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Introduction and Program Overview

The global community confronts an enormous task of stimulating economic growth in rural areas where 75% of the very poor (90% in Africa) currently live and ensuring the nutritional security of a world population that is growing in size and evolving in consumption patterns without intensifying environmental degradation, social security, or adverse consequences for human health. This challenge is not only great but it is also urgent. Today, access to food, sufficient, safe, and nutritious food, is the primary problem for nearly 800 million chronically undernourished people. Unless we act now, the next few decades will almost certainly find us unable to produce agricultural products sufficient to meet the demands of growing populations and changing diets. The majority of poor live in rural areas in developing countries and agricultural and food systems development is vital to economic growth; improving environmental quality; strengthening nutrition, health and child survival; improving the status of women; and promoting democratization.

Over the next 50 years, the global population will increase to 8-10 billion, requiring advances in scientific knowledge across a broad range of agricultural endeavors, i.e., developing more productive food and commodity cultivars, improving nutritional quality of crop and livestock products, reducing food and commodity yield losses due to pests and diseases, ensuring healthy livestock, developing sustainable and responsible fisheries and aquaculture practices, optimizing the use of forests, managing water more efficiently, protecting and improving land productivity, and conserving and managing genetic diversity.

According to an issues paper on an international assessment on agricultural science and technology in reducing hunger and improving rural development, which is being conducted by the World Bank, meeting these demands will require productivity increases and product diversification to improve the livelihoods of the poor, to protect the environment in both developed and developing countries that is grounded in equity, that addresses key issues such as trade, Intellectural Property Rights (IPR), and land tenure, and that enhances agricultural productivity while encouraging the sustainable use of natural resources.

According to Entering the 21st Century – World Development Report 1999-2000, about 900 million people in almost 100 countries are affected by drought and desertification, and by 2025, that number will double. The population of the world has doubled since 1940, but fresh water use has increased fourfold. Water scarcity is becoming more widespread, with concomitant effects on regional peace and global food security. Nearly all of the three billion increase in global population which is expected by 2025 will be in developing countries where water is already scarce. To meet the increasing demand for food in those countries, there is an increasing demand for more efficient production and new ways of utilizing drought-tolerant crops which have a competitive advantage to produce food under conditions of unpredictable and scarce rainfall. According to Dr. Jeff Dahlberg, Seed World, June 2001, water scarcity will require a blue revolution, a revolution that involves turning over acreage currently planted to crops which require heavy irrigation to drought tolerant grains such as sorghum and pearl millet. Dr. Dahlberg states that the blue revolution will be the next major change in agricultural production, and its impact could be as great, if not greater, than that of the Green Revolution.

In developing countries of the semi-arid regions, sorghum and millet, two important cereal grains, make the difference between food security and famine. In the United States, sorghum is important to the balance of trade, is an important feed in the production of beef, and is increasingly in demand as a raw material for food and as a renewable feedstock for production of fuel. In 2001, 58.5 Tg (million tons) of sorghum were produced worldwide, of which 18.4 Tg were produced in sub-Saharan Africa, mainly for direct consumption by humans, and 13.1 Tg were produced in the United States, mainly for livestock feed to produce meat for human consumption. In 2000, the United States exported 6.6 Tg of grain sorghum mainly for livestock feed, and in 1999, U.S. grain sorghum exports were worth $626 million. Large areas are planted to sorghum each year. For example, in 2001 sorghum was produced on 42.6 million hectares (ha, or 166,406 square miles, [sq mi]) worldwide, 22.2 million ha (86,752 sq mi) in Africa, and 3.473 million ha (13,566 sq mi) in the United States. About 500 million people worldwide depend upon sorghum for food, and most of these people are in developing countries where droughts and famine are common occurrences. Clearly, sorghum production and utilization as food and feed are vitally important to developing countries and to the United States.

Millets, which include several types such as pearl millet, finger millet, and proso millet, are cereal crops even better adapted to arid ecosystems than is sorghum, and pearl millet is a staple for 300 million people worldwide. Most of these people are in countries within semi-arid regions where malnourishment is a persistent problem. In 2001, 37.4 million hectares (146,101 sq mi) of millets were harvested worldwide, of which 20.3 million ha (79,361 sq mi) were harvested in sub-Saharan Africa, and 234,720 ha (916.8 sq mi) were harvested in the United States. In 2001, the amount of millets harvested worldwide was 29.2 Tg, of which 13.8 Tg were harvested in sub-Saharan Africa and 436.580 Mg (thousand tons) were harvested in the United States. Millets are crops used mainly for direct consumption by humans in developing countries, and the millets are used mainly for feeding livestock, particularly poultry, in developed coun-

tries. Pearl millet is an important cereal crop which provides food energy and other nutrients to hundreds of millions of people in areas which currently suffer from malnutrition, particularly Africa and southern Asia. The United States and all other participants in the World Food Conference have a stake in promoting the production and utilization of sorghum and pearl millet to help end hunger, particularly in Africa.

In October 1999, the International Food Policy Research Institute (IFPRI) noted that in both developed and developing countries, the rate of increase in cereal yields is slowing from the days of the Green Revolution, partly due to reduced use of inputs like fertilizer and partly due to low levels of investment in agricultural research and technology. In World Food Prospects: Critical Isssues for the Early Twenty-First Century, IFPRI points out that "without substantial and sustained additional investment in agricultural research and associated factors, it will become more and more difficult to maintain, let alone increase, cereal yields in the longer term. The gap in average cereal yields between the developed and developing countries is slowly beginning to narrow, but it is widening considerably within the developing world as Sub-Saharan Africa lags further and further behind the other regions . . . ." In its 2020 Global Food Outlook Report, IFPRI observes that "Cultivating more and more land will not solve Sub-Saharan Africa's food security problems for the long-term. Between 1967 and 1997, the region expanded cereal cultivation by 31 million hectares and roots and tubers cultivation by 8 million hectares. This rate of expansion is not sustainable; therefore, higher crop yields are needed to reduce malnutrition in Africa."

Agricultural research provides benefits not only to producers of agricultural products but also to processors and consumers of agricultural products. Agricultural research has proven itself continuously as providing improvements which yield products of greater quantity and quality, as well as improved health to consumers and broad-based economic growth which goes beyond producers and consumers. In the U.S. Action Plan on Food Security – Solutions to Hunger, published in March 1999, the United States government states that one of the ways that the United States plans to contribute to the global effort to reduce hunger is by the United States' continuing commitment to support international agricultural research through the Collaborative Research Support Programs.

The Collaborative Research Support Program (CRSP) concept was created by the U.S. Agency for International Development (USAID) and the Board for International Food and Agriculture Development (BIFAD), under the auspices of Title XII of the Foreign Assistance Act, as a long term mechanism for mobilizing the U.S. Land Grant Universities in the international food and agricultural research mandate of the U.S. Government. As amended in 2000, Title XII assures a wider inclusion of organizations by including land grant universities, other universities, and their public and private partners in the U.S. and other countries. The CRSPs are communities of U.S. Land Grant Universities and other universities working with USAID and other U.S. Federal Agencies, strengthening and enhancing National Agricultural Research Systems (NARS), collaborating country colleges and universities. The CRSPs also work closely with the International Agricultural Research Centers (IARCs), private agencies, industry, and private voluntary organizations (PVOs) fulfilling their mandate. The Sorghum and Millet Collaborative Research Support Program is one of nine CRSPs currently in operation.

The Sorghum and Millet Collaborative Research Support Program (INTSORMIL CRSP) conducts collaborative research using partnerships between U.S. university scientists and scientists of the National Agricultural Research Systems (NARS), IARCs, PVOs and other CRSPs. INTSORMIL is programmatically organized for efficient and effective operation and captures most of the public research expertise on sorghum and pearl millet in the United States. The INTSORMIL mission is to use collaborative research as a mechanism to develop human and institutional research capabilities to overcome constraints to sorghum and millet production and utilization for the mutual benefit of the U.S. and Less Developed Countries (LDCs). Collaborating scientists in the NARS of developing countries and the U.S. jointly plan and execute research that mutually benefits all participating countries, including the United States.

INTSORMIL takes a regional approach to sorghum and millet research in western, southern, and eastern Africa, and in Central America. INTSORMIL focuses resources on prime sites in the four regions supporting the general goals of building NARS institutional capabilities, creating human and technological capital to solve problems constraining sorghum and millet production and utilization. INTSORMIL's activities are aimed at achieving sustainable, global impact, promoting economic growth, enhancing food security, and encouraging entrepreneurial activities. The six universities currently active in the INTSORMIL CRSP are Kansas State University, Mississippi State University, University of Nebraska, Purdue University, Texas A&M University and West Texas A&M University. In addition, scientists of the Agricultural Research Service of the U.S. Department of Agriculture at Tifton, Georgia participate in INTSORMIL. What were formerly referred to as "host" countries are now referred to as "collaborating" countries to indicate the closer and more collaborative relationships that have developed between the United States and those countries as a result of all that has been accomplished during the past twenty-three years of the INTSORMIL CRSP.

Because sorghum and millet are important food crops in moisture-stressed regions of the world, they are staple crops for millions in Africa and Asia, and, in their area of adaptation, sorghum and millet have a distinctly competitive advantage to yield more grain than other cereals. As wheat and rice products have been introduced to urban populations in developing countries, traditional types of sorghum, because

of some quality characteristics, have not been able to effectively compete with wheat and rice products. However, as a result of research by INTSORMIL researchers and others, improved, food-quality sorghums produce grain that can be used for special ethnic and dietary products as well as for traditional food products. Special white sorghums developed by INTSORMIL collaborative research in Mali have improved characteristics which allow preparation of high-value food products made of as much as 100% sorghum which can compete successfully with wheat and rice products in village and urban markets. Couscous made from food-quality, hybrid sorghum is being market tested in Niger. The development of both open-pollinated and hybrid sorghums for food and feed with improved properties such as increased digestibility and reduced tannin content has contributed to sorghum becoming a major feed grain in the U.S. and in South America. Pearl millet is also becoming an important feed source in poultry feeds in the southeastern United States. Improved varieties and hybrids of pearl millet, like improved lines of sorghum, can be grown in developing countries, as well as the United States, and have great potential for being processed into high-value food products which can be sold in villages and urban markets, thus competing successfully with imported wheat and rice products. These developments are results of the training and collaborative, international scientific research that INTSORMIL has supported both in the United States and collaborating countries.

Although significant advances have been made in improvement and production of sorghum and millet in the regions of developing countries which INTSORMIL serves, population growth rates continue to exceed rates of increase of cereal production capacity. There remains an urgent need to continue the momentum of our successes in crop improvement, improved processing of sorghum and millet, and strengthening the capabilities of NARS scientists to do research on constraints to production and utilization of sorghum and millet.

INTSORMIL maintains a flexible approach to accomplishing its mission. The success of the INTSORMIL program can be attributed to the following strategies which guide the program in its research and linkages with technology transfer entities.

- ***Developing institutional and human capital***: INTSORMIL provides needed support for education of agricultural scientists in both developing countries and the United States. The results of this support include strengthening the capabilities of institutions to do research on sorghum and millet, development of collaborative research networks, promoting and linking to technology transfer and dissemination of technologies developed by research, and enhancing national, regional, and global communication linkages. A major innovative aspect of the INTSORMIL focus is to maintain continuing relationships with scientists of collaborating countries upon return to their research posts in their countries. They become members of research teams of INTSORMIL and NARS scientists who conduct research on applications of existing technology and development of new technology. This integrated relationship prepares them for leadership roles in their national agricultural research systems and regional networks in which they collaborate. From the strategic standpoint, the education of agricultural scientists of developing-country scientists by INTSORMIL contributes to the economic and political stability of developing countries, through cultural ties and long-term scientific collaboration, helping enable the collaborating countries to achieve economic growth necessary to becoming more significant trading partners with their neighbors and the United States. Strategically for the United States, it is crucial to maintain a cadre of both scientists knowledgeable about sorghum and millet within and outside the United States to assure the safety and growth of these two crops in the United States, since both crops are native to Africa.

- ***Conserving biodiversity and natural resources***: Research results of the collaborative research teams include development and release of enhanced germplasm, development and improvement of sustainable production systems, development of sustainable technologies to conserve biodiversity and natural resources and to enhance society's quality of life and to enlarge the range of agricultural and environmental choices. Thus, INTSORMIL promotes conserving millet and sorghum germplasm, conserving natural control of arthropod pests and diseases of sorghum and millet, developing resource-efficient cropping systems, developing integrated pest management programs, developing cultivars with improved nutrient and water use efficiencies, and evaluating impacts of sorghum/millet technologies on natural resources and biodiversity.

- ***Developing research systems***: Collaboration in the regional sites in countries other than the United States has been strengthened by using U.S. and NARS multi-disciplinary research teams focused on unified plans to achieve common objectives. INTSORMIL scientists provide global leadership in biotechnology research on sorghum and pearl millet. The outputs from these disciplinary areas of research are linked to immediate results. INTSORMIL uses both traditional science of proven value and newer disciplines such as molecular biology in an integrated approach to provide products of research with economic potential. These research products which alleviate constraints to production and utilization of sorghum and pearl millet are key elements in fighting hunger and poverty by providing means for economic growth and improved health. New technologies developed by INTSORMIL collaborative research are extended to farmers' fields in developing countries and the United States through partnerships with NGOs, research networks, extension services and the private sector. In addition, economic analysis by INTSORMIL researchers plays a crucial role by enabling economic policymakers

to more intelligently consider policy options to help increase the benefits and competitiveness of sorghum and pearl millet as basic food staples and as components of value-added products.

- ***Supporting information networking***: INTSORMIL research emphasizes working with both national agricultural research systems and existing sorghum and millet networks to promote effective technology transfer from research sites within the region to local and regional institutions. Technology transfer is strengthened by continued links with regional networks, International Agricultural Research Centers, and local and regional institutions. Emphasis is placed on strong linkages with extension services, agricultural production schemes, private and public seed programs, agricultural product supply businesses, and nonprofit voluntary organizations, such as NGOs and PVOs, for efficient transfer of INTSORMIL-generated technologies. Each linkage is vital to development, transfer, and adoption of new production and utilization technologies, with the ultimate goal being economic and physical well-being to those involved in production and utilization of these two important cereals.

- ***Promoting demand-driven processes***: INTSORMIL economic analyses focus on prioritization of research, farm-level industry evaluation, development of sustainable food technology, processing and marketing systems, are all driven by the need for stable markets for the LDC farmer. INTSORMIL seeks alternate food uses and new processing technologies to save labor and time required in preparation of sorghum millet for food. Research products transferred to the farm will seek to spur rural economic growth and provide direct economic benefits to consumers. INTSORMIL assesses consumption shifts and socioeconomic policies to reduce effects of price collapses, and does research to improve processing to yield products of sorghum and millet which are attractive and useful to the consumer. Research by INTSORMIL agricultural economists and food scientists seeks to reduce effects of price collapse in high yield years, and to create new income opportunities. INTSORMIL socioeconomic projects measure impact and diffusion and evaluate constraints to rapid distribution and adoption of introduced new technologies.

The INTSORMIL program addresses the continuing need for agricultural production technology development for the developing world, especially in the semi-arid tropics. There is international recognition by the world donor community that national agricultural research systems (NARS) in developing countries must assume ownership of their development problems and move toward achieving resolution of them. The INTSORMIL program is a proven model that empowers the NARS to develop the capacity to assume the ownership of their development strategies, while at the same time resulting in significant benefits back to the U.S. agricultural sector. These aspects of INTSORMIL present a win-win situation for international agricultural development, strengthening developing countries' abilities to solve their problems in the agricultural sector while providing benefits to the United States.

Administration and Management

The University of Nebraska (UNL) is the Management Entity (ME) for the Sorghum/Millet CRSP and is the primary grantee of USAID. UNL subgrants are made to the participating U.S. Universities and USDA/ARS for the research projects between U.S. scientists and their collaborating country counterparts. A portion of the project funds, managed by the ME and U.S. participating institutions, support regional research activities. The Board of Directors (BOD) of the CRSP serves as the top management/policy body for the CRSP. The Technical Committee (TC), External Evaluation Panel (EEP) and USAID personnel advise and guide the ME and the Board in areas of policy, technical aspects, collaborating country coordination, budget management, and review.

Several major decisions, events and accomplishments of INTSORMIL during the past year occurred in the United States and collaborating countries.

The 2001-2002 Technical Committee was elected. Its members are:

- Dr. Gary Peterson, Chair, Texas A&M University (Southern Africa Regional Program Coordinator)
- Dr. John Sanders, Vice Chair, Purdue University (Agronomy/Physiology)
- Dr. Henry Pitre, Secretary, Mississippi State University (Plant Protection)
- Dr. Bruce Hamaker, Purdue University (Economics/Utilization)
- Dr. Gebisa Ejeta, Purdue University (Horn of Africa Regional Program Coordinator)
- Dr. Wayne Hanna, Breeding
- Dr. Stephen Mason, University of Nebraska (Central America Regional Coordinator)
- Dr. Aboubacar Touré, Institut de Economie Rurale, [Regional (Mali) Coordinator]
- Dr. Peter Esele [Regional (Uganda) Coordinator].

- Ten Mozambican agricultural scientists funded by USAID/Mozambique arrived in July, 2001. Eight of the participants were not adequately competent in English, and so remedial work in the United States was needed to enable them to adequately understand written and spoken

English and articulately express themselves with both written and spoken English. As of September 2002 seven have completed intensive English training and nine have been placed in programs of study for a graduate degree at a CRSP university in the United States with the assistance of the INTSORMIL CRSP Management Entity. One is completing the intensive english language program.

- INTSORMIL was well represented at the meeting of the Global Consortium of Higher Education and Research for Agriculture (GCHERA), July 12-14, 2001 in San Francisco, CA. Dr. David Sammons, Purdue University and INTSORMIL Board of Directors was a key organizer of the conference which hosted representatives of institutions of higher education and research from approximately 140 different countries. Dr. Aberra Debelo and Dr. Aberra Deressa represented the Ethiopian Agricultural Research Organization (EARO). Dr. Hamis Saadan, represented the Ministry of Agriculture and Food Security of Tanzania. Dr. Thomas Crawford, Associate Director of INTSORMIL presented a poster paper on behalf of the CRSP programs.

- The Program Director and the Associate Program Director represented INTSORMIL at the meeting of the CRSP Council Steering Committee, Kona, Hawaii County, Hawaii. November 12-13, 2001

- INTSORMIL initiated two new disciplinary projects with West Texas A&M University and the University of Nebraska and one multi disciplinary project with Kansas State University which includes Kansas State University and Texas A&M University. The disciplinary projects were Sustainable Management of Insect Pests, Dr. Bonnie Pendleton, P.I. and Soil and Water Management for Improving Sorghum Production in Eastern Africa, Drs. Charles Wortman and Martha Mamo, PIs. The multi disciplinary team project is "Enhancing the utilization of grain sorghum and pearl millet through the improvement of grain quality via genetic and nutrition research, Drs. Mitchell Tuinstra, Joe Hancock, Kansas State University and William Rooney and Clint Magill, Texas A&M University.

- Dr. Wayne Hanna,USDA/ARS/Tifton, GA and Principal Investigator for the INTSORMIL "Breeding Pearl Millet with Improved Performance, Stability and Resistance to Pests" project retired July 1, 2002. INTSORMIL re-advertised the project and Dr. Jeff Wilson, USDA/ARS/Tifton, GA wrote the successful proposal for continuing this project. The new project started July 1, 2002.

- INTSORMIL contributed to an exhibit on the nine CRSPs presented at the Fourth Annual Agricultural Research and Education Exhibition and Capitol Hill Reception in Washington, D.C., March 5, 2002. The Program Director and Associate Program Director represented INTSORMIL.

- The major publications organized and published by the ME office @during the year included:

  - INTSORMIL 2001 Annual Report, INTSORMIL Publication 01 - 5.

  - INTSORMIL 2000 Annual Report Executive Summary, INTSORMIL Publication 02 - 01.

  - West African Hybrid Sorghum and Millet Seed Workshop, INTSORMIL Publication 02 - 02.

  - "Inside INTSORMIL" Newsletter, March 2002, INTSORMIL Publication 02 -03.

  - INTSORMIL Directory, Publication 02 - 04, September 2002.

Education

Within INTSORMIL's regions of collaborative research and the United States, education of collaborating scientists contributes to the capability of each collaborating country research program to stay abreast of economic and ecological changes which alter the balance of sustainable production systems. The strengthening of collaborating country research institutions contributes to their capability to predict and be prepared to meet the challenges of economic and ecological changes which affect production and utilization of sorghum and millet. A well balanced agricultural research institution must prioritize and blend its operational efforts to conserve and efficiently utilize its natural resources while meeting economic needs of the population in general and the nutritional needs of both humans and livestock. To this end, education is an extremely valuable component of development assistance.

Year 23 Education (July 1, 2000 - June 30, 2001)

During Year 23, 2001-2002, there were 35 students from 16 different countries enrolled in an INTSORMIL advanced degree program and advised by an INTSORMIL principal investigator. Approximately 51% of these students came from countries other than the U.S.. The number of students receiving 100% funding by INTSORMIL in 2001-2002 totaled 10. An additional 23 students received partial funding from INTSORMIL. Two students were funded under the Mozambique Inter-CRSP project.

Conferences and workshops are an important means of continuing education for scientists doing research on sorghum and millet. Participation in conferences and workshops increases the sharing of information, a key factor in making more efficient research strategies and more efficiently carrying out research. During Year 23, INTSORMIL supported the Sorghum Pests and Diseases Workshop in Managua, Nicaragua, June 10-14, 2002. Forty participants attended the workshop at which they learned about Central America regional state-of-the-art research on

diseases of sorghum and pearl millet. One individual participated in the Parasitic Weed Symposium in France; one person attended the American Seed Trade Meetings in Chicago, Ill; . In addition, a number of scientific writing workshops were offered by an INTSORMIL PI in South Africa, India, and Australia. About 328 individuals improved their scientific writing skills by participating in these workshops. Of the participants at these conferences and workshop INTSORMIL sponsored 174 women and 215 men for a total of 389.

Another important category of education which INTSORMIL supports is non-degree research activities, namely post-doctoral research and research of visiting scientists with INTSORMIL PIs in the United States. During Year 23, eighteen scientists improved their education as either post-doctoral scientists (5) or visiting scientists (13). Their research activities were in the disciplines of plant breeding, agronomy, food quality/utilization, plant pathology, poultry nutrition and Striga physiology. These scientists came to the United States as post-doctoral scientists or visiting scientists from Brazil, El Salvador, France, Ghana, Mali, Nicaragua, Niger, Zambia, Namibia and the United States.

Networking

The Sorghum/Millet CRSP Global Plan for Collaborative Research includes workshops and other networking activities such as newsletters, publications, the exchange of scientists, and the exchange of germplasm. The INTSORMIL Global Plan is designed for research coordination and networking within ecogeographic zones and where relevant between zones. The Global Plan:

- Promotes networking with IARCs, NGO/PVOs, Regional networks (ROCAFREMI, ROCARS, ASARECA, SADC/SMINET, SADC/SMIP and others), private industry and government extension programs to coordinate research and technology transfer efforts.

- Supports INTSORMIL participation in regional research networks to promote professional activities of NARS scientists, to facilitate regional research activities (such as multi-location testing of breeding materials), promote germplasm and information exchange, and facilitate impact evaluation of new technologies.

- Develops regional research network, short-term and degree training plans for sorghum and pearl millet scientists.

Over the years, established networking activities have been maintained with ICRISAT in India, Mali, Niger, Central America and Zimbabwe; SAFGRAD, WCASRN (ROCARS), WCAMRN (ROCAFREMI), ASARECA, ECARSAM and SMIP/SMINET in Africa; CLAIS and CIAT of Central and South America and SICNA and the U.S. National Grain Sorghum Producers Association for the purpose of coordinating research activities to avoid duplication of effort and to promote the most effective expenditures of research dollars. There also has been efficient collaboration with each of these programs in co-sponsoring workshops and conferences, and for coordination of research and long-term training. INTSORMIL currently cooperates with the ICRISAT programs in East, Southern, and West Africa, with WCASRN and WCAMRN in West/Central Africa and with SMIP/SMINET in Southern Africa. Sudanese collaborators have provided leadership to the Pan African *Striga* Control Network. INTSORMIL collaboration with the WCAMRN in West Africa has much potential in allowing INTSORMIL utilization scientists to collaborate regionally. ROCAFREMI is a good mechanism for promoting millet processing at a higher level than has been seen before in West Africa. During the last four years, INTSORMIL, the Bean/Cowpea CRSP, and World Vision International have been working with NARS researchers and farmers in five countries under the West Africa Natural Resource Management Project, creating and using a technology-transfer network in West Africa. INTSORMIL will continue to promote free exchange of germplasm, technical information, improved technology, and research techniques.

Regional Activities and Benefits

West Africa (Niger, Burkina Faso, Nigeria)

In the Niger sorghum hybrid project, new prospective hybrids were tested and some promising lines were identified. A new generation of hybrids, with an improved A line and tan plant color are desired for the hybrid program. Female parents TX623A and 223A were each increased at Lossa station. NAD-1 and F1-223 hybrids were produced at the Tillabery station. With assistance from networking partners, on-farm seed production trials continue and progress has been made in training and production issues.

The couscous and high-quality flour processing unit in Niamey has had continued success in the past year with completion of a large market test of products, additional activities financed through ROCARS, and initiation of entrepreneurial activities.

Progress has been made on sorghum midge control through identification of resistant lines in Niger. New collaboration with the new INTSORMIL PI, Dr. Bonnie Pendleton brings new input into the entomology program.

Micro-dose fertilizer studies show the advantage of small additions of fertilizer during cropping. Economic studies show that farmers are investing in fertilizer and are gaining economic benefit.

New INTSORMIL projects in Nigeria, two focused on millet hybrids and processing, and one on sorghum trials have shown strong contributions to the program. Further links with U.S. collaborators and addition of more PIs in Burkina Faso will also strengthen the regional effort.

West Africa (Mali, Senegal, Ghana)

Generally, the activities in the Western Region of West Africa proceeded well in 2001 in spite of adverse weather conditions in several areas, and some interruptions in travel plans. A strong positive output has been realized from the first full year of INTSORMIL collaborative activities in Ghana and Senegal with activity in breeding, pathology, entomology, agronomy, and *Striga*. The strong Mali research program in IER continues to show leadership in the region, organizing and hosting a West Africa Workshop on Biotechnology, and is procuring, packaging, and distributing seed of several West African nurseries and tests which serve as a means of enhancing germplasm exchange, scientist to scientist cooperation, and collaborative research activities among scientists in several West African countries.

One concern is regarding the best way to organize, coordinate, etc., research activities among the various countries in West Africa. Adding the countries of Ghana, Senegal, Burkina Faso, and Nigeria strengthens the research effort across the region, but the limited funds for these new countries is a problem. Furthermore, there are other PIs in the new countries with interest in becoming collaborators as well as the case of ITA in Food Technology in Senegal which is pursuing a MOU with INTSORMIL. Also, the demands on U.S. PIs in needed travel, etc., is a concern both because of time constraints and money resources. Also, the reduced number of PIs with active collaboration and travel in the area has been a problem. The addition of the new projects and PIs is positive and should help in the future. Positive moves in that area include John Leslie's travel and efforts on behalf of pathology, pathology needs assistance beyond grain toxin studies. The recent addition of Jeff Wilson as a new PI hopefully will contribute in the pathology area, as well as possibly Clint Magill. Bonnie Pendleton has already shown a strong effort in strengthening collaboration in entomology. There is still somewhat of a deficiency in the food technology and sorghum agronomy area. The PI Conference in Ethiopia in late 2002 will serve as a forum where all Host Country and U.S. PIs can develop a better coordinated effort in all of West Africa.

There continues to be a need in the analysis and promotion regarding contract production, marketing, and identity preserved (IP) issues, and use of the tan-plant variety, N'Tenimissa. Hopefully, some short-term help can be identified to fill this need for technical assistance. The very promising activity completed in the 2001 season by a local entrepreneur with assistance from the IER and ROCARS needs to be supported, analyzed, and continued in every possible way.

The project has made some major achievements in all four of the major objectives during this reporting period. The contract production of over 11 tons of N'Tenimissa grains with about 50 farmers in four villages in 2001 and the movement of this identity preserved (IP) grain through the marketing channels certainly is a promising activity in promoting economic growth and moving sorghum to a value-added crop. The sale of 1 kilo bags of N'Tenimissa sorghum flour (Sorgha Phar), the Deli-ken cookies, and the new effort on marketing a sorghum syrup and a non-alcohol sorghum beverage all promote economic growth and improve overall nutrition. The new sorghum breeding cultivars, such as "Uassa", and others in on-farm trials and in the advanced stage of the breeding pipeline offer potential to increase yields and improve quality and value of grain as a cash crop. Agronomic research helps exploit the genetic potential of new and existing cultivars. The development of hybrids in the future certainly would be a big step in improving yields.

The current people in training will strengthen the institutional capacity in Mali. New future training opportunities in Mali, and hopefully with Ghana and Senegal, will materialize to strengthen institutional capacity in those countries.

Horn of Africa (Ethiopia, Eritrea, Kenya, Uganda)

On-going collaborative research has progressed in each of the countries, namely Ethiopia, Eritrea, Kenya and Uganda; the results from each of these studies is documented in this report. Host country PIs in each country have taken keen interest in collaborating with US PIs where partnerships have been developed. Because of expanded collaborative involvement in several countries, more US PIs are needed to provide collaborative linkages with host country scientists. New PIs joining INTSORMIL are expected to take advantage of the opportunities for collaboration in the Horn of Africa region, where host country scientists and programs continue to appreciate and welcome technical support provided by INTSORMIL.

Sorghum breeding efforts in Ethiopia have particularly gone well. Work on development and evaluation of experimental sorghum hybrids have resulted in identification of elite hybrids with potential for wide cultivation in the lowland areas of the country. Efforts on *Striga* control have focused on regional testing of an integrated package of technologies that included tied-ridging as a water conservation measure, nitrogen fertilization, and resistant sorghum cultivars. This activity is managed and implemented as a pilot project with supplemental funding from the Office of Foreign Disaster Assistance (ODA) of the USAID.

In Year 23, under the auspices of IGAD with funds provided by USAID/REDSO/East Africa, a major study assessing the state of dryland research in the Horn of Africa region was completed under the leadership of Dr. John Sanders and in cooperation with a number of agricultural scientists from the Horn of Africa.

The survey provides extensive documentation regarding dryland agriculture in the region, technologies available, and research gaps that can be addressed through future research. A stakeholders' workshop was held in Nairobi, Kenya October 30-November 2, 2001 to discuss the results

of this study and to develop a dryland research agenda for the Horn of Africa.

Southern Africa (Zambia, South Africa, Namibia, Botswana, Mozambique and SIMNET/SMIP, Bulawayo, Zimbabwe)

Most activities were carried out as plannedfor the Southern Africa Region. However, research is on-going and depending on the program, continues to make progress toward objectives, and has produced results that are important to increasing the production and quality of end-products of sorghum and pearl millet in the Southern Africa region.

Hybrid parents have been bred for sorghum and are nearing completion for pearl millet. A large amount of sorghum breeding material and varieties in use have been characterized for resistance to major diseases and sugarcane aphid. Multi-location testing of sets of such lines provides strategic geographic information on distribution and severity of diseases. Factors influencing the incidence and control of sorghum ergot are now better understood, leading to better control of the disease, especially in hybrid production fields. Food quality research can lead to increased use of sorghum in various products. Linking variety qualities to specific end uses is shown to be very important.

Active collaboration exists in sorghum breeding, plant pathology, grain quality, and marketing. Collaboration in entomology has been re-established. Regional pearl millet breeders continue interaction with INTSORMIL at a reduced level due to both retirements in the region and in INTSORMIL. Efforts are on-going to continually refocus activity for increased relevance and generation of useful technology. Collaboration can be improved and increased in all research areas. Additional collaboration is needed in all disciplines for all research objectives. Unfortunately, there are more collaborators and opportunities in Southern Africa than there are INTSORMIL principal investigators.

Central America

Since 1999 the Central America program has increased activity in El Salvador and Nicaragua. The research activities developed for 2000 - 2001 were successfully completed, and administrative procedures for reporting research results and financial expenditures were developed. A conference was held to report research results and plan collaborative research priorities for 2002 - 2006. Communication and coordination of the many groups involved in the program remains a challenge. Graduate education of scientists in national programs is needed, but identification of candidates who are proficient in English with firm commitments to work in national programs is difficult, and funding is limited. On the whole, given the short time in the present collaborative model in Central America, the program is functioning well due to the commitment of scientists in the region and has resulted in selection of improved cultivars, management strategies for fall armyworm and sorghum midge, identified priority disease problems, developed sorghum flour substitution technology, and implemented research on nitrogen rates and nitrogen use efficiency of sorghum germplasm adapted to the region.

Regional Benefits by Technical Thrust

INTSORMIL provides a wide range of documented benefits to collaborating countries, U.S. agriculture, and the broader scientific community. Many of these benefits have reached fruition with greater economic benefits to producers and consumers, improved sorghum and millet research programs, and improvement of the environment. Others are at intermediate stages ("in the pipeline") that do not allow quantitative measurement of the benefits at present, but do merit identification of potential benefits in the future. The collaborative nature of INTSORMIL programs has built positive long-term relationships between scientists, citizens and governments of collaborating countries and the United States. This has enhanced university educational programs and promoted understanding of different cultures enriching the lives of those involved, and hopefully making a small contribution to world peace, in addition to improving sustainable sorghum and pearl millet production in developing countries and in the United States.

Germplasm Enhancement and Conservation

Producing improved seed that seed companies and farmers can use, INTSORMIL researchers in developing countries and the United States have collaborated to develop improved, high yielding varieties and hybrids. Progeny were identified that combine several needed favorable traits into a single genotype. Advanced selections are being evaluated using on-farm trials to measure performance. As research continues to generate new technology, the importance of testing on-farm, and soliciting producer input on research activities will increase. Technology–in this case, improved germplasm–developed by INTSORMIL has been adopted by private industry and used in hybrid production and breeding programs. Impact assessment studies have consistently shown a high rate of return on investment from research conducted by this project.

Breeding sorghum varieties and hybrids for use in developing countries and the United States requires proper recognition of the major constraints limiting production, knowledge of germplasm, and an appropriate physical environment for evaluation and testing. Successful breeding efforts also require knowledge of mode of inheritance and association of traits that contribute to productivity as well as tolerance to biotic and abiotic stresses. Germplasm exchange, movement of seeds in both directions between the United States and collaborating countries, involves populations, cultivars, and breeding lines which carry resistance to insects, diseases, the parasitic weed, *Striga*, drought, and which are tolerant to edaphic stresses, one of which is soil acidity. Research and germplasm development activities in

INTSORMIL attempt to address these essential requirements.

INTSORMIL/Purdue project (PRF-207) addresses major biotic and abiotic constraints (drought, cold, grain mold, and other diseases) that limit productivity of sorghum in many areas of the world. Over the years significant progress has been made in some of these areas. Superior raw germplasm have been identified, mode of inheritance established, chemical and morphological traits that contribute to productivity as well as to tolerance to these stresses have been identified. Selected gene sources have been placed in improved germplasm background, some of which have already been widely distributed. Training of NARS scientists is an important component of our research and development effort. Several years ago INTSORMIL project PRF-207 spearheaded an initiative that brought together several organizations, the USDA, ICRISAT, ARC/Sudan with INTSORMIL, in assembling the Sudan sorghum collections from around the world for organized evaluation and cultivation. The collection was successfully grown, characterized, catalogued, and placed in permanent storage for the benefit of mankind. In this report, they describe the results of an analysis of genetic diversity conducted on the Sudan collection by Cecile Grenier this last year. The study co-authored by all involved in the characterization of the germplasm has been submitted for consideration of publication in an international journal.

INTSORMIL plant breeders also develop elite materials with high yield potential which can be used as cultivars per se or used as parents in breeding programs. Specific germplasm releases (including breeding lines) for collaborating country use include the following.

- Improved yield (for all collaborating countries)
- Improved drought tolerance (Africa and drier areas of Latin America)
- Acid soil tolerance
- *Striga* resistance (West, Eastern Africa, and Southern Africa)
- Midge and greenbug resistance (Latin America)
- Downy mildew resistance (Latin America and Botswana)
- Anthracnose resistance (Latin America and Mali)
- Charcoal rot and lodging resistance (Africa and drier areas of Latin America)
- Head smut and virus resistance (Latin America)
- Foliar disease resistance (for all collaborating countries)
- Improved grain quality characteristics for food and industrial uses (for all collaborating countries)

Generally, the activities in the Western Region of West Africa under the guidance of TAM-222 proceeded well in 2001 in spite of adverse weather conditions in several areas, and some interruptions in travel plans. There has been a strong positive response to the first full year of INTSORMIL collaborative activities in Ghana and Senegal with activities in breeding, pathology, entomology, agronomy, and *Striga* research. The strong Mali research program in IER continues to show leadership in the region, organizing and hosting a West Africa Workshop on Biotechnology, and in the procuring, packaging, and distributing seed of several West African nurseries and tests which serve as a means of enhancing germplasm exchange, scientist to scientist cooperation, and collaborative research activities among scientists in several West African countries.

One concern is regarding the best way to organize, coordinate, etc., research activities among the various countries in West Africa. Adding the countries of Ghana, Senegal, Burkina Faso, and Nigeria strengthens the research effort across the region, but the limited funds for these new countries is a problem. Furthermore, there are other PIs in the new countries with interest in becoming collaborators as well as the case of ITA in Food Technology in Senegal where they are pursuing a MOU with INTSORMIL in case some additional funds become available in the future. Also, the demands on U.S. PIs in needed travel, etc. is a concern of both availability of time and available resources. The reduced number of U.S. PIs with active collaboration and travel in the area has been a problem. The recent addition of the new projects and PIs is positive and should help in the future. Positive moves in that area include Dr. John Leslie's travel and efforts on behalf of sorghum pathology. There are still pathology assistance needs which go beyond grain toxin studies. The recent addition of Dr. Jeff Wilson as a new PI, hopefully, will contribute in the pathology area, as well as possibly that of Dr. Clint Magill. Dr. Bonnie Pendleton has already shown a strong effort in strengthening collaboration in entomology. There is still somewhat of a deficiency in the food technology and in the sorghum agronomy area. Hopefully, the PI Conference in Ethiopia in late 2002 will serve as a forum where all Host Country and U.S. PIs can develop a better coordinated effort in all of West Africa.

The very promising activity done in the 2001 season by a local entrepreneur with assistance from the IER and ROCARS needs to be supported, analyzed, and continued in every possible way.

TAM-222 project has made some major achievements in all the four major strategic objectives during this reporting period. The contract production of over 11 tons of N'Tenimissa grains with about 50 farmers in four villages in 2001 and the movement of this identity preserved (IP) grain through the marketing channels certainly is a promising ac-

tivity in promoting economic growth and moving sorghum to a value-added crop. The sale of 1 kilo bags of N'Tenimissa sorghum flour (Sorgha Phar), the Deli-ken cookies, and the new effort on marketing a sorghum syrup and a non-alcohol sorghum beverage all promote economic growth and improve overall nutrition. The new sorghum breeding cultivars, such as "Uassa", and others in on-farm trials and in the advanced stage of the breeding pipeline offer potential to increase yields and improve quality and value of grain as a cash crop. Agronomic research helps exploit the genetic potential of new and existing cultivars. The development of hybrids in the future certainly would be a big step in improving yields.

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Under TAM-223 progress was made in all research areas. Germplasm was obtained and evaluated for resistance to economically important insect pests. Selections were made to combine insect resistance with other favorable plant traits. Germplasm was identified for advanced testing with resistance to selected insects and diseases that will contribute to production of high grain yield and widely adapted hybrids. Results from previous molecular mapping studies are used in a marker-assisted selection program for greenbug resistance and stay green.

Collaboration with LDC scientists resulted in progress to develop improved, high-yielding varieties or hybrids. Progeny were identified that combine several favorable traits into a single genotype. As research continues to generate new technology, the importance of testing on-farm and soliciting producer input on research activities will increase.

During the life of TAM-223 significant research progress has been achieved. Technology (germplasm) developed by this project has been adopted by private industry and used in hybrid production or breeding programs. Collaboration with research programs in Nicaragua, El Salvador, and Southern Africa (South Africa, Botswana, Zambia, and Mozambique) has significantly increased TAM-223 activity. Impact assessment studies show a high rate of return on investment from research conducted by this project.

In pearl millet breeding, the INTSORMIL ARS-204 project has found that the stability of grain yield of pearl millet across cycles for the population hybrids was encouraging. The failure of the population hybrids to out-yield the local checks was disappointing, but provided important information on the need to more precisely select the parental combinations to match morphological characteristics and local adaptability. The identification of SOSAT-C88 as a good general combiner is significant. The principal investigator doing pearl millet breeding in Georgia, having decided to maximize impact by having visiting scientists spend time with him during the pollinating season, reported that the visit from Moussa Sanogo, pearl millet breeder from Mali to Tifton, GA resulted in a publication in the International Sorghum and Millets Newsletter. The visit by Ferdinand Muuka, pearl millet breeder from Zambia will result in another short manuscript on pollen storage. High coefficients of variation (CVs) for the data from collaborating sites is due to numerous factors, including bird damage, are a concern.

The ARS-204 project is continuing to test the population hybrids in Nigeria, Senegal, and Georgia in 2002 (and possibly in Zambia). This will give them at least two years of data from each location where they have been tested.

Sustainable Production Systems

In the project, Economic and Sustainability Evaluation of New Technologies in Sorghum and Millet Production in INTSORMIL Priority Countries (PRF-205), the Senegal and Mali reports for the three-country study of the potential impacts from new technologies and supporting policies were completed. The final report on Niger is well advanced and was completed in early 2002. The Niger project has been partially supported by ICRISAT. The farmer decision-making model was the same across these three countries and the technologies similar so the comparison and contrast will be instructive.

In 2001-02, the PRF-205 project had several additional sources of funding. One major activity was the Horn of Africa technology introduction, funded separately from PRF 205. Mr. Nega Wubeneh was funded for much of the year by special funds to evaluate the diffusion of *Striga*-resistant sorghum cultivars in Tigray. Moreover, with the uncertainty after Sept. 11, 2001 the project did not attempt to find another graduate student for this past budget year. So with the combination of the three above effects, spending activities during this project period practically stopped.

In the new budget year, the project will be resuming normal levels of activities. There are now two Ethiopian students being supported for their advanced degrees, Nega Wubeneh and Yigezu Atnafe. PRF-205 is keeping Tahirou Abdoulaye as a Post-Doc until at least February 2003, principally to work on a new marketing study in four Sahelian countries with Dr. Ouendeba Botorou. They have also contracted Liborio Cabanilla for three months in the fall to work on the economics of biotechnology in the Sahelian countries. There are three pressing issues here: the optimum level of research versus borrowing involvement in these new technologies; the economics of biosafety; and intellectual property rights. Levi (Liborio) will be traveling to four Sahelian countries plus Nigeria and Ghana. Tahirou will accompany him in the Sahelian countries.

In recent years the PI of PRF-205 has been engaged in several outside activities which have broadened his research interest and knowledge and helped expand the INTSORMIL program coverage. For much of the last two

years, his team has worked on the Horn of Africa new-technology project; which has given intensive exposure to many of the six countries in the Horn. This gives a greater feeling of confidence about becoming more involved in field research in the Horn of Africa countries. Their early field specialization had been on the Sahel countries. During this budget year, the PRF-205 PI was involved in an evaluation of the economic impact of an eight-country project in North Africa and the Middle East. Technical inputs to this project were provided by ICARDA and IFPRI. The project was concentrated in the dryland crop and range areas in these countries. The relationship between wheat and barley in this region is similar to that between maize and sorghum in the Sahel. Also, the critical problem in the rangeland of common access and property ownership is also important for different activities in much of the INTSORMIL target region. These North African and Middle Eastern countries are also very concerned with many of the marketing problems that are important in INTSORMIL target regions. So this project should enable INTSORMIL to move into some new areas taking advantage of the experience in a higher-income region.

In West Africa, INTSORMIL's main collaborative agronomy research activities, UNL-213, have been focused in Mali and Niger. However, a memorandum of understanding was signed in 1999 with INERA, the NARS of Burkina Faso, and collaborative research was initiated in Burkina Faso. Under Memoranda of Agreements signed with ROCARS and ROCAFREMI, INTSORMIL also participates in the West and Central African Sorghum and Millet Research Networks. In research conducted during the past four years, it was determined that high-yielding grain sorghum genotypes that are tall or have high vertical leaf area distribution can be more competitive with weeds and, therefore, be a useful component of integrated weed management programs. Studies on management of late-maturing Maiwa pearl millet in southern Niger were initiated. Because this variety of pearl millet tillers profusely, it provides a unique opportunity to integrate grain production for human consumption and forage production to support livestock. Initial results that tillers can be harvested 65 to 85 days after planting for use as livestock feed without reducing grain or stover yield point to development of a more economically rewarding cropping system for millet farmers in the Sahel.

The UNL-213 project has been extremely productive in graduate education of West African collaborating scientists; agronomic research which has led to publication in scientific journals, the publication of extension bulletins, and the transfer of improved practices to pearl millet producers; and strengthening the activities of the West and Central Africa Pearl Millet Research Network. In the U.S. the project has documented the potential for pearl millet as a new grain crop in the Great Plains, and developed production practice recommendations for planting date, row spacing, and nitrogen fertilizer application. Research activities expanded from West Africa to Central America in 2001.

The major managerial issues facing Project UNL-213 is balancing INTSORMIL efforts with other responsibilities in National Research Systems and/or in U.S. universities. Although electronic communication has improved the situation, communication remains problematic both in planning and reporting research activities. There is continuing difficulty in identification of potential graduate students from West African and Central American countries largely due to the need for English language skills. Funding of graduate student studies is becoming increasingly difficult with flat budgets along with increased costs (especially overhead and stipend), and due to fewer supplemental funding opportunities from other sources. Although effective programs have been established, the future is somewhat uncertain due to the weak institutional strength of national programs. The pending merger of the West and Central Africa Pearl Millet and Grain Sorghum Research Networks has potential to enhance project activities. Nebraska research on pearl millet is severely constrained by the lack of a pearl millet breeding program in the Great Plains, and the lack of private sector investment in developing pearl millet as an alternate grain crop.

Activities to date of UNL-219 have addressed the INTSORMIL objectives of increased yield and improved institutional capacity. Collaborating researchers in Ethiopia are working with farmers to address production constraints associated with water deficits and low soil fertility. Tillage and implement options are being tested at various semi-arid sorghum production areas in Ethiopia. Tillage effects on organic matter and soil physical properties are being assessed for improved soil water management. In eastern Nebraska, soil fertility management options are being evaluated, including the use of starter fertilizers for no-till situations and the rotation effect of soybean on sorghum N nutrition. Phosphorus availability indices are being fine-tuned for soils of Nebraska, Ethiopia and Mozambique.

An INIA researcher from Mozambique has started his Master's degree program on soil fertility management at the University of Nebraska. Two researchers are being recruited for Master's degree studies at Alemaya University in Ethiopia.

Sustainable Plant Protection Systems

INTSORMIL's approach to developing sustainable plant protection systems is integrated pest management (IPM). Two key elements of IPM for sorghum and millet which are central to INTSORMIL plant protection research are genetic resistance of sorghum and millet to insect pests, pathogens, and the parasitic weed, *Striga*, and practices to control insects and pathogens with minimal use of chemical pesticides. INTSORMIL entomologists and plant pathologists work closely with plant breeders, agronomists and food scientists to develop more effective means to manage pests of sorghum and millet in order to provide higher yields of higher quality grain per unit area cultivated. Intensification of agricultural production, which can help remove pressure

on fragile ecosystems, depends on many factors; sustainable, plant protection is essential to increase production of food and feed from sorghum and millet in economically and ecologically sustainable ways. In crop protection, a wide range of sources of resistance for insects, diseases, and *Striga* have been identified and crossed with locally adapted germplasm. This process has been improved immensely by INTSORMIL collaborators developing effective resistance screening methods for sorghum head bug, sorghum long smut, grain mold, leaf diseases and *Striga*.

Witchweeds (*Striga* spp.) are obligate parasitic weeds of significant economic importance. Control methods available to date have been costly and beyond the means of farmers in developing countries. While combining several control measures may be necessary to eradicate *Striga*, crop losses to *Striga* can be effectively minimized through host-plant resistance. In the INTSORMIL project, *Striga* Biotechnology Development and Technology Transfer (PRF-213), the goal has been to exploit the unique life cycle and parasitic traits of *Striga* to develop sorghum lines that are resistant to *Striga* because of disrupted interaction between the parasite and the host. *Striga* research in PRF-213 employs a mix of biotechnological approaches towards understanding the genetic basis of *Striga* resistance and towards identification and enhancement of genetic variants that discourage *Striga* parasitism. Early work focused on the key biochemical signals required in germination of *Striga*. Recent emphasis has been on genetic mechanisms expressed at and post infection. In this report, we describe a study by Abdalla Mohamed who recently completed a Ph.D. dissertation characterizing "Hypersensitve Response to *Striga* Infection" as a strong defense mechanism. Hypersensitive response appears as a necrotic lesion at the point of parasitic attachment and discourages further penetration of the parasite into host roots. It is a highly heritable trait, and as such, serves as a powerful genetic trait that is readily incorporated into improved sorghum cultivars.

INTSORMIL's *Striga* research program is progressing well. Investigators in Project PRF-213 have made significant advances in the understanding of the biology of host parasite interaction in *Striga* parasitism. The work is exemplary and provides parallel for similar gains in maize and other crops. Collaborative linkages with ICRISAT and several NARS have been developed and strengthened. Training of NARS scientists is an important component of INTSORMIL's *Striga* research and development effort. Seed supply is likely to be a bottleneck in efforts to promote an expanded cultivation of these varieties. However, INTSORMIL received additional support in Year 22 to cooperate with the NARS of Ethiopia to organize and deliver a sorghum production technology package in *Striga*-affected areas in Ethiopia. This pilot project, currently underway in Ethiopia and implemented by supplemental funding from the Office of Foreign Disaster Assistance at USAID, promotes an integrated *Striga* control package that includes moisture conservation through use of tied ridging, nitrogen fertilizers, and *Striga* resistant sorghum cultivars in *Striga* endemic areas of the country. Primary focus of the project is the production and delivery of seed of *Striga* resistant sorghum cultivars to poor subsistence farmers through a community based seed multiplication and distribution scheme. The integrated package is aimed at demonstrating the enhanced benefit of *Striga* control through the added use of moisture conservation and fertility improvement.

In INTSORMIL's project on agroecology and biotechnology of stalk rot pathogens of sorghum and millet (KSU-210), collaborating investigators have collected important new populations of Fusarium, and new species have been identified. Some of these species are now being used in field tests on sorghum to determine their relative pathogenicity, primarily for stalk rot. Plans for cooperative work on grain mold of both millet and sorghum are being developed. Molecular diagnostic tools have been developed and should speed diagnoses. During the 2001-2002 year, the identification of fumonisin values for samples from village granaries has been a major accomplishment, as was the coordination required to obtain these samples. The species observed in these samples suggest that aflatoxins may be a major risk as well as moniliformin. Evaluations for moniliformin will be made during the coming year. Additional species have been identified, and remain to be described. Identifying the correct causal agent(s) for grain mold requires that, at the least, the major species being recovered be correctly identified, thus formal taxonomic descriptions of these new species needs to continue. Molecular diagnostic tools are being developed for these species, but validating them requires a sufficient sample to determine their validity. Studies of mycotoxin production under field conditions are needed, and the mycotoxigenic profiles of newly described species continue to need to be developed. The putative contamination of sorghum by a Fusarium mycotoxin problem in Japan, for example, indicates just how easy it is for even well-equipped 1st world laboratories to misidentify some of these compounds. As before species identification appears to be critical in estimating the risks posed by mycotoxins, and many of the Fusarium species common on sorghum do not make high levels of many of the common mycotoxins (but are toxic). We have begun a collaborative effort to identify mycoviruses that could be used as biological control agents for fungal pathogens of sorghum.

Investigators of project KSU-210 have also been carrying out systematic strain collection and strain identification; their development of AFLPs as a means to distinguish species should accelerate this process. The Principal Investigator has been on sabbatical leave from January 2001– August 2002, and work, while he has been gone, has focused on the continuing characterization of existing collections.

Toxicology work now requires a collaborator who can test the effects of toxins in commercial animal feeds and who can model their effects in laboratory systems, using human and animal cell lines as models.

The development of the Scientific Writing and Fusarium Laboratory workshops were not a part of the original planned activities, but have been a very successful outreach effort that will be continued. The Scientific Writing and Fusarium Laboratory workshops serve as interdisciplinary venues for scientists in developed and developing countries that work on various crops to exchange information and to interact with one another in an informal setting.

While on sabbatical leave the KSU-210 PI has edited the Proceedings of the INTSORMIL 2000 Sorghum and Millet Pathology Conference. This will require a continuing significant effort in the coming year. The total number of submissions (91) is well over twice that originally envisioned (35-40), and the final size is nearly 1200 pages of text and tables plus figures. Some manuscripts have required extensive editing for style, and others have required drastic cutting as they came in more than four times as long as the maximum requested in the initial guidelines.

INTSORMIL's project on agroecology and biotechnology of fungal pathogens of sorghum and millet from the Greater Horn of Africa (KSU-211) has changed its geographic focus to Central America. A short course was conducted at Kansas State for two collaborators, Ings. Reina Guzman (El Salvador) and Sergio Pichardo (Nicaragua). The laboratories in the host countries are being updated very slowly and much improvement remains as El Salvador and Nicaragua were involved in political strife for nearly twenty years. The objectives of the collaborative project are on schedule as were initially planned.

Advanced training and degrees are vitally needed to ensure future success of sorghum production in Central America. Due to budget constraints within INTSORMIL, other funding sources need to be investigated for support of Central American students. Student support for two semesters in the U.S. would partially alleviate training needs in the near future without potential problems of admittance for M.S. and Ph.D. students. The objectives of the collaborative project are on schedule as were initially planned.

MSU-205 research activities in Honduras, in collaboration with scientists at the Panamerican School of Agriculture (EAP), Zamorano, Honduras, were concluded in 2001. Students from the EAP were trained under MSU-205 and have returned to Central America to provide agricultural expertise. The extension of MSU-205 into Nicaragua and El Salvador in 1998 has provided MSU-205 the opportunity to investigate entomological constraints to sorghum production on large farms compared with the low input, subsistence farming systems in Honduras. The research collaboration with scientists in INTA, UNA, UNAN and Nicaraguan Grain Sorghum Producers Association (ANPROSOR) in Nicaragua and CENTA in El Salvador has proved to be extremely beneficial in developing plans and coordinating, implementing and conducting scientific investigations in these countries. Investigations of the specific insect pest problems identified in the respective countries have yielded the basic biological information needed for developing and recommending effective insect pest management programs.

This coordinated effort among scientists and administrators was particularly obvious in the planning and conduct of the Sorghum Crop Protection Workshop held in Managua in June 2002. In the United States, research investigations in 2001 and 2002 have been conducted or are in progress to determine levels of damage by fall armyworm on sorghum in different plant growth stages, as well as refining economic threshold levels for this lepidopterous pest on whorl stage plants and for sorghum midge on the panicles. This information will assist farmers in decision-making regarding the application of insecticides to control these pests.

The new INTSORMIL project (WTU-200), Sustainable Management of Insect Pests, with Dr. Bonnie Pendleton of West Texas A&M University as the principal investigator initiated its activities in the spring of 2002. As planned, the PI traveled to Southern Africa to review INTSORMIL activities in entomology, plant pathology, breeding, grain quality, and marketing and end use and establish collaborative research. The PI plans to travel to West Africa to review sorghum research in October 2002. Research on management of insect pests of sorghum and pearl millet was planned for with entomologists and other scientists in Botswana, Mali, and Niger. Communication and interaction were encouraged among scientists employed by the different agencies and in different countries within a region so research efforts would not be duplicated. Determination of the distribution of greenbug biotypes in Texas was begun and should proceed more rapidly this year. DNA from sorghum lines developed for resistance to different biotypes of greenbug was extracted and progress is being made to use AFLP to try to locate and map genes for resistance to different biotypes of greenbug. Thesis programs of four graduate students were directed during this reporting period. The students obtained very significant results from their research on greenbugs. Tiecoura Traore from Mali was identified to come to West Texas A&M University to learn English and begin graduate studies in IPM and entomology.

Utilization and Marketing

In the last couple years, INTSORMIL PRF-212 project has expanded their work on nutritional quality of sorghum from the extensive studies done with John Axtell on protein digestibility to include a research focus on starch digestibility of cooked and raw sorghum. They have verified preliminary data from 2000-2001 that shows the high protein digestibility mutant lines have correspondingly high starch digestibility using an in vitro digestion system with protease pretreatment followed by amylase digestion. Higher starch digestibility of the mutant sets it apart from the normal sorghum genotypes tested in this study and brings its digestibility to a comparable level to maize and rice. Moreover, normal cultivars tested with a range of protein digestibilities revealed cooked starch digestibility values ranked simi-

larly. High starch digesting sorghum cultivars could be quite valuable for use in weaning and other foods where high energy availability is important. In the last two years, breeding work on the high protein digestibility mutant to convert it to a hard kernel type has been minimal due to the passing away of John Axtell. Lines have been carried forth and, as reported last year, a vitreous, hard kernel type was identified containing the mutant protein bodies. However, consistency and stability still seem to be problems. In the next year, a new effort at Purdue with Dr. Gebisa Ejeta will focus on this research problem. In India, the Mahyco Research Foundation project that finished in 2001 has also produced promising mutant lines. A chicken nutrition study showed mean true amino acid digestibilities for the mutant sorghum that were about 19% higher than the normal parent. The goal of PRF-212 is to find a way to improve protein and starch digestibility of sorghum grain in an acceptable kernel type.

PRF-212 is also interested in better understanding of some of the fundamental properties of sorghum components that affect textural properties of cooked foods. The goal is to identify ways to improve sorghum grain use in traditional and processed foods. In this regard, starch (amylopectin) structure of eight sorghum cultivars was different enough from that of maize and rice to lead to a hypothesis that the relatively hard gels of cooked, cooled sorghum pastes and rapid staling of sorghum flat breads, etc., may by linked to structure. Sorghum amylopectin, the large branched starch molecule, has comparably longer short linear chains that are involved in reassociation on cooling or storage to affect product quality.

The sorghum couscous/flour project in Niger progresses well, however this year there is no new data to report. The Cereal Technology group at INRAN has just completed a large-scale market test of pilot-plant production of high-quality flour, couscous, and degué (a breakfast food) from NAD-1 hybrid sorghum and is in the process of analyzing the data. They have entered into a collaboration with a few local entrepreneurs to get the product out into the marketplace.

With INTSORMIL's project on food and nutritional quality of sorghum and millet (TAM-226) there is also progress on several fronts. In Mali, an entrepreneur has produced N'Tenimissa, a white tan plant sorghum developed by the IER, under identity preserved marketing arrangements and has profitably sold decorticated sorghum in small packages. This occurred when the large bakery in Bamako did not want to continue use of sorghum flour in cookies because the Government had subsidized wheat flour. This is encouraging since the INTSORMIL TAM-226 project has worked for many years to encourage this concept. It is important that scientists learn that yield should be measured in terms of useful units of grain in order to produce economic returns to farmers.

New markets for value-enhanced white food sorghums are being promoted by the U.S. Grains Council from TAM-226 research on food sorghum processing and prototype products. In Japan, value-enhanced white food sorghums are processed into several commercial snack foods. Sorghum flour was demonstrated effectively in nearly 20 traditional Japanese foods by Japanese chefs and food processors.

Several mills are producing sorghum flour for niche markets in the U.S. Total use is still very low but new products for celiacs and ethnic foods exist.

In Central America, white sorghums are used in cookies and other products as a substitute for wheat or maize.

The antioxidant level in certain bran fractions of special sorghums is higher than that of blueberries. These special sorghums with high levels of phenols and antioxidants produce excellent chips and baked products.

Several parental sorghum lines released from the Texas A&M program are used in commercial hybrids grown in Mexico and United States. ATx 635 hybrids have outstanding milling properties. The protein content of food sorghums is higher than that of other commercial sorghums. A dry milling technique can be used to determine the best milling sorghum to produce products with the lightest color.

Antifungal proteins appear related to grain mold resistance in sorghum. Mold resistance is necessary for improved food type sorghum production on a consistent basis.

TAM-226 activities in Honduras, El Salvador and Southern Africa are top priority. The opportunity to develop a more comprehensive program in El Salvador and Honduras is challenging because there is a lack of effective personnel with the knowledge required to do value-added processing research. TAM-226 will try to develop a relationship with Dr. Saldivar at ITESM in Mexico to help with the program in El Salvador. The NGO Activities at the University of Pretoria in South Africa continue. The chance to interact with a good cadre of Southern and East African students at University of Pretoria is a unique opportunity.

The uncertainty of funding from year to year inhibits commitments to graduate training. Inflation has eroded away much of our graduate training capabilities. The project utilizes significant research funded by other sources for the mold and breeding research support that is necessary for this project. Their ability to attract additional financial support for the work has allowed continued productivity. The funds from INTSORMIL have relatively little buying power since we have about the same number of total dollars we had 20 years ago.

The addition of new PIs working on breeding and molds at TAMU will help. Also the project on animal feeding and breeding at KSU will provide useful interaction.

Millet research has been minimized as funds from INTSORMIL decrease in actual buying power. Millet is not a crop in Texas and the leveraged funds from other sources are all for sorghum research.

The new INTSORMIL multidisciplinary project, KSU-220 (Enhancing the Utilization of Grain Sorghum and Pearl Millet through the Improvement of Grain Quality via Genetic and Nutrition Research) with Dr. Mitchell Tuinstra as principal investigator was subgranted in January, 2002. There are four components, KSU-220A (Sorghum/Millet breeding), KSU-220B (Poultry Nutrition), TAM-220C (Sorghum Breeding) and TAM-220D (Biotechnology). TAM-220C and TAM-220D were unable to access funds for 2001-02 until after the reporting period. These funds will be treated as carryover and will be spent in the 2002-03 reporting period. Although the inability to gain access to the INTSORMIL funds limited progress in some research areas, most of the research projects outlined in the proposal were initiated. Excellent progress was made on initiating nutrition research and germplasm characterization studies. Good progress has also been made on developing research plans with international collaborators in Africa and Central America. Lucius Bamaiyi, from Nigeria, and Soumana Souley from Niger have been identified and selected for graduate training, but due to the increased time now required to process foreign applications, will not be able to gain admission to TAMU and KSU before January 2003.

Biotechnology

Collaborative research of the INTSORMIL research team is proving useful to sorghum breeders worldwide. The use of DNA-based markers for genetic analysis and manipulation of important agronomic traits is becoming increasingly useful in plant breeding. In a recent study, 190 sorghum accessions from the five major cultivated races, namely bicolor, guinea, caudatum, kafir, and durra, were sampled from the world collection maintained by ICRISAT. Genetic variation was detected using RAPD primers. Only 13% of the total genetic variation was attributable to divergence across regions, but South African germplasm exhibited the least amount of genetic diversity, while the genetic diversity within the West African, Central African, East African and Middle Eastern regions was high among the 190 samples from the world collection. This research showed that molecular markers can be used to help identify suitable germplasm for introgression into breeding stocks. Selecting the most divergent accessions for introgression may increase the probability of extracting suitable inbred lines to improve the yields of varieties and hybrids. The INTSORMIL project PRF-205 has contracted Liborio Cabanilla for three months in the fall of 2002 to work on the economics of biotechnology in the Sahelian countries. There are three pressing issues here: the optimum level of research versus borrowing involvement in these new technologies; the economics of biosafety; and intellectual property rights. Levi (Liborio) will be traveling to four Sahelian countries plus Nigeria and Ghana to conduct this study.

Determination of the distribution of greenbug biotypes in Texas has begun and should proceed more rapidly this year. DNA from sorghum lines developed for resistance to different biotypes of greenbug was extracted and progress is being made to use AFLP to try to locate and map genes for resistance to different biotypes of greenbug. DNA from sorghum lines developed for resistance to different biotypes of greenbug was extracted and progress is being made to use AFLP to try to locate and map genes for resistance to different biotypes of greenbug. Thesis programs of four graduate students were directed during this reporting period. The students obtained very significant results from their research on greenbugs. Investigators of project KSU-210A have also been carrying out systematic strain collection and strain identification; their development of AFLPs as a means to distinguish species should accelerate this process. This research team plans to purchase equipment to automate much of this process during the coming year.

In INTSORMIL's project on agroecology and biotechnology of stalk rot pathogens of sorghum and millet (KSU-210), collaborating investigators have collected important new populations of Fusarium, and new species have been identified. Some of these species are now being used in field tests on sorghum to determine their relative pathogenicity, primarily for stalk rot. Plans for cooperative work on grain mold of both millet and sorghum are being developed. Molecular diagnostic tools have been developed and should speed diagnoses.

In this reporting year, INTSORMIL advertised for a biotechnology project. The proposal which most completely met the INTSORMIL needs and terms of reference was a component of the new Multidisiplinary project, KSU-220. This activity will conduct research on developing and characterizing recombinant inbred (RI) sorghum mapping populations to identify markers for grain mold resistance, anthracnose resistance, and improved nutritional characteristics. The project will convert RAPDs and AFLPs linked to grain-mold resistance in the sorghum variety, Sureño, to more useful sequence-tagged site markers. A library of potential mold-resistance induced genes from subtracted-suppressive-hybridization experiments will be established. The multidisciplinary team will evaluate the feasibility of marker-assisted selection for grain mold resistance.

Future Directions

Based on its achievements, the INTSORMIL team is well positioned to contribute even more effectively to ending hunger and raise incomes. With its increasing strength of scientific expertise in developing countries, INTSORMIL is now able to more effectively reduce constraints to production and utilization of sorghum and millet to the mutual benefit of developing countries and the United

States. Advances in sorghum and millet research over INTSORMIL's first 22 years and the training of sorghum and millet scientists by INTSORMIL in the United States, Africa and Central America now enable scientists from developing countries and the United States to jointly plan and execute mutually beneficial collaborative research. These collaborative relationships are keys to INTSORMIL's success and will continue as fundamental approaches to meeting the INTSORMIL mission. In the future, INTSORMIL will target NARS collaborative ties that reflect regional needs for sorghum and/or millet production. These ties are in the sorghum and millet agroecological zones of western, eastern, and southern Africa, and Central America. By concentrating collaboration in selected sites, INTSORMIL optimizes its resources, builds a finite scientific capability on sorghum and millet, and creates technological and human capital that have a sustainable and global impact.

In the past, INTSORMIL focused a major part of its resources on graduate student training and generating research particularly useful within the scientific community. The INTSORMIL agenda for the future continues to include graduate student training and generation of scientific knowledge and information to scientists, but will be more focused and directed toward users of the technology generated by INTSORMIL research. Future strategies of INTSORMIL will maintain INTSORMIL's current, highly productive momentum, build on its record of success, and accomplish a new set of goals. INTSORMIL's global strategy for 2001-2006 is intended to contribute to the shift of sorghum and pearl millet from subsistence crops to value-added, cash crops, and proposes to produce scientific knowledge and technologies to: contribute to economic growth, improve nutrition, increase yield, and improve institutional capability to meet global, regional and national needs.