rice



The* Striga *rootlet attaches to the host plant through its organ of attachment, the haustorium

produced by host roots has not been identified. *Striga* spp. produce adventitious roots (Musselman, 1980) which penetrate the host root along with the primary haustorium. Numerous *Striga* plants may penetrate and attach to a single host plant, influencing the degree of infestation and extent of crop damage.

Host Range and Specificity

The three economically important *Striga* species have a broad host range. *S. hermonthica* and *S. asiatica* commonly parasitize species of Poaceae including sorghum [*Sorghum bicolor* (L.) Moench], pearl millet [*Pennisetum glaucum* (L.) R. Br.], maize (*Zea mays* L.), rice (*Oryza sativa*), and sugarcane (*Saccharum* spp.). *S. gesnerioides* parasitizes dicot species, primarily cowpea [*Vigna unguiculata* (L.) Walp.], tobacco (*Nicotiana tabacum*) and sweet potato (*Ipomoea batatas*). Host specificity is thought to be based on meeting the needs for germination, attachment, penetration, and the overall nutritional requirements of the parasite. Host plants may supply *Striga* with other compounds such as hormones (kinetin, IAA) in addition to water and minerals. However, *in vitro* studies have shown that *Striga* spp. may vary in these requirements as well; exogenous compounds may be essential in some parasitic species and not in others. Ramaiah (1987) acknowledged that **interspecific variability** in *Striga* spp. may be based on germination requirements, preconditioning requirements, chromosome number, and pollination behavior. Other requirements such as haustorial initiation factor and nutritional requirements may contribute to interspecific variability. It is conceivable that host specificity may develop through any of the adaptation mechanisms ranging from preconditioning to successful parasitism. This concept may account for the host specificity reported in several *Striga* species.

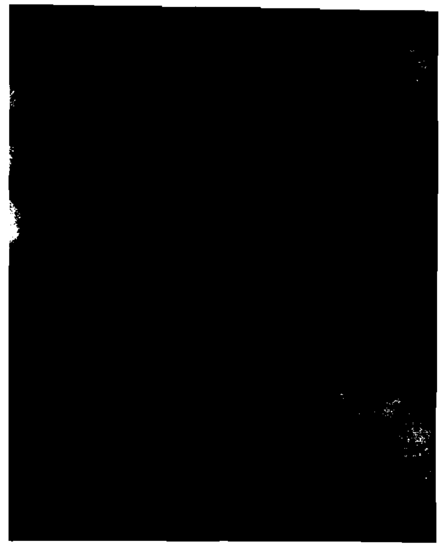
Equally important, particularly to host plant resistance breeding, is the extent of **intraspecific variation** (Wilson Jones, 1955; Bebawi, 1981; Parker and Reid, 1979). Cross-inoculation experiments of *S. hermonthica* on sorghum and millets in Sudan (Wilson Jones, 1955) and in West Africa (Bebawi, 1981) have provided evidence of *Striga* strains specific for these corps. Ramaiah (1987) and Obilana (1987) also suggested that strains of *S. hermonthica* have developed in restricted ecological zones of Africa. It has also been suggested that strains specific to a host cultivar exist (Bebawi, 1981; Ramaiah and Parker, 1982). These observations need to be verified through careful inbreeding of the parasite followed by cross inoculation of known differential hosts. Such work has not been reported owing to the logistic difficulties.

Neither **interspecific** nor **intraspecific** variation can be explained on the basis of co-evolution of host and parasite (Vasudeva Rao and Musselman, 1987). *Striga* has an extraordinary elasticity and capacity to adapt to new host species. Wilson-Jones (1955) in his early work in Sudan observed that *S. hermonthica* successively adapted to new crops through slow but gradual buildup of new "biological forms." Recent work in Ethiopia (Fasil Reda, personal communication) has shown that the important food crops teff (*Eragrostis teff*) and barley (*Hordeum vulgare*), which once were perceived to be immune to *Striga*, have become susceptible, presumably to newly formed virulent strains. Similarly, in Sudan pearl millet was recently introduced in Eastern Gedarif in land heavily infested by a *S. hermonthica* strain that attacked sorghum but not millet. Initially millet was grown free from *Striga* as expected, but in a few years it was reported that *Striga* populations developed in these millet fields. It is not clear whether this was brought about by gradual adaptation of "sorghum *Striga*" to millet or by the introduction of "millet *Striga*" via millet seed produced in Western Sudan where millet is the usual host.

Mechanisms of Resistance

Recognition of the *Striga* seed's requirement for a host-derived germination signal suggested **low stimulant production** as a possible mechanism of resistance. Sorghum genotypes do differ in the amount they produce of the chemical germination signal (Ramaiah and Parker, 1982; Hess *et al.*, 1992). Several sorghum landraces in the World Sorghum Collection were identified as low germination stimulant producers (Ramaiah, 1978), using the laborious double-pot technique (Parker *et al.*, 1977). Some of these were later found to show good levels of field resistance to *Striga*. Crop genotypes which

Germination



Haustorial initiation

produce normal levels of germination stimulant but which produce abnormally **low amounts of haustoria initiator**, the second host derived signal required for *Striga* development, should not only be resistant to *Striga* but should also deplete the *Striga* seed population in the soil by promoting suicidal germination. We have identified some maize genotypes which express this trait (Reda *et al.*, 1993) but have not yet field-tested them for *Striga* resistance.

Saunders (1933) described host-plant resistance based on **mechanical barriers**, which impede invasion of cortical cells by haustoria, thickened inner walls of the endodermal cells, and hardened vascular cylinders of host roots. Lignified pericycle cells and endodermal cells thickened with silica deposits physically obstruct attachment of haustoria to roots of sorghum genotypes known to have good field resistance (Maiti *et al*, 1984).

Another suggested resistance mechanism is **antibiosis** (Doggett, 1988; Ramaiah, 1987) in which germination and attachment are normal, but subsequent development of the parasite is discouraged. **Root growth habit** of host plants has also been implicated as an avoidance mechanism (Dixon and Parker, 1984; Cherif-Ari *et al.*, 1990).

Genetics of Host-Plant Resistance

Investigations of the genetics of host-plant resistance to *Striga* have been hampered by the scarcity of resistant germplasm and the lack of a reliable technique for evaluating germplasm. Field evaluation of crop germplasm for *Striga* resistance in artificially or naturally infested experimental plots is cumbersome, unreliable, subject to a variety of confounding factors, and, thus, inefficient. Genetic differences among host germplasm may also be obscured by diverse and shifting populations of the parasite.

Saunders (1933) suggested that resistance to *S. asiatica* was recessive in two sorghum crosses and partially dominant in a third genotype. Kulkarni and Shinde (1985) found "field tolerance" to the same species to be governed by non-additive gene action. Obilana (1984), defining resistance as "low total number of *Striga* per sorghum plant," reported gene action to be non-additive with overdominance of susceptibility, and estimated that two to five genes control the resistance reaction. Ramaiah (1987) reported that in three out of five sorghum parents studied, susceptibility was dominant over resistance, while in one parent resistance was dominant and in the other parent resistance was partially dominant.

Information on mode of *Striga* inheritance in millets, maize and cowpeas is even more limited. In cowpeas Aggarawal et al. (1984) found a pattern similar to sorghum where genetic control varied with parental source background and mechanism of resistance. They reported a monogenic dominance in one set of crosses whereas in another set susceptibility was dominant and appeared to be controlled by two nuclear genes. Genetic variation for resistance or tolerance to *Striga* in maize has been reported (Kim *et al.*, 1985; Ransom *et al.*, 1990) but the modes of inheritance in these sources have not been sorted out. Few, if any, pearl millet genotypes with a satisfactory level of resistance have been found. Resistance where found was reported as dominant (Ramaiah, 1987).

Genetics of Striga Virulence

Genetic information on *Striga* is even more scarce than information on host resistance. The genetic data on host plant resistance cited above were generated by plant breeders developing *Striga*-resistant genotypes for immediate use. The genetics of host and parasite genotypes and their interactions are not necessarily within the mandate or in the short-term interest of a plant breeder in a developing country. However, without a good knowledge of the nature of the genetic variability in the parasite population and its interaction with host genotypes, total exploitation of host-plant resistance may not be possible. For instance, addressing the possibility of increased virulence in the parasite population associated with evident phenotypic changes requires such knowledge. Yet we can not begin to sort out host-parasite genetic interactions clearly until we are able to test a uniform host genotype (line or hybrid) against a specific "strain" of *Striga*. To do this we would need to inbreed through repeated selfing or sib-mating for several generations of *Striga* populations, each grown on a uniform host genotype. "Strains" thus developed could then be tested against an array of host differentials which can distinguish *Striga* "strains". The array of *Striga* "strains" and host differentials thus developed could be used to characterize new sources of *Striga* and host populations, and identify *Striga* virulence genes properly. The existence of such a collection of virulence genes (or gene-to-gene resistance) would provide the opportunity for crop breeders to pyramid genes for a broader and more durable resistance to *Striga*.

Our Approach

Understanding mechanisms of host plant resistance is vital to successful crop breeding efforts. Evaluation of host plant resistance to *Striga* under field conditions without regard for the basis of resistance has been slow and inefficient. We have made the characterization of mechanisms of resistance the focal point of our efforts to develop resistant crop genotypes. We focus on understanding the specific signals involved in the development of successful parasitism as well as the various interactions between host and parasite (Figure 1). Our working hypothesis is that the complex trait of *Striga* resistance can be broken down into component parts based on knowledge of each of the stages involved. Because it is an obligate parasite, interactions between *Striga* and its host plant play a crucial role in the survival of the parasite. One of our major thrusts is to decode the chemical signals controlling the various interactions between host and parasite which lead to successful parasitism. Disrupting these interactions offers unique opportunities for controlling *Striga* by multiple interventions throughout its life cycle (Figure 1). Our overall plan is to identify sorghum genotypes which fail to interact normally at each stage of *Striga*'s interaction with its host.

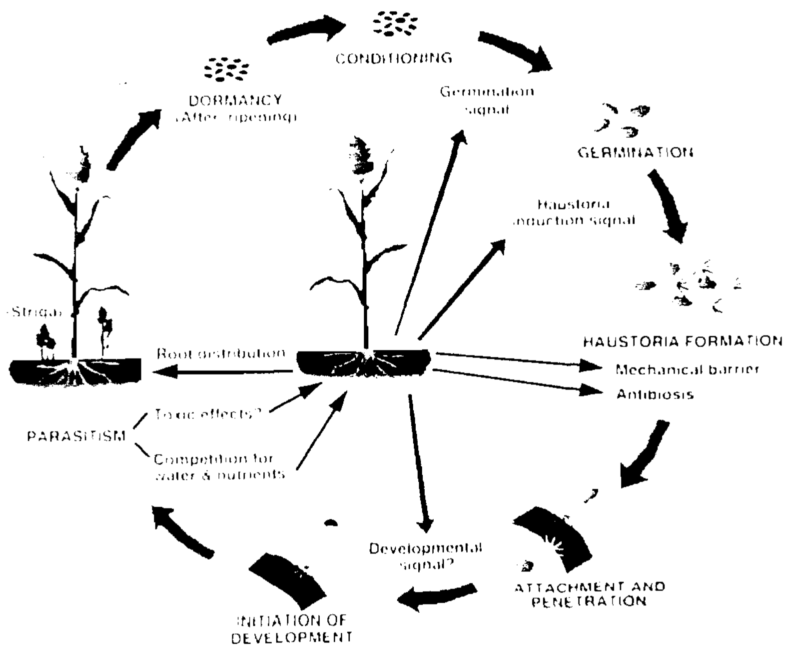


Figure 1. Life cycle of* Striga *spp. and potential mechanisms of host resistance.

It is plausible that in all crops genetic variation exists for production of germination stimulant, haustorial initiation factor, and for other signals required for successful parasitism. Conventional breeding methods can be used efficiently once appropriate assays are developed and the germplasm is properly catalogued. Host crop cultivars combining genes for more than one mechanism of resistance to *Striga* should be more durable and stable across *Striga* populations and ecological zones than many of the single-gene resistant sources currently available.

Control of Striga germination

The most completely characterized mechanism of resistance to *Striga* is unusually low production of host plant root exudate compounds required for germination of *Striga* seed (Worsham, 1987). Roots of host and many non-host plants exude a variety of compounds that are highly effective germination stimulants, but they are often present at very low levels so their isolation and identification have been difficult. The first natural stimulant to be identified was strigol, exuded by roots of cotton, which is not a host for *Striga* (Cook *et al.*, 1972). We identified the first host-derived *Striga* germination stimulant, a group of unstable oily compounds from sorghum root exudate, which we collectively call **sorgoleone** (Netzley *et al.*, 1988). We now believe that sorgoleone is of relatively little importance in controlling *Striga* germination. More recently, **sorgolactone** and **alectrol**, analogs of **strigol**, have been identified as the major germination stimulants from sorghum (Hauck *et al.*, 1992) and cowpea (Muller *et al.*, 1992) root exudate. We have subsequently identified strigol as the major *Striga* germination stimulant from maize and proso millet root exudate, and as a minor component of sorghum root exudate (Siame et al., 1993). The chemical structures of these compounds are presented in Figure 2.

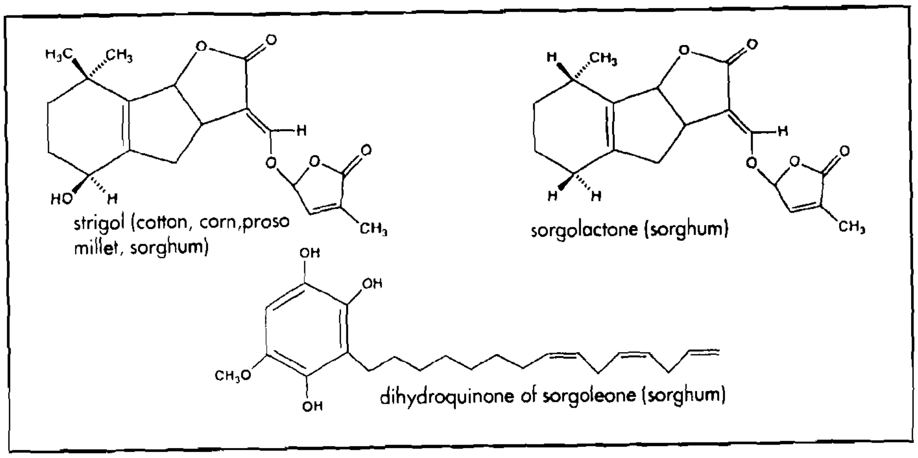


Figure 2. ***Striga germination stimulants isolated from different crops.***

By serially diluting exudates of host roots until they no longer stimulate complete germination of *Striga* seeds, we compare the amount of stimulant produced by different hosts. We found that sorghum genotypes differ by as much as a billion fold in the amount of stimulant they produce (Figure 3) (Weerasuriya et *al.*, 1993). Among germplasm available to us, sorghum genotypes which produce the highest amount of stimulants are the Kaoliangs of China which presumably evolved in the absence of exposure to *Striga* infestation. We have catalogued our *Striga*-resistant sorghum collections to identify those which utilize low stimulant production as their mechanism of resistance. Our method of screening for this trait is described in a later section.

We found that high stimulant production is strongly dependent upon daylength. For sorghum genotypes capable of producing high levels of stimulant, decreasing the daylength from 16 hr. to 2 hr. increases stimulant production a million fold (Weerasuriya *et al.*, 1993).

***Striga* control by manipulation of ethylene biosynthesis:** We recently confirmed (Babiker *et al.*, 1993) earlier reports that endogenous ethylene is the ultimate trigger for *Striga* germination. This finding raises the possibility of controlling *Striga* by manipulation of ethylene biosynthesis. Ethylene is produced from methionine via S-adenosyl methionine, which is transformed into ACC, the immediate precursor of ethylene. We find that ethylene production in *Striga* seeds is limited by their capacity to convert ACC into ethylene. Germination stimulants break *Striga* seed dormancy by enhancing their ability to convert ACC into ethylene.

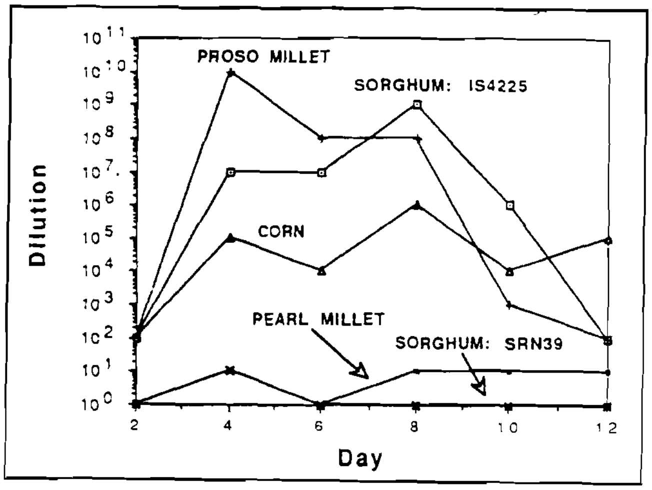
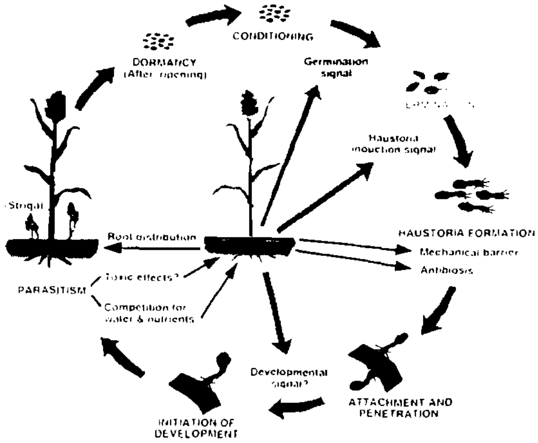
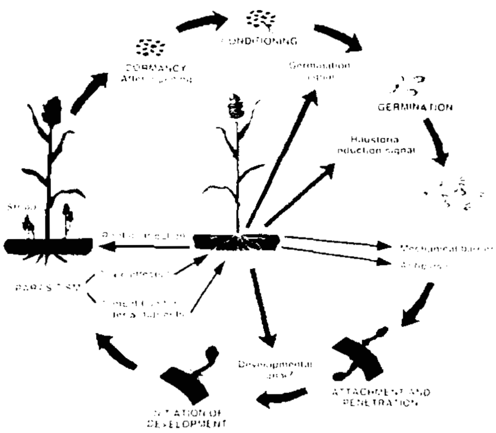


Figure 3. Production of Striga *germination stimulants (strigol-type) by different hosts. Note the logarithmic scale of dilutions that give at least 25% germination of* Striga *seeds.*



Stage 1 Germination

Based on this finding, we have initiated screening of chemicals for their effects on ethylene biosynthesis. Rather than natural or synthetic germination stimulants, which have been unsatisfactory in previous tests mainly due to their short persistence in soil, we have used chemicals already widely used in agriculture. This approach avoids any problem of limited market potential for products designed specifically for *Striga*, and the expense and delay of registering and obtaining approval of new products. Selection of products for screening was based on prior knowledge of their ability to enhance ACC synthesis and/or conversion to ethylene, and their commercial availability for agricultural uses. Using this approach, we have shown that combinations of thidiazuron, a substituted urea with cytokinin-like activity widely used as a cotton defoiliant, and auxin-type herbicides such as 2,4-D readily stimulate *Striga* seeds to produce ethylene and to germinate. This combination of chemicals



Stage 2 Haustorial initiation

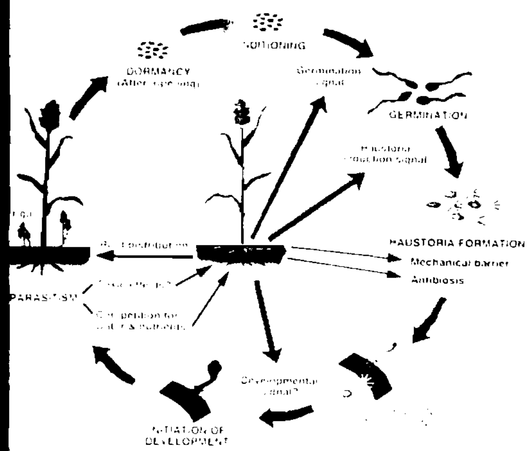
could be useful in cleaning up *Striga*-infested fields by suicidal germination. If this had to be done in the absence of a host crop, a year of crop production would be lost. But there is a possibiity that this treatment could be used even in the presence of the host crop, because the *Striga* germination and subsequent development induced by these chemicals is abnormal, with radicle growth inhibited, plumules emerging prematurely, and the embryo failing to differentiate normally. We are investigating the impact of these chemicals on development of *Striga* parasitism in *Striga*-infested fields. Combining this chemical approach to *Striga* control with the use of resistant cultivars should delay the emergence of new virulent strains of *Striga* and thus prolong the period of usefulness of the resistant cultivar.

Control of haustorial initiation and attachment

After germination, the developing *Striga* root requires yet another signal from the host root in order to differentiate into a specialized haustorium by which it attaches to the host root. *Striga* seedlings survive only if they succeed in attaching to a host root within 5 days following germination. A simple degradation product of host root lignin, 2, 6-dimethoxybenzoquinone, strongly stimulates haustorial initiation (Lynn and Chang, 1990) but the active signal from undamaged roots seems to be less stable and has not yet been identified. We are developing a quantitative assay for production of this second host-derived developmental signal. A host plant which produces abnormally low amounts of haustorial initiator, but high amounts of germination stimulant, should not only be resistant but should also deplete the population of *Striga* seed in the soil.

Host insensitivity to Striga-derived "toxin"

Diversion of water, minerals, and photosynthetically fixed carbon from the host is only a minor component of the *Striga*-induced reduction in host crop productivity (Press et al., 1990). Host productivity is decreased mainly through diminished photosynthetic efficiency (Press *et al.*, 1990). Host damage due to *Striga* (stunting, bleaching, and wilting) is often evident even before the emergence of the parasite. Such symptoms of *Striga* damage in the field suggest possible involvement of toxins. Injection of crude *Striga* extract into the stem of maize seedlings is reported to cause necrotic symptoms at a distance from the injection point (Efron et al,1988). We have likewise found that crude extracts of *Striga* leaves and stems can induce loss of chlorophyll and wilting of susceptible host plants. Little effect is seen until after the host seedling has exhausted its seed reserves and is growing photosynthetically. These observations suggest that *Striga* produces toxic compounds which are transported to host photosynthetic tissue and produce the observed inhibitory effects. We also find that host genotypes differ



Stage 3 Attachment and penetration

widely in their sensitivity to this *Striga*-produced "toxin". The highly resistant genotype SRN 39 is much less affected by *Striga* extract than are other sorghums we have tested. SRN 39 seems to have multiple mechanisms of resistance (low stimulant production and insensitivity to *Striga* toxin), possibly accounting for its broadly expressed resistance.

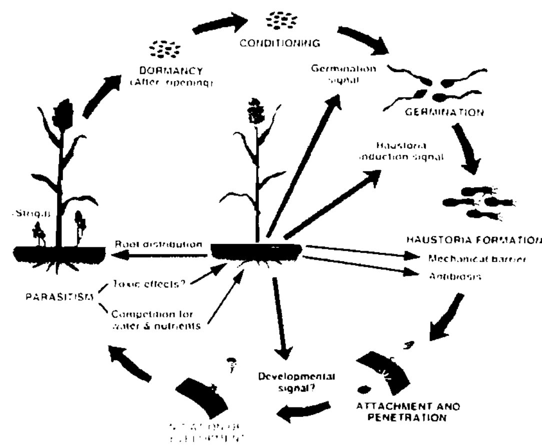
We are currently using the *Striga* toxin as a screen for identifying clones of *in vitro* cultured sorghum cells with enhanced resistance to the toxin. We adjust toxin concentration and exposure time to eliminate all cells except a few survivors, which we rescue on toxin-free medium and utilize to establish new clones. We have about 100 progeny of these selected and regenerated sorghum clones which will be tested for enhanced *Striga* resistance in the field.

In vitro culture of Striga

Because of the risk of its escape, we do not grow *Striga* in our fields or greenhouses in Indiana. All field studies with *Striga* are done in collaborator's fields already infested with *Striga*, mostly in Africa. All our work with *Striga* in the United States is done under strict quarantine regulations approved by the US Department of Agriculture and the Indiana Department of Natural resources. We only work with the early stages of *Striga* development, never permitting *Striga* plants to grow to maturity and produce a seed crop.

However, there is a way we can study *Striga* growth and development in the laboratory without significant risk of escape. We have established *in vitro* cultures of *S. asiatica* which are completely dependent upon nutrients we provide in the medium, nutrients *Striga* normally obtains from its host. Our cultures are quite delicate, and do not survive when removed from the refined laboratory conditions we provide.

With our *Striga* cultures we are finding that after germination and attachment to host roots in response to host-derived signals, further development of *Striga* is also dependent upon other chemical signals produced by host plants. In fact, the whole *Striga* life cycle may be under the control of the host plant via specific chemical signals. This strong dependence on specific host-derived signals makes *Striga*'s strict host specificity understandable.



Stage 4 Differentiation stage

We are characterizing the later developmental signals and plan to devise a simple assay to screen for their production by host genotypes. Our study of host-parasite interactions subsequent to attachment may lead to recognition of additional mechanisms of resistance which we may be able to exploit.

Breeding Crops for Host Plant Resistance to *Striga*

Terminology: There has been considerable confusion in use of the terms **resistance** and **tolerance** in host plant response to *Striga*. We recently proposed (Ejeta *et al.*, 1991) a working definition that is parallel to terms commonly used in host-plant resistance to pests and pathogens. To us, a crop genotype that, when grown under *Striga* infestation, supports significantly fewer *Striga* plants and has a higher yield than a susceptible cultivar, is designated "resistant". In contrast, "tolerant" genotypes stimulate germination of *Striga* seeds and support as many *Striga* plants as do susceptible genotypes, without showing a concomitant reduction in grain production or overall plant productivity. Host genotypes that are totally free of *Striga* when grown under infested conditions would be termed "immune", but such genotypes have not yet been identified.

We direct our research almost exclusively toward resistance rather than tolerance. Tolerant genotypes provide a short term gain at the expense of increasing the total *Striga* seed inoculum. We consider tolerance to have little value as a long-term breeding objective.

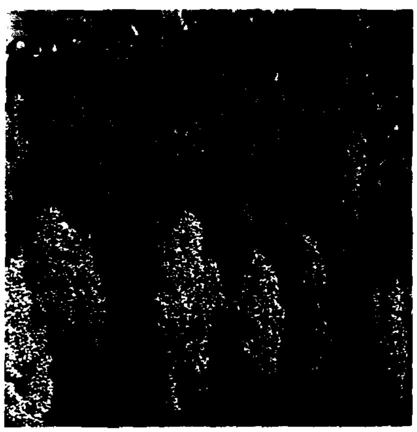
Development of *Striga* resistant crop cultivars

Progress in breeding crop cultivars with broad and durable resistance to *Striga* has been limited by four major factors (Ejeta *et al.*,1991):

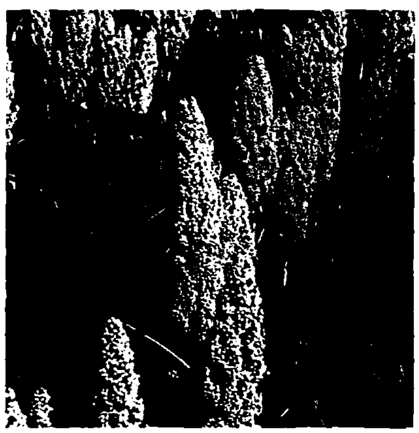
1. Resistance to *Striga* is species-specific
2. Presence of intraspecific or physiological variants of *Striga*
3. Paucity of resistance genes in crop germplasm
4. Lack of rapid and effective screening techniques

Screening a large number of genotypes in *Striga*-infested fields is often inefficient due to the complex interactions among host, parasite, and the environment that affect the establishment of the parasite as well as the response of the host. Quick and simple screening techniques increase the efficiency of a crop breeding program.

When reliable screening methods are made available, germplasm is properly catalogued and clear genetic information is



Segregating sorghum population derived from a cross (Framida X SRN 39)



Elite sorghum line combining striga resistance with high yield and grain quality

obtained. Ramaiah et al (1990) recently reported a single recessive gene for low stimulant production in three sorghum genotypes, using as an index percent *S. asiatica* seed germination in the presence of sorghum root exudate collected with the double pot technique (Parker *et al.* 1977). We (Hess and Ejeta, 1992) conducted a pot study in Niger using known volumes of *S. hermonthica* seed; we established that resistance in SRN 39, a stable source genotype of sorghum, is inherited as a recessive trait controlled by one or two genes. Singh and Emechebe (1990) found a monogenic dominant inheritance in cowpea genotype B301 in a pot-culture study where *Striga* attachment to host root was used as an assay.

Sorghum: We recently developed an agar gel assay (Hess et al., 1992) that separates sorghum genotypes on the basis of their capacity to stimulate *Striga* seed germination (Table 1) and is simple, rapid, reproducible, and non-destructive. *Striga* seeds preconditioned to germinate rapidly when exposed to germination stimulant are randomly dispersed in an agar gel in a Petri dish, and a germinating sorghum seed is introduced. As the sorghum root grows through the agar, it exudes germination stimulant, which is readily detected by microscopic examination for germination of nearby *Striga* seeds. We have simplified the assay so that instead of laboriously counting germinated and ungerminated seeds and calculating percent germination, it is only necessary to measure the distance of the furthermost germinated seed from the host root. We found that this rapid measurement of germination distance correlates well (r=0.93) with percent germination (Hess *et al.*, 1992).

Table 1. Production of* Striga *germination stimulant (germination distance) and number of* Striga *plants supported by resistant and susceptible sorghum genotypes.

Genotype	*Striga* reaction[a]	Germination distance[b]	*Striga* plants per plot in N. Carolina	Sudan	Niger
		(cm)		No.	
SRN 39	R	0.3	2	0	2
Framida	R	0.3	5	1	7
P 954063	S	1.8	47	37	38
Shanqui Red	S	2.5	212	46	73
IS 4225	S	3.7	314	85	169

[a] R = resistant; S = susceptible
[b] Mean maximum distance from host root that Striga seeds germinated

Using the agar gel assay we confirmed (Vogler, *et al.*, 1993) both the low stimulant production in SRN 39 and its simple recessive inheritance (Table 2). Segregating progenies derived from a large intercrossing program have also been screened for low stimulant production and grouped into high and low stimulant producers. Representative samples of these genotypes were further tested for field reaction to *S. asiatica* in North Carolina and against *S. hermonthica* in Sudan and Niger in Africa. The results (Table 1) indicated correspondence between the agar gel assay and field

Table 2. Mean germination distances of* Striga asiatica *seed from the agar gel assay and segregation of sorghum cultivars SRN-39, Shanqui Red, and their F_1, F_2, and backcross progeny.

Pedigree	Seedlings	Mean germination distance[1,2]	Segregation: Expected	Observed[3]: S	Observed[3]: R	Chi Squ.	< P <
	No.	cm					
SRN 39 (P_R)	25	0.372^{d}					
Shq. Red (P_S)	23	2.339^{a}					
($P_S \times P_R$)F_1	25	1.764^{b}					
($P_R \times P_S$)F_2	174	1.612^{bc}	3:1	125	49	0.9272	0.5-0.25
BC_R	30	1.174^{c}	1:1	16	14	0.8000	0.75-0.5
BC_S	32	2.000^{ab}	1:0	32	0	0.0000	1.0
($P_R \times P_S$)F_1	20	1.693^{b}					

1 Maximum distance from the sorghum root at which *Striga* seeds germinated.

2 Means with the the same letter are not significantly different as determined by Duncan's multiple range test at alpha = 0.05.t

3 S=# of susceptible plants: maximum distance for germination of *Striga* seeds was > 1.0 cm.
R=# of resistant plants: maximum distance for germination of *Striga* seeds was < 1.0 cm.

resistance to *Striga*. These *Striga*-resistant selections are currently under wide international testing for agronomic adaptation and stability of resistance as in the SRN 39 parental source. Many of these progenies possess superior yield potential, broad adaptation, and excellent grain quality in addition to their *Striga* resistance.

Several years of testing in *Striga*-infested experimental fields in Africa resulted in our identification of sorghum SRN 39 as a genotype with stable resistance to *Striga* (Hess and Ejeta, 1992). Collaborative efforts between our program at Purdue and the national agricultural research programs in Sudan and Niger have established SRN 39 as a superior *Striga*-resistant sorghum cultivar in farmer's fields. In contrast to other sources, SRN 39 exhibits broad-based resistance across *Striga* species and strains. This line also has drought resistance and good food quality attributes. SRN 39 was officially released for commercial cultivation by farmers in *Striga*-endemic areas of Sudan, where it was grown in over 24,000 acres in 1991, its first year of release. We have used SRN 39 extensively in intercrosses with other *Striga*-resistant sorghum lines as well as with high yield potential genotypes. As mentioned above, SRN 39 is resistant not only because it produces extremely low levels of germination stimulant, but also because it is relatively insensitive to *Striga* toxin.

We have integrated the agar gel assay for germination stimulant production into our sorghum breeding program for *Striga* resistance, and have adapted the technique to screen millet, maize, and cowpeas. It should be noted that the assay detects only those crop genotypes that are resistant to *Striga* because they encourage little or no germination of *Striga* seed in the soil. With the gel assay we are able to exploit the low stimulant production mechanism of resistance and develop *Striga*-resistant crop cultivars in a much shorter period of time than was previously possible.

Maize: Our limited screening of maize has already identified a genotype (B 37) which is a low stimulant producer, to our knowledge the first maize genotype to be identified as bearing this characteristic.

We are currently adapting the gel assay to screen for low production of the haustoria initiation signal. Failure by the host plant to produce sufficient signal to initiate haustoria would prevent attachment of germinated *Striga* seeds to its roots, and thus confer resistance. Our results indicate that production of germination stimulant and haustorium initiator are independently inherited. Sorghum genotypes seem to differ much less in production of haustorium initiator than in germination stimulant. We have identified two maize genotypes which produce low amounts of haustorial initiator; none yet have been found in sorghum. We attach considerable importance to field tests of the maize genotypes which produce relatively little haustorium initiator. They produce normal high levels of germination stimulant, so if they are resistant they could be helpful in diminishing the *Striga* seed inoculum in the soil by promoting suicidal germination.

Cowpeas: For screening cowpeas we have the advantage, as mentioned above, that they produce germination stimulants and haustorial initiator to which our S. asiatic responds, although cowpeas are not a host for this *Striga* species. *Striga*-resistant cowpeas which have been previously reported have resistance mechanisms other than low production of these signals (Singh and Emechebe, 1990). We have found cowpea genotypes that produce low amounts of haustorial initiator. We are also using mutagenesis to create cowpea variants we will screen for low production of both germination stimulant and haustorial initiator. Initial screening will be done using our laboratory assays, followed by field evaluation in Africa. Meanwhile we plan to determine whether *S. gesneroides* will similarly fail to respond to exudate from these genotypes. Cowpeas that produce low levels of either of these signals should be resistant to *S. gesneroides*, for which this crop is a major host. Promising cowpea genotypes identified by our laboratory screens and field tests could be crossed with the resistant cowpea genotypes already identified to take advantage of multiple mechanisms for a more durable resistance.

Pearl Millet: Pearl millet is a natural host for *S. asiatica*, but the strain of *S. asiatica* that occurs in the US and which is therefore available to us does not germinate in response to root exudates from pearl millet. As described above, it readily responds to exudate from proso millet. This strain of *S. asiatica* does initiate haustoria in response to exudate from pearl millet, so we can screen pearl millet for haustoria initiator. Our collaborator, Dr. Dale Hess at the ICRISAT Sahelian Centre in Niger is using the agar gel assay to screen pearl millet genotypes for production of germination stimulant to which West African millet-specific strains of *S. hermonthica* respond.

Screening against in vitro cultures of Striga

We use our *in vitro* cultures of suspended *Striga* cells (described earlier) to identify host genotypes which may produce factors toxic to *Striga*. We test extracts of host roots and other tissue to see if they kill *Striga* cells or inhibit their growth. If such genotypes can be found, they should be strongly resistant to *Striga*. They would help us reach our goal of combining *Striga* resistance genes, based on two or more mechanisms, to obtain a durable resistance not readily overcome by single gene mutations in *Striga*.

Evaluation of Breeding Methods

In a recent report (Ejeta *et al.*, 1991) we proposed breeding methods that should be effective for development of crop germplasm with increased resistance to *Striga*. As we better understand host-parasite interactions, develop appropriate assays, and properly characterize our crop germplasm, we can adopt breeding methods that have been utilized effectively for other traits, as listed below.

Early generation testing: Pedigree breeding permits plant breeders to use their skills of estimating field performance from single plant behavior. Experienced plant breeders do this well for many traits. However, the nature of *Striga* is such that evaluation of segregating progenies in the field is impossible. For adjacent plants in a progeny row it is difficult to determine with any certainty which is infested by *Striga*. Our alternative has been to defer selection for *Striga* resistance until true breeding progenies are derived and to instead subject early generation segregates to selection for agronomic and grain quality parameters. Development of a simple screen, such as the agar gel assay (Hess *et al.*, 1992), that allows the non-destructive evaluation of single seeds, facilitates early generation testing and increases the efficiency of a crop breeding program.

Use of F_1 hybrids: In many countries, including the United States, Argentina, Brazil, India, and most of Europe, the use of F_1 crop hybrids has revolutionized agriculture. *Striga* has not been endemic to many of these countries and therefore no effort has been made to incorporate genes for *Striga* resistance into commercial hybrids. Sorghum and maize hybrids developed and released for commercial cultivation in India and Africa do not have resistance to *Striga*. We do not know of previous efforts directed to developing parental lines with genes for *Striga* resistance with the goal of developing *Striga*-resistant sorghum, maize, or millet hybrids. We have recently initiated introgression of the low germination stimulant production gene into agronomically acceptable parental lines of sorghum. We have tested some sorghum hybrids with promising results. We believe that grain sorghum and maize hybrids that combine yield potential, adaptation, and grain quality with a good level of *Striga* resistance will make a significant contribution to crop agriculture in *Striga*-endemic environments.

Use of population improvement: Random mating crop populations are effective for enhancing germplasm for various traits in both self- and cross-pollinating species. We proposed that development of random mating crop populations with multiple sources of *Striga* resistance, followed by repeated and deliberate evaluation under *Striga*-infested environments, encourages the formation of genotypes with unique gene combinations. We have developed a random mating sorghum population, PP-36, which has been under evaluation in Sudan and Niger. We plan to continue selection for 4-5 cycles before testing elite progenies for enhanced resistance to *Striga*. This approach may provide empirical evidence for the possibility of developing a broad-based, durable resistance to *Striga*.

Use of molecular markers: Molecular markers such as isozymes, RFLPs (Restriction Fragment Length Polymorphisms) or RAPDs (Random Amplified Polymorphic DNA) can provide a powerful approach in learning about the genetic basis of variation in certain traits. There is growing evidence that these markers would be useful for manipulating particularly complex traits. Efficient manipulation of traits in a breeding program requires detailed knowledge of their genetic bases. In some parental backgrounds, the genetics of *Striga* resistance has been found to be complex both with regard to number of genes and to environmental effects (Kulkurni and Shinde, 1985). Genetic linkage maps for the major crops are under construction in different laboratories, with the greatest advance made in maize. RFLP linkage analysis is based on the fact that the DNA marker identifies or "marks" the chromosomal segment in its vicinity, and allows that segment to be followed through various genetic manipulations (Stuber, 1989). Other homologous segments which may have alternative alleles at the marker locus may be replicated repeatedly in different progenies which may then be compared to assess their effects on *Striga* resistance. Molecular markers have advantages, in contrast to morphological markers (Tanksley, 1983), because alleles at most loci are codominant, genotypes can be determined at whole plant tissue and cellular levels, and there is little or no limit to the number of markers that can be monitored in a population.

As part of our interdisciplinary *Striga* research at Purdue University, we participate in molecular mapping of the sorghum genome (Melake Berhan *et al.*,1993) and the use of molecular markers in selection for durable resistance to *Striga*. We have a genetic linkage map of sorghum under construction, based on RFLP and RAPD analyses in a population derived from two diverse sorghum genotypes from Africa and China. The procedure in sorghum is greatly facilitated by the evident homology between maize and sorghum since the maize unique sequence probes hybridize readily with the sorghum genome. To date 166 maize probes hybridized to sorghum DNA and 92 detected polymorphic variation between the parental genomic background. We currently have a project underway to saturate this map with RAPD markers and subject our recombinant inbred lines to bulk segregant analysis with the goal of mapping the gene for low stimulant production. We have also generated recombinant inbred lines, segregating populations, and advanced breeding lines that combine genes for *Striga* resistance from several germplasm backgrounds. We plan to test many of these for *Striga* resistance in the field and employ RFLP technology to identify progenies that contain unique fragments that may be associated with *Striga* resistance.

Integrated control strategies

The *Striga* problem may be too widespread and too severe to control by using a single approach. We have repeatedly stressed the need to combine multiple genetic mechanisms of resistance in order to obtain durable host plant resistance. It may also be necessary to combine other approaches with host plant resistance to obtain effective broad-scale *Striga* control. The use of chemical inputs as a supplement to resistant cultivars may discourage the formation of new strains of *Striga* and thus protect against breakdown of resistance. Therefore, research on other *Striga* control techniques using cultural practices and chemical treatments in *Striga*-infested fields has been an integral component of our efforts.

We have shown the beneficial effects of herbicide and/or supplementary nitrogen on resistant and tolerant sorghum genotypes in *S. hermonthica*-infested fields in Sudan. Under these conditions susceptible sorghums are so heavily infested that they produce no grain, and may die so early that the *Striga* count never reaches high levels. These data show that one additional input such as herbicide or nitrogen can profoundly diminish *Striga* infestation, especially for the resistant cultivar SRN 39. The herbicide is applied to the soil a month after the sorghum is planted, allowing *Striga* seeds to germinate so that they are then killed by the treatment. With a tolerant genotype that produces normal levels of germination stimulant, this procedure should significantly diminish the *Striga* seed population in the soil. Yield data from this experiment indicate that SRN 39 may reach nearly its full yield potential with just one of these inputs, whereas the higher-yielding, *Striga*-susceptible sorghum requires two inputs in order to reach its yield potential.

Summary

Because of its parasitic nature, *Striga*'s interactions with its host plant play a crucial role in its survival. Throughout the life cycle of *Striga* there are several sequential host-parasite interactions, and their disruption offers unique opportunities for controlling this harmful parasite. Our overall strategy is the identification and exploitation of crop genotypes in which the host-parasite interaction, at each of the different stages of parasitism, does not develop normally. Assuming that genetic variation in hosts exists or can be created for each of the stages, we plan to develop appropriate screening methods, at each stage, for these resistance-conferring characteristics. We will employ conventional breeding methods to pyramid these multiple genes for *Striga* resistance into a single genetic background, thus producing enhanced levels of durable resistance.

Our emphasis up till now has been on the initial *Striga*-host interaction, the control of *Striga* germination by host root-produced chemical signals required for *Striga* seeds to germinate. We have identified and characterized these chemicals, developed simple methods to screen hosts for their production, identified genotypes that are resistant because they produce limited amounts of the signals, determined the inheritance mechanism of this trait, incorporated this specific resistance-conferring trait into improved sorghums for use in *Striga*-infested areas, and have embarked on international testing of these sorghums for broader adaptation and utilization. We are also involved in the molecular characterization of the genes conferring *Striga* resistance using RFLP and RAPD technologies.

In the future we will apply this approach to subsequent stages of *Striga* parasitism: haustorial initiation signal production, host influence on attachment/penetration, host-derived signals controlling *Striga* differentiation as well as antibiosis factors, and possible *Striga*-derived factors which seem to control host growth. Most of our research has been done on sorghum, but the interactions of *Striga* with corn, pearl millet, and cowpeas will receive increasing attention.

We are encouraged that our approach in our research efforts with our collaborators can make a contribution toward diminishing the devastation caused by *Striga*.

References

Aggarawal, V.D., N. Muleba, I. Drabo, J. Souma, and M. Mbewe. 1984. Inheritance of *Striga gesnerioides* resistance in cowpeas. p. 143. *In:* Parker *et al.* (eds.) Proc. Second International Symposium on Parasitic Weeds. ICARDA. Aleppo. Syria.

*Babiker, A.G.T., G. Ejeta, L.G. Butler, and W.R. Woodson. 1993. Ethylene Biosynthesis and Strigol-Induced Germination of *Striga asiatica*. Physiologia Plantarum, in press.

*Babiker, A.G.T., L.G. Butler, G. Ejeta, and W.R. Woodson. Enhancement of ethylene biosynthesis and germination with cytokinins and 1-aminocyclopropane-1-carboxylic acid in *Striga asiatica* seeds. 1993. Physiologia Plantarum, in press.

*Babiker, A.G.T., T. Cai, G. Ejeta, L.G. Butler, and W.R. Woodson. 1993. Enhancement of ethylene biosynthesis and germination in *Striga asiatica* seeds by thidiazuron and selected auxins. Physiologia Plantarum, in review.

Bebawi, F.F. 1981. Intraspecific physiological variants of *Striga hermonthica*. Exp. Agric. 17:419.

*Butler, L.G. 1989. *Striga*: Scourge of African cereals. INTSORMIL Publication # 89-1, University of Nebraska, Lincoln, NE.

*Butler, L.G. 1991. Biotechnology research on *Striga*. In S.K. Kim (ed). Combatting *Striga* in Africa. Proceedings, International Workshop organized by IITA, ICRISAT, and IDRC, August, 1988. IITA, Ibadan, Nigeria, p. 42-47.

*Butler, L.G., G. Ejeta, and D.E. Hess. 1989. *Striga*: A model for collaborative interdisciplinary research. p.119-122. Proc. International Sorghum and Millet CRSP Conference, Scottsdale, AZ, Univ. Nebraska, Lincoln, NE.

*Butler, L.G., and G. Ejeta. 1991. Several approaches to the *Striga* problem being developed at Purdue University. Proc. 2nd Workshop of the Pan African *Striga* Control Network (PASCON), June 1991, Nairobi, Kenya.

*Butler, L.G., G. Ejeta, D.E. Hess, B. Siame, Y. Weerasuriya, and T. Cai. 1991. Some novel approaches to the *Striga* problem. p. 500-502. *In:* Ransom *et al.* (eds.) Proc. Fifth International Symposium on Parasitic Weeds. Nairobi, Kenya.

*Cai, T., A.G.T. Babiker, G. Ejeta, and L.G. Butler. 1993. Morphological response of witchweed (*Striga asiatica*) to in vitro culture. J. Exp. Botany, in press.

*Chang, M. D.G. Lynn, D.H. Netzly, and L. Butler. 1986. Host recognition in parasitic angiosperms: Chemical regulation of distance between plants. 3rd Ann. Meet., International Soc. Chemical Ecology, p. 25.

*Chang, M., D.H. Netzly, L.G. Butler, and D.G. Lynn. 1986. Chemical regulation of distance: Characterization of the first natural host germination stimulant for *Striga asiatica*. J. Am. Chem. Soc. 108: 7858-7860.

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

Cook, C.E., L.P. Wichard, M.E. Wall, G.H. Egley, P. Coggon, P.A. Luhan, and A.T. McPhail. 1972. Germination stimulants II. The structure of strigol–A potential seed germination stimulant for witchweed. J. Am. Chem. Soc. 94:6198.

Dixon, N.H. and C. Parker. 1984. Aspects of resistance of sorghum varieties to *Striga* species. p. 123-132. *In:* Parker *et al.* (eds.) Proc. Third International Symposium on Parasitic Weeds. Aleppo, Syria.

Doggett, H. 1984. *Striga*, its biology and control, an overview. p. 27-36. *In:* Ayensu *et al.* (eds.) *Striga* Biology and Control. Proc. International Workshop on the Biology and Control of *Striga*. Dakar, Senegal, 14-17 November 1983. ICSU, Paris, France.

Doggett, H. 1988. Sorghum (Second edition), p. 368-404. John Wiley & Sons, New York, N.Y.

Edwards, W.G.H. 1979. Orobanche and other plant parasite factors. p. 235-248. *In:* J.B. Harborne (ed.) Phytochemical Ecology. New York Academic Press.

Efron, Y., S.K. Kim, V. Parkinson, N.A. Boxque-Perez. 1988. IITA strategies to develop *Striga* resistant maize germplasm. FAO Plant Production and Protection Paper. 96:141-153.

*Ejeta, G., and L.G. Butler. 1993. Host plant resistance to *Striga*. 1993. International Crop Science I, D.R. Buxton et al.,eds. Crop Science Society of America, in press.

*Ejeta, G., L.G. Butler, D.E. Hess, and R.K. Vogler. 1991. Genetic and breeding strategies for *Striga* resistance in sorghum. p. 539-544. *In:* Ransom *et al.* (eds.) Proc. Fifth International Symposium on Parasitic Weeds. Nairobi, Kenya.

Hauck, C., S. Muller, H. Schildknecht. 1992. A germination stimulant for parasitic flowering plants from Sorghum bicolor, a genuine host plant. J. Plant Physiol. 139:474-478.

*Hess, D.E. 1989. Resistance to *Striga hermonthica* in sorghum. PhD Thesis, Purdue University, West Lafayette, IN.

*Hess, D.E., and G. Ejeta. 1987. Effect of cultural treatments on infestation of *Striga hermonthica* on sorghum in Niger. *In:* H.C. Weber and W. Forstreuter (eds.). Proc. Fourth International Symp. on Parasitic Flowering Plants. Marburg, Germany. pp. 367-375.

*Hess, D.E., and G. Ejeta. 1988. Genetics of resistance to *Striga hermonthica* in sorghum. Agronomy Abstracts. Anaheim, CA. p. 83.

*Hess, D.E., R.K. Vogler, G. Ejeta, and L.G. Butler. 1989. Phenolic compounds in *Striga*-resistant and -susceptible sorghums. Agronomy Abstracts. Las Vegas, NV. p. 85.

*Hess, D.E., G. Ejeta, and L.G. Butler. 1991. Research into germination of *Striga* seed by sorghum root exudates. p.217-222. In Ransom *et al.* (eds.) Proc. Fifth International Symposium on Parasitic Weeds. Nairobi, Kenya.

*Hess, D.E. and G. Ejeta. 1992. Inheritance of *Striga* resistance in sorghum genotype SRN39. Plant Breeding 109:233-241.

*Hess, D.E., G. Ejeta, and L.G. Butler. 1992. Selecting sorghum genotypes expressing a quantitative biosynthetic trait that confers resistance to *Striga*. Phytochemistry 31:493-497.

*Housley, T., G. Ejeta, A. Charif, D. Netzly, and L.G. Butler. 1987. Progress towards an understanding of sorghum resistance to *Striga*. *In:* H.C. Weber and W. Forstreuter (eds.). Proc. Fourth International Symp. on Parasitic Flowering Plants. Marburg, Germany. pp. 411-419.

Kim, S.K., F. Khadr, V. Parkinson, J. Pajemisin, and Y. Efron. 1985. Maize breeding for *Striga* resistance in Africa. p. 58-74. *In:* Proc. of OAU/FAO Workshop on *Striga*. 23-27 September 1985. Yaounde, Cameroon. FAO, Rome.

Kulkarni, N. and V.K. Shinde. 1985. Genetics of grain yield in sorghum under *Striga* stress. Ind. J. Genet. 45:21-24.

Lagoke, S.T., V. Parkinson, and R.M. Agunbiade. 1991. Parasitic weeds and control methods in Africa. p. 3-15. *In:* S.K. Kim (ed.) Combating *Striga* in Africa. Proc. International Workshops organized by IITA, ICRISAT and IDRC, 22-24 August 1988. IITA, Ibadan, Nigeria.

Lynn, D.G. and M. Chang. 1990. Phenolic signals in cohabitation: implication for plant development. Ann. Rev. Plant Physiol. 41:497-526.

Maiti, R.K., K.V. Ramaiah, S.S. Bisen, and V.L. Chidley. 1984. A comparative study of the haustorial development of *S. asiatica* on sorghum cultivars. Ann. Bot. 54:447.

*Melake Berhan, A., S.H. Hulbert, L.G. Butler, and J.L. Bennetzen. 1993. Theoretical and Applied Genetics, in press.

Muller, S., C. Hauck, and H. Schildknecht. 1992. Germination stimulants produced by *Vigna unguiculata* Walp cv Saunders Upright. J. Plant Growth Regulation 11:77-84.

Musselman, L.J. 1980. The biology of *Striga*, orobanche, and other root parasitic weeds. Ann. Rev. Phythopathol. 18:463-489.

Musselman, L.J. 1987. Taxonomy of witchweeds. p. 3-12. *In:* L.J. Musselman (ed.) Parasitic weeds in agriculture. Vol. 1. CRC Press, Boca Raton, FL, USA.

Musselman, L.J. and F.N. Hepper. 1986. The witchweeds (*Striga, Scrophulariaceae*) of the Sudan Republic. Kew. Bull. 41:205.

*Netzly, D.H., L.G. Butler, M. Chang, and D. Lynn. 1986. Quinones present in biologically active exudates from roots of *Sorghum bicolor*. Fed. Proc. 45: 1566.

*Netzly, D.H., and L.G. Butler. 1986. Roots of Sorghum bicolor Exude Hydrophobic Droplets Containing Biologically Active Components. Crop Science 26: 775-778.

*Netzly, D.H., G. Ejeta, T. Housley, D.E. Hess, and L.G. Butler. 1986. Mechanisms of resistance to *Striga* in sorghum. In S.J. Ter Borg (ed.), Proc. International Symp. on Biology and Control of Orobanche. LH/VPO, Wageningen, The Netherlands, pp. 50-52.

*Netzly, D.H., J.L. Riopel, G. Ejeta, and L.G. Butler. 1988. Germination stimulants of witchweed (*Striga asiatica*) from hydrophobic root exudate of sorghum (*Sorghum bicolor*). Weed Sci. 36:441-446.

Obilana, A.T. 1984. Inheritance of resistance to *Striga* (*Striga hermonthica* Benth.) in sorghum. Prot. Ecol. 7:305-311.

Okonkwo, S.N.C. 1966. Studies on *Striga senegalensis*. I. *In vitro* culture of seedlings. Effect of various sugars and glutamine. Am. J. Bot. 53:687-693.

Parker, C. and D.C. Reid. 1979. Host specificity in *Striga* species - some preliminary observations. p. 79-90. *In:* Musselman *et al.* (edS.) Proc. Second Symposium on Parasitic Weeds. 16-19 July 1979. Raleigh, North Carolina, USA.

Parker, C., A.M. Hitchcock, and K.V. Ramaiah. 1977. The germination of *Striga* species by crop root exudates. Techniques for selecting resistant crop cultivars. Proc. 6th Asian-Pacific Weed Sci. Soc. Conf., Indiana, Indonesia 1:67.

Patterson, D.T. 1987. Environmental factors affecting witchweeds growth and development. p. 27-41. *In:* L.J. Musselman (ed.) Parasitic weeds in agriculture. Vol. 1. CRC Press, Boca Raton, FL, USA.

Press, M.C., J.D. Graves, and G.R. Stewart. 1990. Physiology of the interaction of angiosperm parasites and their higher plant hosts. Plant Cell and the Environment 13:91-104.

Ramaiah, K.V. 1978. *Striga* resistance work at ICRISAT. *In:* A. Kambal (ed.) Proc. First International *Striga* Workshop. 5-8 November 1978. Khartoum, Sudan.

Ramaiah, K.V. 1987. Breeding cereal grains for resistance to witchweed. p. 227-242. *In:* L.J. Musselman (ed.) Parasitic weeds in agriculture. Vol. 1. CRC Press, Boca Raton, FL, USA.

Ramaiah, K.V. and C. Parker. 1982. *Striga* and other weeds in sorghum. p. 291. *In:* House *et al.* (eds.) Sorghum in the Eighties. Proc. International Symposium on Sorghum. ICRISAT, Patancheru, India.

Ramaiah, K.V., V.L. Chidly, and L.R. House. 1990. Inheritance of *Striga* seed germination stimulant in sorghum. Euphytica 45:33-38.

Ransom, J.K., R.E. Eplee, and M.A. Langston. 1990. Genetic variability for resistance to *Striga asiatica* in maize. Cereal Res. Communication 18, 4:329.

*Reda, F., L.G. Butler, G. Ejeta, and J.K. Ransom. 1993. Screening of maize genotypes for low *Striga* stimulant production using the agar gel technique. Proceedings of First Crop Science Conference for Eastern and Southern Africa, Makerere University, Kampala, Uganda, June 14-18, 1993, in press.

Saunders, A.R. 1933. Studies on phanerogamic parasitism with particular reference to *S. lutea.* p. 128. S. Afr. Dept. Agric. Bull.

*Siame, B., and L.G. Butler. 1991. Isolation and characterization of water-soluble germination stimulants for *Striga.* International INTSORMIL Conference. Corpus Christi, TX. pp. 258-259.

*Siame, B., K. Wood, G. Ejeta, and L.G. Butler. 1993. Isolation of Strigol, a Germination Stimulant for *Striga asiatica*, from Natural Host Plants. J. Agric. Food Chem., in review.

Singh, B.B. and A.M. Emechebe. 1990. Inheritance of *Striga* resistance in cowpea genotype B301. Crop Sci. 30:879-881.

Stuber, C.W. 1989. Molecular markers in the manipulation of quantitative characters. *In:* Plant Population, Genetics, Breeding, and Genetic Resources. Brown A.H.D, M.T. Clegg, A.L. Kahler, and B.S. Weir (eds.) pp. 334-350.

Tanksley, S.D. 1983. Molecular markers in plant breeding. Plant Mol. Biol. Rep. 1:3-8.

Vasudeva Rao, M.J. and L.J. Musselman. 1987. Host specificity in *Striga* spp. and physiological strains. p. 13-25. *In:* L.J. Musselman (ed.) Parasitic weeds in agriculture. Vol. 1. CRC Press, Boca Raton, FL, USA.

*Vogler, R.K., G. Ejeta, and L.G. Butler. 1991. Selecting sorghum genotypes for *Striga* resistance using an agar gel assay. International INTSORMIL Conference. Corpus Christi, TX. p. 266.

*Vogler, R.K., G. Ejeta, and L.G. Butler. 1991. Inheritance of low stimulation of *Striga* seed germination in sorghum cultivar SRN 39. Agronomy Abstracts. Denver, CO. p. 120.

*Vogler, R.K. G. Ejeta, and L.G. Butler. 1993. Genetic control of low-stimulant production and its potential as a predictor of field resistance against *Striga asiatica* in sorghum (in review).

*Weerasuriya, Y. 1991. Stimulation and inhibition of *Striga* seed germination. International INTSORMIL Conference. Corpus Christi, TX. p. 259.

*Weerasuriya, Y. 1992. Root exudation of germination stimulants by hosts and other plants for *Striga asiatica* and production of antibodies to *Striga* seed surface antigens. M.S. Thesis, Purdue University, West Lafayette, IN.

*Weerasuriya, Y., G. Ejeta, and L.G. Butler. 1992. Production of host-derived developmental signals for witchweeds. Agronomy Abstracts. Minneapolis, MN.

*Weerasuriya, Y., B. Siame, D.E. Hess, G. Ejeta, and L.G. Butler. 1993. Influence of conditions on the amount of *Striga* germination stimulants exuded by the roots of several host corps. J. Agric. Food Chem., in review.

Williams, C.N. 1961. Growth and morphogenesis of *Striga* seedlings. Nature 189:378.

Wilson Jones, K. 1955. Further experiments on witchweed control. II. The existence of physiological strains of *Striga hermonthica*. Empire J. Exp. Agric. 23:206.

Worsham, A.D. 1987. Germination of witchweed seeds. *In:* Musselman, L.J. (ed.) Parasitic Weeds in Agriculture. Vol. I. *Striga*. CRC Press, Boca Raton, FL. pp. 45-61.

(* publications from our research program)

Acknowledgments

Our research on *Striga* is partially supported by USAID Grant No. DAN 1254-G-00-0021-00 through INTSORMIL, the International Sorghum and Millet CRSP, by Program Support Grant No. DSAN-XII-G-0124, by Grant No. GA AS 8905 from the Rockefeller Foundation, and by the McKnight Foundation.

We are grateful to Drs. L. S. Hardin and D. W. Thomas for their continued encouragement and support.

Thanks to current and former students for photographs in this publication.

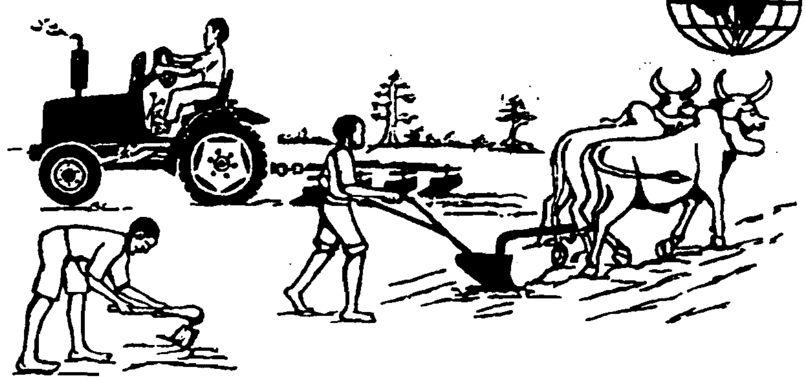
Dedicated to the memory of D. W. Thomas, Director of International Programs in Agriculture at Purdue University.

Sudanese farmers comparing a local Striga-susceptible sorghum (left) with SRN-39 (right), the first Striga-resistant variety released for commercial cultivation in the Sudan.

Institut d'Economie Rurale

A COLLABORATIVE RESEARCH VENTURE

INTSORMIL



October 1993

147

Introduction

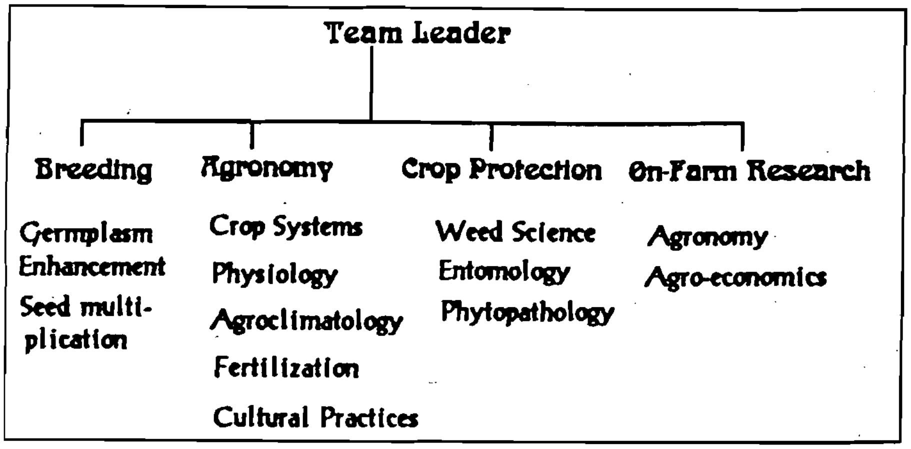
The role of Agriculture in the economy of Mali is crucial : it has contributed an average 48% to GDP over the past 5 years.

Seventy five percent of the population is in rural areas, of which 70% are directly employed in agriculture. The principal cereal crops, sorghum and millet account for over 75% of Mali's total cereal production. Sorghum and millet are the staple cereals in the country. Both crops occupied about 1.5 million ha, (75 percent of the total land in the country) and produce about 1.3 million tons. Sorghum and millet are grown throughout Mali, about 60% of the cultivated area is in the south, which receives more than 800 mm of rain annually and about 30% in the central, 500-800 mm rainfall area. The total annual rainfall in Mali varies from 0 mm in the north to 1300 mm in the south. The cropping season lasts up to 5-6 months in the south, beginning in May and Lasting until October- November. As one moves to the north, the rains begin progressively later and end earlier. The soils are generally loamy sand, sandy loam, or sandy, and are classified within the Aerosol group in the north, and as either Luvisols or Alfisols in the sudanian ecological zone.

Principal Constraints To Sorghum And Millet Production

* Climatic constraints :
  - Great variability in quantity as well as in temporal distribution of rainfall
* Edaphic constraints :
  - Low soil fertility (deficiencies in nitrogen and phosphorus)
  - Soil degradation
* Biological constraints :
  - Weeds (Striga, etc...)
  - Insects and Diseases
* Socio-Economic constraints :
  - Lack of well organized agro-industry
  - Low incomes of producers
  - Lack of equipment
  - Existence of disabling diseases
  - Rural exodus

Sorghum and Millet Sub-Program



Stations and sub-stations

	Sorghum	Millet
Stations	Sotuba (principal)	Cinzana Principal)
	Cinzana	Koporo
	Longorola	Sotuba
Sub-Stations		
	Samanko	Baramandougou
	Katibougou	Samanko
	Massantola	Katibougou
	Bema	Massantola
		Bema

Institut d'Economie Rurale (IER)

Institute of Rural Economy of Mali, under the Ministry of Rural Development (Agriculture, Livestock, forestry) has the national responsibility for sorghum and millet research.

A director general, a deputy director general and the Department heads have the overall responsibility of leading the IER.

The current director general is Dr. Oumar Niangado and the deputy director general Lassine Dembélé.

Agricultural research in Mali began in 1925 under the French colonial administration (at M'Pessoba). Until independence in 1960, crop research was conducted at Kogoni and N'Tarla. In 1962, the Malian government assumed administrative control of Agriculture research with the creation of IER, attached to the Ministry of Agriculture. Until 1977, crop research was conducted almost entirely under contract by a number of French agricultural research institutes notably IRAT.

Some changes occurred by the mid 1970's by a growing number of qualified Malian researchers, graduates of the Institut Polytechnique Rural (IPR) at Katibougou, which opened in 1965. The Malians began to develop their own research agenda. USAID became the major donor for agricultural research in Mali. At the same time, IER began to participate in regional research activities and collaborative research with some international organizations.

During 1990, the Malian government began a major reorganization of agricultural research with the merge of the two important research institutes INRZFH and IER. The new IER is developing long and medium-term research goals and objectives. The emphasis has been on regionalization and decentralization and encouraging interdisciplinary problem oriented research.

IER has 5 departments under the Director General and Deputy Director general. The department of Agronomy is responsible for agronomic research on all crops in Mali, and is also responsible for coordinating and controlling agronomic research undertaken in Mali by regional and international organizations. The sub-programs of sorghum and millet belong to the program Cereals and Food legumes which is one of the 7 programs of research in IER. Six regional research centers shelter all the stations and sub-stations which are responsible for one or two specific program(s). The principal research station for sorghum is located at Sotuba just outside Bamako while that of millet is located at Cinzana about 45 km from Ségou.

History Of Intsormil

Title XII "Famine Prevention and Freedom from Hunger" begun in 1975 when the US Congress approved an amendment to the Foreign Assistance Act of 1961. The main goal of the title XII was to make the expertise in science technology of US Universities more accessible to developing countries, and thus help them solve food and nutrition problems. The concept of "Collaborative Research Support Programs" CRSPs was one of the ways of achieving this objective.

By 1977, research area on sorghum and millet production had been chosen to become among the first two CRSPs. Thus, the International Sorghum and Millet Program-INTSORMIL - was born. The sorghum/millet CRPS was officially established in 1979 and the grant was later extended to 1985. At the time INTSORMIL was begun there were ongoing sorghum/millet projects, funded in part by AID at Kansas State University University of Nebraska, Texas A & M University and Perdue University Then, an important decision was made that INTSORMIL would focus on collaborative research among universities and host countries, rather than pairing each university with one host country to work on a single research objective.

INTSORMIL has been in Mali informally since November of 1979. A formal Memorandum of Agreement to allow transfer of funds was signed in Mali on October 10, 1984. Since, 10 amendments were signed between The Institute of Rural Economy of Mali and the Entity Management of INTSORMIL, indicating the work plan and budget of each fiscal year.
About 10 projects have been collaboratively planned by IER and US Scientists in 1992-1993. Current INTSORMIL/IER research projects cover all disciplines. The Program has interacted not only with IER but also with TROPSOILS, Ciba-Geigy, ICRISAT/WASIP and has been supported by USAID/MALI over the years.

Purpose Of INTSORMIL In Mali

The primary purpose of INTSORMIL is to :

- develop technology to increase and improve sorghum/millet production,
- collaborate with IER researchers to apply that technology,
- provide vital assistance in training scientists in Mali,
- provide on site counselling,
- provide assistance to IER in personal training and institution building.

Collaborative Program

The INTSORMIL collaborative program in Mali is a multidisciplinary research program. The vital collaboration continues to provide efficient use of resources. The program has centered around Malian scientists and each Malian scientist develops research plans cooperatively with a US counterpart which provides for effective research planning, communication and coordination. Each year during the cropping season, INTSORMIL collaborators travel to Mali consult, review progress and plan future activities with Malian Scientists.

The program includes all aspects of sorghum/millet improvement with major emphasis on germplasm enhancement, utilization and quality, physiology of drought adaptation, nitrogen efficiency, soil management, insect pests, disease control strategies and Striga control.

Research Accomplishments

BREEDING

Three local photosentive cultivars have been improved and are grown by farmers on a significant area (CSM 388, CSM 219, CSM 63).

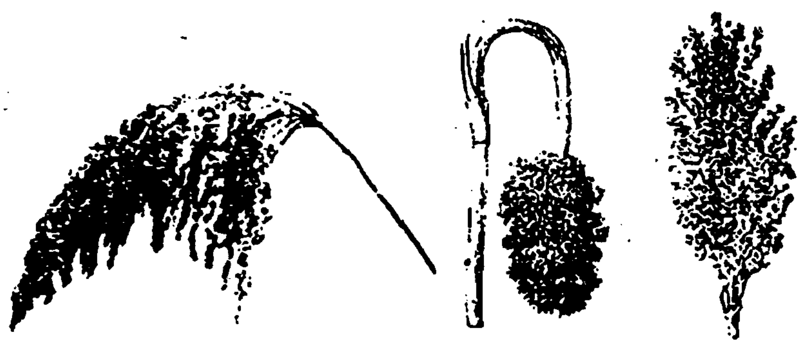
Seven improved sorghum lines from Malian program have been released (Malisor 84-1 to 84-7) with promising results.

Testing in Texas and Mali has demonstrated that the drought response in Mali is similar to the drought response in west Texas increasing probability of success.

Germplasm from US Breeders and the sorghum conversion program has been incorporated into the Malian breeding programs.

Varieties of millet selected for the tallest expression of the D_2 dwarfing complex (1.7 to 1.9 m) have given good performance in millet/legume intercropping studies.

Dwarf (D_2) inbred lines selected at Cinzana from progenies of crosses between Mali and UNL-118 lines appear promising as germplasm sources to develop dwarf varieties for intercropping.



ENTOMOLOGY

① The adverse effect of head bugs on the grain food quality of introduced sorghum across west Africa was first recognized and documented in Mali.

② The INTSORMIL collaborative sorghum entomology research programin Mali has discovered the source of genetic resistance to head bug (*Eurystylus marginatus*) which has been a major constraint to the quality of grain sorghum in Mali.

③ A reliable technique for screening for head bug resistance has been developed and is used cooperatively by the breeders and the entomologists.

④ Inheritance of head bug resistance is quantitative and primarily recessive.

PATHOLOGY

INTSORMIL collaborative research has shown :

① Grain yield increase of 20 % can be obtained by treating seed with Apron plus.

② Protection from head bugs will be a requirement for evaluation of grain mold resistance.

③ Long smut (*Tolyposporium ehrenbergii*) is severe in the drier regions of Mali.

④ Anthracnose (*Collectrotrichum graminicola*) is a very serious sorghum disease in Mali.

⑤ Leaf spot is not as serious in southern Mali as other diseases.

AGRONOMY

① INTSORMIL / IER research has demonstrated the millet or sorghum planted after peanut or cowpea results in 36-63% yield increases.

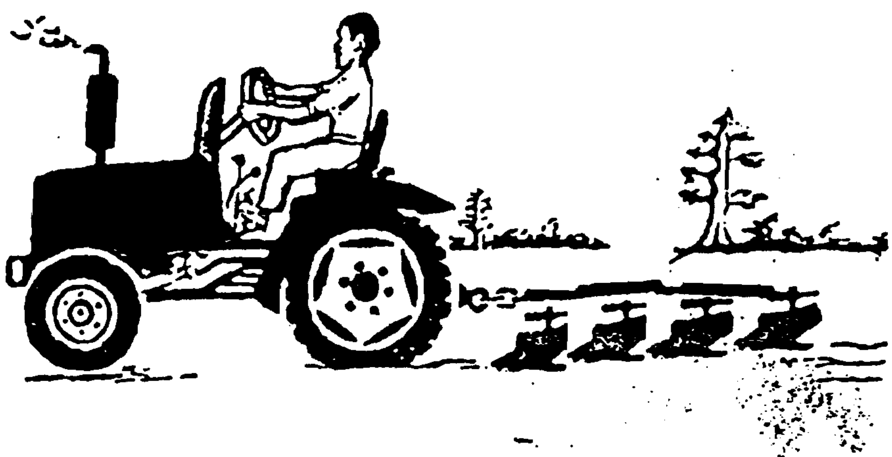
② INTSORMIL collaborative research has shown an increase in pearl millet grain yield and biomass production due to previous cowpea crops and equivalent to the application of 30 to 40 kg/ha N.

③ The study of sorghum response to nitrogen suggests a relationship between response to N and genotype as well as environment.

④ Joint INTSORMIL/TROPSOILS Collaboration program has addressed soil chemical properties associated with nutrient deficiencies toxicities in sandy soils of the Cinzana Station. Some Durra varieties from Niger and northern Mali show tolerance to soil toxicity.

⑤ Genotypes of sorghum which accumulated high amounts of proline had significantly greater heat and desiccation tolerance. Landraces obtained from Mali has high heat and desiccation tolerance.

⑥ A method of screening large numbers of sorghum and millet lines for early generation and selection for seedling stage drought resistance using a charcoal pit has been adapted and is used.



GRAIN QUALITY AND UTILIZATION

① Sorghum and millet postharvest technology systems in Mali were documented in 1979 and strategies for evaluating the quality of cereals, especially sorghum, for tô were devised.

② Mini tests for evaluating milling and tô properties were developed and currently are used in the laboratory.

③ Sorghum with hard endosperm and thick pericarps was definitely required for efficient traditional hand pounding.

④ The size and shape of pearl millet kernel affects dehulling properties significantly.

⑤ The souna types, have reduced yields of decorticated grain.

⑥ Tô quality of millet cultivars does not vary as much as it does among sorghum.

⑦ Head bugs reduced sorghum milling yields and produced tô with unacceptable texture and Keeping properties.

⑧ Parboiling can convert sorghum and millet into acceptable products. It improves dehulling yields, especially for soft grains. The cooked milled products can be eaten like rice.

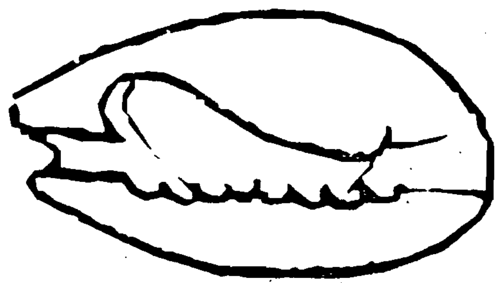
⑨ The combination of cowpea and millet flour (1:3) significantly improved the nutritional status of young children. This technology has been transferred to many villages especially in the Cinzana area.

INTSORMIL FUNDING TO IER

The INTSORMIL funding to IER comes through the INTSORMIL MALI Project- "Cooperative Research on Sustainable Systems for Production, Utilization and Marketing of Sorghum and Millet in Mali". The annual budget allocated to IER has increased since the beginning of the formal Memorandum of Understanding signed in 1984.

The annual budget allocation for each amendment is divided in two parts. A part is available to IER and the other part held by INTSORMIL/NEBRASKA for Mali purchases. The funds available to IER is utilized in personnel, equipment, supplies and travel. The transfer of funds is made from INTSORMIL/University of Nebraska to IER based on IER's request. The amount that is held by INTSORMIL/NEBRASKA is utilized as specified in the Mali project budget.

However, the main source of funding for sorghum and millet research and development in Mali is the national budget. All salaries, staff benefits, and operational funds are provided from national sources.



Coordinators

Dr. D.T. Rosenow Sorghum Breeding, Texas A & M University, Lubbock, Texas, USA

Dr. Aboubacar Touré, Sorghum Breeding, SRA/Sotuba, DRA/IER, Bamako, Mali

Institutions Involved

Institute of Rural Economy (IER), Bamako, Mali

Texas A & M University, College Station, Tx

University of Nebraska, Lincoln, NE

Purdue University, Lafayette, Indiana

Kansas state University, Manhattan, Kansas

INSTITUTION BUILDING

The most significant impact of INTSORMIL has been the strengthening of the IER both through staff training and research capacity building.

INTSORMIL has built and equipped a Agro-physiology Laboratory at the Cinzana Agricultural Experiment Station to provide support for the expanded activities in agronomic and drought research being conducted by IER Scientists (Neutron probe, Psychrometer, Microscope, Infra-red thermometer, Leaf Area Meter, Porometer, Li Cor photosynthesis analyser, Spectrophotometer, etc.).

Since the beginning of the INTSORMIL activities in Mali in 1979, 3 vehicles were purchased to facilitate domestic travel of Scientists.

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

Equipment for the Food Technology Laboratory was provided and personnel were provided short term training programs in the U.S (Tadd, mixers, pH meters, oven, scales, sieves, etc.).

A number of senior staff in sorghum and millet research within the IER are INTSORMIL trainees.

INTSORMIL has played significant roles in consulting and cooperating with IER in giving a positive direction of growth.

INTSORMIL has provided computer systems/word processors for DIALCOM and software to IER Scientists.

Interdisciplinary and cooperative research in sorghum and millet which are in place at the IER are mainly due to INTSORMIL / IER collaborations. Multidisciplinary approach to solving technical problems have been promoted by the INTSORMIL.

INTSORMIL has provided graduate training for 14 key Malian scientists.

Short term training in the USA for Malian scientists has provided by INTSORMIL in physiology, breeding, soil fertility, food technology, entomology and weed science. Over 10 scientists have received this type of training.

Each year, US scientists travel to Mali to review and plan research activities with their counterparts in Mali.

Malian scientists trained by INTSORMIL PI's

Name	Year graduated	Degree sought	Discipline	Funding
Moussa D. Traoré	1985	PhD	Physiology	C
Sidi Bekaye Coulibaly	1991	MS	Physiology	C
Siriba Dioné	1991	MS	Physiology	C
Abdoul W. Touré	1992	MS	Agronomy	C
Adama Coulibaly	1992	MS	Agronomy	C
Ousmane Coulibaly	*	PhD	Agroeconomics	C
Karim Traoré	1990	MS	Breeding	O
Minamba Bagayoko	1990	MS	Agronomy	O
Aboubacar Touré	1992	PhD	Breeding	O
Abdoul A. Sow	*	PhD	Soils	O
Mamadou Doumbia	*	PhD	Soil Fertility	O
Assa Kanté	1987	MS	Food Techn.	O
Mamourou Diourté	1988	MS	Pathology	O
Abdoulaye Traoré	*	PhD	Agronomy	C

* = currenly studying in USA.
C = completely funded by INTSORMIL
O = other source

Thesis And Dissertations Completed During 1985-1992

Bagayoko, Minamba. December 1989. Residual effect of previous cropping systems on sorghum grain and stover yields. M.S. University of Nebraska, Lincoln (advisor, S.C. Mason).

Coulibaly, Adama. May 1992. Relationship between growth rate and tiller number in sorghum. M.S., Kansas State University, Manhattan, KS. (advisor, R. Vanderlip).

Coulibaly, Sidi Bekaye. August 1991. Physiological characteristics of drought resistant sorghum. M.S. University of Nebraska, Lincoln (advisor, C.Y. Sullivan).

Dioné, Siriba. October 1991. Influences of abscisic acid on sorghum growth and stress resistance. M.S. University of Nebraska, Lincoln (advisor, C.Y. Sullivan).

Kanté, Assa. 1987. Factors affecting the porridge quality of sorghum and pearl millet. MS. Texas A & M University, College Station, Tx. (advisor, L.W. Rooney).

Touré, Abdoul W. May 1992. Effect of rate on time of application on pearl millet response to nitrogen. M.S. University of Nebraska, Lincoln (advisor, J. Maranville).

Touré, Aboubacar. May 1992. Heterosis, combining ability and breeding potential studies for grain yield and yield components in guinea sorghum (*Sorghum bicolor* L. Moench). PhD. Texas A & M University, College Station, Tx. (advisors, D.T. Rosenow and F.R. Miller).

Traoré, Karim. December 1989. Comparative growth of Normal and Yellow pearl millet (*Pennisetum americanum* L. Leek). M.S. University of Nebraska, Lincoln (advisor, D.J. Andrews).

Traoré, Moussa. 1985. Physiological and morphological mechanisms of drought resistance in sorghum and pearl millet. PhD. University of Nebraska, Lincoln (advisor, C.Y. Sullivan).

COLLABORATING SCIENTISTS

Dr. **M. Traoré**, Plant Physiology, Permanent Secretary of the Ministry of Rural Development, Bamako, Mali

Dr. **O. Niangado**, Millet Breeding and Improvement, Director General IER, Bamako Mali

Dr. **A. Touré**, Sorghum Breeding, Sorghum Team Leader, IER, Sotuba Mali

Dr. **L.W. Rooney**, Cereal Chemistry & Food Technology, Texas A & M University, College Station, Tx

Dr. **C.Y. Sullivan**, Plant Physiology, University of Nebraska, Lincoln, NE

Dr. **D.T. Rosenow**, Sorghum Breeding, Texas A & M University, Lubbock, Tx

Dr. **R.A. Frederiksen**, Sorghum Pathology, Texas A & M University, College Station, Tx

Dr. **G.L. Teetes**, Entomology, Texas A & M University, College Station, Tx

Dr. **S.C. Mason**, Agronomist, University of Nebraska, Lincoln, NE

Professor **W. Stegmeir**, Millet Breeding, Kansas State University, Ft. Hayes, KS

Dr.**A.B. Onken**, Soil Fertility TROPSOILS, Texas Agr. Exp. Station, Lubbock, Tx

Dr. **J.W. Maranville**, Agronomist, University of Nebraska, Lincoln, NE

Dr. **F.R. Miller**, Sorghum Breeding, Texas A & M University, College Station, Tx

Dr. **R.L. Vanderlip**, Agronomist, Kansas State University, Manhattan, KS

Dr. **J.H. Sanders**, Agr. Economics Purdue University, Lafayette, IN.

Ms. **M. Haïdara**, Food Technology, IER, Sotuba, Mali

Mr. **I. Goïta**, Food Technology, IER, Sotuba, Mali

Mr. **S. Dioné**, seed physiology, IER, Sotuba, Mali

Mr. **A.W. Touré**, Sorghum Agronomy, IER, Sotuba, Mali

Ms. **A. Berthé**, Food Technology, IER, Sotuba, Mali

Ms. **S. Coulibaly**, Sorghum Breeding, IER Cinzana, Mali

Mr. **Amadou Sy**, Sorghum Breeding, IER Samanko, Mali

Mr. **A. Traoré**, Agronomist, IER, Sotuba, Mali

Mr. **M. Diourté**, Sorghum Pathology, IER, Sotuba, Mali

Dr. **Y. Doumbia**, Sorghum Entomology, IER, Sotuba, Mali

Mr. **K. Traoré**, Millet Breeding, IER, Cinzana, Mali

Mr. **M. Bagayoko**, Agronomy, IER, Mopti, Mali

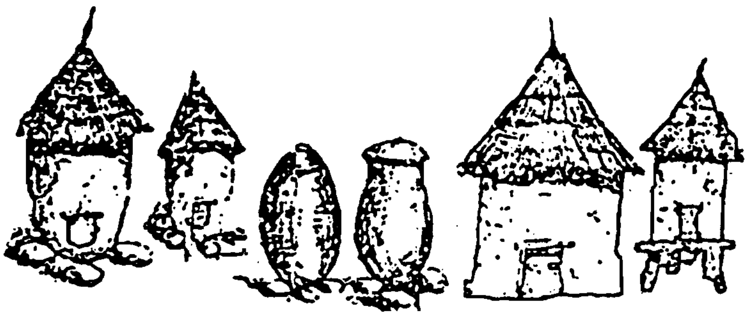
Mr. **M. N'Diaye**, Millet Pathology, IER, Cinzana, Mali

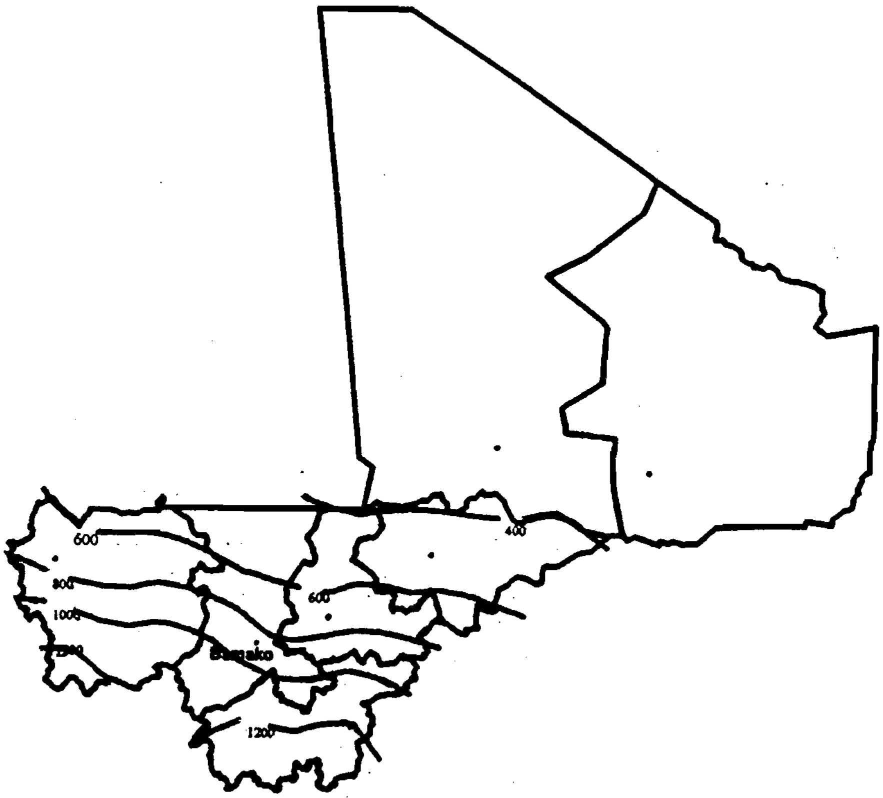
Ms. **N. Diarisso**, Sorghum Entomology, IER, Sotuba, Mali.

Mr. **S. Traoré**, Millet Agronomy, Millet Team Leader, IER, Cinzana, Mali

Ms. **Mariam Diarra**, Sorghum Pathology, IER, Sotuba, Mali

Dr. **B. Dembelé**, Weed science, IER, Sotuba, Mali





Institut d'Economie Rurale
BP258, Bamako, MALI
Tel : (223) 22 26 06