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Proceedings International Sorghum and Millet CRSP Conference

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Proceedings

International Sorghum and Millet CRSP Conference

1991

INTSORMIL

July 8-12, 1991

Royal Nueces Hotel
Corpus Christi, Texas

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Welcoming Address

John Yohe[1]

On behalf of the INTSORMIL Board of Directors, Principal Investigators and the Management Entity Office, it gives me great pleasure this morning to welcome you to this opening session of the 1991 INTSORMIL International Sorghum/Millet CRSP Conference.

INTSORMIL initiated the Biennial CRSP conference series in 1983. Attendance has grown with each meeting. Today we have 199 persons registered from 12 States in the U.S. and 27 different countries. There are representatives from three International Agricultural Research Centers (ICRISAT, IFPRI, and ICRISAT), four private seed companies and the U.S. National Grain Sorghum Producers Association (NGSPA).

I look around this audience and see new faces and old friends. I see senior sorghum and millet scientists from Africa and ICRISAT. I see senior NARS administrators who value the collaborative research relationship between INTSORMIL and their staff. I see graduate students from around the world. I see INTSORMIL graduates who have accepted major administrative responsibilities in the NARS of their home countries. I see the cream of the crop of developed and developing world sorghum and millet science. We have come to share our ideas and concepts about how to make further contributions to resolution of hunger and poverty in those developing countries where sorghum and millet are major food grain crops.

We are all here because we are concerned about feeding the world in the 1990's. We know that today in the developing world there is deterioration of quality diets and concomitant increase in hunger. In Africa, both the absolute number of people and the share of population that is hungry are increasing. Similar trends are being observed in Latin America. If our present progress in food production, within the context of current population growth rates in the developing world continues, we will be faced with food emergencies in a few years. The gap between population growth and food production is increasing. We must work toward strengthening our research toward a sustainable, productive agriculture. We must learn to protect our soil, conserve water, and to improve the productivity of the marginal soils where sorghum and millet are grown. We must work together to maximize our efforts in the most efficient manner possible. Our resources are limited and declining. We have a monumental task to accomplish.

Today we are experiencing the results of twelve years of collaboration between U.S. sorghum/millet scientists and Host Country sorghum/millet scientists. It is very gratifying to me to see the positive results of this collaboration. Together we have developed sorghum/millet collaborative research activities that bind us into an international research network on these two crops. We are finding that progress is being made in alleviating major constraints to improved production and utilization of these two crops. New technologies developed are the release of varieties/hybrids in Colombia, Honduras, Sudan, Mali, and Niger, water harvesting/conservation technologies in Botswana and major progress is being made toward the control of *Striga*, the devastating parasitic weed of sorghum in Africa and Asia.

One of the important measures of our collaborative development is that over the past eight years the integration and participation of our NARS collaborators has grown and developed significantly. Eight years ago our conference programs consisted mainly of presentations by our U.S. principal investigators. This week eight out of 21 key subject matter presentations will be given by Host

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Country Principal Investigators from Sudan, Mali, Honduras and by Host Country guest speakers from Ethiopia and Burkina Faso. In addition, NARS Directors of Research will discuss regional prioritization of production constraints within an agricultural sustainability framework. Thus this conference is our Collaborating National Programs conference.

Our program planning committee is to be commended for their work in developing the program agenda in which you will be participating for the next five days. They have assembled a group of outstanding speakers who can speak with authority on the subjects of "Impacts of New Sorghum/Millet Technologies", "Opportunities for Mutual Benefit through Interaction", "Networking", "Utilization, Quality, and Product Development", and "Sorghum and Millet as Sustainable Systems Components". Our hosts, the Texas A&M University Agricultural Experiment Station at Corpus Christi, Texas and Texas A&M INTSORMIL collaborators from Lubbock and College Station, Texas have arranged for field tours which will include sorghum and millet germplasm and breeding material from INTSORMIL collaborators from Texas A&M University, the University of Nebraska, Purdue University and Mississippi State University. Arrangements have been made to visit commercial disease screening nurseries of Dekalb Plant Genetics, Cargill Hybrid Seeds and Pioneer Hi-Bred Seed Company. We hope that you will find much useful information from these tours.

Our graduate students from the INTSORMIL research program and from the SADCC/ICRISAT/INTSORMIL training program have prepared a poster session which will be of interest to each one of you. We encourage you to support our students by visiting the poster sessions and reviewing their research. You will find it to be interesting, relevant, and supportive of our collaborative activities both here in the U.S. and with your collaborating sites.

I trust that our conference program will spark a great deal of discussion and interaction over the next five days. Our INTSORMIL staff is here to serve you. We hope that you will enjoy the field tours and other sites of interest here in Corpus Christi. Welcome to you all.

Keynote Address

Agricultural Research in the New World Order

Donald L. Plucknett[1]

These are times of profound change. President George Bush speaks of a New World Order, a world profoundly different from the one we see now. I guess some of us might agree we are already living at least in the early stages of something that might be termed a New World Order. What might that new vision of the world encompass, what might it mean for those who work to make agriculture better, and especially what does it mean for agricultural research? That will be the subject of this paper.

The New World Order

What does the New World Order mean? I don't claim to have any special understanding, but I believe it includes at least some if not all of the following:

- a hunger for freedom, especially individual freedom,
- a hunger for peace,
- a hunger for democracy,
- the decline and probable fall of communism,
- rapid movement toward market economies, rising interest in individual incentives and privatization,
- growing interdependence of nations and regions.

The above list of interests or concerns does not give full perspective to the other tides of change that are sweeping around us. Some that are having major impact include:

- the global debt crisis,
- interest in free trade, markets,
- trade restrictions and the potential for trade wars,
- realignments brought about by Europe 1992,
- rapid changes in Eastern Europe,
- rise in ethnic awareness and desire for ethnic identity and power,
- increasing civil and regional conflicts,
- rise of environmentalism,
- a desire for sustainable development, and sustainable agriculture.

In addition to the list above, there are also some major concerns that weigh heavily on any agenda for the future; these include:

- continued high population growth,
- growing awareness of the role of technological change in development fueled by science and technology, but tempered by- -
- in some circles, a growing distrust of science and technology.

Growing Expectations

People around the world are looking at the changes and developments taking place and are concerned that all of this could change their own lives as well as those of their families. Expectations are high in many places that profound positive change will happen, and such hopes are especially high in Eastern Europe. But what about the reality? Will change take place rapidly enough to match expectations?

Let's look for a moment at Eastern Europe and the situation there, since today that may be the place of greatest expectations. As we

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all know, Eastern Europe is in great turmoil. The problems are not only political, but economic and ethnic as well. Moving from a centrally-planned economy to a market economy is proving to be very difficult. As one speaker pointed out last year at a Hudson Institute conference on global agriculture, there are scores of books telling how to convert a capitalistic economy to communism, but no book that tells how to convert a communistic economy to a market economy.

Some symptoms of the problem in Eastern Europe:

1. Land ownership and property rights problems are staggering. In the more extreme communist countries, e.g. Romania and Bulgaria, almost everything was state owned, while in Yugoslavia and Poland perhaps as much as 80 percent of the land is privately owned. How can state assets be sold to private owners? How do you price assets from enterprises that have never had to satisfy a market or make a profit in the sense of a market economy? In Poland, land is given away on a voucher system, while Hungary has held land auctions in which lands were sold cheaply. In East Germany, lands are sold at market prices.

2. What will Ministries of Agriculture do now in these countries? Before, public employees administered the national agricultural plan, but now what will their role be?

3. How can private farmers be supported in an economy where, e.g., most farm equipment is inappropriate for small private farms, where spare parts and agricultural inputs are lacking or in short supply, where they may have been growing the wrong crops (at least in the sense of meeting market needs), where advisory services are almost completely lacking, and where research was organized to suit a completely different economy?

4. In countries where communism was most extreme, e.g. Romania and Bulgaria, the decline in the land area being tilled is alarming. For example, in those countries 20 percent less land was tilled in 1990 than in 1989, and it is feared an added 20 percent decline in area tilled may have occurred this year.

Significance for Agricultural Research

You might ask, what does all of this have to do with agricultural research or, in particular, with me and my work? I guess I would have to answer, plenty.

When people have high expectations of significant change in their lives, they will look for the source and direction of possible change. The growth of individual freedoms and personal incentives are tailor-made for agricultural development. So too are the growth of market economies, the growth of the private sector, and an increased interest in natural resource management. I haven't even mentioned yet the tremendous need to boost agricultural production to meet the needs caused by population growth. We should never forget the equivalent of another India will be added to the world population by the year 2000.

Agricultural scientists are change agents of the highest order. We all know that, I think — at least intuitively — but we may not be able to muster the arguments needed to make the case. I believe we can and must learn to make that case and make it strongly, whenever and wherever we can. To do that, we must understand and be able to explain the tremendous contribution of agricultural research in the past. Agriculture research has a great record; can you explain it to your administrators, to your politicians, to local community leaders? I hope you can, because it is essential that the message of the importance of agricultural research be told clearly and well.

There are troubling signs around today in agricultural research. Many of our leaders have never done agricultural research themselves, indeed, some are not even agriculturists at all. I commonly hear it said that agriculture is too important to be left to agriculturists. All right, let's say we accept that, but then where are informed decisions made, who makes them, and are the views of agriculturists encouraged and heard? I am disturbed by the declining attention being given to agriculture at AID and the World Bank, for example. I am also concerned about how hard it is to get the agricultural research message to be heard by donors.

There is a battle going on now inside many international donor agencies between different constituency groups, notably between concerns for the environment, privatization, structural adjustment and peace. As a senior person with AID pointed out recently, democracy, peace and the environment are all competing for position, perhaps hegemony, in AID, instead of finding reasonable compromise. Note that agriculture wasn't even mentioned in that list.

The struggle, if that isn't too strong a word, for attention and power in organizations is likely to involve agriculture and environment, probably to the detriment of agriculture. We in agriculture must find ways to find common cause with environmental groups so we can work together to improve natural resource management without losing agricultural productivity.

But let's leave that for now and go on to talk about the contribution of agricultural research and what might be expected from it in the future.

From Traditional to Scientific Agriculture

We are nearing the end of the most remarkable century in the history of agriculture. The Twentieth Century, and particularly the latter half of this Century, was when agriculture changed from a resource and tradition-led enterprise to a science-based industry. The change to a science-based agriculture has meant higher and more stable production and a better way of life for hundreds of millions of people.

Before this century, and for most of the history of mankind, agriculture was an uncertain business. Producers had to rely on their own experience and intuition for innovations. Options for change in production techniques or ways to improve production were few indeed. The consequence was frequent crop failures and famine. Yields were generally low and unstable. Life for rural folk was difficult and unlikely to change.

Famines were frequent in the past; in fact famine was a constant companion of man over the centuries. Almost every country experienced severe famines at one time. Both Egypt and Rome experienced severe famines. Famine played a role in the fall of Rome. Famines were frequent in France, England, Ireland, Scotland, Wales, Germany, Denmark and Sweden. All Europe was scourged by the great famine of 1315-1317, when one-fourth to three-fourths of the population of the Continent died from a combination of plague, the Black Death and famine. We all know of the Irish potato famine of 1845-50, when an estimated one and a half million people died and another one million emigrated to this country. In more recent times famine has ravaged Asia. China recorded more than 1800 famines between 108 BC and 29 AD. Most devastating were four famines in the nineteenth century, when in 1810, 1811, 1846 and 1849, some 45 million people died. Nine million died there in the famine in 1875-78. A half million starved in China in 1920. The last great famine in India was in West Bengal in 1943.

Recent famines are mostly geo-political in nature. Include here the famine in Bangladesh in 1974-75, and those recent famines in Africa, notably in Ethiopia and Sudan. The latter two were aggravated by drought, but deaths would certainly have been lower had political considerations not ruled.

The Rise of Modern Agriculture

Since the dawn of agriculture perhaps 10 to 12 thousand years ago, most progress in production has been slow and halting. Farmers led the way in improvements, mostly by trial and error, and crop failure was frequent. Options for farmers were few and new information was hard to come by and slow to spread. Innovators and good observers were most likely to discover ideas that would improve crop or animal husbandry. Crop rotation, irrigation, use of legumes, manuring, and other practices were largely the discoveries of farmers. Farmers also developed almost all of the established breeds of farm animals, and were responsible for most of the selection that led to the crop varieties we now consider landraces.

For most of man's history, production increases came largely as a result of expansion of the area cultivated. Such expansion is still going on, although at a slower pace. Other than land expansion, however, there were very few means available to farmers to increase production per unit of land cultivated. Under such conditions, the productivity of an individual farmer was low, and many persons had to be employed in agriculture just to make a meager living and to provide small surpluses to feed the landless and a growing urban population.

Modern agriculture had its origins in the latter part of the Nineteenth Century, but especially during the Twentieth Century. The basis for this change was the advent of scientific agriculture. Discoveries in agricultural chemistry concerning the nutrient requirement of plants led to the development of the fertilizer industry and to a dramatic increase in fertilizer use, especially since World War II. Also, the rediscovery of Gregor Mendel's laws of genetics in the early 1900s established the basis for plant breeding. By then, agricultural research was on its way to improving farm life in Europe, North America, Australia, New Zealand and Japan, and its efforts would be felt in other countries in years to come (e.g. see Figure 1).

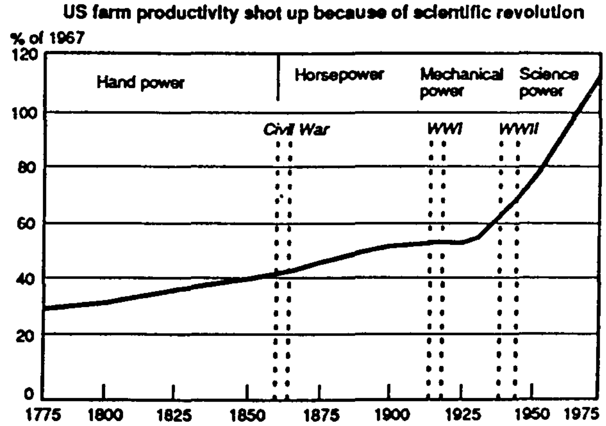
Yields in Europe, North America, and Australia increased fairly slowly during the first half of the Twentieth Century. Most of the varieties used were traditional landraces, and plant nutrition needs were met mostly by animal manures and crop rotations. Fertilizer use increased slowly during this time, from about 2 million tons worldwide at the beginning of the century to 4 million tons at the start of World War I, to 9 million tons in 1938-39 (Wortman and Cummings, 1978). Fertilizer consumption in 1945 was 7 million tons; from there it increased sharply to 21 million tons in 1955, 31 million tons in 1965, about 90 million tons in the mid-1970s and 132 million tons in 1987 (IFDC, 1989).

So higher fertilizer use was one of the keys to improvements in developed country agriculture. And crop breeding advances were also beginning to make their contribution to crop productivity. An outstanding advance was the development of hybrid maize (corn) in the United States. First developed just before World War I, hybrid maize began to be used on farms in the 1930s. A specialized seed industry grew up to take advantage of the scientific gains made by the breeders. From the time of the Civil War (1861-1865) to the 1930s US maize yields were about 1400 kg/ha (25 bushels per acre). Since the introduction of hybrid maize in the 1930s yields have increased more than fourfold, to 6,700 kg/ha (120 bushels per acre).

The Green Revolution

One of the reasons Asia did not succumb to famine and massive starvation this century can be attributed to the success of the Green Revolution. Simply put - the Green Revolution had to do with the adoption and spread of new semidwarf wheat and rice varieties in Asia in particular, and, to a lesser extent, rice in Latin America. It was successful because the new varieties were much higher yielding, bringing dramatic gains in agricultural performance in countries where previous stagnation of crop yields had caused widespread gloom and de-

Figure 1. U.S. farm productivity shot up because of scientific revolution.



Source: Office of Technology Assessment.

spair, because no improvements in productivity could be foreseen.

The U.S. played a large role in the Green Revolution. The vision and commitment of the Ford and Rockefeller Foundations in establishing the International Rice Research Institute (IRRI) and the International Center for Corn and Wheat (CIMMYT) were instrumental in bringing this about. Many American scientists were involved in developing the new wheat and rice varieties, and the Agency for International Development quickly became a full partner with the foundations in supporting IRRI and CIMMYT. The Green Revolution dramatized the potential of a productive agriculture; it proved national investments in agricultural research and development could pay big dividends. It also showed how international agricultural research could benefit developing countries. Countries in Asia began to move forward, using gains in agricultural productivity as the engine of growth. Support for agriculture was given high priority by governments, with very good results, and countries once considered hopelessly behind have reached, or are nearing, self sufficiency or self reliance in basic staples.

The new rice and wheat varieties were developed to be input-responsive, but high input use was not a prerequisite for good performance. The big innovation of the Green Revolution, as far as inputs are concerned, was developing new varieties of wheat or rice that would not fall down (lodge) when nitrogen fertilizers were applied to them. It was, of course, fortuitous that the dwarf lines also tended to be earlier maturing, to produce many shoots (tillers), to produce more seeds per plant, to be less sensitive to daylength, to have a higher harvest index and to have increased resistance to pests and diseases. Indeed, the semidwarf cereals became a new paradigm in cereal improvement.

There have been many benefits from the Green Revolution in rice and wheat, and a major benefit has been increased food production and yield stability. During the period 1961-80, average wheat yields in all developing countries rose 37 percent; the area planted rose 34 percent while production doubled. At the same time population in the developing countries increased by only 50 percent. During that 10-year period wheat production in developing countries grew by some 80 million tons, spurred especially by dramatic production gains in Asia.

Rice too saw tremendous gains in production. Annual growth rates in production for the periods 1946-55 to 1976-80 were 3.11 percent for Southeast Asia, 2.55 for South Asia and 2.54 for East Asia. Both Southeast Asia and South Asia have doubled rice production since 1956-65. Indonesia has almost tripled its rice production during that time. A 1990 IRRI publication stated: "Today, rice production in Asia is twice that of 25 years ago; average yields have increased 72 percent. The land area planted to rice has increased only 17 percent, while population has grown by 67 percent. The increased production from semidwarf rices is conservatively estimated to feed 700 million people" (IRRI, 1990).

The new wheats and rices were not accidents, nor "miracles". They were developed by agricultural scientists who benefitted from many years of good research in several countries. They were truly a product of international cooperation. Continued improvements in production have been possible only because improved varieties of both wheat and rice are being bred at research stations. Breeders must find ways to improve yield potential of food crops as well as new and more resilient forms of resistance to pests and diseases — to do that requires better knowledge of the pests themselves as well as the genetic makeup of the potential parents-to-be used in breeding. International cooperation in agricultural research has helped increase the knowledge base concerning major pests and diseases as well as new parental lines to help overcome such problems through crop breeding.

Productivity Benefits - Yield Gains

Yields of most crops in developing countries are well below their potential. For most countries, the yield gap — the yields that farmers obtain as contrasted with yields obtained on experiment stations — is also quite wide.

Perhaps because of the small size of their country and the extreme land reclamation and development efforts required to meet their own needs, the Dutch have long been interested in high agricultural productivity. In the 1970s a group of Dutch scientists undertook to determine, in their own words, "the absolute maximum food production of the world, the upper limit of what can be grown on all suitable agricultural land" (Linneman, et al. 1979). To do this they had to estimate what the maximum theoretical yields for crops might be. Theoretical yields were calculated using optimum conditions of sunlight, moisture, and nutrients, and without attack from insects and diseases. They expressed maximum potential yields in terms of grain equivalents (GE).

Table 1 shows maximum production in grain equivalents of six classes of agricultural land ranked according to potential productivity. Note that land with very high productive potential is estimated to have a theoretical yield of more than 25,000 kg GE/ha/yr (25,000 kg GE/ha would be equivalent to about 400 bushels per acre of corn or wheat).

Table 1. Land productivity classes for the potential agricultural land.

Land productivity class	Land productivity	Maximum production grain equivalent of potential agric. land kg/ha/yr
I	extremely high	more than 25,000
II	very high	more than 20-25,000
III	high	more than 15-20,000
IV	medium	more than 10-15,000
V	low	more than 5-10,000
VI	very low	less than or equal to 5,000

Table 2 shows the "absolute production of grain equivalents per ha of the continents and the world" that were calculated by the team. Differences in continents are due to differences in land quality, solar radiation, number of days that crops can be grown, and other factors relating to productivity potential. Note that Europe, Australia, and North America — where scientific agriculture predominates and high yields are common — are not highest in theoretical potential. Highest potential was calculated for Latin America, followed by Africa and Asia. The high potential productivity calculated for Africa will perhaps surprise some people, when one considers present productivity levels on that continent. The key point is that the margin between potential productivity and actual productivity may indeed be quite wide for a given continent, given existing management systems and levels of improved technology, and that significant productivity gains are possible, provided suitable technologies are available for farmers.

Table 2. The absolute maximum production of grain equivalents (per hectare) of the continents and the world. (After Linneman, et al. 1979)

	Average MPGE (kg/ha/yr)*
South America	18014
Australia	10447
Africa	14259[2]
Asia	13182[1]
North & Central America	11250[3]
Europe	10454[4]
Total Average	**13368**

MPGE = Maximum Production Grain Equivalents

*Average of detailed estimates of soil regions, excluding production on potentially irrigable land.

[1]for best Asian irrigated lands,=28.6 t/ha grain equivalents
for Pakistan—24.2 t/ha grain equivalents

[2]for Kenya—21.5 t/ha grain equivalents
for Madagascar-rice-(dbl cropping) 17.7 t/ha grain equivalents
for Senegal-rice-(dbl cropping) 16.9 t/ha grain equivalents

[3]for USA-Pac. Northwest-wheat-15 to 18 t/ha grain equivalents

[4]for Netherlands-wheat-10.5 t/ha grain equivalents
for Finland-wheat-7.2 t/ha grain equivalents

Is There a Yield Take-off Point?

Yield levels in most countries are far below the theoretical potential yield. How, then, do we go about moving up on the yield curve? Are there any patterns that can be observed?

Throughout history, yearly productivity gains in annual crops have largely been small and marginal, about 2-15 kg/ha/yr (1 percent or less). Gains of this order are too small to be of much general benefit, especially as populations and food needs rise. Professor C.T. de Wit of the Netherlands and his colleagues (1979) suggest that economic and social constraints on the growth of agricultural productivity cause average grain yields to remain low, with very low annual rates of increase. However, in their studies, a yield level of 1700 kg/ha/yr seemed to be a kind of transition point for productivity growth in agriculture. Below 1700 kg/ha, annual rates of increase were only

Figure 2. Wheat yield trends in U.K. and U.S. (after DeWit et al. 1979)

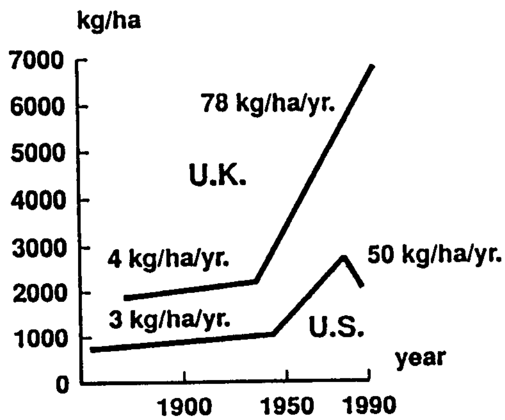
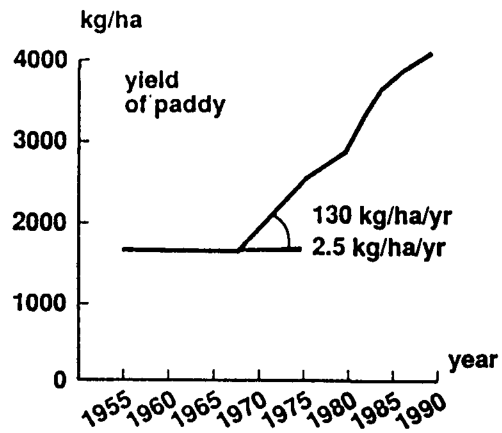


Figure 3. Rice yield trends in Indonesia (after DeWit et al, 1979



17 kg/ha (1 percent per year), but above 1700 kg/ha, the annual rates of increase jumped to 50-85 kg/ha/yr, an increase of 4 - 5 percent per year. These authors speculate that this yield level represents a kind of transition from "traditional agriculture with little outside input to modern agriculture with considerable input of outside resources". Figure 2 shows the transitional point (takeoff point?) of wheat yields in the UK and the USA just after World War II. In both these countries wheat yields began to climb in the 1950s with the advent of new varieties and improved practices. Figure 3 shows the transitional point for rice in the late 1960s in Indonesia. After centuries of almost stagnant rice productivity, Indonesia has achieved very high growth rates in rice productivity. de Wit and his co-workers (1979) go on to say that just below the transitional point, farmers tend to move more and more onto marginal lands to meet food and production needs, destroying natural ecosystems in the process. Thus, identifying this transitional point and moving beyond it could significantly affect efforts to protect the environment.

Figure 4 shows advances in maize yields in the USA from the 1860s to the present. Note again the virtually level productivity of maize till the 1930s, when the yield takeoff began as a result of the release of hybrids.

The yield takeoff thesis is borne out by data from Mexico, first for wheat in the Yaqui Valley of the State of Sonora (Figure 5) and second for wheat in Mexico in general (Figure 6). Here a developing country rose in a few years to match world class productivity values in wheat.

The idea that there may be a yield takeoff point is fascinating, regardless of whether the takeoff point is about 1700 kg/ha/yr, as de Wit and his colleagues suggest, or whether it is lower or higher. The important point is that the data do suggest: (1) there is a clear transitional point where yields move well beyond the 1 percent (or less) annual rates of gain in productivity to rates of gain as high as 2 percent or even higher, (2) the latter rates seem to signal a shift toward modern agriculture, and (3) in most cases, those rates of gain can be sustained for a number of years.

Lessons In Agricultural Technology That Can Be Drawn From the Past

History tells us several things concerning productivity and agricultural technology: (1)

Figure 4. Maize yields in the United States, 1860-1990.

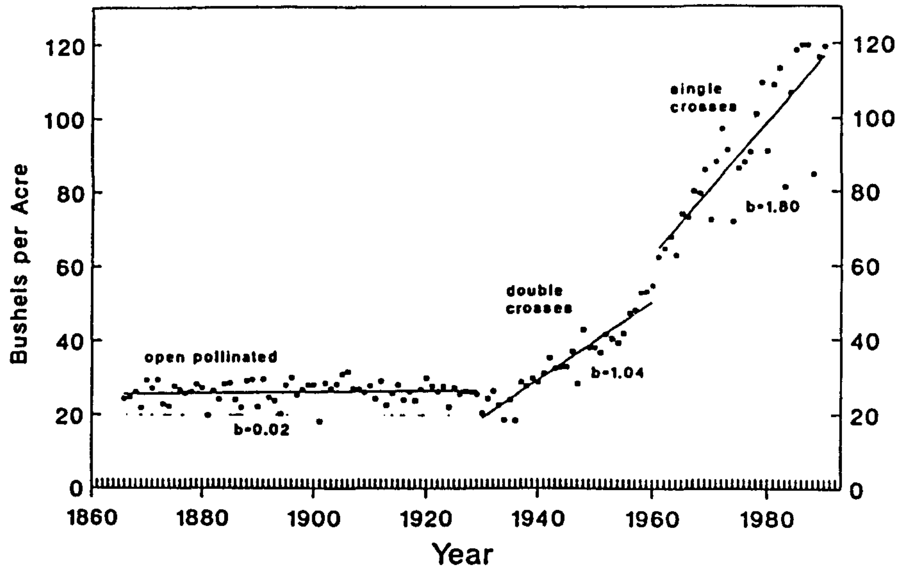


Figure 5. Wheat yield trends in Yaqui Valley, Mexico.

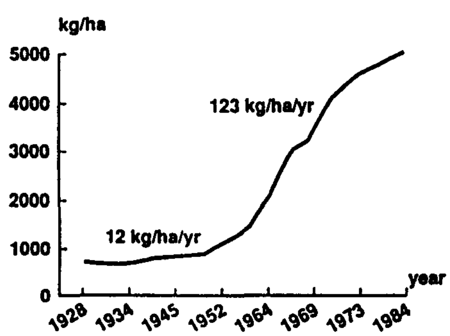
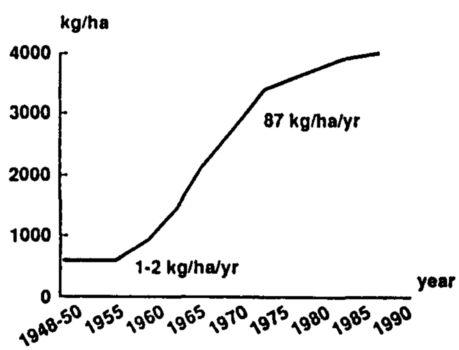


Figure 6. Wheat yield trends in Mexico.



higher yields are still attainable in most crops, provided the technology is available and is adopted; (2) once higher yields are attained, it takes more and better research just to maintain those yields and keep them advancing, even slowly — this is the concept of maintenance research (Plucknett and Smith, 1986); (3) future gains in productivity can be expected through a combination of plant breeding and improved crop and natural resource management; (4) plant breeding and crop improvement efforts have paid off handsomely, in most cases cereal improvement has resulted in productivity gains of 1-2 percent per year; (5) in cereals in particular, gains in productivity have largely come through improvements in harvest index, not through increased production of plant biomass; (6) crops can be tailored more and more to the conditions — even harsh conditions — under which they will be grown; (7) needed gains in productivity must come through research that is well supported and that has continuity. Our experience with international agricultural research tells us that research should be linked closely from national to international levels to ensure greatest benefit to all partners. Again, there is no reason for a country to have to go it alone in agricultural research.

An Emerging Global Agricultural Research System

Seven years ago Professor Vernon Ruttan of the University of Minnesota called attention to the fact that we were moving toward a global agricultural research system (Ruttan, 1984). In his opening remarks he made the following perceptive statement: "We are, during the closing decades of the 20th century, approaching the end of one of the most remarkable transitions in the history of agriculture. Prior to the beginning of this century almost all increases in agricultural production occurred as a result of increases in the area cultivated." Ruttan then stated that: "by the end of this century there will be no significant areas where agricultural production can be expanded by simply adding more land to production. Expansion of agricultural output will have to be obtained almost entirely from more intensive cultivation in the areas already being used for agricultural production. Increases in food and fiber production will depend in large measure on continuous advances in agricultural technology. It is imperative that over the next several decades we complete the establishment of agricultural research capacity for each commodity of economic importance in each agroclimatic region of the world". Those were true and powerful words then, and they still are today.

The IARCs were established to help developing countries improve their agriculture. Thus the centers worked on new technologies and particularly on germplasm that was more widely adapted, more resistant to pests and diseases, and more tolerant of environmental stresses. They trained thousands of young scientists to become effective researchers in their own right, and also helped developing countries to improve their research capacity. The relationship at first with developing countries was that of a mentor or advisor. As time has gone on, those earlier somewhat paternalistic approaches have led to collaborative partnerships, true peer relationships.

Today the global system consists of three main types of players, national agricultural research systems of developing countries, international agricultural research centers, and advanced laboratories and institutions in the industrialized countries, including private sector institutions. These players interact in a variety of ways, including bilateral agreements, multilateral arrangements, contracts, and research networks. The global system is founded on scientific and research needs; no one has passed legislation calling for its formation, no one has appropriated funds to ensure its establishment. With its subsequent growth and development, it can truly be said that today agricultural research is the world's largest and most collaborative research enterprise. Almost every country of the world is involved in some way and has invested some of its own funds to participate. Many developing countries worry frequently about the possibility that science and technology developments will continue to pass them by. The global system provides a means for such countries to participate in research on problems important to them and to the world.

The global system, being informal, depends largely on goodwill and the meshing of the perceived needs of numerous research organizations. Self interests is a strong motivator, and in its work there is something useful for almost every country.

Probably the biggest problem facing the global system and its potential effectiveness is the weakness of many National Agricultural Research Systems (NARS). Considerable time and effort and resources of IARCs and donors have gone into trying to strengthen NARS. Unless their capacities are improved, many NARS will never be able to participate fully in the global system and benefit from the work of the IARCs and partners in the industrialized countries. Funding for training, for improving facilities and even for operation of NARS is being provided through various donors.

Common Misconceptions

Several misconceptions exist concerning agricultural science and technology, especially as it relates to international efforts.

1. The USA is the world's major source of scientific information in agriculture, and doesn't have anything to learn from others. Fact: While the USA was for many years the leader in agricultural research and technology, it is fast losing that position for two major reasons: (1) the rest of the world has invested more and is rapidly catching up, so the near monopoly of the US is fading. As an example, the OTA (1981) pointed out that US expenditures in 1959 represented about 27% of global agricultural research expenditures; by 1974 the US proportion had dropped by 10 percent to 17.9 percent. And this was at a time when globally public investment in agricultural research globally increased threefold, (2) the US itself has begun to draw back from sustained investments in agricultural research, and our capacity is not as strong as it once was.

2. The world food problem is solved. Fact: Despite very significant gains in productivity and production of basic staples, some 700 million people still are chronically or seasonally hungry (Norwegian Research Council for Science and the Humanities (NAVF), 1990). It will take sustained commitment and vigilance to keep agricultural production moving, especially in Asia where continued population growth and levelling or declining yields are deeply worrying. It should not be forgotten that at present global population growth rates by 2000 we must feed the equivalent of another India.

3. We have too many surpluses anyway, so let's reduce agricultural science investments. Fact: Our surpluses amount only to a few months reserve at best.

4. New technology drives farmers out of business; therefore, let's declare a moratorium on agricultural research to make sure fewer people get hurt. Fact: Farmers need an array of options to choose from. Good research produces those options. Also, good research needs sustained efforts, it cannot be turned on and off in response to economic downturns. Indeed, in times of trouble options for farmers can be of great help.

5. It isn't only agriculture that needs attention, it's the environment; that's where the big problems lie. We can afford to deemphasize agriculture so the environment can get more attention. Fact: Farmers, ranchers and other producers are the stewards of most of our natural resources. To protect and enhance the environment requires good information on the resources and their rational management. If we neglect agriculture, we will certainly harm the environment eventually.

6. International cooperation in science and technology only strengthens our competitors, thereby weakening us. Fact: We benefit directly from such international cooperation, and it is in our best interest to stay involved as a participant, benefitting from access to new materials and ideas developed elsewhere.

7. The private sector will do it anyway. Fact: While it is true the role of the private sector was overlooked or undervalued for too long, it is also true there are many areas of agricultural research and development the private sector will not or can not enter, for economic reasons. Plant genetic resource conservation and enhancement, natural resource management, and research on minor crops are but examples. We need a close working relationship, a complementary one, between the public and private sectors.

8. All this "foreign aid" effort in agriculture has been wasted anyway. Fact: The US can be proud of its involvement in development assistance in agriculture. Its support of the IARCs has been a major success, as have programs that helped India, Pakistan, Taiwan, Bangladesh, South Korea, Indonesia and Turkey, for example, achieve significant, sustained agricultural growth.

US Institutions Involved in International Cooperation in Agricultural Science and Technology

Especially since World War II, the US has become heavily involved in cooperation in agricultural science and technology. Much of this effort was stimulated by AID and its partners. Among others, AID has involved USDA and other government agencies, the National Academy of Sciences, US universities, and private firms in its work. Among its instruments for cooperation are the Collaborative Research Support Programs (CRSPS) involving US universities, programs carried out in cooperation with the National Academy of Sciences, specific research contracts and grants, support for the international agricultural research centers, collaboration with the Environmental Protection Agency in studies of global climate change, and support of numerous networks.

USDA has several ways of collaborating, including using PL480 funds to carry out research with developing countries, involvement in global plant genetic resources efforts through the National Plant Genetic Resources Program, research on biological control through its overseas and domestic laboratories, and activities of the National Agricultural Library. USDA, understanding its need to be more directly involved in international science and technology, desires a greater involvement in international matters (Walker, 1990). This should receive high priority from both the Congress and Administration. USDA has much to offer and much to gain from such increased involvement.

A number of US universities are involved in international agricultural science and technology cooperation. Collaborative research, education, training, research consultation, and exchanges of information and materials are all included. US universities are heavily involved in networks created to improve research and information exchange. Some play coordinating or catalytic roles in such networks, others are active members.

Many of the states have direct involvement in international activities, including control of specific pests or diseases, search for biological control agents, participation in early warning systems, database development for important problems, plant or animal quarantine, and other activities.

Private companies enter the picture in developing new seeds, fertilizers, pesticides, machines or other products. Private companies play important roles in biotechnology research and development, and such firms are forming working partnerships with public and private institutions overseas.

Benefits of Past U.S. International Cooperation

There are numerous examples of benefits to the U.S. and its partners in international cooperation in agricultural science and technology. These were recently summarized in a book entitled, **The United States and World Poverty** (see Plucknett and Smith, 1989). Other examples will be presented here.

PL-480. Research Efforts. One of the important side benefits of the PL-480 (Food for Peace) program has been the use of restricted currencies to "develop new information in various fields of scientific research that can be utilized by the U. S. agricultural development community to improve uses and markets for farm and forest products and increase production efficiency. Research conducted under this program is relatively unique in that it is performed by scientists in foreign countries to the mutual benefit of the United States and the cooperating country. Over a 23-year period, (the program) has enabled over 2,000 research projects to be conducted in 32 countries around the world" (Wiese, 1985).

Research under this program emphasizes basic research, to generate new knowledge for; "possible future application to specific agricultural production problems in certain geographic areas". In a study of impact of the program, it was found the research "has been of vital importance to past agricultural development and the potential for its continued development in the United States...." (Wiese, 1985). A quote from the Executive Summary of this study is especially enlightening:

"... the availability and appropriation of foreign currencies have enabled research that would have been impossible to conduct in the

United States because of biological/environmental or financial constraints.... provided essential plant materials to U. S. Collections that has not only given researchers the sources of genetic variability needed to address production problems today, but also to continue to do so in the future."

"... allowed U. S. scientists to take advantage of disease outbreaks in certain countries, in that collaborative research efforts provided very important diagnostic treatment and prevention techniques for use in the cooperating country. Such effort have also given scientists from the United States and other nations the ability to combat the same diseases should they become a problem in the future. Similarly, in countries that have experienced severe environmental degradation as a result of particular production practices, SFC collaborative research has resulted in an improved ability to begin renewal of the soil and water resource base, while at the same time providing U. S. scientists with valuable new information that will enable them to assist U. S. producers to husband these important production resources".

Specific benefits of PL-480 research included:

- Germplasm collection and breeding activities "have yielded a wealth of new information and plant materials....This information and these materials are available to U. S. scientists looking for new sources of biologically active compounds, new fatty acids, waxes, gums, proteins, essential oils, fibers, resins, disease resistance and stress tolerance that will meet developing and constantly changing needs of industry, agriculture and medicine in the United States" (Wiese, 1985).

Collaborative Research Support Programs (CRSPs)

The CRSPs were organized in response to Title XII of the U. S. Foreign Assistance Act of 1975 to strengthen the role of U. S. universities in programs of sustainable agriculture and resource management that help developing countries produce adequate food, fiber, fuel and shelter materials. CRSPs were also meant to contribute to U. S. agriculture. Eight CRSPs have been organized; Bean/Cowpea, Fisheries Stock Assessment, Nutrition, Peanut, Pond Dynamics/Aquaculture, Small Ruminants, Soil Management and Sorghum/Millet. A new Sustainable Agriculture CRSP is being organized.

Scientific Challenges

Intensification of Agriculture. Continuing intensification of agriculture is essential, especially for Asia and elsewhere where population pressures require improved yields on an already-pressured land base. Especially important will be improved production on a sustainable basis on the best lands. Such intensification requires higher and more efficient use of fertilizers, more effective and efficient irrigation, robust and high-yielding crop varieties with multiple pest and disease resistance and stress tolerance, and increasingly meticulous crop management.

Continued intensification will require a better understanding of the production environment, including an appreciation of socio-economic constraints. More detailed mapping of soil and water resources, and their variation, will be required. A field-by-field understanding may be required to fine-tune the use of input factors that lead to greater intensification. Land use planning may be required where population pressures for urbanization and non-agricultural use are most critical.

Better understanding of the total crop environment is necessary for intensification. If crop growth models can help achieve this, they should be used. Continued intensification will require the world's best scientific minds, drawn from many disciplines, working in concert to understand the nature of existing, and emerging, problems. Solutions must then carry over into existing farming systems, especially in already-sophisticated agriculture. A larger challenge may be to find ways to accelerate the establishment of more intensive, rational and sustainable systems in countries where agriculture is less well developed, but is experiencing pressures that may be impossible to handle effectively without an improved agricultural research capacity.

Effective use of genetic resources. One of the success stories of the past two or three decades has been the collection, conservation, and utilization of crop germplasm. The global agricultural research system has been a key player in this. Indeed, it is difficult to see how the gains made could have been achieved without the participation of the global system.

The USA has been a major participant and beneficiary of the global germplasm effort. The US National Plant Genetic Resources Program is the largest in the world and every year it interacts with more than 100 countries in germplasm exchange and research. Like most countries, the US is not self-sufficient for germplasm, since all of our major crops originated elsewhere. Indeed, we are absolutely dependent on global collaboration in exchange and research on plant genetic resources. International testing of germplasm has provided a means to test and evaluate crop germplasm in many locations and conditions. Today, almost any country can obtain the plant materials it needs to improve its agriculture from the global system.

Sustainable agriculture. There is much talk today about sustainable agriculture, some of it laudable, some of it troubling. Agriculturists have always known that if agriculture was to secure its future, it must manage and protect the production environment. Today, however, concerns for the environment amid a plethora of real and perceived threats have brought new actors on the agricultural stage. I am glad for this increased interest and involvement; what we need now is an effective means to communicate with these newly-interested parties and ensure that our common concerns can be translated into a stronger agriculture.

Some persons equate sustainable agriculture with low-input, no-input, regenerative, or organic farming. Such a definition neglects the demand and productive side of agriculture so as to ensure a main aim of conservation of the natural resource base. I much prefer the definition that requires agriculture to meet changing human needs, rather than the steady-state, low productivity systems preferred by some persons seeking an alternative agriculture.

Research can, and does, play a significant role in sustainable agriculture. Improved varieties with increased resistance to pests and diseases and increased tolerance to environmental stresses clearly play a significant role. Research to improve soil and water management, more effective use of fertilizers, crop management practices, and related topics also contributes. Still, measuring the effectiveness of research aimed at sustainability will be difficult. There will be much that international collaboration can do in building a strong scientific knowledge base for sustainable agriculture.

Sustaining Agricultural Yields (Maintenance Research). Once yield gains have been made, they must be sustained (Plucknett and Smith, 1986). Only an effective research system can ensure that yield gains are protected and maintained. For crops or commodities where yield gains have been significant, an ever-increasing research effort is required just to maintain the gains achieved. The Hawaii sugar industry estimates that probably more than 80% of its research effort in sugarcane is devoted to maintenance research to protect past gains. Increasingly, the global agricultural research system will play a larger role in maintenance research in crops and commodities where yield gains have been achieved. International cooperation in science and technology will be especially important in providing new technologies and strategies to improve maintenance research capacity in national agricultural research systems.

Yield Potential. A worrying concern is that of tropical rice where yield potential has not increased since the trend-setting modern variety, IR-8. We have a special responsibility to work on rice yield potential and to identify from where possible future gains in yield potential may come. I believe the yield potential of rice is one of the greatest strategic research problems facing the global agricultural research community in a time of rapid population growth, especially in Asia.

Yield potential needs to be explored also in wheat and the grain legumes. Carefully-planned, linked research carried out on a global basis could help a great deal to understand yield potential for important crops. The US should stand ready to provide funds and collaborative efforts to support such essential, strategic research.

Important and Emerging Plant and Animal Diseases. Besides genetic resource conservation and utilization efforts, plant and animal protection may be one of the most important problem areas the global system can tackle. The record of accomplishment in such work is good: international efforts to understand major or emerging diseases, monitor them through early warning systems, and search for sources of resistance that can be incorporated effectively has been an important achievement. The capability exists to advance this work even further in the future. Understanding the global status of important diseases and locating sources of resistance are essential, and the global system should be a major player in assembling and maintaining the necessary databases and genetic collections. Biotechnology can help here by identifying genes for resistance and improving disease diagnosis.

Important and Emerging Plant and Animal Pests. Here I include weeds and insects and other pests. Again, the global system provides a marvelous opportunity to understand the global status of important pests and to establish and maintain easily-accessible data bases for use by scientists. International efforts in pest control can be highly effective. The successful biological control effort for cassava mealybug in Africa by IITA and its partners has shown clearly how targeted research can lead to widespread successful control of a major crop pest.

Strategic Agronomic Research. We all know that much agronomic research can be highly location-specific, and in technology transfer terms, would be termed vertical (narrow) transfer. For such location-specific work, the global system can help mostly by improving research techniques and by training researchers. However, there are topics that could be termed strategic agronomic research, and these need more attention. Improved agroecological characterization and models for transfer of technology from one place to another using better soil or agroclimatic data are but two examples. Improved efficiency of fertilizer, water, and other inputs is certainly included. The global system needs to examine carefully those areas of crop and natural resource management that truly are strategic and solve these problems for horizontal (wide) technology transfer.

Biotechnology

Biotechnology offers new tools to agriculture. That is my message here. Its effects are already being seen in new diagnostic techniques and a much-improved knowledge base concerning the molecular and cellular basis of genetics. The global system has much to learn from biotechnology, but biotechnology in turn has much to learn from the global system. I do not expect much help for a while from biotechnology in improving yield potential because yield seems to depend on multiple genes and their many interactions. However, yields are already being **protected** through improved diagnostic techniques and single gene transfers. So I see immediate or early gains in crop protection through biotechnology but would anticipate gains in yield potential only over the longer term. The global system and especially the IARCs can play a toolmaker role for biotechnology. Here scientific advances would be turned into tools by a research system most knowledgeable about the problems needing new tools. This could and should be a productive partnership.

Conclusions

Agricultural research faces tremendous challenges in this time of great change that, in part, has been characterized as the New World Order. The great accomplishments of agricultural research have not recognized as they should be. Most people do not know that agriculture before this century, and even in the first half of this century, was a difficult and uncertain business. Rather, many people romanticize the "good old days" of agriculture as a time when things were more pristine, more perfect. They are fooling themselves, and others, if they believe that, but why shouldn't they believe it if no one tells them the truth? And who else will tell the truth if it isn't agriculturists who understand the importance of scientific agriculture and its contributions?

Agricultural research must communicate several things if it is to protect its rightful place in science and in agricultural development.

1. It must communicate the sense of urgency that is needed today. The world food problem is not solved. There are critical problems that require solution, and many of these problems will require international collaborative efforts in research to solve them.

2. Productivity gains are essential, especially since the land frontier has shrunk or is shrinking rapidly in most places. Hence, intensification of agriculture is an imperative, and increasing productivity is the only solution to meet intensification needs.

3. Once yield gains have been made, they must be sustained. Only creative and innovative agricultural research focused on the major problems can undergird past yield gains.

4. To answer the necessary and correct calls for sustainable agriculture and environmental protection, we must be ready and able to point out that both will require a deeper and broader knowledge base that has its foundations in biological, physical and socioeconomics research. The solution to such problems is not anti-intellectualism, or arguments against technology, but improved knowledge and management at all levels.

5. Agricultural research can never be satisfied with routine, imitative research; it needs creativity in basic and strategic research, and innovation in applied and adaptive research. It should promise to weed out unproductive and ineffective research and make bold efforts to find new ways to identify and solve major problems.

6. Results of research must be communicated quickly and effectively to stakeholders. Agricultural research provides a number of products: (a) from the creative side of strategic and applied research- new ideas, understanding of basic processes, publications, education of researchers who can handle the strategic research questions of tomorrow, and (b) from the innovative side of applied and adaptive research - new products, materials, techniques, that will advance agriculture, education and training of scientific innovators and inventors.

7. Attempts should be made now to help the public understand that "agriculture is everybody's business", that an effective agriculture is a necessary precondition for development of a country, that ensured, stable supplies of agricultural products are in everyone's interests. The only way such supplies can be met is through a strong agriculture that includes an underpinning of research capacity to identify, analyze, and solve key problems and constraints that limit agricultural production or economic health of agricultural industries.

References

de Wit, C.T., H.H. van Laar and H. van Kuelen. 1979. Physiological potential of crop production. Chapter 2, In: Plant Breeding Perspectives, J. Sneep and A.J.T. Henriksen, eds. CABO Publication No. 118, Pudoc, Wageningen, The Netherlands. pp. 47-82.

IFDC. 1989 Global Fertilizer Perspective, 1969-95. International Fertilizer Development Center, Muscle Shoals, Alabama. Technical Bulletin T-35.

IRRI. 1990. IRRI Rice Facts. International Rice Research Institute, Manila.

Norwegian Research Council for Science and the Humanities. 1990. Sustainable Development, Science and Policy. NAVF, Sandokervelen, Oslo, Norway. 579 pp.

Plucknett, Donald L. and Nigel J.H. Smith. 1986. Sustaining agricultural yields: As productivity rises, maintenance research is needed to uphold the gains. Bioscience 36(1):40-45.Wortman, Sterling, and R. Cummings Jr.

Plucknett, Donald L. and Nigel J.H. Smith. 1989. Benefits of international collaboration in agricultural research. Chapter 4. In: Wennergren, E. Boyd et al: The United States and World Poverty : A Survey of the History, Current Operations, and Issues of the U.S. Foreign Assistance Program. Seven Locks Press, Cabin John, Maryland, pp. 113-127.

Ruttan, Vernon W. 1984. Toward a global agricultural research system. Paper prepared for "Workshop on Agricultural Research Policy and Organization in Small Countries", Wageningen, Netherlands, Sept. 12-14, 1984.

Walker, James L. 1990. The domestic agricultural research system and the national research network: Potential for the future and implication for development cooperation programs. Background paper prepared for the Agriculture 2000 Task Force; presented October 15, 1990 at the Workshop in Minneapolis, Minnesota.

Wiese, Karen 1985. Impact assessment of the U.S. Department of Agriculture Special Foreign Currency Research Program (1958-1980). Prepared for OICD (Office of International Cooperation and Development), USDA, by Associates in Rural Development, Inc. Burlington, Vermont. 56 pp.

Wortman, Sterling, and R. Cummings Jr. 1978. To Feed This World. Johns Hopkins, Baltimore, 440 pp.

Session I:

- Setting Direction for Sorghum in the 1990s
- Trends in Agriculture Assistance within A.I.D.'s Reorganizational Scheme or the Role of Agriculture in the "New" A.I.D.
- Cereal Consumption Shifts and Policy Changes in Developing Countries: General Trends and Case Studies from the West African Semiarid Tropics
- U.S. Grain Sorghum Economic Overview and INTSORMIL Research Impact

Session Chair: Ronald Brown

Speakers: Jack Eberspacher
Robert Schaffert
Christopher Delgado
Bobby Eddleman

"Setting Direction for Sorghum in the 1990s"

Jack Eberspacher[1]

First, let me thank Dr. John Yohe for the invitation to address this group this morning. As the executive director of the National Grain Sorghum Producers, I am pleased to be a part of your activities. I believe this group met at Purdue University in February 1990, shortly after I came aboard. At that particular time we were embroiled in resolving significant inequities for sorghum producers in the Federal Crop Insurance program. Although, I was not able to attend that meeting, we were fortunate that Dr. Lloyd Rooney was able to represent the National Grain Sorghum Producers Association.

After having been with the organization for a year and a half, I am much better prepared to speak to you about the activities of the entities that I serve as the executive director. I have had in recent months the opportunity to visit with various individuals in your organization, and today I have a better understanding of your organization. I'm sure that some of you have questions about the structure in which we operate under. I would like to give you a brief overview of how the three organizations operate that I work with, so that you may have a better understanding of our capabilities at this time.

We have three checkoff programs or checkoff boards which are mandated by state laws in Nebraska, Kansas and Texas. The checkoff dollars collected by the boards are to be used in the research, promotion, education and market development of sorghum. In a good crop year, the three state checkoff programs could collect a total of 1.5 million to 1.7 million dollars. When you compare these checkoff dollars to corn checkoff dollars in a state where producers predominantly grow corn you can see that we are on a much smaller scale. A state like Iowa can checkoff several millions of dollars on corn. So our sorghum checkoff dollars have to be invested very wisely, and the research that we fund has to be well-targeted.

We also have an entity we refer to as the U. S. Grain Sorghum Federation. The Federation is made up of our three checkoff programs plus the national association. What we do under the Federation is pool monies that can be utilized on cooperative projects, thereby reducing duplication of efforts and investing our dollars more economically.

The National Grain Sorghum Producers Association is essentially the legislative arm. The National Grain Sorghum Producers is funded by annual membership dues from producers. These dues are above and beyond the monies the producers provide through the checkoff programs. Annual membership dues are $40 a year. There are 90,000 potential members or farmers producing sorghum in the United States and only 2,500 are active members. This gives you some indication of the funding we have and the amount of work that we have ahead of us in building a truly strong national organization.

In this past year, the national association has undergone a dramatic change in its focus and in its operating philosophy. Today, we openly cooperate with agribusinesses. In the spring of 1990, we initiated our first corporate membership program. Today, I am happy to say we have 24 corporate members of the National Grain Sorghum Producers, and we have two additional commitments to join the organization after the first of September. To become a corporate member of the National Grain Sorghum Producers, companies pay annual dues of $1000. These monies provide us with unencumbered funds to work with in building a strong membership base. Along

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with annual corporate membership dues, we also have sponsorship opportunities. Companies that have a significant investment in the sorghum industry can invest more money through sponsorship of specific activities that are designed to satisfy the overall philosophy of their company. Today, more than ever, it is essential that organizations such as the National Grain Sorghum Producers and agribusinesses work closely together. An excellent example is in the pesticides area. It is much better for the chemical companies to work with the producers' organizations to establish creditability with EPA. Together they can more effectively present the case as to why the loss of a pesticide would be adverse for producers and agriculture. Just as important is the cooperation that we have with our seed companies. I believe that an especially close relationship between the seed companies and the association is crucial to the development of a strong, stable sorghum industry.

Your conference at Purdue University last February was centered around sorghum's nutritional quality. It is my firm belief that, if we are to recapture part of our domestic market that we have lost to other feedgrains or expand our overseas markets, we, as an industry, must focus our attention on delivering a more nutritionally uniform end-product for our end-users. I think a good question to be asked is how much influence do genetics have in nutritional quality of sorghum verses agronomics or environment? Some researchers tell us that it is primarily the environment or agronomics that influence the nutritional values and that this is well documented from earlier research. However, for me it is still a question as to what influences the nutritional quality of sorghum the most; genetics or environment. I believe that it is imperative that we determine as closely as we can what influences most the nutritional value of our sorghum. Of course, we all realize that we cannot develop a product strictly on nutritional quality alone; there are many other attributes that have to be considered, such as stay-green capability, standability, yield and resistance to insect pests.

Our basic approach to bolstering the U.S. sorghum industry is to simply approach it from a marketing standpoint. In other words, we must ask questions of end-users. We must also ask questions of our producers and determine if the questions and the answers are valid. We talked to the cattle feeders, and asked them what do we need to do with our product to get you to feeding sorghum again. Their response was: "When are you going to determine which varieties are more conducive for feeding cattle?" and "Your end-product is too inconsistent." When we talk to the producers, we ask them why they grow corn rather than sorghum. Many times the response is that corn has a better farm program and that corn will out-yield sorghum. Then I have to ask myself, what can I do to develop a better farm program for sorghum. And second, do we need better yields to be competitive with corn. What about thinking in terms of optimum production? I am very happy to say that we are approaching both of these scenarios today in a scientific manner. We have projects underway at Kansas State and Texas Tech where we hope to identify in more depth differences among sorghum varieties. We have a significant project underway with Texas A&M where Dr. Bobby Eddleman and Dr. Ron Lacewell are analyzing all of the "what ifs" sorghum were on par with corn with respect to target and loan prices. The association has been responsible over the years for improving the farm program for grain sorghum from 89% to 95% of corn based on nutritional values alone.

However, when we look at other positive aspects of the sorghum industry today, we find that the positive natural attributes of sorghum are directly in line with the underlying philosophy of the 1990 farm bill. Sorghum is more efficient in water usage, requires less fertilizer and pesticides and is significantly more tolerant to aflatoxin than corn. In dairy, sorghum bolsters milk protein 15% over corn. With the dairy industry moving to a protein pricing system, the dairyman can add profits of as much as 75 cents per head per day in feeding steam-flaked sorghum over steam flaked-corn or dry-rolled corn.

In the initial review of the "Effects of Setting Sorghum Prices on Par With Corn," we see some rather dramatic things happening: 1) potentially we could bolster producers' profits across the board; 2) we provide for dryland producers, whether they grow wheat, barley, oats or corn, a more viable alternative; 3) we could boost producer profits yet potentially reduce government spending; and 4) we may even be able to provide a well thought-out blueprint as to how a better farm program for producers should be developed. This project will be completed this October, and barring no complications, we will begin to pursue our objective in setting sorghum prices on par with corn this fall. Specifically, the individual we need to convince is the Secretary of Agriculture who can make this happen with one sweep of his pen. If we become successful in setting the sorghum program on par with corn, we could conceivably see sorghum acreage increase as much as 56% in the first year, immediately challenging our one-time high production of 18 million acres of sorghum.

I would like to take these final few minutes of my allotted time to discuss with you the role the National Grain Sorghum Producers Association can play in assisting INTSORMIL. Again, perhaps the single, greatest avenue of influence that we have for you is in legislation. In the past, we have not been a key player in lobbying, if we wish to call it that, for research dollars in the sorghum industry. I am happy to say that today not only is the national association concerned about federal research dollars, but our state associations are concerned as well. Today I can tell you who we are targeting as the keynote speaker at our 1993 research and utilization conference. His name is R. D. Plowman, Administrator for the Agriculture Research Service. When we bring people from Washington to our conferences, they learn about us and the fact that sorghum has a viable place in agriculture. When they begin to learn about us, then we begin to learn about them; we develop a relationship and positive things begin to happen. If there is one thing that you should have confidence in, it is the National Grain Sorghum Producers Association's ability to properly present the needs of our industry to the appropriate people in Washington. This past year has been a successful year for the association in resolving 1990 farm bill problems. As a result of our efforts, we prevented the loss of millions of dollars for our producers due to inequities on the farm program. We have begun to lay significant groundwork with the Secretary of Agriculture and the administrator of ASCS in telling them what the sorghum industry is all about.

In closing, I would like to say that we as an association are very optimistic about the future of the sorghum industry. Recently, we have initiated roundtable discussions to analyze the plausibility of establishing a grain sorghum advisory council which will help to establish direction for the U.S. sorghum industry. In April, our president, Jeff Casten, and I met with Robert Schaffert with the AID program. If Mr. Schaffert knows what our domestic objectives are, then he can look internationally for the determinants that will help us satisfy our objectives. Development of an advisory council will not be easy; however, we all will be a significant benefactor of a properly designed advisory council that provides the necessary direction for the sorghum industry. Today, within our capabilities, we, the various Grain Sorghum Producers entities, are prepared to assist you in your needs as well as provide you with our needs. Together we can develop a more dynamic grain sorghum industry. Again, thank you for the opportunity to be a part of this conference.

Trends in Agriculture Assistance within A.I.D.'s Reorganizational Scheme

Robert Schaffert[1]

I would like to paraphrase Richard Bissell's, Assistant Administrator for the Bureau of Science and Technology, comments made at the Agribusiness Leaders Seminar on May 30, 1991 in St. Louis, Missouri.

> "Agriculture at the Agency for International Development is going through a major transformation. Anyone you ask, both within and outside the Agency, can testify that this traditional stronghold of A.I.D. technical expertise has been under enormous pressure in recent years. The question that few can answer is what it will look like when we reach a new consensus. Let me give you some outline of what I see as our focus in coming decades."

> "Our traditional strengths, and where A.I.D. has contributed to miraculous improvements in the standard of living in developing countries, is in productivity of agriculture. Our support of technological innovations, through crop genetics research as well as applied operations research in developing countries, has paid off enormously......."

He goes on to state that the agriculture sector is pressed to incorporate two revolutions in recent years. One is sustainable agriculture, the merging of natural resource strategies into agriculture in a way that profits both the environment and agriculture production. A.I.D. is launching a proactive growth of work in sustainable agriculture that will be marked as a major developmental innovation of the late twentieth century. The second is agribusiness, which is less far along in being incorporated into A.I.D. programming.

Bissell completes his introduction with this phrase;

> "As the Agency goes through its current reorganization, we have an opportunity to focus our efforts on all three aspects of an agriculture strategy: production, natural resources, and agribusiness. Only in that way will we begin to help the developing countries meet their food and nutrition challenges of the next century."

The Agency is currently undergoing a major reorganization that was initiated by Dr. Ronald Roskens, A.I.D. Administrator, less than a year ago. On May 8,1991 a "Management Action Plan" was announced to the A.I.D. staff. The complete reorganization, Roskens said, was scheduled to be in place by September 30, 1991. Some now speculate that the reorganization will be announced by September but may take much longer to completely implement. The general impression or recommendation is to focus effort to a greater degree and to do fewer things, but to do them better. Greater emphasis will be placed on the services A.I.D. delivers. The nitch for agriculture in A.I.D. after the reorganization is not clear at this time.

Over the last several years there has been a steady decline in the resources directed to agriculture programs in A.I.D., at least in the traditional sense of agriculture. With a redefined and broader sense of agriculture, some figures actually show an increase in funds to agriculture programs. The same argument holds for human resources in the area of agriculture. There is repeated omission of any direct reference to agriculture in the new A.I.D. Mission Statement, in the new reorganization structure, and the new 4 + 2 initiative: Democracy, Family, Private Enterprise, Environment + Management and Evaluation.

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During the last 30 years, since the beginning of A.I.D., the world has undergone enormous changes. There have also been radical changes even within the last year or so. The political and economic interests of the U.S. and other countries have changed. The U.S. has the largest foreign debt in the world. The U.S. faces a world in which it has strong competition. The developing countries themselves have changed perspectives toward international economic assistance. The A.I.D. of today is also different from the A.I.D. of the past. The way of doing business in Washington has also changed.

Today A.I.D. finds from 80 to 90 percent of its budget earmarked. The amount of dollars that Congress appropriates to A.I.D. has been rather constant during the past years and is not expected to increase. Congress is working on a new Foreign Assistance Act that is expected to be finalized sometime in 1992. Many of these changes are not yet reflected in the design and purpose of U.S. foreign aid programs.

Washington is full of advocacy groups, many of which have significant influence with Congress. Many of these groups have been very successful in earmarking funds in the A.I.D. appropriations for their causes. The voice supporting agriculture development for the poor and resource starved developing countries is weak and often nonexistence. I don't need to tell you what happens when others get more and the total amount remains the same.

You might ask; what does this mean for the A.I.D. programs that we have and are participating in? Let me tell you that the CRSP model has received a favorable review and is generally recognized as quite successful. Other programs operating with the same set of basic premises have also been successful. These being, forming partnerships and working in a collaborative mode, working on problems of mutual benefit, and having a long-term strategy and objective and long-term funding mechanisms. I have heard references made that the CRSPs are among the most successful research programs in agriculture in the U.S. today. This results from the long term commitment and availability of funds. As a result of this success as well as recent documentation of CRSP impacts from around the world, and a lot of work and effort of the CRSP Council, the Office of agriculture was able to implement a much needed increase in most of the CRSP budgets in Fiscal Year (FY) 1991.

But don't bask in your success and think you are on easy street. Nothing could be farther from the truth. As some of you have pointed out to me, the FY 92 budget figures for the Office of Agriculture do not reflect the continuation of this 20 percent increase. In the A.I.D. budget process, the final decision depends upon a lot factors. A constant flow of impacts and success stories are necessary to maintain and improve the flow of funding resources, 4+2, Evaluation.

Lets go back and look at what is influencing today's foreign assistance programs in agriculture. Dr. Bissell summarized in three words what I think very well describes the future priorities of agriculture in A.I.D.; production, natural resources, and agribusiness. Now I think production must coordinate with natural resources and agribusiness to survive over the long run. The CRSPs will have to change and evolve to meet these new realities and priorities of the Agency if they expect to survive and be productive in this new world order.

The strong point of the Sorghum and Millet CRSP during the past 13 years has been production, and that continues to be important. I think natural resource management has also been an important component of your research agenda. This aspect was also significantly strengthened in the last five year extension proposal. The technical committee has seen fit to design a new project, if you permit me to put it in my words, relating to prescription agriculture. The success of the "green revolution" was based on intensive use of inputs for greater production. The success of transforming marginal or less productive lands into productive lands will require designing and developing new cultivars and production systems that best respond to these conditions and are more efficient in utilizing nutrients, either from the soil or applied fertilizers. This new project along with your "agronomy" projects and your projects from the "plant protection thrust" is a good start in this area. But I think there are still other components that need to be evaluated in the area of biodiversity. For example, the incorporation of the native legumes from the semi-arid tropics into cropping systems and developing pools of sorghum and millet germplasm with a higher concentration of desirable genes.

What about "sori"? What about the new cultivars that don't get planted by the farmers? What about the composite flours, and all the other new products and processes that come out of your projects? What about prices and marketing? It only counts when it impacts. You need that link between your research and the end user, the private enterprise. You must find a way to connect and network with the private sector.

Over the next several months, you need to attentively watch the reorganization of A.I.D. You will need to follow closely the new order of priorities of the Agency and you may need to make some adjustments in your program to continue to keep INTSORMIL on the leading and cutting edge, as it is today. You need to be proactive in publicizing the impacts; not only in production, but also in human resources and institutional building, natural resource management and enhancement, and your interaction with agribusiness and private enterprise.

Cereal Consumption Shifts and Policy Changes in Developing Countries: General Trends and Case Studies from the West African Semi-Arid Tropics

Christopher L. Delgado and Thomas Reardon[1]

Introduction

One of the central aspects of food policy in the developing world is the growing disarticulation between what food staples the tropical areas produce and what they consume. This is especially true of the tropical areas that have traditionally relied upon the three major coarse grains: maize, sorghum, and millet. This paper focuses on sorghum, but in practice it is difficult to separately analyze the roles of sorghum and millet where these two crops are both used for human nutrition.

After showing that other cereals have tended to outpace sorghum in production and consumption in most parts of the developing world over the past twenty years, the paper will show that sorghum continues to play a dominant role in human nutrition in the West African Semi-Arid Tropics (WASAT), alone among the world's regions. Yet even in the WASAT major changes are occurring. The rest of the paper will examine consumption trends and their determinants in detail in the major producing and consuming area for sorghum in the WASAT. This will provide a case study of the economic policy issues involved in the increasing substitution in consumption patterns of imported wheat and rice for domestic millet and sorghum. The paper will conclude with consideration of some broader issues raised by the overall patterns.

The Shifting Place of Sorghum in the World

Sub-Saharan Africa stands out as the only major region of the world where sorghum and millet have the dominant role in cereals production. The two crops account for a four times larger share of total 1988 cereals production in that region than is the case in Latin America, and a nine times larger share than in Asia, as shown in Table 1. In 1988, Sub-Saharan Africa was also the absolute largest producer of sorghum and millet. At 22.4 million metric tons, production in the region just exceeded the total for Asia (excluding China).

Furthermore, the only major region where sorghum output growth has outstripped population growth over the 1961 to 1988 period is in Latin America, due to the spectacular successes in feed grain production in Brazil. With this exception in mind, Table 1 also shows that the output growth rates both of maize (a competitor) and of all cereals exceeded those of sorghum/millet.

Net trade flows need to be added to production trends to get a rough idea of consumption patterns by region. The country categories involving Africa in the analysis of world sorghum trade in Table 2 reflect FAO practice, which are different from the IFPRI categories in Table 1.

Asia (excluding China) is the major importing region of the world; the main commodity involves feed sorghum for the rapidly growing economies of East Asia such as Taiwan, Japan, and Korea. Net trade flows were 20 percent higher in the 1985/87 period than in the late 1960s. Latin America has gone from being a clear net exporter to being a marginal importer, even though the volume of trade in sorghum has doubled since the late 1960s. As

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Table 1. The place of millet/sorghum in world food/feed production by region 1988 and growth 1961-88.

	Millet/Sorghum			Maize			All Cereals		
	Production, millions of metric tons	Annual growth rate 1961-88	Share of all cereals (%)	Production, millions of metric tons	Annual growth rate 1961-88	Share of all cereals (%)	Production, millions of metric tons	Annual growth rate 1961-88	Share of all major food staples[a] (%)
Asia excl. China	21.3	0.8	7	30.1	3.2	9	319.6	3.1	87
China	11.6	-0.5	4	73.8	5.6	23	317.8	4.1	87
North Africa/Middle East	6.6	0.7	8	7.7	2.4	9	84.8	2.5	92
Sub-Saharan Africa	22.4	1.1	44	18.9	2.3	37	51.4	1.7	56
Latin America	11.1	7.4	11	54.8	2.9	53	103.8	3.2	82
Developed Countries	20.3	1.2	3	220.1	3.0	29	768.8	2.2	93

Source: Data are from the FAO Production Tape 1989, with aggregation and calculation by IFPRI.

Notes: [a]Includes total cereals plus roots and tubers, pulses, peanuts, bananas and plantains.

a whole, developing countries are marginally net importers, and developed countries as a whole are modest net exporters.

Despite the important role of sorghum in cereals production in the "developing market economies" category of Africa, the region as a whole is a net importer, which is indicative of the important role of the crop as a human food source in that region, since the use of grain sorghum as a feed is relatively limited in Africa. Yet major changes are occurring in the use of sorghum for human nutrition in Africa, especially in the WASAT.

Shifting Cereals Patterns in West Africa

As elsewhere in the tropics, policy attention in the WASAT has turned to the major imbalance between the composition of cereals consumption and that of production. Annual per capita rice and wheat consumption in West Africa as a whole rose by more than 16 kilograms from the early 1960s to the early 1980s, whereas millet and sorghum consumption fell by more than 22 kilograms. Maize consumption increased by less than 1 kilogram per person per year over the same period.

Besides the growing drain on foreign exchange, policymakers are concerned about the outlook for production of coarse grains. They account for four-fifths of cropped area in a Sahelian agricultural sector that continues to employ roughly three-quarters of the overall population. The prospects for decreasing unit production costs for coarse grains in the WASAT appear good. However, Sahelian wheat production prospects remain poor, and rice production growth has lagged behind consumption growth (15 percent of cereals production in the early 1980s and 21 percent of consumption).

To improve on estimates of the sources of growth in sorghum production in the WASAT over the 1961 to 1989 period, World Bank data sets for three producing countries are analyzed in Table 3. Sorghum grew at about the same rate as overall cereals production over the period, which was less than the approximately 3 percent rate of population growth, leading to a decline in per capita production. Furthermore, approximately two-thirds of the growth in production over the period came from growth in area harvested.

The use of the FAO Supply Utilization Accounts data permits an estimate of the growth of consumption of sorghum and millet in West Africa from the late 1960's to the mid 1980's, following the disappearance concept. In the major countries of the WASAT, as in West Africa as a whole, the growth in human consumption of all cereals clearly exceeded the growth in sorghum consumption as food. Even so, the consumption of all cereals grew more slowly than population in Burkina Faso and Mali, and human consumption of sorghum per

Table 2. World trade in sorghum by region 1966/68 and 1985/87.

Region	Trade Activity	1966-68 Avg. (000 Mt)	1985-87 Avg. (000 Mt)
Asia excluding China	Export	88	249
	Import	4,100	5,252
	Net exports	-4,012	-5,003
China	Export	0	501
	Import	1	678
	Net exports	-1	-178
Latin America	Export	871	2,107
	Import	51	2,206
	Net exports	820	- 99
Near East (developing market economies)	Export	45	191
	Import	7	30
	Net exports	39	161
Africa (developing market economies)	Export	4	10
	Import	59	221
	Net exports	- 54	-211
Developing countries	Export	1,008	3,058
	Import	1,466	3,381
	Net exports	-458	-323
Developed countries	Export	5,971	6,898
	Import	4,896	5,904
	Net exports	1,075	993

Source: Underlying data are from the 1988 FAO Agricultural Trade Tape.

capita appears to have fallen for all major countries in the region, as shown in Table 4.

The use of cereals as feed in the region has grown at about the same rate as human consumption, but from a very much smaller base. Except for Niger and Senegal, where sorghum has kept up with other cereals in this regard, other cereals have contributed more than sorghum to growth in feed use. Since the feed growth rates include by-products, it should be noted that the growth in feed use in the region is accounted for largely by the use of wheat by-products from flour mills and rice by-products!

The greater rates of growth in human consumption of other cereals relative to millet and sorghum suggest that the relative share of food supply accounted for by millet and sorghum in West Africa has declined since the late 1960s. The major shares of sorghum and millet in human consumption of all food staples in the region, especially in the interior countries such as Burkina Faso, are shown in Table 5. It can be seen that the proportions have fallen distinctly since the late 1960s. For all of West Africa, the share of sorghum and millet in human food staple consumption has fallen from 36 percent to 31 percent. On the other hand, the shares remain high, and the available data confirm the dominant role of sorghum over millet.

Table 3. Performance of sorghum relative to total cereals in selected West African countries 1961-1989.

Country	Annual growth rate of sorghum production (%)	Annual growth rate of total cereals production (%)	Annual growth rate of sorghum's share in cereals production[a] (%)	Share of yield in growth of sorghum production[b] (%)	Share of area harvested in growth of sorghum production[c] (%)
Burkina Faso	2.32	2.45	-0.14	31	68
Mali	2.28	2.09	0.18	57	42
Senegal	1.43	1.8	-0.37	21	78

Source: The data used is from a World Bank data set, distinct from the more usual FAO data, provided by an operational division of the Bank dealing with agricultural issues. This permitted more consistent estimates for sorghum as distinct from millet, and a longer time period for regression work. The compound annual growth rates are estimated using regression techniques.

Notes:

[a]"Cereals" includes the following: rice, millet, maize, sorghum and wheat.

[b]The ratio of the growth rate of sorghum yield to the growth rate of sorghum production, and

[c]The ratio of the growth rate of sorghum area harvested to the growth rate of sorghum production.

[d]The last two columns may not sum to 100 due to rounding error.

Table 4. Annual growth in use of millet/sorghum compared to total cereals in West Africa 1966/70 - 1982/86.

	Food		Feed	
	All cereals (% per annum)	Millet/Sorghum (% per annum)	All cereals (% per annum)	Millet/Sorghum (% per annum)
Burkina Faso	2.5	1.6	4.1	1.6
Mali	2.7	2.1	2.7	2.1
Niger	3.2	2.6	2.4	2.6
Senegal	3.6	2.4	3.8	4.0
Nigeria	4.0	2.7	2.9	2.5
All West Africa (16 countries)	3.4	2.2	3.9	2.3

Source: Compound growth rates between mid-points calculated from data in the 1988 FAO Supply Utilization Accounts tape.

Table 5. Share of sorghum and millet in human consumption of all major food commodities in West Africa 1966/70 and 1982/86.

	Avg. annual consumption per capita of Millet/Sorghum 1966/70 (kg/capita)	Share of Millet/Sorghum 1966/70 (%)	Share of Millet/Sorghum 1982/86 (%)
Burkina Faso	139[a]	60	53
Senegal	65	37	34
Nigeria	71[b]	39	36
All West Africa (16 countries)	66	36	31

Sources: Calculated from data taken from the 1988 FAO supply utilization accounts tapes and Delgado and Miller (1985).

[a]Millet 52.4 kg/capita and sorghum 86.4 kg/capita.

[b]Millet 29.9 kg/capita and sorghum 41.4 kg/capita.

Table 6. Changing cereals use patterns in West Africa 1966/70 - 1982/86.

	Millet/Sorghum		Maize		Rice		Wheat	
	66/70 (%)	82/86 (%)	66/70 (%)	82/86 (%)	66/70 (%)	82/86 (%)	66/70 (%)	82/86 (%)
Crop Share of all Cereals used as Food								
Burkina Faso	74	64	8	9	3	7	2	2
Mali	74	67	10	11	12	17	1	3
Niger	96	88	—	3	3	5	1	4
Senegal	46	38	8	9	38	43	8	9
Nigeria	78	64	15	10	4	14	3	10
All West Africa	61	50	14	12	14	21	4	8
Share of all Cereals used as Feed								
Burkina Faso	92	60	6	5	—	—	—	3
Mali	81	73	10	11	4	3	1	11
Niger	98	95	—	1	2	2	13	12
Senegal	76	77	4	7	7	4	13	12
Nigeria	80	74	14	9	1	1	6	15

Sources: Calculated from data in the 1988 FAO Supply Utilization Accounts Tape.

Note: Shares are of cereals use during the period in question in the country in question. Cereals use is calculated using FAO's disappearance concept. Rows will not sum to 100 because consumption of minor cereals, either domestic or imported.

The share of cereals consumption accounted for by sorghum and millet fell by about one-sixth in all of West Africa from the late 1960s to the second half of the 1980s. Details by WASAT country and West Africa as a whole, by food and feed, are given in Table 6. At the same time as the share of sorghum and millet declined by 11 percent of total cereals consumption, the share of rice and wheat grew by the same amount. Maize made relatively little progress in the region over the same period. Since wheat can only be produced in the region under cold season irrigation at high cost, and rice production is certainly not likely to expand to meet demand at current world price levels, these trends have raised considerable concern in the region with respect to the future of imports (Delgado and Miller, 1985).

Determinants of Changing Patterns of Cereal Use in West Africa

Aggregate-level Evidence

Some observers posit that the rise of rice and wheat consumption in West Africa over the 1970's and 1980's is the consequence of the declining domestic production of coarse grains, thus attributing shifting consumption patterns to deficiencies in sorghum and millet supply. Excess demand was met by imports, on this account, and it is primarily rice and wheat that are available on international markets. However, it seems more likely that changes in cereal consumption patterns in the WASAT have primarily been driven by demand. Despite bumper harvests in the Sahel in 1985 and 1986, and a consequent fall in coarse grain prices to one-third to one-tenth their 1984 levels, commercial imports of wheat and rice continued at high levels. In Mali, for example, commercial rice and wheat imports still accounted for 8 percent of total imports in 1986, a year of bumper domestic stocks of coarse grains.

Commercial rice and wheat imports in Burkina Faso over the past twenty years are not significantly correlated with coarse grain production. Reardon, Delgado, and Thiombiano (forthcoming) regressed rice and wheat imports from 1970 to 1986 against an index of self-sufficiency in coarse grains, population, share of population living in urban areas, and the world price of rice in real terms. Only the degree of urbanization had a significant effect (positive). Work on rice imports in Senegal, which grew steadily over the last two decades, shows that they were not significantly correlated with movements in domestic cereal production (Lombard 1988).

If changing cereals patterns are primarily demand-driven, then the question arises as to the role of relative cereals prices. Some observers believe that the changing cereals demand patterns are caused by relatively low rice and wheat prices, especially in the mid-to late-1980's. From 1970 to 1986, world cereals prices as a group fell about one-third relative to the price of manufactures. However, rice prices fell 1.5 times as fast as coarse grain prices, implying that rice was getting cheaper relative to both coarse grains and manufactures on international markets. Similar trends could be observed in national rice and wheat prices relative to coarse grains and manufactures in most of West Africa.

The world price of rice was more than one-third cheaper relative to the world price of sorghum in the 1982-86 period than in the late 1960s, as shown in Table 7. Even though there was a substantial recovery in 1988, it can be seen that rice appears to be cheaper for the long-haul relative to sorghum after the 1985 U.S. Farm Bill. Similarly, the consumer price of rice relative to coarse grains fell greatly in West Africa through 1986, but has recovered more recently to levels that are comparable to (or presently exceed) the "normal" levels of the late 1960s. A major factor in this evolution has been the escalating cost of coarse grains in West Africa during the 1984 drought and the bumper crops (and thus falling prices) thereafter.

On the other hand, the experience with wheat in West Africa is very diverse; adding Ghana and Nigeria to Table 7 would only amplify this conclusion. As in the case of the relative price of rice, wildly fluctuating prices for local staples in the denominators have been responsible for much of the variation in price ratios among countries. Nevertheless, wheat pricing policy in the 1960s and 1970's was very different across the region, with high subsidies in Senegal, especially in the earlier part of the period, and some taxation in Burkina Faso. Since the mid-1980s, with the grow-

Table 7. Indices of relative consumer food prices in the West African Francophone 1966/70 - 1987/88. (1974/78 = 100).

Country	Price of Rice/Price of Traditional Staple[a]				Price of Wheat Bread/Price of Traditional Staple[a]			
Annual Averages	1966/70	1982/86	1987/88	1987/88 ratio[d]	1966/70	1982/86	1987/88	1987/88 ratio[d]
Burkina Faso	148	105	134	2.5	150	222	278	5
Côte d'Ivoire	142	67	n/a	n/a	94	94	n/a	n/a
Mali	105	84	120	2.3	100	81	116	3.7
Niger	129	81	131	2.8	200	96	150	3.5
Senegal	67	67	78	1.4	46	96	104	2.7[b]
World Market	106	68	91	3.1	94	98	118	1.5[c]

Sources: See Delgado (1989)

[a]All indices are computed by comparing the average of the ratios of consumer prices are per kg. in the years in question to the average of the 1974-1978 period. Traditional staples are millet for Mali, Niger and Senegal; soghum for Burkina Faso; cassava for Côte d'Ivoire. World prices are f.o.b. export prices.

[b]1987 only

[c]For the world wheat market, the price of grain (US N° = 1 soft red winter, f.o.b.) was used, therefore, the absolute ratio for the world market should not be directly compared to the ratios for individual countries, which have bread prices in the numerators.

[d]Average of the actual ratios of consumer prices for 1987 and 1988.

n/a = not available.

ing share of wheat in consumption and the increased concern for fiscal austerity, there has been considerably more uniformity within the region in fixing the nominal price of bread at a level not very different from world import parities.

Given the possibly temporary nature of the world price dip, many fear that low cereals prices in the WASAT will induce cereal production resources to permanently leave the agricultural sector. Therefore, given the view that changing relative prices have both promoted past substitution in cereals consumption patterns and that the process could even be reversed if rice and wheat prices were raised, they have advocated commercial policies to increase domestic rice and wheat prices in the WASAT relative to all other prices. Nigeria, for example, has attempted to ban all rice and wheat imports. The Club du Sahel has urged creation of a regional protected zone for cereals in West Africa, characterized by a high common external tariff for cereal imports from outside the region (Delgado 1991).

One approach to assessing the role of prices in promoting the change in West African consumption patterns in sorghum producing areas is to examine national level annual data on average consumer prices (in the capital city), GDP per capita, consumption (total disappearance) by cereal, and non-cereal expenditures in a theoretically-consistent framework. This would allow the role of various long-term trends in relative price in influencing consumption patterns to be considered in detail.

Such a framework is provided by the Almost Ideal Demand System (AIDS) (Deaton and Muellbauer 1980). This was estimated separately for secondary aggregate annual data from 1966 to 1986 for Mali, Senegal, and Burkina Faso.[2] Key results are given in Table 8. In addition to the tenuous nature of secondary national-level data in the WASAT, it should be borne in mind that such estimations implicitly assume that many other factors remain constant. An example of pertinence would be the distribution of income, since the use of the level of GDP per capita assumes that income was not becoming increasingly concentrated in towns over the period (which is most probably not true). Disclaimers aside, the aggregate results seem useful for looking at long-term trends.

The results show inelastic demand response of the expected sign to changes in own-price for coarse grains. For example, a long term rise of 1 percent in the price of sorghum in Mali, other things equal, is associated with a 0.07 percent decrease in the quantity demanded for coarse grains. These compensated elasticities represent long-term adjustments, and can be expected to be considerably more elastic than short-run responses.

Cross-price elasticities measure the substitution effects of changes in the prices of other crops on the quantity demanded of coarse grains. They show virtually no impact of wheat prices and very little impact of rice prices on coarse grains consumption. Finally, coarse grains appear to be income-inelastic in the long run. The estimated negative or insignificant expenditure elasticities are surprising in view of the basic poverty of the region.

The results for rice suggest that the quantity demanded is somewhat responsive to the price of rice in the long-run, and quite responsive to income. On the other hand, there is little substitutability with wheat (near-zero cross-price elasticities). For Mali and Burkina Faso, two interior countries, the quantity of rice demanded is responsive in the expected positive manner to the price of coarse grains (in Mali, for example, a 1 percent increase in coarse grains prices is associated with a 0.75 percent increase in the quantity demanded of rice.)

The aggregate results are somewhat misleading for assessing the impact of policy-induced changes in relative cereals prices in the short to medium run on consumption patterns. The price changes and responses modeled are in fact long-term trends arising from vari-

[2] See Delgado (1989) for a discussion of data sources.

Table 8. Demand elasticities for grain from aggregate data in three Sahelian countries 1966-1986.

(Cell values are compensated demand elasticities: a 1% change in the variable in the left hand column is association with the % change in demand indicated in the corresponding row)[c]

	Mali	Senegal	Burkina Faso
% change in Sorghum/Millet/Maize[a] demand with respect to a 1% change in:			
Own-price	-0.07	-0.11	-0.50
Wheat price	0.05	-0.03	0.02[b]
Rice price	0.24	0.13[b]	0.05
Income	-0.28[b]	-0.24	1.13[b]
Rice demand			
Own-price	-1.50[b]	-0.66	-0.96
Wheat price	-0.08[b]	0.01	-0.39
Sorghum/Millet/Maize price	0.75	0.13[b]	0.48
Income	0.91[b]	-0.17	1.71
Wheat demand			
Own-price	-0.20	0.36	-0.51
Rice price	-0.26[b]	0.02[b]	-0.60
Sorghum/Millet/Maize price	0.47	-0.06[b]	0.32
Income	2.44	0.51	0.73[b]

[a]Burkina Faso estimates are for millet/sorghum only.

[b]Not statistically significant at 10%.

[c]Estimated by separate complete demand systems regressions by country, 21 years of annual data with sources detailed in Delgado (1989). The Almost-Ideal Demand System (AIDS) estimator was used and homogeneity and symmetry were imposed.

ous exogenous as well as endogenous forces. They are not really comparable to the responses that governments could expect from sectoral price policies in the short to medium run.

Primarily, this is because in the long-run WASAT countries are no longer able to deliberately keep domestic price relatives for importable and domestic cereals at levels far different from world price relatives, because of the fiscal cost of the subsidies involved. Furthermore, taxation of importable cereals to raise their relative prices cannot be maintained under austerity conditions for very long, due to the welfare and political costs in the areas now heavily dependent on imports (Delgado 1991; Reardon, forthcoming).

In addition, the aggregate results do not sufficiently capture the effects of structural change on consumption coming from changes in non-price factors, such as income distribution. Therefore, diagnosis of what is really pushing consumption behavior in the WASAT and of what can feasibly be done about it requires detailed micro-level work that takes into account the relevant non-price factors.

Micro-Level Evidence[3]

The careful household-level surveys available do not support the notion that major shifts in cereals consumption patterns in the Sahel are driven by price changes. Three household-level studies provide consumer price elasticities for the Sahel: the Purdue University/

[3] This section draws heavily on section 2 of Reardon (forthcoming).

SAFGRAD study, the IFPRI/Centre d'Etudes, de Documentation, et de Recherches Economiques et Sociales (CEDRES)—University of Ouagadougou study, and the Tufts University/Direction Nationale de la Statistique et de l'Informatique (DNSI) study of Bamako and secondary Malian cities.

Each of the surveys covered one year, with frequent re-interviewing of the same households. Therefore, they each provide considerable depth as to household behavior, but they do not allow for major adaptations over time to fundamental changes in incentives.

Savadogo (1986), based on the Purdue University survey of 65 households in Ouagadougou in 1982/83, found a negative cross-price elasticity (-1.1) between rice (grain-form only, excluding prepared-rice purchases) and wheat on one hand, and all coarse grains combined on the other. He surmised that the negative elasticity was caused by very low variation in the rice price over the study period. Only the own-price effects on rice consumption appeared to be significant, however, and these were relatively high (-2).

Reardon, Delgado, and Thiombiano (forthcoming), based on the IFPRI/CEDRES survey in Ouagadougou in 1984/85, with a sample of 125 households, found that own-price elasticities for rice expenditures were not significant. Cross-price elasticities between rice (grain-form and prepared-form purchases) and millet/sorghum, and between rice and maize, were negative and significant (-1.7 for maize/rice, and -3.2 for rice/millet-sorghum). Hence, when the when coarse grain prices increased, rice expenditure fell. However, they found no significant cross-price elasticity between wheat products and coarse grains.

Rogers and Lowdermilk (1988), using data from a survey conducted in 1985/86 by the DNSI in seven regional capitals in Mali, with a sample of 576 households, found that rice (grain-form only, excluding prepared-rice purchases) expenditure had a negative and significant (but inelastic) own-price elasticity (-.68), as did millet/sorghum (-.53). Yet they found that the price of rice did not significantly influence millet/sorghum expenditure; nor did the price of millet/sorghum significantly influence rice expenditure.

Although limited in time dimension, the survey results above suggest the predominance of urbanization in explaining the shift to rice in the national diets. Urbanization changes employment patterns, the value of women's time, and increases the cost of returning home for the midday meal. These factors make rice, and in particular "fast-food" or street vendor rice, very attractive to poor consumers.

Urbanization and Changing Consumption Patterns[4]

Imported rice and wheat are consumed mainly in urban areas in most of the Sahel. Moreover, the share of rice and wheat is high not only in Sahel coastal cities, but also in urban areas far inland. The population of the Sahel doubled from 1965 to 1983, but the urban population more than quintupled; the average share of the urban population was 12 percent in 1965, and 22 percent in 1983 (Gabas and Giri, 1987). It is clear that urban consumption patterns have had and will have increasing impact on national diet and import patterns.

Frequent-interview household surveys contradict the belief that it is mainly the richer consumers that eat imported cereals, even if this was perhaps true during and immediately after the colonial era. In general, they show that rice is very important in the diet of the urban Sahelian—particularly the poorest third of the population. A survey of the literature shows that the share of rice in urban cereal consumption ranges from 37 to 66 percent, with an average of 52 percent. On the other hand, consumption of wheat products such as bread and noodles is far less prevalent than that of rice; the average share of wheat products in cereal expenditures varies from 7 to 17 percent.

[4] This section draws heavily on section 2 of Reardon (forthcoming).

In the surveys where the data collected permitted stratification by income group, households in the poorest third of the urban population were found to spend at least as high a share of income on rice as did the richest third of households. However, richer consumers spent a much greater share of their cereal expenditures on wheat products than did the poor.

The great success of rice in street-restaurant sales of prepared foods is also an important factor in the increase in importance of rice in general in the urban Sahel (Reardon and Delgado, 1987; Sautier et al. 1989). Reardon, Thiombiano, and Delgado (1988) showed the importance of purchases of prepared rice from street vendors in overall rice purchases in Ouagadougou — especially for the poor. Fifty percent of the poor tercile's rice expenditure went to prepared rice dishes consumed in small roadside restaurants, versus only 10 percent for the richest tercile. These results concur with results from rapid-reconnaissance surveys in Niamey, Bamako, and Dakar, reviewed in Bricas and Sauvinet (1989). Relatively poor urban workers are typically far from home at midday, and need to buy a cheap but filling meal near the worksite. The richer consumers usually can return home to eat rice or coarse grain dishes prepared in their own kitchens, with better access to transport and typically living closer to the main business centers of town.

Furthermore, at home in the kitchen, the lower processing/preparation costs of rice appear to be an incentive for its consumption (Thiombiano, 1985; Sautier et al. 1989.). The opportunity cost of women's time is increasing due to their increasing involvement in the labor market. This trend is part of a larger trend in the Third World toward "convenience foods" often made from fine cereals such as wheat (Byerlee 1983; Senauer, Sahn, and Alderman 1986).

In sum, the switch to rice consumption in the WASAT appears to be driven by structural factors rather than shorter-run factors such as harvest shortfalls or price dips. This makes the substitution tendency persist despite short-run increases in the relative price of rice (due, for example, to bumper harvests of millet and sorghum in 1986).

The assessment of changing grain patterns in the urban WASAT would not be complete without considering maize. The present importance of maize in urban consumption patterns in the WASAT is low: the share of maize in total cereal consumption is rarely greater than one-seventh in Sahelian cities.

Yet maize appears to be attractive to urban consumers. There is a high degree of substitutability among the various coarse grains in many typical Sahel dishes (Reardon, Delgado, Thiombiano, 1988; Sautier et al. 1989). Furthermore, the ratio of maize to sorghum prices tends to dip in the hot/dry and rainy seasons. This is because of the timing of humid coastal maize harvests and Sahel sorghum harvests. Reardon, Delgado, and Thiombiano (forthcoming) found for Ouagadougou that the cross-price elasticity of millet/sorghum expenditure with respect to the price of maize was significant and positive (.6), indicating that they are substitutes and that consumers are sensitive to their relative price. Moreover, maize is easier to process than either millet or sorghum.

Changing Cereals Demand Patterns in Rural Areas of the Sahel[5]

A survey of the literature shows very little rice and wheat consumption in rural areas, where millet, sorghum, and maize reign supreme. The exceptions to this rule — where rice is an important item — are found in three types of areas: (i) highly monetized or semi-urban rural zones — especially where households produce cash crops or have substantial off-farm activity (e.g., northern Peanut Basin of Senegal; (ii) rice-growing areas (e.g., Casamance in Senegal); (iii) drought areas receiving food aid, principally of wheat, but also of rice (for example, see Reardon and Matlon (1989) for the case of Burkina).

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[5] This section draws heavily on section 2 of Reardon (forthcoming).

The "conventional wisdom" is that, except in 'cash cropping' areas, Sahel peasants are subsistence farmers, depending mainly on their farms for 'food entitlement', and thus buy very little of their food (Kowal and Kassam, 1978; CILSS/Club du Sahel, 1981; Giri, 1983; OECD, 1988). But household survey evidence shows that: (i) WASAT farm households purchase a substantial share of the coarse grains they consume. Some examples: Dione (1989) found in 1985/86 in rural Mali that 39 percent of sample households were net buyers; Kelly et al. (1990) found in 1988/89 for Senegal that 75 percent of caloric intake came from purchased grain in the Sahelian zone, and 20 percent in the Sudanian zone; Reardon and Matlon (1989) found in 1984/85 for Burkina that 43 percent of caloric intake came from purchased grain in the Sahelian zone, and 37 percent in the Sudanian zone.

The implication is that price policy affects real incomes from the demand side and not just the supply side (Weber et al. 1988). The localized importance of cash cropping (Weber et al. 1988), as well as the generalized substantial importance of non-farm activities to household income (Reardon, Delgado, and Matlon, 1991), are key determinants of the importance of purchased grain in the rural diet.

Maize consumption is in general not yet substantial, but one finds it important in certain zones, at certain times and places — in maize production zones such as in parts of Mali (Dione (1989)); and in zones where it is "imported" into the zone from higher potential zones, mainly in drought years, such as the Sahelian and Sudanian zones of Burkina Faso in the drought year 1984/85 (Reardon and Matlon, 1989); and in Northwestern Niger, during drought years (Hopkins and Reardon, 1989).

Yet, maize consumption and production have made important progress over the last decade in Mali, Burkina Faso, and Senegal, starting from a small base (Sautier et al. 1989). On the demand side, maize appears to attract rural WASAT consumers because it is cheaper than millet and sorghum in most zones, especially during drought years (Reardon, Delgado, and Matlon, 1987), and it is usually available in drought years in the Sahelian and Sudanian zones from regions with better rainfall such as the Guinean zone in the southern belt of the Sahel (CRED, 1987).

Conclusions with Respect to Changing Consumption Patterns in the WASAT

In sum, we argue four related sets of points. First, changes in cereals consumption patterns in the major sorghum-producing areas of the WASAT are demand-driven. Second, these changes are widespread. The urban poor in at least several Sahel capitals are major consumers of rice, mostly in cooked form outside the household. The rich eat substantial quantities of rice at home. Third, long-run changes in relative prices may have played a role in changing consumption patterns, but they probably have not been the leading factor of change. Non-price factors, such as household income and employment patterns, are important. Price policies to reverse the trends of the past twenty years would need to be sustainable in the long-run to work, and they cannot be unless the needs of the burgeoning urban populations for a convenient source of cheap calories are met. Fourth, rice and wheat prices would have to increase very substantially over those of millet and sorghum before encouraging shifts in consumption back to these cereals. In the short term, such policies could be associated with severe negative welfare effects on the urban poor.

We suggest three areas of policy emphasis. First, a careful assessment should be made of the best potential for decreasing unit production costs for different cereals. Coarse grains can soak up a large share of demand for rice for consumption in the home, but only if they are kept very cheap relative to everything else. If rice production costs can be significantly and sustainably lowered, the problem diminishes, however it is doubtful that this could ever be a full solution to the problem on the scale required.

Second, even with progress in lowering coarse grains production costs, better processing technologies are required to permit coarse grains to better meet the needs of urban food consumers. These needs involve shorter and less arduous preparation times, better storability and suitability for commercial preparation.

Third, there needs to be a way to soften the impact of higher rice prices on the urban poor. Cheaper and easier to prepare sorghum, millet and maize food dishes, from imports or own production, are likely to be a major component of any solution.

Some General Policy and Economic Research Issues Involving Sorghum

The discussion above highlights that the central issue in taking advantage of the opportunities offered by sorghum for grain and biomass production increases in semi-arid areas is to keep the unit price of grain low relative to competing grains. This means that major and sustained yield increases will be a necessary, if not a sufficient, condition for using sorghum as a major rural development tool.

On the demand side, sorghum must compete with maize for rural food demand in traditional preparations, and for industrial and feed demand. With respect to urban demand, sorghum faces the unavoidable handicap of requiring better processing technologies in order to be a contender for the dynamic part of Third World markets for direct human consumption of grain.

Sorghum utilization research is of great value in diagnosing those areas where additional processing technologies, or improved marketing policies, can assist in providing sorghum producers with viable long-term markets. However, such research cannot be a substitute for a basic push on lowering per unit production and distribution costs for grain sorghum. Without this, the crop will be left behind, even in those remote parts of the world where high transport costs presently afford traditional cereals a high degree of natural protection against imported cereals.

On a more upbeat note, it appears that many of the areas of the Third World where smallholder sorghum production is important are on the verge of a rebirth of rapid demand growth for livestock products. This process was well underway in the 1970s, and was largely choked off by the debt problem and international dumping of the 1980s. The semi-arid areas have always had a special advantage in producing livestock products under low animal husbandry technology conditions. Use of sorghum technology as a fundamental motor of development of smallholder farming in the WASAT and in the semi-arid areas of Eastern and Southern Africa will probably require more serious consideration of the use of livestock feeding as a way to minimize transport costs to market for bulky commodities, and to add value on the farm. Relative prices and costs remain a central issue. Farm-household level research into the specific issues and options in different zones is highly indicated.

References

Bricas, N. and R. Sauvinet, "The trend towards diversification in Sahelian food habits", paper presented at Seminar on Regional Cereals Markets in West Africa, (Lomé: CILSS/OECD/Club du Sahel, 1989).

Byerlee, D., "The increasing role of wheat consumption and imports in the developing world", (Mexico: CIMMYT Economics Program Working Paper no. 83/4, 1983).

CILSS/Club du Sahel, L'intensification des cultures pluviales dans les pays du Sahel, Synthesis of Bamako Seminar, 12-14 May, 1981.

CRED, "The dynamics of grain marketing in Burkina Faso," (Ann Arbor: Center for Research on Economic Development, University of Michigan, 1987).

Deaton, A. and J. Muellbauer (1980). An Almost Ideal Demand System. The American Economic Review, Vol. 70, No. 3, June: 312-326.

Delgado, C., "Cereals protection and agricultural development strategy in the Sahel", Food Policy, (April, 1991).

Delgado, C. "Questions à propos d'un éspace régional protégé pour les céréales au Sahel", Economie Rurale, April 1990.

Delgado, C., "Why is rice and wheat consumption increasing in West Africa?" Paper presented to the European Seminar of Agricultural Economists, (Montpellier: 1989).

Delgado, C. L., and C. P. J. Miller. 1985. Changing food patterns in West Africa: Implications for policy research. Food Policy, Vol. 10, No. 1 (February): 55-62

Delgado, C.. and T. Reardon. "Policy issues raised by changing food patterns in the Sahel" in CILSS/Club de Sahel, Cereals Policies in Sahel Countries: Acts of the Mindelo Conference, Paris, 1987.

Dione, J., "Informing food security policy in Mali: Interactions between technology, institutions, and market reforms", Ph.D. Thesis (Michigan State University, 1989).

Gabas, J.-J. and J. Giri, "The food situation in the Sahel: An assessment", in CILSS/Club du Sahel, 1987.

Giri, J., 1983, Le Sahel demain: catastrophe ou renaissance? Paris: Editions Karthala.

Hopkins, J. and T. Reardon, Annual crop and livestock transactions patterns for rural households in western Niger, Project Document III Submitted to USAID/Niger, (Washington: IFPRI, October, 1989).

Kelly, V., T. Reardon, A. Fall, and B. Diagana, IFPRI/ISRA project: Preliminary results for sub-zones of the Sahelian and Sudanian zones of Senegal, Project Document IV, (Washington: IFPRI, July 1990).

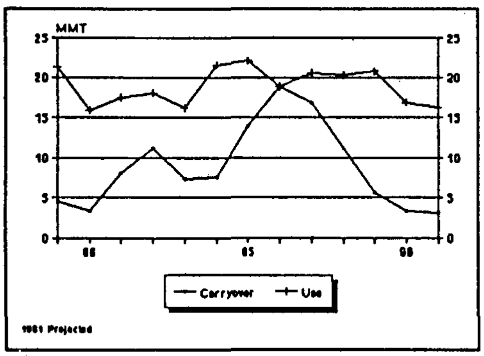
Kowal, J.M. and A.W. Kassam, Agricultural ecology of savanna: A study of West Africa, (Oxford: Clarendon Press, 1978).

Lombard, J., Problèmes alimentaires et stratégies de survie dans le sahel sénégalais: les paysans serer, Thèse de

doctorat de troisième cycle, Université de Paris X - Nanterre, U.F.R. de Géographie, (Paris: January, 1988).
Organization for Economic Cooperation and Development/Club du Sahel, The Sahel Facing the Future, (Le Sahel face aux futurs), (Paris: OECD, 1988).
Reardon, T., "Agricultural development and policy issues raised by rural household income diversification in the West African Semi-Arid Tropics", mimeo, Washington: IFPRI, 1990).
Reardon, T. "Cereal imports in West Africa and the potential impacts of Sahelian regional protection", World Development, forthcoming.
Reardon, T., C. Delgado, and P. Matlon, "Household income diversification in the Sahel: implications for agricultural policy and development strategy", IFPRI Working Paper, 1991.
Reardon, T., C. Delgado, and P. Matlon, "Farmer marketing and the composition of cereals consumption in Burkina Faso", paper presented at the IFPRI/ISRA conference on The Dynamics of Cereals Consumption and Production Patterns in West Africa (Dakar: 1987).
Reardon, T. and P. Matlon, "Seasonal food insecurity and vulnerability in drought-affected regions of Burkina Faso" in D. Sahn (ed.) Seasonal Variability in Third World Agriculture: The Consequences for Food Security (Baltimore: Johns Hopkins University Press, 1989).
Reardon, T., C. Delgado, T. Thiombiano. Substitution of Imported for Traditional Cereals in Household Food Consumption in Ouagadougou, Burkina Faso. Forthcoming, IFPRI research report.
Reardon, T., T. Thiombiano, and C. Delgado, "La substitution des céréales locales par les céréales importées: La consommation alimentaire de ménages à Ouagadougou, Burkina Faso," *Serie des Résultats de Recherche, no. 002* (Ouagadougou: CEDRES, University of Ouagadougou, June, 1988).
Rogers, B.L., and M. L. Lowdermilk, "Food prices and food consumption in urban Mali", Final Report of the Tufts/-DNSI/AID Food Price Project (October 1988).
Sautier, D., M. O'Deyé, N. Bricas, and M. O'Deyé, Mil, maïs, sorgho: techniques et alimentation au Sahel, (Paris: Editions L'Harmattan 1989).
Savadogo, K., "An analysis of the economic and sociodemographic determinants of household food consumption in Ouagadougou, Burkina Faso", Ph.D. Thesis, Purdue University, 1986.
Senauer, B., D. Sahn, H. Alderman, "The effect of the value of time on food consumption patterns in developing countries: Evidence from Sri Lanka", American Journal of Agricultural Economics, Vol. 68, No. 4, (November, 1986).
Thiombiano, A., "Modèle socio-économique de comportement alimentaire en milieu urbain", Mémoire de DEA, ESSEC, Université de Ouagadougou, Burkina Faso, February, 1985.
Weber, M.T., J. M. Staatz, J.S. Holtzman, E.W. Crawford, and R.H. Bernsten, "Informing food security decisions in Africa: Empirical analysis and policy dialogue", American Journal of Agricultural Economics, vol. 70, no. 5 (December 1988).

The U.S. grain sorghum carryover/use ratio is forecast at 19.3% for 1990/91, down from the recent high of 100% in the 1986/87 marketing year. The U.S. total feed grains carryover/use ratio is forecast at 18.2% for 1990/91, while the world feed grains carryover/use ratio is projected to remain at last year's level of 15.1%, the lowest since the mid-1970s, with the exception of 1983. This relatively tight level of U.S. and world feed grain supplies is somewhat offset by large U.S. and world wheat supplies. Large wheat supplies and the wheat export subsidy policies of the U.S. and the European Community have eroded the wheat/corn price spread and increased the feeding of wheat in lieu of feed grains.

Figure 3. U.S. Sorghum: Carryover and Use 1979-1991.

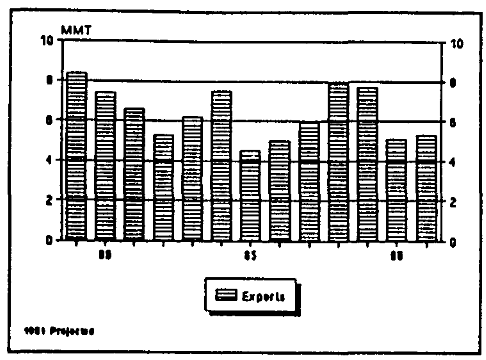


Estimated U.S. planted acreage of grain sorghum for 1991 production is 11.05 million acres (MA), down from the 11.1 MA reported in the March 28 planting intentions, but up 5% from 1990 actual planted acreage of 10.54 MA. While the planting estimates are above 1990 acreages, they should result in only a small increase in ending stocks, assuming a normal crop, if domestic use remains strong and exports in 1991/92 hold near the 1990/91 level.

U.S. grain sorghum exports rose substantially during the last half of the 1980s decade, reaching a high of 7.9 MMT in 1988 and holding steady at 7.7 MMT in 1989. Exports are projected to fall to 5.1 MMT during 1990/91 as the impacts of tighter supplies and the competition from wheat in world markets are felt. The forecast for 1991/92 exports is around 5.3 MMT.

Mexico was an important and growing import market for U.S. grain sorghum during the last decade. In 1989, Mexico was the second largest importer of U.S. grain sorghum. This trend is expected to increase through the 1990s. The much discussed free trade agreement with Mexico could be beneficial for grain sorghum. However, while grain sorghum exports to Mexico could be expected to increase, corn exports may increase relatively more as trade barriers are reduced or eliminated.

Figure 4. U.S. Sorghum: Exports 1979-1991.



Summary

U.S. grain sorghum trade tended to grow in the 1980s, but the pace has slowed considerably in the early 1990s. U.S. production, while trending upward in the 1980s, has increased

Table 1. Planting intentions and acreages (Million Acres).

Commodity	1991 June 27	1991 March 28	Actual 1990	June 27 91 as % of 90
Corn	75.91	76.10	74.17	102%
Sorghum	11.05	11.10	10.54	105%
All Wheat	70.03	69.00	77.29	91%

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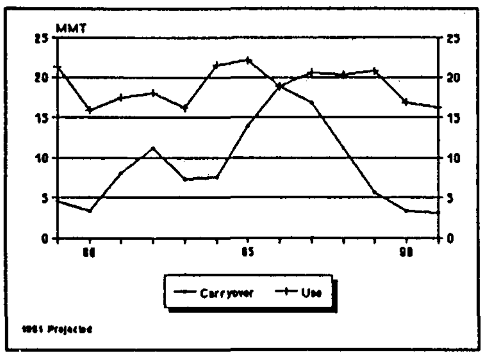

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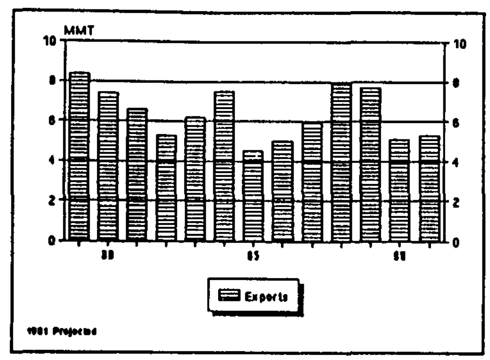

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All Wheat	70.03	69.00	77.29	91%

substantially in variability primarily due to U.S. farm policy shifts and weather variability.

U.S. grain sorghum use has outpaced supply in the last four years, and U.S. ending stocks are down to levels not seen since the beginning of the last decade. Potential growth in demand (in the short run) that may come from the USSR, Eastern Europe and Mexico as a result of their changing political and economic structures may strengthen U.S. grain sorghum exports.

International trade negotiations and domestic policies will be important factors determining the direction of trade in grain sorghum in the 1990s. The current round of GATT may end without agreement to phase out all barriers to free trade. However, it seems clear that the specific rules of grain trade are likely to change in coming years.

INTSORMIL Research Impact

Significant variety/hybrid improvement programs at three of the INTSORMIL institutions (Kansas, Nebraska, Texas) focus on variety improvement for the U.S. as well as the developing world. The economic benefits from public investment in research to develop biotype E greenbug resistant varieties and improved food quality sorghums under the INTSORMIL program were estimated with a multisector simulation model of the U.S. agricultural economy. The model estimates changes in domestic consumer and producer welfare and government program payments, as well as foreign sector impacts. It takes into account the price determination and demand-supply linkages among 63 geographical regions of agricultural production in the U.S., among domestic and foreign demands, among 32 primary farm commodities and 34 agricultural and food processing activities, and among the factor markets.

The model incorporates government program provisions such as target prices, deficiency payments, CCC loans, marketing loans, and generic PIK programs. The price support provisions are given, but the price differentials (or, namely, the deficiency payments) in commodity markets are treated as endogenous since the price paid by consumers (market price) is endogenously determined by the market equilibrium conditions. Set-aside and slippage effects on the participating acres and per acre yields of each program crop are also taken into account.

Study Design

Technology is appraised by setting up different versions of the model for each technological possibility. Simulation results for each technology (and farm program provision) scenario are then compared to evaluate the impacts of technological changes on domestic and foreign consumers and producers. Technology changes were measured as yield changes and chemical cost reductions per acre for greenbug resistant varieties developed from INTSORMIL research versus older nonresistant varieties. Specifically, the average of 1987-89 yields of the newer resistant varieties and the older nonresistant varieties of 1974-76 vintage were determined for each subregion in the Northern Plains and Southern Plains regions using grain sorghum performance tests for Kansas, Nebraska, and Texas locations. Chemical cost reductions for resistant varieties were estimated using insecticide materials and information on the number of applications required for resistant and nonresistant sorghums.

Figure 5. Yield differences of greenbug resistant vs nonresistant sorghum.

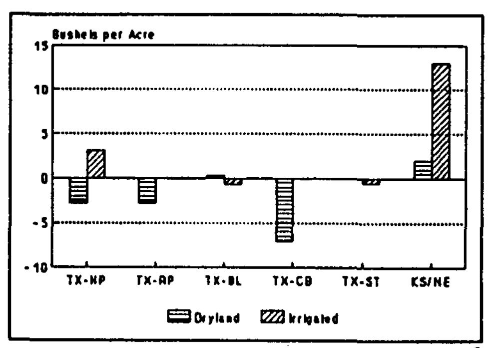
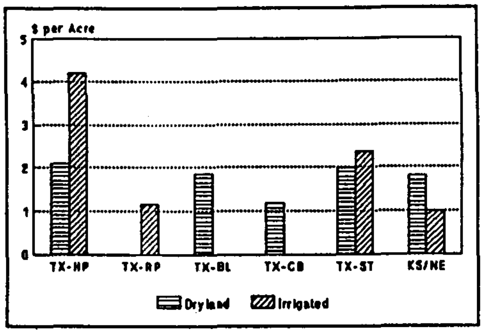
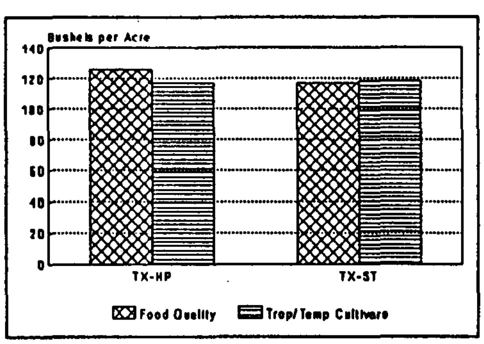


Figure 6. Reduced chemical costs from greenbug resistant sorghums.



Yield data for the food quality varieties indicated that only under irrigation in the Texas High Plains and South Texas regions would these sorghums be expected to compete favorably with other sorghum varieties and irrigated corn or wheat. Hog feeding budgets under current technology use combinations of corn, sorghum, soybean meal, and high protein swine feeds. Sorghum comprises an average 20% of the total ration by volume (weight). Food quality sorghums have shown hog feeding values of 105% relative to red sorghums. A 5% increase in feeding efficiency of food quality sorghum implies an overall 1% increase in hog feeding efficiency.

Figure 7. Yield of irrigated food quality vs other tropical/temperate sorghums.



The effects of the resistant varieties and food quality sorghums were simulated by modifying the sorghum production budgets in the agricultural simulation model by the yield and production cost differences. South Dakota and Oklahoma yields and production costs were assumed to change in the same proportion as in Kansas/Nebraska and Texas, respectively. New production budgets for food quality sorghums were included in the model to compete with red sorghum and other grain crops in the Texas High Plains and South Texas regions. The feed use requirement to produce and finish hogs to the same slaughter weight as under current technology was decreased 1% to reflect the overall increase in feeding efficiency from substituting food quality sorghums for red sorghums. Food quality sorghums also were allowed to substitute pound-for-pound for food corn exports to Mexico.

Economic Benefits from GbE Resistant Sorghums

U.S. producers of sorghum, oats, and rice were primary beneficiaries of the resistant variety improvements ($273 million welfare gain) through the substitution of sorghum for wheat, corn, and barley production in the Great Plains Region and the increased production of rice to replace reduced wheat output. U.S. consumers experienced welfare losses of $248 million through reduced domestic consumption and production use of wheat, corn, and barley. However, lower participation rates for these commodities reduced the quantity going into government programs and rising market prices reduced the level of deficiency payments to farmers. Hence, a $364 million savings to taxpayers in government program costs was fostered by the variety improvements. The $116 million net gain to the consumer-taxpayer plus the $273 million increase in producers welfare result in a $389 million net welfare gain to the U.S. under current farm commodity program provisions. When the impacts on foreign consumers and producers are included, world net welfare gain is $114 million from the resistant sorghums. Additionally, the balance of trade in agricultural commodities for the U.S. is improved by $182 million.

Figure 8. Social benefits from greenbug resistant sorghums with farm programs.

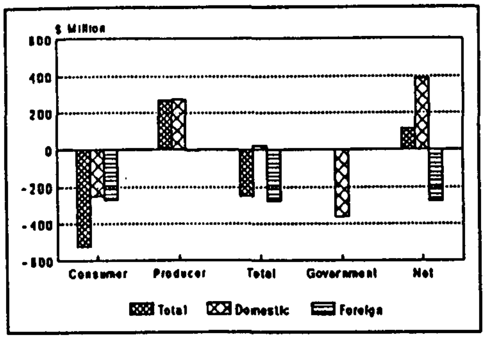
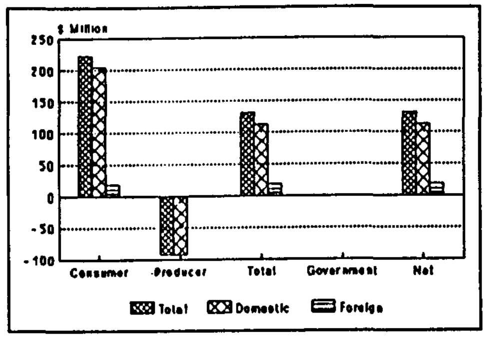


Figure 9. Social benefits from greenbug resistant sorghums without farm programs.



In order to distinguish the farm commodity program effects from the technology effects, simulations were made without any farm commodity programs. Sorghum market price would be 7% (15 cents per bushel) higher without the resistant sorghums. Production would be down 15% (171 million bushels), but harvested acreage would be little changed (up 1%, or 149 thousand acres). The largest impact would be felt in the corn sector whereby harvested acreage would increase by 1.22 million acres, resulting in a 133 million bushel increase in corn production to offset the decline in sorghum output.

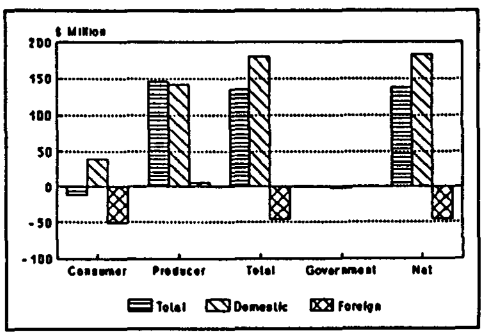
Domestic and foreign consumers would experience total welfare gains of $205 million and $21 million, respectively, from the resistant sorghum technology. Much of the U.S. consumer welfare gain ($158 million) comes from the effects of the technology on processed commodities, principally soybean oil, fluid milk, fed and nonfed beef, and poultry products. U.S. producers would experience a welfare loss amounting to $92 million from the resistant sorghum technology advance, while foreign producers would lose $3 million in welfare. The net social benefit to the U.S. society is $113 million, and world net welfare gain from the resistant sorghums is $131 million. However, the U.S. balance of trade in agricultural commodities would decline by $16 million.

Economic Benefits from Food Quality Sorghums

When budgets for food quality sorghum in the Texas High Plains and South Texas regions are introduced into the model under 1989 farm program provisions, food quality sorghum displaces some of the red sorghum, corn, wheat, oats and silage crop acreage. Total sorghum production (food quality plus red sorghum) increases 21.5% and total sorghum harvested acreage increases 9%. U.S. producers of feed grains, food grains and hogs would be major beneficiaries, experiencing a $141 million increase in welfare. Domestic consumers' welfare would increase $39 million while foreign consumers would experience a $51 million welfare loss. These consumer welfare effects come from the numerous consumption relationships among agricultural commodity markets. Total social benefits to the domestic and foreign sector from the food quality sorghum would be $134 million.

Participation rates in farm commodity programs for red sorghum, corn, wheat and rice would decrease and producers would cut back on production. Lower participation rates would reduce the quantity of production going into government commodity programs, thus reducing the level of deficiency payments to farmers. The $321 million reduction in deficiency and marketing loan payments for these commodities would be nearly offset by a $318 million increase in payments for food quality sorghum, barley and oats. Hence, a $3 million savings to taxpayers in government program costs would result from the technology advance. This gain to taxpayers plus the $180 million welfare gain to U.S. consumers and producers would result in a net U.S. benefit of $183 million from the technology. When the $46 million welfare loss to the foreign sector is included, the world net social benefit from the technology would be $137 million. The U.S. balance of trade in agricultural products would be improved by $10 million.

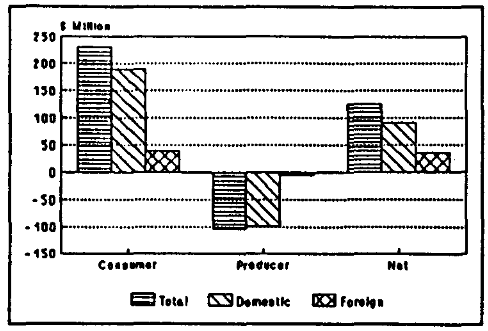
Fig. 10. Social benefits from food quality sorghums under current farm programs.



Without farm commodity programs, sorghum and corn market prices would be 41% (68 cents per bushel) higher than with farm commodity programs. Production and harvested acreage of red sorghum would be down about the same amounts as under the farm program, 220 million bushels and 2,633 thousand acres, respectively. However, red sorghum yields would decrease 6% (3.8 bushels per acre) due to more of the red sorghums being produced on dryland acreage. Production and harvested acreage of corn would be decreased substantially more without farm programs than under the 1989 farm program provisions.

Domestic and foreign consumers would experience welfare gains of $190 million and $40 million, respectively, from the food quality sorghum technology. U.S. and foreign producers would experience a welfare loss of $104 million from the technology, with most of the loss ($99 million) being borne by U.S. producers. Net benefit to the U.S. society would be $91 million from the technology advance. When the $35 million welfare gain to the foreign sector is considered, world net benefit from the technology would be $126 million, and the U.S. balance of trade would be down by $4 million.

Fig. 11. Social benefit from food quality sorghum without farm programs.



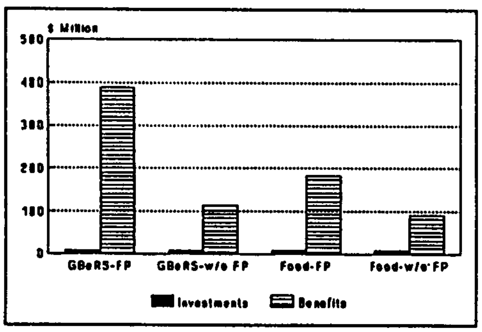
Returns to Research Investment

With farm commodity programs in effect, market prices are distorted from their market equilibrium levels. Thus, the economic benefits to society from technological advances may be substantially biased due to the distortions in market prices. The value that society places on a technological advance may be quite different when market prices are kept at artificially low (or high) levels through government programs than if market forces prevailed in setting commodity prices. Consequently, the rate of return on the research investment to the U.S. society is estimated under conditions of both with 1989 farm commodity programs and without farm programs.

Total funding for INTSORMIL programs including non-federal matching funds for Kansas, Nebraska and Texas over the 1979-1989 period was $21.7 million. Of this total, $14.7 million was used to fund research in sustainable plant protection systems, germplasm enhancement and conservation, and sustainable production systems. INTSORMIL and matching funds for research to develop insect resistant sorghum and insect control strategies was $2.85 million over the 1979-1989 period. Based on each dollar of INTSORMIL and matching funds leveraging three dollars of other funds to support the research, an estimated $8.54 million was invested in the total insect resistant and control research program at the three universities over the 1979-1989 period.

INTSORMIL and matching funds for research to develop tropical adapted sorghum varieties, including the food quality sorghums, amounted to $2.4 million over the 1979-1989 period. Total investment in the hybrid sorghum breeding programs at the three universities was an estimated $7.18 million based on the 3:1 leverage ratio.

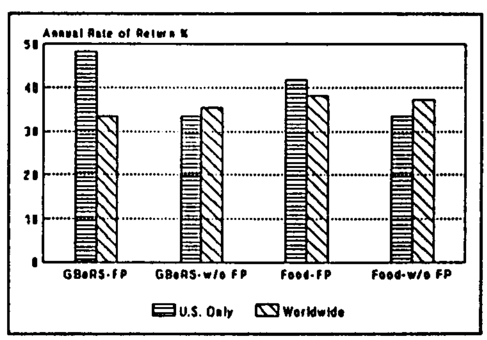
Fig. 12. U.S. research investment and U.S. net benefits from sorghum variety improvements.



Varietal development research cannot be readily turned on and off to influence output and productivity. Production-oriented research in the U.S. typically has its greatest impact on farm level productivity and output 8 to 10 years after the initial investment and is not obsolete on the average until 16 to 20 years after initial investment. This benefit flow pattern has been typical of variety research and development for the past four decades. Research to develop biotype E greenbug resistance in sorghums preceded the initiation of the INTSORMIL program. Because of this previous investment and research activity, a longer lag between initial investment and adoption of the resistant sorghums was used in calculating the rate of return on the research investment. The conditions imposed on the rate of return calculations were that a) consumers' plus producers' surplus without the presence of the farm program provides a measure of the undistorted benefit from the research investment; b) net U.S. benefit is an appropriate measure of research benefits when the interest is in evaluating the separate effects of farm commodity programs and technology advance; c) there is a 10-year lag between initial investment and first adoption of the technology; d) the research investment is maintained at 80% of the level in year 10 for succeeding years in order to offset biological degradation of the new sorghum varieties; e) the technology adoption rate is such that a 20-year period is required for realization of the full benefits of the technology; and f) a 5% inflation rate.

Under these conditions the $8.54 million invested in the resistant sorghum research earns a 33.4% domestic return per year without farm programs. When spillover benefits to foreign consumers and producers are included, the annual return is 35.6%. When the impacts of farm commodity programs are considered, the research investment returns 48.2% annually in the U.S., but only 33.4% annually when foreign spillovers are included. Potential net U.S. benefits from food quality sorghum research would provide a 33.5% annual domestic rate of return on the $7.18 million investment without farm commodity programs, and 37.2% with foreign spillover benefits included. With 1989 farm commodity program provisions, the research investment would earn 41.7% each year in the U.S., but only 38.2% annually with foreign spillovers included.

Fig. 13. Annual rate of return on sorghum variety improvement research investment.



Concluding Comments

The development and adoption of the sorghum varieties have differential benefits depending on the farm program policy setting. Under a continuation of current policy, U.S. producers gain while U.S. consumers lose in welfare as a result of the resistant sorghum technology. However, the decrease in government program costs for other competing commodities under the farm program coverage more than offsets the consumer losses and hence net U.S. social welfare increases substantially. If the farm program is eliminated, an increase in net U.S. social welfare from the resistant sorghum technology is realized, but U.S. producers incur a welfare loss. In contrast, both U.S. producers and consumers would gain from the food quality sorghum technology under a continuation of current farm program policy. However, elimination of the farm program would result in U.S. producer welfare losses from the food quality technology advance.

The sensitivity of the economic benefits arising from government program interventions in commodity markets raises the question of selecting appropriate shadow (undistorted) prices for evaluating the profitability of public investments in agricultural research that are subject to policy distortions. Apparently in the U.S., market prices are significantly distorted for commodities covered under the farm program provisions. Thus returns to investments using these distorted market prices are also distorted. The simulation results where all farm commodity program provisions are eliminated correspond to the concept of an undistorted price based evaluation of the research investment.

Session II: Impact of New Sorghum/Millet Technologies

- The Impact of New Sorghum and Millet Technologies in the Evolving Grain Market of Southern Africa
- Farm Level Potential of Sorghum/Millet Research in Semiarid West Africa
- The Economic Impacts of Hageen Dura-I in the Gezira Scheme, Sudan
- The Impacts of New Sorghum Cultivars and Other Associated Technologies in Honduras

Session Chair: Glenn Johnson

Speakers:
David Rohrbach
Barry I. Shapiro
Mohamed M. Ahmed
Miguel A. López-Pereira

The Impact of New Sorghum and Millet Technologies in the Evolving Grain Market of Southern Africa

David D. Rohrbach[1]

Sorghum and millet are of declining importance through most of the Southern Africa Development and Coordination Conference (SADCC[2]) region of southern Africa. These were principal cereal staples before the onset of the colonial economy at the turn of the century. Thereafter, the spread of mines, mills and publicly controlled grain markets encouraged the rapid expansion of maize. As the urban and industrial demand for maize increased, a framework of grain policies was established favoring the extension of production area and further growth in consumption. By the late 1980's, maize production had extended into regions agroecologically more suited to the production of sorghum and millet. Maize had come to dominate the consumption systems of every SADCC country.

Sorghum and millet currently account for roughly one-quarter of the area planted to coarse grains in southern Africa. While recognized for their relative drought tolerance, or acid soil tolerance in the case of finger millet, sorghum and millet are primarily treated as food security crops. These grains tend to be viewed as of limited importance to the commercial agroeconomy. As a result, they receive little attention in national strategies to develop the agricultural economy. Most policies affecting the production and marketing of sorghum and millet are simple extensions of policies originally defined for maize.

The future of sorghum and millet in the economies of southern Africa remains open to question. But two recent changes offer the prospects for a significant change in the structure of incentives to produce and consume these crops. First, improved technologies are becoming available, particularly improved seed with the promise of large yield gains. Second, grain markets throughout the region are being liberalized. Regulatory controls and trade subsidies favoring maize are being removed. Major investments are still required for the development of sorghum and millet markets. But the small grains should become increasingly competitive, particularly on rural markets within the semiarid regions. In combination, these adjustments should encourage renewed growth in the production and utilization of sorghum and millet.

This paper reviews the competitive position of sorghum and millet in the SADCC economies noting the historical relation between productivity, production and market position. It argues that returns to investments in developing improved technologies can be maximized by targeting technology improvements toward well defined market niches. Grain market reforms currently being implemented in many SADCC countries are changing the structure of these niches. Sorghum and millet will principally remain competitive in rural consumption systems. As productivity gains are achieved, the contribution of these crops as essential sources of food security should increase. Yet in addition, sorghum and millet should improve their competitiveness as specialized inputs for industrial uses such as opaque beer malt and composite flour. A large residual market may ultimately be exploited for low quality grain in the stockfeed industry.

Declining Production Trends

Sorghum and millet are declining components of most coarse grain cropping systems in the SADCC region. Much of this decline occurred early in the century. Available data suggest, however, that during the past three decades production has continued to drop in

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[2] SADCC includes Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, Swaziland, Tanzania, Zambia and Zimbabwe.

seven of nine SADCC countries (Table 1)[3]. In sharp contrast, maize production has increased in eight of these nations.

The gain in the relative importance of maize results from changes in both area planted and yields. Governments and extension services throughout the SADCC region have historically been encouraging the expansion of maize production. Correspondingly, maize plantings have increased while lands allocated to sorghum and millet plantings have remained stagnant or declined. Growth trends in the yields of the alternative grains are more variable. Improved maize technologies have been widely adopted in Swaziland, Tanzania, Zambia and Zimbabwe. Improved technologies for sorghum and millet have generally remained unavailable.

Semiarid regions account for more than one-half of the production area of southern Africa. Yet sorghum and millet now account for only one-quarter of cereal grain plantings (Figure 1). Several SADCC countries with large semiarid regions grow comparatively little of the drought tolerant grains. In Zimbabwe, for example, semiarid regions subject to frequent drought and average annual rainfall levels below 650 mm account for 75 percent of the smallholder farming areas. But two-thirds of the grain production area in these regions is planted to maize. Similarly, two-thirds of Zambia is agro-ecologically suited to sorghum or millet, including the extensive acid soil regions of the north. Yet small grains now account for only 12 percent of total coarse grain plantings in this country.

Partly due to the failure to exploit agro-ecological advantages, per capita imports of cereal grains have sharply increased over the past three decades. Wheat consumption is growing rapidly throughout the SADCC region. Per capita maize imports have increased in all but two SADCC countries. Even in Botswana, where sorghum accounts for over 90 percent of the area planted to grains, the largest share of cereal calories now come from maize. Maize also dominates the Namibian market.

In 1991, every SADCC country except Zimbabwe appears likely to import maize. Grain shortages in Zimbabwe have led to the discontinuation of this country's maize exports. As a result, the region will have to import the yellow maize - a grain widely viewed as inferior and most suited to animal feed. Before the cutoff of exports, Zimbabwe was selling its white maize for more than twice the world market price. Such circumstances simply reinforce national commitments to increase the production and productivity of maize.

The rising costs of food shortfalls in the outlying semiarid areas of each SADCC coun-

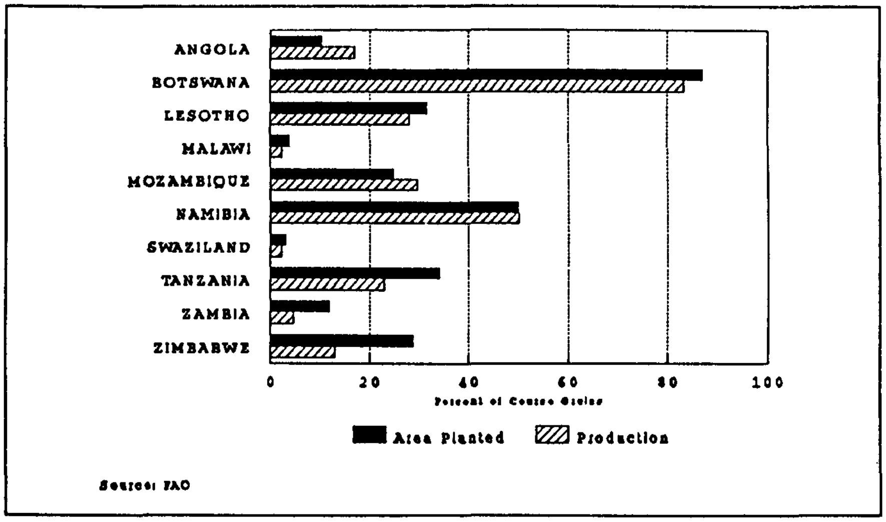
Table 1. Average Annual Growth in Coarse Grain Area, Production and Yield, 1961-65 to 1986-88

	Average Annual Growth in Area Planted		Average Annual Growth in Grain Yield		Average Annual Growth in Grain Production	
	Sorghum and Millet	Maize	Sorghum and Millet	Maize	Sorghum and Millet	Maize
Angola	0.5	2.1	-1.2	-3.9	-0.7	-1.8
Botswana	-0.7	3.6	1.7	-1.4	1.0	2.2
Lesotho	0.2	0.4	-1.6	0.7	-1.4	1.1
Malawi	-2.0	1.4	0.2	0.5	-1.8	1.9
Mozambique	-0.8	1.6	-0.6	-1.4	-1.4	0.2
Swaziland	-8.5	-0.6	2.9	5.0	-5.6	4.4
Tanzania	3.7	2.6	0.2	2.7	3.9	5.3
Zambia	-3.2	-1.3	0.6	3.4	-2.6	2.1
Zimbabwe	0.1	2.1	-0.3	1.4	-0.2	3.5

Sources: FAO (1988a), FAO (1988b).

[3] These data are probably not very accurate. But they do offer a rough sense of production trends. Historical data for Namibia were not available to the author.

Figure 1. Relative importance of sorghum and millet in the coarse grains cropping systems of southern Africa.



try have also increased concern. Governments are searching for ways to reduce the high costs of domestic drought relief programs. In this context, recognition is growing that maize plantings have passed the boundaries of genetic adaptability and that the production of drought tolerant crops should be encouraged. Food security objectives are being extended to encompass the goal of raising small grains production in semiarid regions. Yet the more dominant view of national food security remains tied to the level of aggregate maize supplies.

No country in southern Africa, with the possible exception of Botswana, has a well defined development plan for its semiarid areas. National development policies designed to serve high potential areas are simply extended, with little adjustment, to serve the drought prone regions. Marketing boards are mandated to extend their services into the low rainfall areas. Credit agencies are told not to discriminate in the distribution of their funds. Drought relief programs distribute the same food and inputs throughout the country. Little investment is made in agricultural research relevant to these regions. Extension advice is, correspondingly, largely irrelevant. Poorly defined policies have brought consistent food deficits, dependence on drought relief and reliance on industrially milled maize.

In the midst of these pressures, international banking and donor institutions have demanded the reduction of national budget deficits, the devaluation of exchange rates and the elimination of market controls. Maize subsidies are being withdrawn. Public support for parastatal market facilities in outlying sorghum and millet growing regions is being reduced or eliminated. Most structural adjustment strategies are being driven by the need to resolve national and parastatal budget constraints. Again, there are few positive strategies for the development of semiarid regions.

The reduction of subsidized support for the maize economy will not necessarily improve the competitive position of sorghum and millet. Without productivity gains drawn from improved technologies, the semiarid areas of the SADCC region may be worse off after structural adjustment. These policies may simply reinforce the status of semiarid regions as semi-subsistence economies. Dramatic improvements in average (and minimum) small grains yields are needed to establish a sustainable cropping system capable of generating both food supplies and income adequate to encourage continuing farm investment. Competitive, private market linkages are needed to encourage the movement of surplus grain both to industry and to other farming areas experiencing food deficits.

Competitive Technologies

The historical decline in the competitive position of small grains in the SADCC economies has largely resulted from differences in the relative productivity of these crops. Little improved sorghum or millet technology has been released in the SADCC region. A few hybrids developed for the South African brewing and stockfeed industries have been promoted, on a limited scale in Zimbabwe, Lesotho and Botswana. Improved varieties have been released in several SADCC countries, including Serena and Tegemeo in Tanzania, SV1 and SV2 in Zimbabwe and ZSV1 in Zambia. But few farmers have adopted these cultivars. Most farmers in the SADCC region have little or no access to improved small grains seed. The vast majority of crop area planted to small grains remains in traditional, local varieties.

In contrast, most SADCC countries have strongly encouraged the development and adoption of improved maize. Hybrid seed has been broadly adopted in Zimbabwe, Zambia, Swaziland and Lesotho. Improved varieties have been widely adopted in other SADCC countries. Many of these cultivars have wide adaptability across agroecological zones. Some have proven remarkably hardy under conditions of drought. As a result, improved maize offers higher yields than the traditional varieties of sorghum and millet even in many semiarid zones (Table 2). The widespread assumption that small grains will necessarily perform better than maize is untrue. When rains are favorable, improved maize can perform significantly better than sorghum or millet. In many instances, when rains are poor, improved maize does not perform appreciably worse.

Farmers still view sorghum and millet as essential food security crops. While maize offers higher average yields than sorghum or millet in many drier farming areas, this grain still offers a higher probability of no grain harvest. Most farmers in semiarid regions grow a combination of these crops. Maize is planted in the hope rains will be favorable, sorghum and pearl millet are planted to ensure a limited harvest if rains fail.

Small farmers throughout the SADCC region are well aware of the advantages associated with improved technologies. In Zimbabwe, for example, maize hybrids have been tried by more than 90 percent of all small farmers. These hybrids are consistently purchased and planted by 80 percent of the farmers in the driest regions of the country (Table 3). Many small farmers have expressed interest in improved varieties of hybrids of sorghum and millet, but varieties released by the national research service are not widely available.

Efforts to promote the use of fertilizer, agricultural credit, and to encourage participation in the national grain market have been primarily linked with the maize enterprise. Such development strategies have proven successful in many high rainfall zones - particularly those situated with better access to market infrastructure. The relevance of these technologies and institutions to the low rainfall regions remains limited. Extension workers in these zones are more likely to be familiar with a national recommendations for maize than with the requirements for growing sorghum or mil-

Table 2. SADCC: Average coarse grain yields in semiarid cropping systems (kg/ha).

	Seasonal rainfall	Maize	White sorghum	Red sorghum	Pearl Millet
Ramakwebane[a]	431 mm	1147 kg	526 kg	906 kg	804 kg
Nata[a]	445 mm	1677 kg	1272 kg	1269 kg	879 kg
Semukwe[a]	309 mm	664 kg	629 kg	645 kg	651 kg
Senanga[b]	n.a.	604 kg	408 kg	408 kg	502 kg
Gwembe[c]	n.a.	896 kg	450 kg	450 kg	270 kg
Lowveld[d]	n.a.	766 kg	-	666 kg	-

[a]Zimbabwe 1988/89 cropping season - crop cuts from farmer fields.
[b]Zambia 1988/89 cropping season - extension worker estimates.
[c]Zambia 1989/90 cropping season - extension worker estimates.
[d]Swaziland 81/82 to 83/84 cropping season average - extension worker estimates.

Table 3. Zimbabwe: Participation in the commercial grain poduction economy, 1980's.

Rainfall Zone	Proportion of Households				
	Using improved seed[a]	Applying fertilizer	Receiving credit	Receiving extension advice	Selling grain
High rainfall[b] (800-1000 mm)	94 %	85 %	34 %	53 %	79 %
Medium rainfall[c] (450-800mm)	96 %	19 %	2 %	23 %	46 %
Low rainfall[d] (less than 600 mm)	78 %	3 %	4 %	25 %	34 %

[a]maize seed; [b]Hurungwe, Mangwende, Bushu; [c]Mudzi/Mutoko, Buhera, Chibi, Ramakwebane, Nata; [d]Mazvihwa, Semukwe, Binga.
Source: Rohrbach, Stack, Hedden-Dunkhorst and Govereh (1990).

Table 4. Zimbabwe: Average returns to labor earned in the production of alternative coarse grains in semiarid production systems, 1990.

	Finger Millet	Pearl Millet	Sorghum	Maize
Production Kg/Ha	389	44	635	1273
Labor hours/Ha	530	253	367	332
Labor Hr/Kg	1.36	0.57	0.58	0.26
Official price (Z$/MT)	300	250	225	225
Transport costs (Z$/MT)	27.50	27.50	27.50	27.50
Z$/labor hour	0.20	0.39	0.34	0.76
Local price (Z$/MT)	633	397	319	303
Z$/labor hour	0.46	0.70	0.55	1.16

Source: Rohrbach (1991)

let. Though extension advice may be available, the credibility of this advice is limited. Few farmers produce grain for the commercial market.

The lack of improved technologies for semiarid regions ultimately limits the commercial viability of this agricultural system. Cropping systems in semiarid regions tend to be semi-subsistence in orientation. Incentives to invest scarce labor and cash resources are low (Table 4). Among grain enterprises, maize earns the highest returns to labor. But the returns to labor allocated off the farm are commonly higher than those allocated to the production of any grain for the official market.

In Zimbabwe, for example, the official minimum wage for casual labor is Z$4.50 per day. Institutional minimum wages are much higher. The average returns to sorghum and millet priced at official levels lie less than 70 percent of the wage for casual labor. If grain is priced closer to local, informal market levels available for small transactions from household to household, the returns to labor invested in small grains production approach those available off the farm. But these returns simply justify continuing production for household consumption. Such returns do not justify production for the commercial market.

As a result of low, and highly variable, labor returns, small farmers in semiarid regions are more likely to invest scarce cash resources off the farm than in crop production. Priority is placed on the payment of school fees necessary to get children into urban jobs. Crop production is viewed widely as a semisubsistence activity. Should new technologies become available, farmers are most likely to invest in low cost inputs, such as improved seed, requiring limited labor allocations and offering large labor returns.

Persisting Rural Food Deficits

Semiarid farming systems in southern Africa can generally be classified as food deficit. Virtually all small farm households living in these areas face periodic food deficits. Most consistently purchase a portion of their food grain requirements. Grain must be shipped in from higher rainfall zones. Most commonly, such shipments take the form of industrially milled maize meal. This is virtually all that is available at local retail outlets.

The magnitude of grain supply deficits facing semiarid regions is much larger than is commonly recognized. Governments see the costs of food distributed under drought relief programs. But the quantities of grain distributed under these schemes tend to depend more on the logistical constraints of food distribution and the political pressures to move food into certain communities than the level of need. Following poor rains in 1989, farmers in Mazvihwa, Zimbabwe derived one-half of their 1.2 MT average household grain supply from maize grain distributed through food for work and direct drought relief programs (Table 5). Farmers in three other regions experiencing large production shortfalls received almost nothing. These households, instead, had to purchase their grain supplies.

Grain markets are poorly developed in most semiarid areas of the SADCC region because of historical government controls on national grain trade. Designed to stabilize grain prices and support smallholder incomes, these controls have effectively discouraged the development of private market links. Public sector trade channels extract grain surpluses to feed large industrial grain millers. Households facing deficits are correspondingly forced to rely either on grain distributed through government channels or on meal distributed through the large-scale urban milling industry. Little grain moves directly from surplus to deficit farming regions. In the example of Zimbabwe cited above, the three of four smallholder farming areas with limited access to grain distributed as drought relief purchased at least one-quarter of their consumption requirements in the form of industrially milled maize.

Though aggregate grain production has grown in Zimbabwe in the years since independence, at least a portion of the small farm population has required drought relief in virtually every year since 1980. Following poor harvests in 1990, almost one-quarter of all farm households in Zimbabwe were receiving drought relief (MLARR, 1991). Drought during the 1990/91 cropping season has raised the proportion of households needing relief even further. Recent estimates suggest the driest regions of the country face grain supply deficits equal to between 50 and 80 percent of their consumption requirements.

If the average annual shortfall of grain in Zimbabwe's semiarid regions lies in the range of 20 to 30 percent of consumption requirements, this implies a need for an additional 100,000 to 150,000 Mt of grain. An occasional

Table 5. Zimbabwe: Grain consumption patterns in semiarid regions following drought, 1989 (kg).

Grain	Ramakwebane	Mazvihwa	Nata	Semukwe
Harvested Grain				
Maize	55	329	307	280
White Sorghum	95	17	54	101
Red Sorghum	175	13	131	95
Pearl Millet	314	80	475	173
Finger Millet	0	21	8	4
Drought relief	41	649	0	86
Maize meal purchases	394	19	300	351

Source: SADCC/ICRISAT (various years)

shortfall approaching 75 percent of consumption requirements implies a need for 375,000 MT of grain. The nation's production of sorghum and millet would need to double to meet this requirement. Improving food security has to be a key objective underlying efforts to improve sorghum and millet technologies.

Grain Market Liberalization

During the past few years, most SADCC countries have initiated some form of grain market liberalization. In general, restrictions on who can buy and sell grain are being removed. This should encourage the movement of grain direct from surplus to deficit regions. But the ultimate impact of these changes on sorghum and millet markets and production incentives is unclear.

Sorghum and millet have a premium niche on many rural markets. The prices for small grains on most informal, private markets in the SADCC region are consistently higher than those for maize (Table 6). These also tend to be higher than the prices of industrially milled maize meal. If a household runs short of grain, it is likely to purchase the cheapest source of available grain calories - maize or maize meal. While sorghum and millet represent close substitutes for maize in the production system, these are not close substitutes in the rural grain market.

Sorghum and millet are primarily traded on rural markets as sources of flavoring and malt for traditional beer. Farmers throughout SADCC's semiarid regions tend to retain grain required for their own consumption and only sell their surplus. But small sales are commonly made to meet critical cash requirements. The beer trade, in fact, offers poorer households a means to earn income necessary to purchase cheaper calories in the form of maize meal. The additional profit can be used to meet other household requirements such as school fees. The largest proportion of grain sales by households in Zimbabwe's food deficit regions are in the form of beer (Table 7).

If inter-regional grain trade increases as a result of the removal of movement controls, the largest impact may be on the prices of maize grain. Larger quantities of maize will flow from regions of high productivity (and high rainfall) into regions of grain deficit. This should lower the relative prices of maize grain in comparison with its chief substitute, industrially milled meal. Maize could become a more prominent component of the diets of small grains producers.

The effect of liberalization of small grains markets is less clear. In many regions, the limited and variable levels of small grain trade will not justify investments in building a grain trade market. Such investments will have to be built on the strength and profitability of the maize trade. But once longer distance trade channels are built around the maize trade, the more limited small grains market could significantly expand.

If the productivity of sorghum and millet significantly improve, these relations could sharply change. Higher levels of production will reduce the need for maize imports. Higher

Table 6 SADCC: Informal market prices for alternative grains.

	Finger Millet	Pearl Millet	Sorghum	Maize	Maize Meal
Tanzania 86/7 Tsh/kg					
Producer	17.6	n.a.	9.9	8.3	
Consumer	25.5	n.a.	17.3	10.2	19.6
Zambia 1990/91 K/kg					
Rural Markets	15.5	23.7	10.4	6.8	6.3
Zimbabwe 1990 Z$/kg					
Rural Market	0.6	0.4	0.3	0.3	0.5
Swaziland 1990 E/kg					
Rural Market	-	-	1.0	0.4	0.8
Lesotho 1989 M/kg					
Rural Market	-	-	0.7	0.4	0.8

Sources: MDB (1987a); MDB (1987b); SADCC/ICRISAT (various years)

Table 7. Zimbabwe: Grain sales in food deficit regions, 1988/89.

	Grain sold as grain	Grain sold as beer
Percent of households selling in this market		
Nata	2%	50%
Semukwe	29%	73%
Ramakwebane	9%	48%
Mazvihwa	49%[a]	68%
Percent of grain sold in this market		
Maize	37%	63%
Sorghum	10%	90%
Pearl Millet	17%	83%
Finger Millet	11%	89%

[a]The high proportion of grain sellers in Mazvihwa resulted from the significant flow of maize grain into the area in conjunction with a food for work drought relief program. In effect, Mazvihwa is a grain surplus region.
Source: Hedden-Dunkhorst (1990).

Table 8. SADCC: Official coarse grains selling prices to industry.

	Finger Millet	Pearl Millet	Sorghum	Maize
Tanzania 87/88 Tsh/kg				
NMC Selling	18.1	18.1	18.1	12.2
Zimbabwe 87/88 Z$/MT				
GMB Selling	300	250	239	222
Botswana 1990 US$/MT				
Retail	-	-	426	362

Sources: MDB (1987a); MDB (1987b); AMA (1990); Early Warning Unit (1991).

yields could help reduce market prices to levels competitive with the costs of maize or maize meal imports.

Industrial Demand

Much interest has been expressed in opportunities to exploit the industrial demand for sorghum and millet in the SADCC region. This interest derives from two principal sources. First, several parastatal marketing authorities in the region have built large stocks of sorghum or millet amidst limited commercial demand. During the late 1980's Zimbabwe held sorghum stocks, equal to several years of industry purchases, and millet stocks which were virtually unsalable. At the end of the decade, Botswana held sorghum stocks higher than the average level of domestic grain production. Marketing authorities in Tanzania and Zambia have similarly experienced difficulties disposing of surplus stocks of small grains.

The principal reason small grains stocks have mounted is that official selling prices for sorghum and millet have commonly been set well above those for maize (Table 8). As a result, these grains will only be purchased for uses for which maize is not a close substitute. As in the rural market, this has limited the demand for sorghum to opaque beer flavoring or malt. Since the millets have no specialized industrial uses, these have simply remained in stock. Over time, most of these small grains stocks have been disposed of at significant losses - for prices less than the original cost of purchase. The parastatal marketing authorities have correspondingly encouraged the liberalization of small grains markets as means to reduce their trading account deficits.

The losses incurred by these parastatal authorities could have been reduced if they had chosen to move grain back into rural markets for sale to households experiencing food deficits. But grain marketing parastatals throughout the SADCC region are primarily geared to extracting grain to serve the urban market. Few parastatals move grain direct from surplus to deficit rural markets outside the bounds of specialized, government mandated drought relief programs.

As long as the production productivity of sorghum and millet remain low, the industrial demand for these grains will remain limited. A sense of the magnitude of productivity gains required is evident in assessments of the relative demand for sorghum in the recently liberalized small grain market of Zimbabwe. Large-scale commercial farmers now grow a high yielding brown sorghum hybrid (DC75) on contract for the opaque brewing industry. Commercial hybrid yields average 3.5 MT/Ha. Even with this level of productivity, however, sorghum remains a premium input destined primarily for malt. Maize remains the cheaper source of starch.

The second source of interest in the industrial utilization of small grains lies in their potential to offset requirements for grain imports. Particular interest has been expressed in the use of high quality white sorghum in composite bread flour. The technical feasibility of low levels of substitution (10-20 percent) has been proven, at least on a pilot scale. If sorghum can be supplied at a price cheaper than the true exchange price of wheat, substitution should be economically viable. While the commercial viability of this opportunity needs further testing, the principal constraint to its exploitation appears the lack of a consistent supply of consistently high quality white sorghum grain. Larger-scale commercial farmers will not grow white sorghum either because maize is more productive or because of fear of losses due the birds. The white sorghum commonly marketed by small farmers tends to be lower quality grain. In addition, this tends to be highly variable in size, shape and hardness. As a result, extraction rates are sub-economic.

As markets are liberalized, industry gains the opportunity to contract for grain of the quality desired. The principal opaque brewer in Zimbabwe has done this. Over time, contracting may be initiated by the milling industry. But the costs of managing these contracts and the costs of private grain assembly and transport will limit these contracts to larger farmers located nearer to major processing plants. Most small farmers with lower and more variable production levels will not be able to compete in these markets.

The largest potential source of industrial demand for small grains is the stockfeed industry. This already employs heavily discounted, poor quality grain rejected by the brewers. Again, however, sorghum and millet productivity must remarkably rise for these grains to be competitive with maize. Such productivity implies hybrid grain grown on large commercial plots close to major transport links.

Impact of New Technologies

Efforts to develop and disseminate improved technologies for small grains should be guided by an understanding of the competitive structure of demand for these commodities. New technologies must exploit each crop's production, market and utilization niche. In most SADCC countries, maize will continue to be a chief cereal staple regardless of the productivity gains which might be achieved for sorghum and millet. Maize processing industries and market linkages are well established in the higher rainfall regions of most countries where maize is highly productive. Countries such as Botswana and Namibia which are almost entirely semiarid, will tend to find maize imports cheaper than the cost of domestically produced grains.

Ample scope remains, however, for exploiting the relative drought tolerance and malting power of small grains. Highest priority must be placed on improving the productivity of small grains as basic food security crops. Significant improvements are needed in both minimum and average yields attainable in drought prone regions. Sorghum and millet should ultimately prove significantly more productive than maize in the extensive semiarid areas of the SADCC region. Without these gains, migration to overcrowded urban areas will increase and national food security will worsen.

Both the taste and malting qualities of improved cultivars require consideration. The improved Serena variety retains only a small market in Tanzania because of its bitter taste. In regions of consistent grain deficit, the malting quality of this grain fails to compensate for its poor quality as porridge. A strong premium market already exists for good malting quality grain employed in the rural beer industry. This offers an important source of income for some of the poorest households in the SADCC region.

As governments withdraw parastatal support for sorghum and millet trade, as maize meal subsidies decline and as grain prices are allowed to vary over time, the returns to crop storage should increase. The extended storability of millets, in particular, is a highly favored trait. Storability allows the maintenance of an inter-annual food security stock. More storable grains can also be held in anticipation of favorable market prices.

Secondary priority should be attached to efforts to encourage the commercial production of sorghum and millet for the industrial market. The chief justification for such support, as long as rural food (and beer) supplies remain limited, may be to encourage public and political recognition of the value of these crops. High public priority may be attached to the development of small grains technologies if these are viewed as important industrial crops.

Longer run efforts to exploit the agricultural potential of SADCC's extensive semiarid regions should link commercial production to a demand structure incorporating industrial markets. The opaque brewing industry and bread milling and baking industry represent premium sources of demand requiring particular types of grain. The stockfeed industry represents a much larger residual demand for lower quality output.

Selected References

Agricultural, Technical and Extension Services (1984) "Dryland Crop Budgets, Communal Area Production, 1984/85 Season, Agritex Advisory Notes No. 13/84" Harare (mimeo).

Agricultural Marketing Authority (AMA) (1990) "Grain Situation and Outlook Report" Agricultural Marketing Authority, Harare.

Food and Agriculture Organization of the United Nations (FAO) (1988a) Production Yearbook FAO, Rome.

____________ (1988b) Production Tapes FAO, Rome.

____________ (1988c) Trade Yearbook FAO, Rome.

Hedden-Dunkhorst, Bettina (1990) "The Role of Small Grains in the Semi-Arid Farming Systems of Smallholders in Zimbabwe - Preliminary Findings" Draft 3.

Market Development Bureau (MDB) (1987a) "Annual Review of Sorghum, Millet Cassava and Beans" Ministry of Agriculture and Livestock Development, The United Republic of Tanzania, Dar-es-Salaam.

____________ (1987b) "Annual Review of Maize and Rice" Ministry of Agriculture and Livestock Development, The United Republic of Tanzania, Dar-es-Salaam.

____________ (1990) "Annual Review of Agricultural Marketing 1989/90" Ministry of Agriculture, Livestock Development and Cooperatives, the United Republic of Tanzania, Dar-es-Salaam.

Ministry of Agriculture (1990) "Crop Production Estimates" Government of Zambia, Lusaka (mimeo).

Ministry of Finance and National Commission for Development Planning (1989) "Traditional Crops Promotion Study: Options in the Baking Brewing and Stockfeed Industries" Consultancy Report, Lusaka.

Ministry of Lands, Agriculture and Rural Resettlement (1991) "Monthly Food Security Bulletin Vol 5, No. 5, May 1991" National Early Warning Unit, AGRITEX, MLARR, Government of the Republic of Zimbabwe, Harare.

Ministry of Lands, Agriculture and Rural Resettlement (1989) "First Annual Report of Farm Management Data for Communal Farm Units 1988/89 Farming Season" Farm Management Research Section, MLARR, Government of the Republic of Zimbabwe, Harare.

Rohrbach, David D. (1990) "Small Grain Production, Marketing and Utilization in Zimbabwe" Paper presented at the Small Grains Workshop of the Ministry of Lands, Agriculture and Rural Resettlement, ENDA-Zimbabwe and the Canadian International Development Agency, 5-7 March 1990, Harare.

____________ (1990) "Marketing Constraints and Opportunities for Sorghum and millet in Southern and Eastern Africa" Paper presented at the Seventh Regional Workshop on Sorghum and Millet Improvement in Eastern Africa, 24-28 June 1990, Nairobi.

Rohrbach, David D. and Jayne Stack, Bettina Hedden-Dunkhorst and Jones Govereh (1990) "Agricultural Growth and National Food Security" in T.S. Jayne, M. Rukuni and J.B. Wycoff (eds.) Integrating Food and Nutrition Policy in Zimbabwe: Proceedings of the First Annual Consultative Workshop on Food and Nutrition Policy University of Zimbabwe, Harare.

SADCC/ICRISAT Surveys (various years) refers to survey data collected by the Economics Unit of SADCC/ICRISAT during informal reconnaissance investigations in Zimbabwe, Lesotho, Swaziland, Zambia and Tanzania.

Farm Level Potential of Sorghum/Millet Research in Semi-arid West Africa

Barry I. Shapiro, Ousmane Coulibaly and John H. Sanders[1]

Introduction

In the West African Semi-arid Tropics (WASAT), where sorghum and millet are the predominant cereals, public investment in research is the principle means of obtaining new technologies. This paper first considers evidence of the overall performance of sorghum/millet research in semi-arid West Africa. Then, after reviewing recent trends, the paper assesses the farm-level potential of millet research in one agro-climatic zone with relatively low crop production potential.

Overall trends and shifts in production and consumption have led to pessimism about the impacts of sorghum and millet technologies developed so far and the prospects for future research impacts. Two related questions arise given this gloomy overall picture: first, whether it is worthwhile to invest in sorghum and millet research if production and consumption patterns are so discouraging; secondly, whether research on sorghum and millet will have a farm-level impact in semi-arid West Africa.

A closer look at the regional level and disaggregated data reveals that there have been some technological successes in the three principal cropping regions of semi-arid West Africa. An important innovation in the lower rainfall region of the WASAT has been shorter cycle cultivars of sorghum and millet[2]. These cultivars have been developed as a response to lower rainfall over the last twenty-five years and provide some drought escape. Farmers have been selecting for earliness themselves and requesting shorter cycle cultivars from breeders, who have responded to this demand. Adoption of new cultivars developed by research organizations has begun.

Varietal improvement addresses the effects of low and variable rainfall, but the soil fertility constraint is not addressed. In the long run this would not be a more sustainable system. The potential of a fertilizer technology to be adopted in the lower rainfall zone is the principal concern of the second half of this paper.

The analysis of these technologies is based on empirical evidence from two sites in the Niamey Region of Niger. These sites are located in a lower potential cropping zone for the semi-arid West African region where not only is rainfall lower and more variable, but the sandy soils are low in fertility. Whole-farm models based on actual field work are used to assess the potential of this technology. If technology can be successfully developed for this harsh region, this would provide encouraging evidence that further successes could be achieved in other agro-ecological zones of semi-arid West Africa with higher crop potential.

The paper is organized as follows. First, some overall production and consumption trends are presented. Then, salient features of the brief history of cereal technology development in West Africa are highlighted. Next, some research successes in the higher rainfall regions of semi-arid West Africa are reviewed. Then, the new millet/cowpea technology is evaluated for the two Niamey Region sites in the lower rainfall zone. Finally, the implications of the results for millet/sorghum research potential in the rest of the region are discussed.

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[1] Senior Economist, International Livestock Centre for Africa (ILCA), Addis Ababa, Ethiopia; Graduate Assistant and Professor, Department of Agricultural Economics, Purdue University, West Lafayette, IN 47907.

[2] New shorter cycle cereal cultivars of sorghum and millet that provide some drought escape have been developed for the Sudanian and Sahel-Sudanian Zones.

Production and Consumption Trends and the Impact of Millet/Sorghum Research in West Africa

The overall agricultural production trends for West Africa are discouraging. Per capita production has been declining at an average annual rate of over 1% during the past 30 years (OTA; Jayne, Day and Dregne). A crisis perspective has been popularized regarding the region. At first, the goal was to attract funding for development assistance. More recently the aim has been to gain support for drought relief and food aid programs that are the result of natural disasters and other disasters precipitated by war and mismanagement.

Promoting a crisis perspective has been a faulty strategy, however, since the attention span of the West for disasters, even famine, is short. There is a growing perception that development efforts have not made and cannot make an impact. The conventional wisdom is now that little tangible impact has resulted from the high investment in technical assistance to agriculture in Africa. Development funds may now wind up being diverted from African development to support the transitions of the economies of Eastern Europe.

Shifts in consumption from domestically produced to imported food crops are also taking place. Food imports have been growing faster than population in the eighties, an average annual rate of 3-4%. This food is imported to meet growing demand for rice and wheat, mainly in urban areas (World Bank, 1986; Savadogo). Substitution of imported for domestic cereals has been encouraged by an exchange rate overvaluation in West African countries that share the common currency of the Franc CFA. This overvaluation favors imports at the expense of domestic production by making imports relatively less expensive.

There is also evidence of shifts from sorghum to millet production in drier, more degraded areas of the West African semi-arid tropics (WASAT) and from sorghum to maize in wetter areas such as northern Nigeria (Norman et. al.; Balcet and Candler). In drier areas, as land quality has been deteriorating with the disappearance of fallow, cereal yields have been falling. More stress-tolerant millet is replacing sorghum in the Central Plateau of Burkina Faso and the Niamey and Maradi Regions of Niger (Ames; Swinton and Mamane; Shapiro, 1990). In higher rainfall regions, shifts of crop acreage from sorghum to maize apparently are the result of increasing demand for maize and the availability of improved shorter cycle maize cultivars. Hybrid maize breeding has been very successful in several countries of southern and eastern Africa.[3]

Despite the present disturbing trends in production and consumption, millet and sorghum are likely to remain the dominant food crops in semi-arid West Africa for the foreseeable future. These are the principle crops of at least 70% of the population (Matlon, 1990). Moreover, cereals occupy nearly 70% of total cultivated area, and sorghum and millet cultivation account for about 80 percent of total cereal production (Matlon, 1987).

The policy environment is also changing and this may shift production and consumption patterns in favor of millet and sorghum. Structural adjustment policies remove biases that distort the relative costs to consumers of alternative imported cereals. Hence, the ratio of domestic over imported product prices will shift in favor of domestically produced sorghum and millet. This could slow down the substitution of rice and wheat for millet and sorghum in urban areas of West Africa.

The continuing importance of sorghum and millet in semi-arid West Africa and research successes with other crops in the higher rainfall regions of the WASAT described in Section IV and in other parts of Africa help to justify the continued support of millet and sorghum research. But, the question of whether research on millet and sorghum can have an impact in West Africa still needs to be addressed.

[3] Major successes have occurred in Zimbabwe, Zambia and Kenya. (Karanja).

Brief history of new cereal technology development in the Semi-arid West African Tropics

Substantial efforts to generate new cereal technologies in the WASAT are relatively recent. Most research efforts during and immediately following the colonial period were aimed at the improvement of cash crops such as cotton and peanuts, and more recently maize. In the Sahel, cereal breeding efforts had already begun with the French research organization (IRAT) and were accelerated after 1973 with the increased involvement of the international and national agricultural research agencies. Increased efforts were motivated by the drought of 1968-1973 and the successes of the "Green Revolution" in South Asia.

ICRISAT selection of millet and sorghum began with genetic material from India. The goal was to adapt these exotic varieties to local conditions. Selection based on imported exotics continues, but the emphasis, especially at national research centers such as INRAN in Niger, has shifted to selecting from local millet and sorghum varieties. Recent success has been achieved with improved short cycle cultivars that offer drought escape. Breeding of new cultivars of millet and sorghum, however, has not resulted in substantial introduction on farmers' fields in semi-arid West Africa during the period 1973-86 (Andrews, 1986). Matlon estimates that less than 5% of total sorghum and millet area in the region is presently sown to cultivars from research programs (Matlon, 1990).

Most national research programs in this region are under-financed, understaffed, and inexperienced. In 1986 there were only 11 national scientists involved in sorghum breeding throughout West Africa, with most only educated to the Master of Science degree level (ICRISAT, 1986). International and regional research institutions have only been recently established in the region within the last fifteen years, and in 1986 there were only seven sorghum breeders on their staffs (Matlon, 1990).

The central problem of new cultivar development in Semi-arid West Africa may be that too much has been expected of the breeders. In contrast with other regions of the world where breeding activities have been successful, agriculture in the WASAT takes place under extremely harsh conditions. Rainfall is low and irregular, there are multiple soil fertility problems including very low levels of the two basic nutrients, N and P, and there is minimal purchased input utilization. Asking breeders to resolve all these problems prior to basic improvements in agronomic conditions may be unrealistic. Moderate improvements in the agronomic environment would enable breeders to concentrate on developing cultivars for an improved and less variable environment (Sanders, 1989).

Technology Successes in Different Agroclimatic Zones

Table 1 outlines some technologies successfully introduced into the three principal agroclimatic regions in the West African Semi-Arid Tropics (WASAT)[4]. The introduction of new cotton cultivars with improved agronomy has been combined with increasing levels of chemical fertilizer. Moderately high levels of chemical fertilizer are now utilized on both the cotton and the major cereals, maize and sorghum (Coulibaly). In the Sudano-Guinean zone, water availability is not constraining in most years and introduction of new cultivars and chemical fertilizers has been rapid.

In the Sudanian and Sahelo-Sudanian regions of Burkina Faso, dikes to contain runoff have been rapidly introduced in the last five years (Sanders, et al., 1987). The construction of stone dikes is also proceeding rapidly in the Tahoua Region of Niger. The dikes slow down the runoff of soil and water and accumulate soil from higher up on the toposequence. This water retention is generally accompanied by organic fertilizer application (Wright). Higher-value crops are planted here.

The common basis of the successes of yield increasing crop technologies in the higher rainfall regions is that they entail strate-

[4] These three agroclimatic zones are defined following the World Bank convention of 90% rainfall probability isohytes. Besides rainfall, they also differ in soil characteristics and therefore require specific technology strategies (Gorse and Steeds).

Table 1. Technologies successfully introduced in the three principal agro-ecological regions for crop production of the Sahel.

Zones	Technologies	Responses to principal constraints: Water availability	Responses to principal constraints: Soil fertility
Sudano-Guinean	New cotton cultivars with chemical fertilizer and improved agronomic practices.	Sufficient rainfall in most years in this zone.	Fertilizers utilized in the combined-technology package.
Sudanian	Contour dikes and organic fertilizer Early cereal and cowpea cultivars	Holds the runoff water. Earliness gives drought escape.	Organic fertilizer. Selected for low soil-fertility conditions.
Sahelo-Sudanian	Supplementary irrigation[a] Early cereal and cowpea cultivars. Contour dikes and organic fertilizers.	Full water control. Drought escape with earliness. Holds the runoff.	Rice heavily fertilized. Selected for low soil-fertility conditions. Organic fertilizers.

Source: Adapted from Sanders, 1991.

[a]Only small areas of supplementary irrigation (< 1 ha) provided by government to farmers: are a type of income stabilization for dryland farmers.

gies to simultaneously address what appear to be the critical production constraints to new cultivar adoption in semi-arid West Africa; water availability and soil fertility. The following sections evaluate new technologies that address these constraints for the most difficult zone in the Sahel for crop production.

Technology Impact in the Sahelo-Sudanian Zone

Moving north from the higher rainfall regions towards the Sahara Desert into the Sahelo-Sudanian Zone, the level of rainfall decreases and its variability increases. The soils are mainly sandy and low in fertility. Both factors make the introduction of new technologies more difficult.

Adoption of higher planting densities in better rainfall years and improved shorter cycle cultivars in worse years is beginning to take place in this region. Drought escape in adverse rainfall years can be achieved with varietal improvement. This is an effective intermediate strategy, but without fertilizer will not lead in the long run to a more sustainable production system.

The soils of the Sahelo-Sudanian Zone are mostly sandy dune, unlike much of the Sudanian region where the clay content is higher. Crusting is less of a problem and water infiltration is not a constraint. However, due to the lower and more variable rainfall and the sandy, porous soils, maintaining water available in the soil for plants is still a major problem. These soils are also highly weathered and low in organic matter and natural fertility. Thus, nutrient and water reserves available to plants in these soils are low.

One strategy proposed for these sandy soils is the use of moderate levels of fertilizer and higher planting densities in better rainfall years to simultaneously address the soil and water constraints. Agronomic trials carried out by ICRISAT and INRAN scientists demonstrate that improving soil fertility increases the water use efficiency of plants (Fussell and Serifini; ICRISAT, 1985:42; ICRISAT, 1986:41: ICRISAT, 1987:72; Reddy, 1985, 1986, 1987)[5]. The moderate use of fertilizer would be combined with the higher planting densities and improved shorter cycle varieties.

The moderate use of fertilizer with higher planting densities in better rainfall years improves the response to fertilizer, increasing the effectiveness of the new cereal cultivars and results in a more sustainable system. The specific crop technology option considered for the Niamey Region that addresses these constraints includes improved shorter cycle cultivars of millet and cowpeas, improved cowpea planting density and geometry, and moderate phosphorus and nitrogen fertilizer use. It was developed and field tested in the region by

[5] The physiological mechanism at work here is not entirely understood. Apparently the increased plant matter and root density enable uptake and use of more of the available water. The increased organic material would also be expected to slow the passage of the rainfall through the soil, increasing the water available and used by the plants.

INRAN, ICRISAT, IFDC, and FAO. The remainder of the paper discusses the potential for the introduction of this technology at the two research sites.

Adoption Potential of New Millet Technologies at Libore

The research sites in the Niamey Region are characteristic of land shortage and land surplus systems. Millet/cowpea intercrop predominates on rainfed fields in both systems. At the site along the Niger River at Libore, farmers follow variations of a dual rainfed/irrigated system[6]. Libore is also close to the large urban market of Niamey, the capital of Niger. Average rainfall is 570 mm. and population density is high for Niger, causing land availability to be limited relative to labor. Average rainfed farm size is only about 3.5 hectares. Intensification of irrigated activities has taken place, but not of rainfed activities. Since farm households in this area only have a small area under supplemental irrigation (0.4 hectares), increasing rainfed cereal production is an important goal for these farmers.

At Libore, climatological, resource, and socioeconomic conditions appear to be conducive to the introduction of more intensive production practices. Under current low cash input rainfed practices, with increasing population density and poor rainfall in recent years, land quality has been declining as existing holdings are fallowed less and more marginal land is brought into production (Painter, 1986; Raynaut; Scott-Wendt, 1989; INRAN, unpublished data). As yields decline and the land supply becomes more limited, the potential returns to more intensive production practices increases.

Shorter cycle varieties, in general, do not raise farmer incomes very much in this harsh environment. The strategy for breeding for earliness was introduced to reduce the risk from short seasons and irregular rainfalls.

According to the model results (see Table 2, Option No. 2), the adoption of the early varieties with higher cowpea planting density occurs since this substantially increases rainfed crop income over present practices. Expected rainfed crop income increases by 30%, from $446 under traditional practices to $577. The increase in total income is 13% due to the adoption of the improved cultivars and higher densities. The introduction of improved cultivars and agronomy (without fertilizer) has no effect on overall income variability, but lowers the variability of cash income from rainfed crop production by 13%[7]. The shorter cycle cultivars provide some drought escape through earliness and thus make rainfed crop production more stable in lower rainfall years, enabling more sales. These results are consistent with the observed diffusion at this site.

The observed diffusion of the improved cultivars has been slower than that expected based on these model results. The model results show that they would be adopted in all

Table 2. Effect of various policy instruments on adoption of fertilizer-Libore, Niamey Region, Niger.

Policy or Program	Fertilizer use (ha.)	Millet/Cowpea income (US$)	Total seasonal income (US$)	% Change crop income	% Change total income	C.V. Total income (%)
1. Current practices	n.a.	446	812	-	-	40
2. Improved cultivars	0	578	921	+30	+13	39
3. Input subsidy (10%)	1.2	602	922	+35	+14	41
4. Credit program (10,000 FCFA at 0% interest)	0	576	942	+29	+16	39
5. Phosphorus only	2.1	628	948	+41	+17	44
6. Long cycle millet variety	1.5	624	944	+40	+16	42

Exchange rate = 299 FCFA/US. $1 (IMF, 1989).
Source: Shapiro, 1990, Model results.

[6] Along the Niger River the production system includes some irrigated acreage besides the predominant rainfed activities. Farmers in this dual irrigated/rainfed system intercrop millet and cowpeas during the rainy season and raise irrigated rice during both the rainy and dry seasons.

[7] In utilizing the coefficient of variation (CV) as a measure of risk, skewness is not taken into consideration. The CV only includes the first two moments. However, short cycle varieties increase yields in low rainfall years, thus cutting off some of the lower tail of the income distribution.

types of rainfall conditions, but farmers have only used them in worse years when the rains have arrived late and their own varieties have not established well.

The earliness characteristic makes the new cultivars produce better in low rainfall years, but unable physiologically to take full advantage of normal or longer rainfall seasons. Early millet cultivars also often experience a higher incidence of head girdler ("ragouva") infestation than the traditional longer season cultivars. Since farmers choose a portfolio of cultivars and crops, research institutions may also need to make available varieties with different length of maturity.

In the model results, the new cultivar introduction is not combined with fertilizer, even in higher rainfall years when the response to fertilizer should be the highest. Fertilizer use is not more profitable than the alternative investment in small ruminants. Cash and labor were not found to be constraints to the adoption of fertilizer. Sensitivity analysis that involved making more cash available in a model run resulted in more livestock being purchased after the adoption of improved cultivars, rather than fertilizer being purchased.[8,9]

Interventions to Encourage Fertilizer Use

It is worthwhile to consider ways in which fertilizer introduction could be facilitated, since the adoption of the improved agronomy and shorter cycle cultivars alone may not provide a large enough income increase that farmers will notice. Adoption of improved cultivars also does not create a more sustainable cropping system, without the addition of fertilizer. Thus, the government may want to intervene to improve soil fertility and increase longrun sustainability. Fertilizer can raise rainfed crop income and create a more sustainable system by preventing the mining of soil nutrients[10]. Hence, in the following modeling alternatives policy changes and further technology development are evaluated for their potential impact on the utilization of fertilizer by farmers.

Policy Interventions

Relevant policy interventions that could be taken to encourage fertilizer use on rainfed fields include an input subsidy on fertilizer, a credit program that enables the purchase of fertilizer at a subsidized interest rate, and an output price support (Table 2)[11].

A subsidy on fertilizer use has been successfully employed with cash crops to encourage adoption in Niger and in other regions of the Sahel. The cost of Simple Superphosphate (SSP, the recommended source of P_2O_5) was 50 FCFA per kilogram in Niger in 1988. Placing a 10% subsidy on SSP results in fertilizer adoption on 1.2 hectares of rainfed fields. Rainfed crop income increases by 5% over that due to the introduction of the improved varieties alone (see Policy No.3 in Table 2).

Shortcomings of this strategy should be noted. First, the World Bank has been encouraging Sahelian governments in recent years to remove subsidies on fertilizer to avoid biased technological change and decrease the burden on national treasuries. Another disadvantage is that an effective means of limiting the use of the subsidized fertilizer to rainfed food crops would be required. It would be difficult to prevent farmers from using the subsidized fertilizer on their irrigated rice, which is much more profitable and lower in risk.

Credit is also often mentioned as an instrument to encourage farmers to purchase cash inputs, or to engage hired labor to overcome a shortage of family labor necessitated by the adoption of the new technologies (Krause et al.). Providing 10,000 FCFA even at zero interest results in no fertilizer adoption and no increase in rainfed crop income over the intro-

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[8] The empirical evidence provided by anthropologists who have studied at the farm level in Niger indicates that cash and labor are not the principal constrains to adoption of new technologies (Sutter, 1979, 1984; Painter, 1984).

[9] This result is in contrast to the previous studies of Krause et. al. (1990) and Adesina that found cash to be a constraint to the adoption of fertilizer in the Maradi Region of Niger.

[10] Current crop production practices provide the first benchmark against which the new rainfed technologies would be compared by farmers. When the new technologies are compared to the current activities available to the farm household, without the option to invest in livestock, the fertilizer technology is shown to be adopted since it meets the objectives of the household better than current rainfed crop practices. (Adesina; Krause et. al.)

[11] Sanders has suggested a price support of 50 FCFA to guard against price collapse (Sanders, 1989; Adesina and Sanders). The probability of the price going below 50 FCFA this close to the urban market of Niamey is effectively zero.

duction of improved cultivars. Livestock is more profitable, so more is purchased and the income from raising small ruminants increases by 25% with this increased credit (see Policy No. 4 in Table 3).

Modifying the Adoption Strategy - P Fertilizer Only

Farmers at the INRAN research site along the Niger River are observed to be adopting improved agronomy (higher planting density and better geometry) and shorter cycle cultivars without fertilizer. A next step might involve promoting the use of phosphorus fertilizer only, without nitrogen, in combination with the improved agronomy and short cycle cultivars. This modification of fertilizer technology based on the observed behavior of farmers could be an intermediate step in getting farmers to adopt the combined fertilizers (Jomini)[12].

When the phosphorus only option is added to the activity choices, the model results show P fertilizer being applied to 2.1 hectares before planting. The application of P fertilizer alone raises total rainfed crop income during the season by 41% over current practices and 11% over the adoption of improved cultivars alone (Table 2, No. 5)[13]. The use of P fertilizer alone is more profitable than raising small ruminants and replaces investment in this activity.[14]

The phosphorus only fertilizer strategy would appear to have considerable potential as an intermediate step towards achieving a more profitable and sustainable production system. Since cereals require nitrogen and there is little nitrogen or organic matter in these sandy dune soils, caution has to be taken to ensure that farmers understand this to be an intermediate technology and begin soon to use nitrogen fertilizer. Without nitrogen fertilizer, yields will decline after a few years. Although the model results show potential for phosphorus fertilizer use, this potential is not shown in better rainfall years when greater rainfall should make complete fertilizer use including N most effective.

Further Investment in Breeding Long Cycle Cultivars

Short season varieties are not able to take advantage of those years with a longer rainy season. The principle advantage of short season cultivars is their drought escape mechanism (by maturing early). In longer seasons, the grain quality of the early maturing varieties is often adversely affected when the rains continue during the grain filling stage of plant growth. Furthermore, short cycle varieties are often attacked by disease at the beginning of the season when the rains start early and are attacked by birds later in the season since they are the first crops to mature.

Long cycle varieties have the potential to yield more since they remain longer in the field and can grow more. If improved longer cycle cultivars were available, fertilization would be encouraged in better rainfall years. The potential effect on fertilizer use and income of having a mix of cultivars including longer cycle or full season varieties was tested by adding such a fertilizer/long season cultivar activity to the activity choices in the farm model. The conservative assumption was made that the yields of improved longer cycle varieties used in combination with fertilizer are 20% higher than with shorter cycle cultivars in normal and better states of nature.[15]

The fertilizer/long season cultivar option is adopted on 1.5 hectares before planting and results in 40% more rainfed crop income than that achieved with present practices (Table 2, Number 6). Rainfed crop income is 8% higher than income from adoption of shorter cycle varieties alone. The increase in total seasonal income is 16% over current practices and 3% higher than total seasonal income due to improved early cultivars alone. This is a very

[12]INRAN has started on-farm testing of the preplant application of phosphorus, without later nitrogen application since 1987.

[13]Since there are only two years of on-farm results for this strategy, the assumption is made that a comparable relative level of yields can be obtained in other types of rainfall years.

[14]The increase in income variability is not substantial. Furthermore, the carry over effect into the next year associated with phosphorus use limits the financial risk. Thus, risk aversion as a constraint was not evaluated with the modelling, but may be a factor in this adoption decision, as suggested by analysis done in the Maradi Region of Niger (Adesina et. al.; Krause et. al.).

[15]This assumed yield increase with improved longer cycle cultivars is quite conservative given that the yield increase with improved shorter cycle cultivars in better rainfall years is about 100% in farmer managed, on-farm trials.

encouraging result indicating the returns to breeding a longer cycle cultivar and the potential from this cultivar development to encourage more fertilization.

Adoption of Potential New Millet Technologies at Kouka

At Kouka where cereal crop production is purely rainfed, average rainfall is only 430 mm. In such areas away from the Niger River, population density is also lower. Land is therefore more available relative to labor, in contrast to the other site along the river, and rainfed crop production practices are consequently more extensive. Cultivated area varies from 9 to 14 hectares depending on the amount of seasonal rainfall. Herd sizes of small ruminants are also larger since more land is available for grazing.

The overall income effects from the introduction of the improved agronomy and varieties into this system is an increase of 20% (see Table 3). Use of the improved agronomy and varieties results in expected crop income of $US 409, an increase of 36% over current practices. Per capita income from all sources is $US 70 and $US 48 from crop production.

Adopting the improved agronomy and varieties lowers overall income variability from a cv of 63% to 50%. Improved shorter cycle varieties have been bred to increase yields in adverse rainfall years. The variability of crop income decreases from 49% to 39%, due to the stabilizing effect of the improved shorter cycle varieties on yields in poorer rainfall years.

The use of the improved agronomy and varieties enables these farmers to adjust to difficult climatic conditions, and results in higher income. Presently, farmers in areas such as Kouka are asking for improved shorter cycle varieties and are beginning to use them.

Interventions to Encourage Fertilizer Use

Since the adoption of the new cultivars alone is not a more sustainable system than presently exists, the government may choose to intervene to encourage fertilizer use. As in the case of Libore, this could be done by subsidizing credit or the fertilizer, or by supporting output prices (Table 3). However, under no feasible model scenarios of reasonable policy changes or variations in technical parameters, do the results show potential for chemical fertilizer to be adopted.

For land abundant, lower rainfall areas such as Kouka, intensifying the cropping system will be more difficult except for the introduction of new cultivars. Even with the introduction of improved agronomy and shorter cycle cultivars, the usefulness of the present extensification strategy followed by these farmers is still evident. This involves increasing the area planted to try to maintain production when rainfall is lower and the type of production year expected is worse.

Improvement of Livestock Activities

Improving livestock production and marketing in low rainfall, land extensive areas such as Kouka may be a more effective way to increase farmers' incomes. Developing more marketing opportunities and better availability

Table 3. Effect of various policy instruments on the adoption of fertilizer - Kouka, Niamey Region, Niger.

Policy or program	Fertilizer use (ha.)	Millet/Cowpea income (US$)	Livestock income (US$)	Total income (US$)	% Change crop income	% Change total income	C.V. total income
1. Current practices	n.a.	301	186	503	-	-	.63
2. Improved cultivars	0	409	177	601	+36	+20	.50
3. Price support (50 FCFA)	0	430	177	622	+43	+24	.57
4. Credit program (10,000 FCFA at 0% interest)	0	409	197	621	+36	+23	.50
5. Input subsidy (50%)	0	409	230	653	+36	+30	.54
6. Adaptive livestock choices	0	409	230	653	+36	+30	.54

Exchange rate = 298 FCFA/U.S. $1.
Source: Shapiro, 1990, model results.

of price information would be two such innovations. These innovations would increase the flexibility in the timing of livestock sales, making more sales possible after the rains start. Thus, better adaptive responses to rainfall conditions at the beginning of the season could be made, resulting in increased profitability from livestock activities.[16]

Adding activities to the model that represent the ability to sell livestock and buy livestock or fertilizer after the rains begin results in more investment in livestock. Livestock income is 24% higher than under current production practices with the addition of this activity (Table 3, Option 6). This adaptive livestock strategy does not displace the use of improved varieties, but increases income above that possible only through the introduction of improved varieties.

Comparison of Rainfed Crop Income at the Two Sites

The income from rainfed crop production at Kouka is only 71% of that at Libore. This is so even though only 3.5 rainfed hectares is cultivated at Libore, while from 8.8 to 13.5 hectares (depending on rainfall conditions) is cultivated at Kouka. The difference in rainfed crop incomes between the two regions can, therefore, be related to returns per hectare. Table 4 compares expected net returns per hectare with the different technologies being evaluated for the two systems. Expected gross margins or net returns per hectare under current practices are two times as high at Libore as at Kouka (US$57, as opposed to US$115, respectively).

The difference in returns per hectare under present practices can be explained mainly by yield and price differences since use of cash inputs other than hired labor is currently negligible in rainfed crop activities in the two systems and the use of hired labor is almost the same on a per hectare basis. Under current low input practices, higher yields at Libore would be related to higher rainfall since the soil fertility is even lower than that found at Kouka. Higher prices would be related to closer proximity to the major urban market which strengthens demand for agricultural products. Decomposing the revenue difference per hectare into yield and price effects shows that 60% of the difference is due to higher yields and 31% is due to higher prices at Libore (the rest is due to price-yield interaction).

The income gap between the two regions is widened through the introduction of the new technologies. Due to lower rainfall, the new

Table 4. Comparison of expected net returns under different technologies at Libore and Kouka, Niamey Region, Niger.

	Libore	Kouka	Ratio of net returns per ha.
	----- ($US/ha) -----		
Current practices:			
Millet/Cowpea Intercrop	115	57	2.02
Improved cultivars (Low density)	129	68	1.97
Improved cultivars (High density)	147	69	2.14
Improved Millet/Cowpea w/fert.	175	76	2.30

[16]Sutter has shown that presently farmers mainly make sales and purchases of livestock before the onset of the rains that mark the start of the crop season (Sutter).

technologies would not be expected to perform better at Kouka and this is borne out by the decomposition of the revenue differences with the introduction of the fertilizer technology. The gap in net returns per hectare widens with the introduction of the fertilizer technology and would be 2.3 times higher at Libore. The difference in gross revenue per hectare is 57% due to yield differences and 38% due to price differences. These results substantiate the conclusion that there is much less potential for improving farmer incomes in areas such as Kouka through an intensification of crop production.

Conclusions

Although overall cereal production and consumption trends for West Africa are discouraging, a closer look at the regional level dispels some of the gloom and doom. Past failures, and successes in the higher rainfall zones of the WASAT helps to identify the critical production constraints and a strategy for overcoming them. This paper evaluated the potential of a technology that embodies such a strategy for the Sahelo-Sudanian agroclimatic zone, a cropping zone with lower, more variable rainfall than in much of the region and sandy soils low in fertility.

Even in this harsh environment there is potential for improving crop production where rainfall is sufficient, and resource availability and markets are conducive to an intensification of the crop production system. If new technologies that simultaneously address the dual production constraints can be successful in the Sahelo-Sudanian Zone, research on technologies that incorporate such strategies would be expected to bring about new cereal technology diffusion in less difficult areas of the WASAT. It may be too soon to be overly critical of research efforts made so far in semi-arid West Africa. Efforts to generate new cereal technologies in the WASAT are relatively recent.

Two questions were posed in this paper that are relevant to the support of sorghum and millet research in West Africa. The first question asked whether it is worthwhile to continue to invest in research to improve cereal technologies if production and consumption patterns are changing. The continuing importance of sorghum and millet in semi-arid West Africa and research successes in the higher rainfall zones of semi-arid West Africa help to justify the continued support of cereal research.

The second question was whether research on millet and sorghum can have an impact in West Africa. These model results from the more difficult major crop production zone indicate that millet technologies can make an impact in semi-arid West Africa. Improved short cycle millet and cowpea cultivars combined with better agronomy and moderate levels of fertilizer is a technology combination useful in overcoming water availability and soil fertility constraints in the Sahelo-Sudanian Zone.

The lack of a more profitable fertilizer technology that includes both nitrogen and phosphorus, relative to the alternative investments in small ruminants, helps to explain the present lack of intensification on rainfed fields in areas such as Libore. At this time only early or short-season improved cultivars are available to be combined with fertilizer use. These cultivars are not able to take advantage of those years with a longer rainy season to produce higher yields through greater fertilizer response. If normal or late-season improved cultivars had also been in the crop mix, the model solutions include them with fertilization when the rains are early. Since farmers choose a portfolio of cultivars and crops, research institutions need to make available varieties with different length of maturity.

For land abundant, lower rainfall areas such as Kouka, efforts to intensify the cropping system to make it more sustainable are unlikely to be successful. Under no realistic yield assumptions or feasible policy alternative would farmers adopt fertilization in this region according to the modeling. Alternative strategies to improve incomes in this harsher environment will need to be found or out-migration encouraged. Improved livestock activities could be integrated with low cash input crop production systems. However, it may be better to withdraw some areas from food production and encourage improved pasture and forestry. Migration of most men is already occurring seasonally.

Technology development is an excellent tool for raising farm income. It is notable that even in the harsh rainfed conditions at Libore new early cultivars were being introduced and chemical fertilizer showed potential for raising incomes. It is not surprising that technology development does not appear to be an efficient instrument for the regions with lower rainfall and fewer resources. Technology development needs to be used as a selective instrument in those regions where successes are more feasible technically and economically.

Bibliography

Adesina, Akinwumi A. Farmer Behavior and New Agricultural Technologies in the Rainfed Agriculture of Southern Niger: A Stochastic Programming Analysis, Unpublished Ph.D. Dissertation, Dept. of Agricultural Economics, Purdue University, West Lafayette, IN, 1988.

Adesina, A.A., P.C. Abbott, and J.H. Sanders, "Ex-ante Risk Programming Appraisal of New Agricultural Technology: Experiment Station Fertilizer Recommendations in Southern Niger," Agricultural Systems 27: 23-34, 1988.

Adesina, A.A. and J.H. Sanders, "Peasant Farmer Behavior and Cereal Technologies: Stochastic Programming in Niger," Agricultural Economics, 5:21-38, 1991.

Ames, L. "A Preliminary Report on the Evaluation of New Technologies in Burkina Faso," Department of Agricultural Economics, Purdue University, West Lafayette, IN (mimeo) 30 pages, 1986.

Andrews, D.J. "Current Results and Prospects in Sorghum and Pearl Millet Breeding," in Sixth Agricultural Sector Symposium: Development of Rainfed Agriculture under Arid and Semi-Arid Conditions, ed. T.J. Davis, World Bank, Washington, D.C., 1986.

Balcet, Jean-Claude and Wilfred Candler, "Farm Technology Adoption in Northern Nigeria," Dept. of West African Projects, Agricultural Division 1 (WAPAI), The World Bank, 1982.

Batiano, Andre, IFDC/Niger Annual Report - 1987 (Draft), Niamey, Niger, 1988.

Batiano, A., U.A. Mokwunye and C.A. Baanante, "Agronomic and Economic Evaluation of Alternative Phosphate Fertilizer Sources in Niger," Paper presented at the SAFGRAD/FSU Workshop on Technologies Appropriate for Farmers in Semi-Arid West Africa, Ouagadougou, Burkina Faso, April 1-5, 1985.

Clough, Paul, "Farmers and Traders in Hausaland," Development and change, 12: 273-292, 1981.

Cocks, K.D., "Discrete Stochastic Programming," Management Science, 15(1): 72-79, 1968.

Collion, M.J., Colonial Rule and Changing Peasant Economy in Damagherim. Niger Republic, unpublished Ph.D. Thesis, Dept. of City and Regional Planning, Cornell University, 1982.

Coulibaly, O.N., "Factors Affecting Adoption of Agricultural Technologies by Small Farmers in Sub-Saharan Africa: The Case of New Varieties of Cowpeas around the Agricultural Research Station of Cinzana, Mali," M.S. thesis, Michigan State University, 1987.

Fussell, L.K. and P.G. Serafini, "Crop Associations in the Semi-arid Tropics of West Africa: Research Strategies Past and Future," in H.W. Ohm and J.G. Nagy, editors, Appropriate Technologies for Farmers in Semi-Arid West Africa, Purdue University, West Lafayette, Indiana 1985.

Gorse, J. E. and D.R. Steeds. Desertification in the Sahelian and Sudanian Zones of West Africa, World Bank Technical Paper No. 61, Washington, D. C. 1987.

Institut National de Recherches Agronomiques du Niger, Departemente d'Economie Rural (INRAN/DECOR), unpublished adoption survey, Niamey, Niger, 1987.

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), ICRISAT Sahelian Center Annual Report. 1984, Niamey, Niger, 1985.

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), ICRISAT Sahelian Center Annual Report. 1985, Niamey, Niger, 1986.

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), ICRISAT Sahelian Center Annual Report. 1986, Niamey, Niger, 1987.

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), ICRISAT Sahelian Center Annual Report. 1987, Niamey, Niger, 1988.

International Institute of Tropical Agriculture (IITA), IITA Annual Report and Research Highlights, Ibadan, 1987.

International Monetary Fund, International Financial Statistics, 1989.

Jayne, Thomas S., John C. Day, and Harold E. Dregne, Technology and Agricultural Productivity in the Sahel, Agricultural Economics Report Number 612, Economic Research Service, U.S. Dept. of Agriculture, 1989.

Jomini, Patrick, The Economic Viability of Phosphorus Fertilization in Southwestern Niger: A Dynamic Approach Incorporating Agronomic Principles, Unpublished Ph.D. Dissertation, Dept. of Agricultural Economics, Purdue University, West Lafayette, IN, 1990.

Karanja, Daniel, "The Rate of Return to Maize Research in Kenya, 1955-58," Unpublished Masters Thesis, East Lansing, Department of Agricultural Economics, Michigan State University, 1990.

Krause, M.A., K. Maliki, K.C. Reddy, R.R. Deuson, and M. Issa, "Labor Management Effects on the Relative Profitability of Alternative Millet/Cowpea Intercrop Systems in Niger," Paper presented at the FSR Symposium, University of Arkansas, Fayetteville, 1987.

Krause, M.A., R.R. Deuson, T.G. Baker, P.V. Preckel, J. LowenbergDeBoer, K.C. Reddy, and K. Maliki, "Credit Systems for International Development: The Nigerien Case," American Journal of Agricultural Economics, 72(4): 911-22, November 1990.

Mahaman, Issaka M., Row Broadcast Hill or Strip Placement of P Fertilizer on Millet and Rice in Niger, Unpublished Masters Thesis, Agronomy Department, Purdue University, 1988.

Mahamane, Issa, M. Kadi, A. Beirada, R.R. Deuson, G. Ibro, M. Krause, G. Numa, K.C. Reddy and B.I. Shapiro, Evaluation des Essais en Milieu Reel sur les Cultures Associees Mil-Niebe. Resultat de la Campagne de 1986, Document No. 17F, INRAN/DECOR, Niamey, Niger, October 1987.

Maliki, Kadi, M. Issa, G. Ibro, H. Zarafi, G. Numa, and K.C. Reddy, Synthese des Resultats de Cinq Annees d'Activites: 1983-1987, Document No. 18F, INRAN/DECOR, Niamey, Niger, September 1988.

Mation, Peter J., "Prospects for Improving Productivity in Sorghum and Pearl Millet Systems in West Africa," Paper presented at the Conference on the Dynamics of Cereal Consumption and Production Patterns in West Africa, Dakar, Senegal, July 1987.

Mation, Peter J., "The West African Semi-Arid Tropics," in Accelerating Food Production in Sub-Saharan Africa,

eds. J.W. Mellor, C.L. Delgado, and M.J. Blackie, Johns Hopkins University Press, Baltimore, pp. 59-77, 1987.
Matlon, Peter J., "Improving Productivity in Sorghum and Pearl Millet in Semi-Arid Africa," Food Research Institute Studies, Vol. XXII, No. 1, 1990.
Norman, David W., Mark D. Newman, and Ismael Ouedraogo, Farm Level and Village Level Production Systems in the Semi-Arid Tropics of West Africa: An Interpretive Review of Research, ICRISAT Research Bulletin No. 4, Vol. 1, ICRISAT, India, 1981.
Office of Technology Assessment, U.S. Congress, Continuing the Commitment: Agricultural Development in the Sahel, 1986.
Painter, Thomas M., Peasant Migrations and Rural Transformation in Niger: A Study of Incorporation within a West African Capitalist Regional Economy. c. 1875 to 1982, Unpublished Doctoral Dissertation, State University of New York at Binghamton, 1986.
Painter, Thomas M., "Migrations, Social Reproduction, and Development in Africa: Critical Notes from a Case Study in the West African Sahel," DPP Working Paper No. 7, The Open University, United Kingdom, 1987a.
Painter, Thomas M., "Bringing Land Back In: Changing Strategies to Improve Agricultural Production in the West African Sahel,n in P.D. Little and M.M. Horowitz (eds.), Lands at Risk in the Third World: Local Level Perspectives, Boulder, Colorado: Westview Press, 1987b:144-163.
Rae, A.N. "Stochastic Programming, Utility and Sequential Decision Problems in Farm Management," American Journal of Agricultural Economics, 53: 448-460, 1971a.
Rae, A.N. "An Empirical Application and Evaluation of Discrete Stochastic Programming in Farm Management," American Journal of Agricultural Economics, 53: 625-638, 1971b.
Raynaut, C., "La Circulation de Marche des Cereales et Les Mecanismes d'Ineqalites Economiques," Cahiers du Centre d'Etudes de Recherches Ethnologiques, No. 2, Universite de Bordeaux, 1973.
Reddy, K.C., Rapport de l'Agronomie General Campagne 1984, INRAN/DRA, Kolo, Niger, 1985.
Reddy, K.C., Rapport de l'Agronomie General Campagne 1985, INRAN/DRA, Kolo, Niger, 1986.
Reddy, K.C., Rapport de l'Agronomie General Campagne 1986, INRAN/DRA, Kolo, Niger, 1987.
Reddy, K.C., Strategies Alternatives pour la Production de Mil/Niebe Pendant l'Hivernage, Fascicule No.l, INRAN, Niamey, Niger, 1988.
Reddy, K.C. and Ly Samba, "Farming Systems Research: Some Suggestions for Agronomists," Paper presented at the Regional Agronomists Training Workshop at Bamako, Mali, organized by SAFGFRAD/ICRISAT/USAID, 18-30 September, 1989.
Samba, L.A., R.R. Deuson, K. Maliki, G. Numa, K.C. Reddy, and S. Swinton, Evaluation des Essais en Milieu Reel sur les Cultures Associees Mil-Niebe: Resultats de la Campagne de 1985, Document No. 14F, INRAN/DECOR, Niamey, Niger, September 1986.
Sanders, John H., "A Theory of Agricultural Technology Development for Semi-Arid Sub-Saharan Africa," Chapter 2 in Sustainable Technology Development in the Agriculture of Semi-Arid Sub-Saharan Africa, mimeograph, Dept. of Agricultural Economics, Purdue University, West Lafayette, June 1991.
Sanders, John H., "Agricultural Research and New Technology Introduction in Burkina Faso and Niger," Agricultural Systems, 30:139-154, 1989.
Sanders, John H., P. Wright, P. Granier, and K. Savadogo, Resource Management and New Technologies in Burkina Faso: A Stable Agricultural Development, A Report to the West Africa Division of the World Bank, 1987.
Savadogo, Kimseysinga, Analysis of Livestock in the Farming System, Draft of report prepared for World Bank, School of Economics, University of Ouagadougou, Ouagadougou, Burkina Faso, October 1989.
Scott-Wendt, John, Rejuvenation of Desertified Sandy Soils in Sahelian West Africa, Proposal submitted to USAID/Mission to Niger, 1989.
Scott-Wendt, J., L.R. Hossner and R.G. Chase, "Soil Chemical Variability in Sandy Ustalfs in Semiarid Niger, West Africa," Soil Science, June 1988.
Shapiro, B.I., unpublished survey results, INRAN/DECOR, Niamey, Niger, 1987.
Shapiro, B.I., New Technology Adoption in Two Agricultural Systems of the Niamey Region of Niger, Ph.D. Dissertation, Department of Agricultural Economics, Purdue University, West Lafayette, IN, 1990.
Sivakumar, M.V.K., "Predicting Rainy Season Potential from the Onset of Rains in Southern Sahelien and Sudanian Climatic Zones of West Africa, Agricultural and Forest Meteorology, 42:295-305, 1988.
Stewart, J. Ian, Response Farming in Rainfed Agriculture, WHARF Foundation Press, Davis, California, 1988.
Sutter, J.W., "Social Analysis of the Nigerien Rural Producer," in Niger Agricultural Sector Assessment, Vol. II, Part D, USAID/Niger, 1979.
Sutter, J.W., Peasants, Merchant Capital and Rural Differentiation: a Nigerien Hausa Case Study, Unpublished Ph.D. Dissertation, Cornell University, Ithaca, NY, 1984.
Swinton, Scott M., " Drought Survival Tactics of Subsistence Farmers in Niger," Human Ecology, 16 (2): 123-144, 1988.
Swinton, S.M. and A. Mamane, Les Exploitations Agricoles Dans Trois Villages de Madarounfa Face a la Sercheresse de 1984, Document No. 15F, Departement de Recherches en Economie Rurale, Institut National de Recherches Agronomiques du Niger, 1986.
Vierich, H.I.D. and W.A. Stoop, "Changes in the West African Savanna Agriculture in Response to Growing Population and Continuing Low Rainfall," Agriculture, Ecosystems and Environment, 31:115-132, 1990.
World Bank, World Development Report (1984), New York: Oxford University Press, 1985.
World Bank, World Development Report (1985), New York: Oxford University Press, 1986.
Wright, Peter, "Water and Soil Conservation by Farmers," in Herbert W. Ohm and Joseph G. Nagy, eds., Appropriate Technologies for Farmers in Semi-Arid West Africa, International Programs in Agriculture, Purdue University, West Lafayette.

The Economic Impacts of Hageen Dura-I in the Gezira Scheme, Sudan

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Introduction

Over the last three decades, several improved sorghum varieties, including Dabar and Gadam El Hamam, were developed and released to farmers in Sudan. However, the total area in these varieties introduced on farmers' fields has been negligible (Ejeta, 1988). In 1983, the first commercial sorghum hybrid, Hageen Dura-I (HD-I) was released. This hybrid is high-yielding and early-maturing with good grain quality and stable yields between years (Ejeta, 1988).

Hageen Dura-I was released with much enthusiasm and seed production was accelerated after the 1984-85 drought. With the high prices of the drought year, farmers all over the country rushed into production. A substantial output response and an inelastic demand resulted in a sorghum price collapse in 1985-86. One of the principal sorghum buyers, the Agricultural Bank of Sudan, stopped purchasing HD-I even though it had been encouraging farmers to plant the new hybrid. As a result, a price differential opened up between HD-I and local cultivars.

However, farmers in the principal irrigated Scheme, the Gezira, have begun an adoption process. Since the sorghum area is so large in the Gezira Scheme and the yield increases with the introduction of HD-I are substantial, there have already been significant benefits from the introduction of HD-I. On the average two-thirds of the area in HD-I in Sudan was in the Gezira Scheme between 1984-85 and 1990-91. Also, the Gezira represents 45% of the irrigated area in the country. In addition to the large sorghum area and the substantial yield increase from HD-I in the Gezira Scheme, Gezira is selected for this study because the other irrigated schemes in the Sudan tend to imitate the Gezira.

In the first section of this paper, the role of sorghum in the Gezira Scheme is summarized. Secondly, the diffusion of HD-I in the Gezira during the '80s is outlined. The economic surplus model is then presented followed by estimates of the costs, benefits and internal rates of return to the research on HD-I. Finally, some implications and conclusions are drawn.

Sorghum in the Gezira Scheme

Sudan has approximately 1.9 million hectares under public irrigation, of which 45% or 875,000 ha are under Sudan's largest project, the Gezira Scheme (D'Silva, 1986). The Gezira is located in the Central Clay Plain between the Blue and White Niles and irrigated by gravity flow from the Blue Nile (Figure 1). The principal crops in Gezira have been cotton and wheat. The crop mix is set by the Sudan Gezira Board (SGB) principally to obtain the government's foreign exchange goals through exports of cotton and groundnuts and through the reduction of wheat imports. For both cotton and wheat, SGB performs land preparation, determines the area, varieties and time of sowing, supplies seeds, water and loans, undertakes fertilization and pest control and transports and markets the products. The farmer undertakes the field operations such as sowing and irrigation.

Sorghum is the principal staple grain utilized for producing the local bread and for other products. Farmers in the Gezira have always demonstrated substantial interest in increas-

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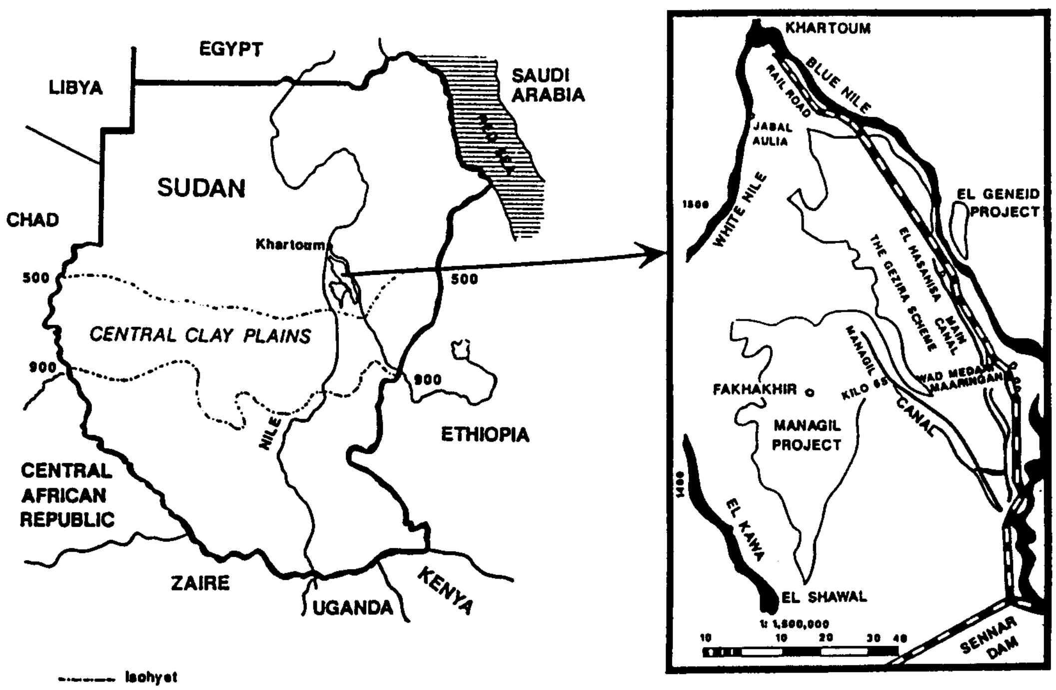
ing their sorghum production. All decisions in production and marketing of sorghum and groundnuts are undertaken by the tenant farmers except for the area in these two crops. Maximum areas are set for sorghum by the SGB. Sorghum area in the Scheme averaged 33% of the total crop area between 1981-82 and 1988-89. In most of the '80s, there was more crop area in sorghum than in either wheat or cotton.

Sorghum yields in the Gezira are almost twice those of the rainfed farms. Over the period 1976-90, average yields in the Gezira

Figure 1. The location of Gezira Scheme in Sudan.



were 1.2 metric tons/ha as compared to 681 kg/ha in the rainfed mechanized farms. Over the period 1985-1990, Gezira irrigated sorghum production ranged from 54 to 64 percent of total irrigated sorghum production and from 6 to 24 percent of the sorghum produced in the country (Table 1). The irrigated sector produced from 11 to 40 percent of the sorghum produced in the Sudan over this period. The 40 percent was the contribution of the irrigated sector during the major drought year 1984-85.

In the drought year, 1984-85, the two rainfed areas (mechanized and non-mechanized traditional) reported average yields of 205 and 240 kg/ha, whereas the Gezira reported 919 kg/ha. In the year following the drought, sorghum area and production in the Gezira increased 1.4 and 2.5 times, respectively. So the irrigated regions play an important role in guaranteeing availability of sorghum and in responding in the next year to the high prices of the drought year (D'Silva, 1986). The irrigated regions serve as a safety valve helping Sudan to have a more reliable supply of sorghum since the irrigated regions are fairly insensitive to drought conditions. Recently, the government has placed even more emphasis on food production (sorghum and wheat) under irrigation due to the low rainfall levels in 1989-90 and 1990-91. In 1990-91, sorghum area in Gezira was 213,445 hectares as compared to 185,000 ha in 1989-90 and 176,000 ha in 1988-89.

Introduction of HD-I

Hageen Dura-I was released in 1983. The initial seed of HD-I came from the joint research program between ARC and ICRISAT. Seed of HD-1 for reproductions was given to the Sudan Gezira Board (SGB) in the 1983-84 season. After the 1984-85 drought, public agencies and eleven private companies rushed into seed production in response to the high sorghum prices. There were substantial seed sales for the 1985-86 crop year. The sorghum area in the mechanized rainfed sector increased from 2.06 million ha in 1984-85 to 3.72 million ha in the 1985-86 season. A substantial output-response and an inelastic demand resulted in a sorghum-price collapse. A large price differential (40 to 50%) was then observed for HD-I compared with locally-preferred sorghums.

Most farmers then refused to buy HD-I seeds for the 1986-87 season. Hence, public seed-producers (National Seed Administration (NSA), Gezira Scheme, and Rahad Scheme) drastically reduced their seed production (Table 2). The private seed companies initially reduced the area planted in certified seed production and then stopped production one year later. Over the period 1986-88, the Sudan Gezira Board was unable to sell even 20% of its HD-I seed stock (Table 2).

However, in the Gezira Scheme, there were some farmers who had substantially increased their sorghum yields with HD-I. They apparently began to develop a preference for the

Table 1. Sorghum production in the Gezira, in the irrigated zone, and in the country.

	Sorghum Production Gezira	Sorghum Production Irrigated (1,000 m.t.)	Total Sorghum Production	Gezira Irrigated	Gezira Total (%)	Irrigated Total
1983-84	228	359	1,806	64	13	20
1984-85	264	436	1,097	61	24	40
1985-86	400	650	3,524	62	11	18
1986-87	244	454	3,277	54	7	14
1987-88	196	352	1,363	56	14	26
1988-89	264	468	4,425	56	6	11
1989-90	238	392	1,536	61	15	26

Source: Agricultural Situation and Outlook, Ministry of Agriculture and Natural Resources, Dept. of Agricultural Statistics and Economics, Khartoum, Sudan, various issues.

Table 2. HD-I certified seed production and sales by public and private seed producers in Sudan.

Season	Sudan Gezira Board Production (m.t.)	Sudan Gezira Board Sale (m.t.)	Sudan Gezira Board Sale % Stock	National Seed Administration Production (m.t.)	National Seed Administration Sale (m.t.)	National Seed Administration Sale %Stock	Private Companies Production (m.t.)	Private Companies Sale (m.t.)	Private Companies Sale %Stock
1983-84	18.00	—	—	—	—	—	—	—	—
1984-85	75.27	18.00	100	12.47	—	—	—	—	—
1985-86	412.83	75.27	100	81.81	11.20	90	162.09	—	—
1986-87	23.40	61.83	15	36.41	66.62	81	21.87	33.40	20
1987-88	—	72.00	18[a]	22.85	51.60	100	—	18.00	12
1988-89	31.38	17.98	19	36.20	25.40	89	—	—	—
1989-90	89.78	103.18	100	8.60	36.00	21	—	—	—
1990-91	124.76[b]	123.83	100	85.85	85.00	100	0.67[b]	—	—

%Stock = Sales as a percent of the accumulated stock.

[a]Including the Rahad Scheme production of 1986.

[b]Estimated from area planted date and post yield averages.

Note: Production is one year lagged, e.g., the seed produced in a season will be available for sale the next season.

Source: Yousif, O.A.F. (1989), and Seed Propagation Unit at SGB, and the National Seed Administration records.

"Kisra" (leavened bread from fermented dough) of HD-I. They also discovered a number of characteristics they liked about HD-I. They continued to buy seeds from SGB. In response to higher sorghum prices since 1988-89, diffusion of HD-I accelerated and the demand for seeds expanded. Hence, the public seed-producers increased HD-I seed production in 1990-91. The Rahad Scheme also resumed HD-I seed production in 1990-91. One of the 11 private seed companies that had stopped seed production after the 1986/87 season began to plant HD-I seeds again in the 1990/91 season. Overall, there were substantially increased activities of the seed producers in 1990/91 to respond to the increased seed demand from the high sorghum prices.

The price differential that opened up between HD-I and traditional varieties in 1985/86 has almost disappeared in the Gezira during the 1989/90 season (Figure 2). There are two hypotheses to explain this price differential. One hypothesis links the price differential to low sorghum prices in good rainfall years. When sorghum prices are high and the output is low, varietal price differentiation disappears. However, real sorghum prices declined substantially between 1986 and 1988 while the price differential narrowed. Hence, the price differential is more likely to be associated with consumer tastes. Farmers in Gezira apparently began to develop a preference for HD-I products. Almost all farmers reported that they either preferred or were indifferent to "Kisra" of HD-I relative to their traditional sorghums (field interviews, 1990).

HD-I diffusion started rapidly in 1985/86 in response to the high prices of the drought year (Figure 3). With the relatively low prices in the 1987-88 season, the area in HD-I collapsed in the 1988-89 season. Due to the recovery of the sorghum market since late 1988 and the apparent evolved preferences for HD-I products, diffusion accelerated reaching 17,336 hectares in the 1990-91 crop year.

Early in the 1990-91 season, both the NSA and the SGB sold all their seed stocks. Many Gezira farmers complained about their inability to obtain HD-I seeds and chemical fertilizer for sorghum in the summer of 1990. In spite of considerable expansion of public seed production of HD-I in 1990-91, the ability of the input markets (seeds and fertilizer) to respond rapidly to high sorghum prices is a principal constraint to increased HD-I diffusion in the irrigated regions presently according to farmer interviews.

HD-I responds well to better management, including fertilizer, good land preparation, sufficient irrigation, higher density, and thinning. Without these treatments, the farm yields of HD-I are reduced. The better farmers obtained 3.28 m.t./ha from HD-I with high fertilization as compared to 1.13 m.t./ha for the traditional varieties without fertilizer or 1.45 m.t./ha with 47 kg/ha of Urea (Table 3). To obtain the

Figure 2. The price differential of HD-I relative to traditional varieties.

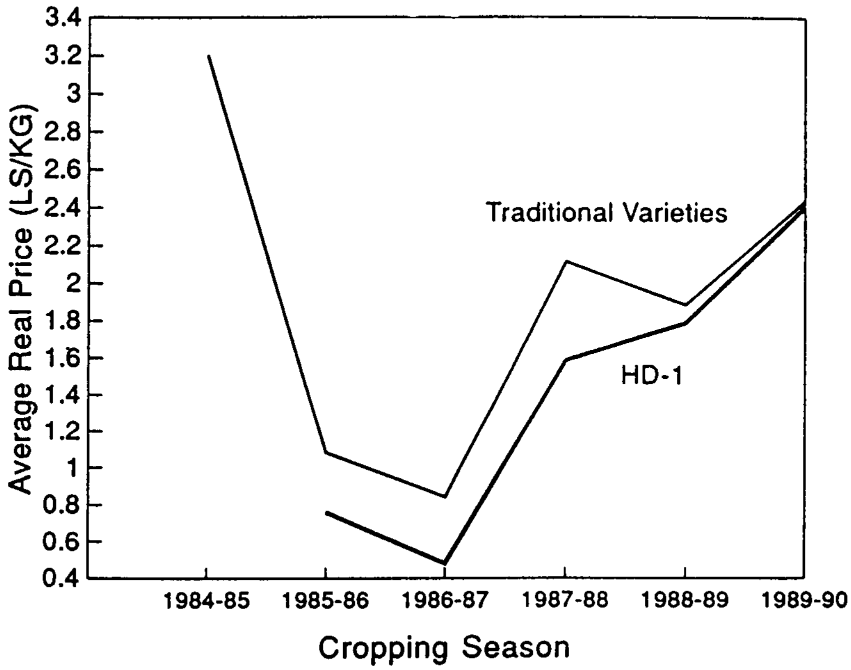
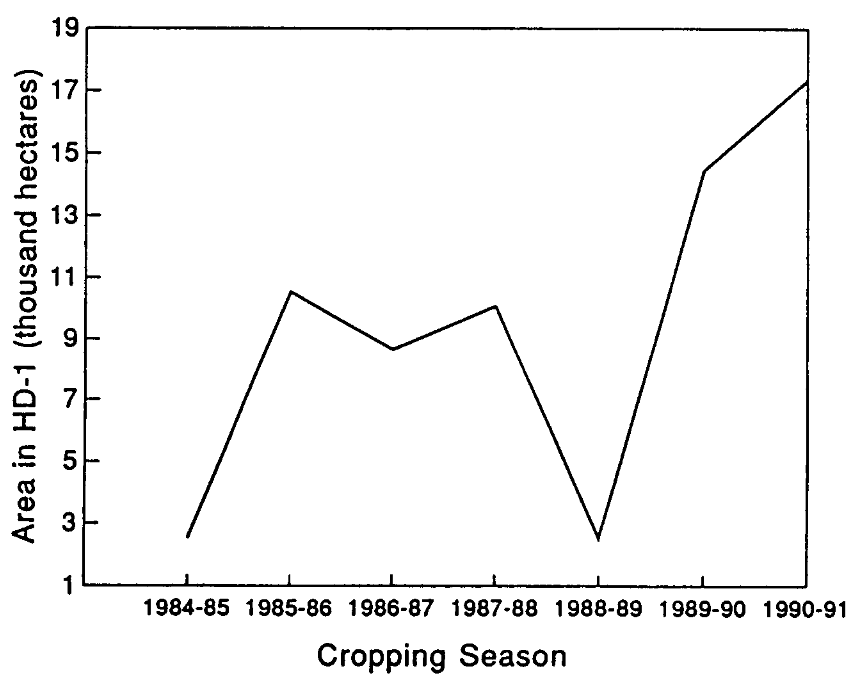


Figure 3. Current diffusion of HD-I in the Gezira Scheme.



higher yields, farmers utilized the extension recommendations of 190 kg/ha of Urea and 95 kg/ha of triple superphosphate, sufficient irrigation water, and improved land preparation.

The introduction of HD-I is associated not only with increased farmer demand for fertilizer and other improved agronomic practices but also with increased marketed surplus. With traditional sorghum cultivars, consumption for home and hired workers were the principal outlets for the low sorghum-output levels. Those farmers producing local cultivars purchased substantial quantities of sorghum, 12 to 25% of their production, over the period 1984-1990. In contrast, farmers producing HD-I sold 25 to 33% of their production.

With HD-I, there are larger quantities of sorghum available so farmers are marketing more sorghum. This will make the irrigated regions an even more significant safety valve of available cereals in poor rainfall years when harvests are low in the rainfed vertisols, the principal sorghum-production area in the Sudan. Moreover, Gezira farmers are selling their surpluses over the entire crop year. This should help stabilize the annual sorghum-price variation.

There are numerous benefits to the introduction of HD-I in the irrigated area, including increased utilization of fertilizer and better management, increased marketed surplus, reduced price variation within the season, and substantial increases in sorghum yields. In the calculation of benefits only the yield increases were included. The other indirect benefits from the marketed surplus and price stability are difficult to quantify and hence were not incorporated in this study. This omission would bias downward the estimates of benefits.

Model for Estimating Social Returns

A common framework for analyzing the welfare effects of technological change in agriculture has been the partial-equilibrium approach based on the concept of economic surplus (Bieri et al., 1972). Social returns to HD-I research are measured in terms of consumer and producer surpluses resulting in the shift from the sorghum-production function. The adoption of HD-I is assumed to result in the pivotal divergent shift in the supply function to avoid overestimation of the total benefits (Fig. 4). A divergent shift implies that absolute reduction in average cost is greater for marginal farms than for infra-marginal farms (Lindner and Jarrett, 1978). The nature of supply shift in the case of HD-I is unknown.

Assuming market equilibrium, the shift in the supply curve from S_n to S_0 would increase

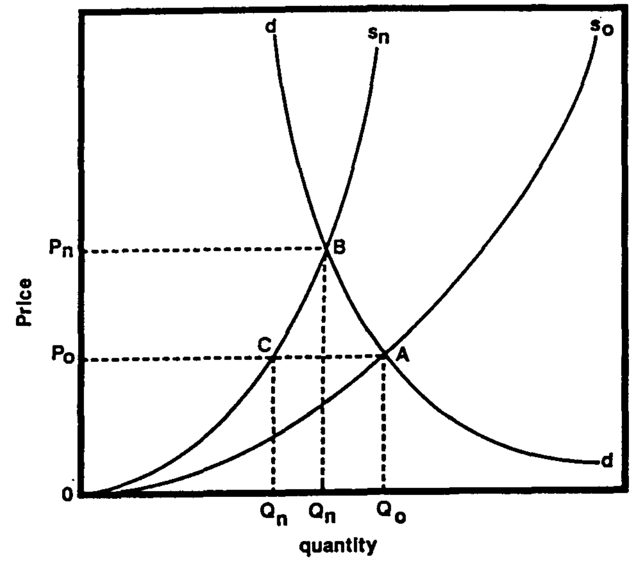
Table 3. Average sorghum yields for new (Hageen Dura-I) and traditional cultivars from farmer interviews in the Gezira project, 1985-1989.

Cultivar	Fertilizer Level (Per ha)	Mean Yields (m.t./ha)
Hageen Dura-I	190 kg Urea and 95 kg Simple Superphosphate	3.28
Hageen Dura-I	95 kg Urea and 95 kg Simple Superphosphate	3.07
Hageen Dura-I	190 kg Urea	2.84
Hageen Dura-I	95 kg Urea	2.35
Hageen Dura-I	47.5[a] kg Urea	2.05
Hageen Dura-I	No fertilizer	1.17
Traditional Cultivar	47.5[a] kg Urea	1.45
Traditional Cultivar	No fertilizer	1.13

[a]Above zero and less than 95 kg/ha. Mean values utilized

Source: These data were from interviews in 1990 of 56 farmers in four different regions of the Gezira project. Farmers were asked to recall data about cultivars, yields, area, prices, costs, and production practices over the last six crop seasons. Data were recorded only when farmers expressed certainty about the specific values. Since sorghum was the principal food crop and they were the decision-makers growing it, most farmers did not have difficulties in recalling the principal information. Data for 1984/85 were not included as the recall was better for the last five years.

Figure 4. Supply Shift with New Technology.



the consumer surplus by approximately area ABC plus area B P_n P_0 C and the producer surplus by area ACO minus area B P_n P_0 C. The increase in social benefits would be area ABC plus area ACO (Figure 4). Following Akino and Hayami (1975), the following approximation formulae hold in equilibrium:

$$Area\ ABC \frac{1}{2} P_o Q_o \frac{[k(1+a)]^2}{\alpha+\eta}$$

$$Area\ AOC = k P_o Q_o$$

$$Area\ B P_n P_o C = P_o Q_o \frac{k(1+\alpha)}{\alpha+\eta} =$$

$$\left[\frac{1-\frac{1}{2}k(1+\alpha)\eta}{\alpha+\eta} - \frac{1}{2}k(1+\alpha)\right]$$

where P_0 and Q_0 are, respectively, the actual price and quantity of sorghum, α and η respectively, the absolute values of the price elasticities of supply and demand, and k is the rate of shift in the production function.[2]

The annual rate of shift in the sorghum production function k is defined as:

$$k = (1 - Y_T / Y_H)L$$

where Y_T is the average yield of the traditional varieties, Y_H represents the average yield of HD-I and L is the proportion of total land planted in HD-I to total sorghum land in Gezira.

Data

The technological change was measured as yield changes per hectare for HD-I versus traditional varieties. Specifically, the average of 1985-86 to 1989-90 yields of HD-I and the yields of traditional varieties were determined for high and low levels of fertilization. The grain-sorghum yields on farmers' fields were utilized for the yield differences. The yield effects in the model compared HD-I with the local sorghum at low fertilizer utilization (47.5 kg Urea/ha) resulting in a yield advantage of 0.6 t/ha, i.e., 41%. The high fertilization level gives 1.83 m.t./ha yield advantage (Table 3).

[2] The relationship between the rate of shift in the production function (k) and the rate of shift in the supply function (h) is given by: $h = (1 + \alpha)k$

A 1.75 m.t./ha yield difference was utilized in the calculation. The total sorghum area in the Gezira Scheme was available in the Scheme records, and the area in HD-I was calculated from the seed sales to Gezira farmers by both the SGB and NSA.

The expected diffusion of HD-I was projected under two assumptions. First, in the most pessimistic case, HD-I would continue at the 1990 diffusion level of 17,000 ha (9% of average sorghum area) since farmers in the Gezira Scheme apparently developed the taste for HD-I products and are unlikely to shift back to much lower yielding, traditional cultivars. Second, a diffusion ceiling of 35 and 50 percent were assumed as a moderate and high diffusion level. These levels were justified by the yield advantages of HD-I which makes it very attractive to sorghum producers. Moreover, sorghum is a principal food crop and farmers will continue to grow it. However, as the rainfed regions increase sorghum productivity and as urban incomes grow, higher-value crops such as fruits and vegetables would be expected to be substituted for sorghum in the irrigated sector. Hence, diffusion ceilings of 35 and 50 percent rather than 80 to 90 percent were utilized. Both the 35 and 50 percent diffusion ceilings were projected utilizing the ordinary logistic function estimated from the few years of past diffusion (Figure 5).

The estimates of the average rate of shift in the sorghum-production function (k) due to HD-I are shown in Table 4. The estimates of the price elasticity of demand (η) for sorghum are available from the Abdelrahman study (1990) of the demand for cereals in Sudan. The range of estimates was -0.25 and -0.8 for the Hicksian and Marshallian elasticities, respectively. This range is adopted in the study as the lower and upper bounds for η.

The price elasticity of supply (α) of 0.29 was estimated assuming a constant elasticity response function, utilizing 18 years of sorghum area and prices in the Gezira. Although the relative magnitudes of the changes in consumer and producer surplus were sensitive to

Figure 5. Current and Projected Diffusion of HD-I in Gezira Scheme.

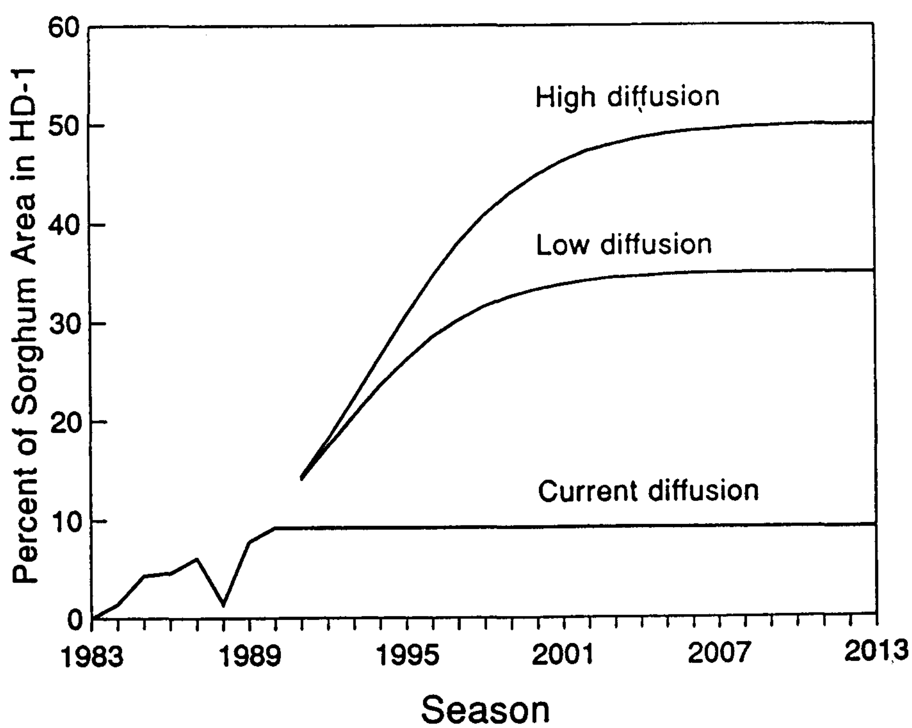


Table 4. Estimates of the average rate of shift in sorghum production function (k) due to HD-I introduction in Gezira with high fertilizer utilization.

	Diffusion Level		
Period	Continue with present level	35% ceiling	50% ceiling
1984-1989	0.02	0.02	0.02
1990-1995	0.04	0.09	0.10
1996-2001	0.05	0.17	0.22
2002-2007	0.05	0.18	0.26
2008-2013	0.05	0.19	0.27

Note: The 35% and 50% levels of diffusion were estimated using the familiar logistic function and the 1984-1990 adoption data.

the choice of specific values for η, and α, social benefit defined as the total change in economic surplus is not very sensitive to the choice of these parameters (Akino and Hayami, 1975).

Data on the expenditures on HD-I breeding research were estimated from the ARC research cost per scientist year. Included in the cost per scientist year is the total cost of all support, i.e., technicians, administrative staff, field workers, and research assistant, assuming one full-time scientist, in addition to land rent, water charges, and miscellaneous material. Extension costs from Global 2000 and the Gezira Scheme were also included. This stream of costs was converted to real 1989 prices.

Results

Research Benefits

The Gezira is one of the largest irrigation Schemes in Sub-Saharan Africa. So introducing new technology with the yields of Hageen Dura-I has a substantial economic payoff.The internal rates of return to the HD-I breeding without any further extension of the absolute area in HD-I were 23 to 31% for the two different fertilization levels (Table 5). Even with the higher diffusion ceilings of 35 to 50%, the rates of return increase only to 29% to 39%. These are all respectable rates of return on a public investment and comparable in magnitude to those obtained for rice breeding in Japan by Akino and Hayami (1975), 25 to 27%; to hybrid corn in the United States by Griliches (1958), about 35%; and those for poultry research in the U.S. by Peterson (1967), about 20%. The average rate of return on investment in Sub-Saharan Africa was estimated at 23.5% in the 1970s and only 6.2% in 1980-87 (World Bank, 1987).

Alternative methods used to evaluate the economic efficiency of the HD-I breeding program were the net present value and the annualized net present values of the returns. At the present extent of HD-I diffusion, the net present value of the returns exceeds 4.5 million U.S. dollars with low fertilizer utilization. This is equivalent to an annual net benefit of more than a million dollars received for 30 years, the time period in this model. The shift to the higher fertilizer technology increased the net present value of the return on investment by approximately $10 million and the annual flow of returns by more than $2 million (Table 5).

So whatever the assumptions about the levels of diffusion, the benefits from HD-I by all measures are still substantial and more than pay for these investments in research. For several reasons these estimates should be considered a lower bound on the benefits from HD-I research:

1. The study accrued all the research costs for the development and extension of HD-I in Sudan, but only the benefits in the Gezira Scheme.

2. The higher diffusion ceiling of 50% is still conservative. The yield advantage of HD-I (about 41% to over 100%) is very attractive to farmers.

3. There were other benefits for farmers discussed above not included in these calculations.

Table 5. Present and potential returns to the introduction of HD-I with different diffusion rates and fertilization levels.

	Internal rates of return		Net present value of returns (U.S.$, 1989)		Annual flow of returns (U.S.$, 1989)	
	η=-0.25	η=-0.8	η=-0.25	η=-0.8	η=-0.25	η=-0.8
<u>Present returns</u>						
9% diffusion Low fertilization	23	22	4,668,000	4,447,000	1,032,000	983,000
9% diffusion High fertilization	31	31	14,669,000	13,860,000	3,244,000	3,065,000
<u>Potential returns</u>						
35% Diffusion Low Fertilization	29	29	21,744,000	20,230,000	4,808,000	4,474,000
35% Diffusion High Fertilization	37	36	57,199,000	50,893,000	12,649,000	12,254,000
50% Diffusion Low Fertilization	31	30	30,187,000	27,616,000	6,675,000	6,107,000
50% Diffusion High Fertilization	39	38	83,283,000	71,971,000	18,417,000	15,915,000

Note: For calculation of benefits and costs of the research, the following assumptions were made: The price elasticity of supply is 0.29; discount rate of 13% was utilized; the time period of analysis is the seven years before release and then benefits occur from 1984 until 2013. The exchange rate for converting to 1989 U.S. dollars was 18.0 S.P./U.S.$; this was the street rate in the spring of 1989.

Distribution of benefits

At the lower price elasticity of demand, all the benefits from HD-I research are received by consumers from the lower prices and output shift. The negative producer gains result from the combination of the inelastic demand and the divergent supply curve. The price collapse of 1985/86 in response to the substantial output increase is some evidence that the price elasticity of demand for sorghum is very inelastic. The potential technology of composite flour can shift the sorghum demand curve. Also devaluation can make Sudanes sorghum more competitive in world markets. A total price elasticity of demand of -0.8 may be possible in the future.

The negative change in producer surplus does not mean that individually all sorghum farmers in Gezira would be worse off with the introduction of the new technology. Cochrane (1979) explains the adoption by producers of new technology with the theory of the treadmill. Initial adopters benefit from HD-I but later adopters do not as total market supply will increase, causing the product price to fall. The losers from the HD-I introduction are those who do not adopt and the later adopters. The non-adopters face a lower output price as well as a higher unit cost from the traditional low-yielding varieties. Nevertheless, even in the low demand elasticity case, most of the sorghum produced in Gezira is utilized by farmers for their own home consumption. With the more elastic sorghum demand, the producers benefit directly at a later stage of diffusion when supply shifts at a higher rate.

Factors Influencing Performance and Implications for Other Regions

There were high returns to sorghum research in the Sudan even with diffusion only onto the Gezira project. Successful technologies in the Gezira are expected to quickly move into the other irrigated projects. In the Rahad project, farmers have begun requesting the project administrators for seed as the information from the Gezira project of the high yields and acceptable seed quality of HD-I has been disseminated. With small additional public investments, this diffusion onto other irrigated projects could be accelerated by facilitating the availability of seeds, fertilizer, and farm trials.

The returns to sorghum research are high, justifying these public investments and encouraging increased investments in research. The irrigated regions, especially the Gezira, are expected to have a continuing large role in sorghum production especially over the next decade. These irrigated regions will be the lowest-cost producing areas due to high yields. It will continue to be less risky to utilize high chemical input levels in the irrigated regions and to therefore get over 3 t/ha. These higher yields at high input levels with HD-I are already a substantial increase over mean sorghum yields under irrigation in Sudan. With the vertisols struggling with yields of 0.6 to 0.8 t/ha (normal years) and trying to raise these yields to over 1 m.t./ha, the irrigated areas can play a more important role in national sorghum production over the next decade.

In the next two decades, sorghum will undoubtedly be replaced in irrigated regions by higher-value crops, such as fruits and vegetables, as the internal and export demands for these commodities increase with income growth and increased trade. Efficient irrigated production can achieve very low production costs in most commodities, so in the long run, only those products with the highest value-added would be produced. The principal sorghum region in the future will be the rainfed vertisols.

Because of the inelastic domestic demand for sorghum in Sudan, price collapse often results in years of good rainfall when the rainfed output is high. In bad years, cereal shortages and high prices were observed. This results in substantial price instability between years and adversely affects sorghum production in the country. On the policy side, price support would be very expensive. An alternative solution is to increase utilization of sorghum. For example, the commercial production of composite flour from wheat and sorghum for bread making can utilize surplus supplies of sorghum and reduce wheat imports in Sudan. The technical feasibility of this technology was demonstrated by the Food Research Center (FRC) of the Agricultural Research Corporation (ARC) (Wicker, 1989). Utilization of sorghum as a feed for poultry and livestock is another way to expand demand. With improved technologies such as HD-I, Sudan sorghum may compete in the world market as the unit cost of production declines. Devaluation would also encourage increased exports. This study encourages economic research in this area of demand expansion as it has potential benefits for both producers and consumers.

Conclusions

The introduction of HD-I into the Gezira Scheme is beginning to be a success story. In 1990-91, an estimated 17,343 ha of HD-I were planted there, 7% of the total sorghum area in this irrigation project. Farmers were eager to plant more and HD-I diffusion is expected to accelerate in the Gezira, especially in 1991-92 with the very high sorghum prices of 1990-91. Even at the most pessimistic projection of no further area expansion of HD-1, the annuity from this research pays for about 20 percent of the agricultural research national budget for the Agricultural Research Corporation (ARC).

Good agricultural research has had a high social payoff in the Sudan and this is important information for research resource allocation. These returns to research can increase over time as diffusion proceeds. There also is substantial potential for HD-I to expand into other irrigated regions of the Sudan, such as Rahad. Irrigation technologies are self-contained units similar to broiler technologies, so much less regional adaptation is required than in the case of most agricultural technologies. This study demonstrates that the potential social benefits from HD-I research are substantial, indicating that the investment in research funding was socially profitable.

However, for a technological change to succeed, the institutional and policy environments have to be favorable. The full benefits described here cannot be realized without making two essential inputs, i.e., seeds and fertilizer, widely available to farmers. The demand for HD-I seeds and fertilizer may reach up to 600 and 16,000 m.t., respectively, by the year 2000, with 50% maximum diffusion and high fertilizer utilization. The private seed industry will need to respond to seed demand along with the public sector. In the past, fertilizer imports have often been dependent upon foreign aid. A higher priority needs to be put upon making the foreign exchange available for the required fertilizer for sorghum and other irrigated and non-irrigated crops.

References

Akino, M., and Hayami, T., 1975. Efficiency and equity in public research: Rice breeding in Japan's economic development. American Journal of Agricultural Economics 57:1-10.

Ayer, Harry A., and Schuh, G. Edward, 1972. Social rates of return and other aspects of agricultural research: the case of cotton research in Sao Paulo, Brazil. American Journal of Agricultural Economics 54:557-569.

Abdelrahman, Ali Hasab-Elrasoul, 1990. An analysis of consumer demand for cereals using an AIDS model: an application to Sudan. Master's thesis, Iowa State University (unpubl.).

Bieri, J., De Janvry, A. and Schmitz, A., 1972. Agricultural technology and the distribution of welfare gains. American Journal of Agricultural Economics 54:801-808.

Cochrane, W.W., 1979. The Development of American Agriculture. Minneapolis: University of Minnesota Press.

D'Silva, B.C., 1986. Sudan's Irrigated Subsector: Issues for Policy Analysis. International Economics Research Service, U.S. Dept. of Agriculture, Washington, DC.

Ejeta, Gebisa, 1988. Development and spread of Hageen-Dura I, the first commercial sorghum hybrid in the Sudan. Applied Agricultural Research 3:29-35.

Griliches, Z., 1958. Research costs and social returns: hybrid corn and related innovations. Journal of Political Economics 66:419-431.

Habash, M.K., 1990. "Potential returns and constraints to the adoption of new technologies in the mechanized rainfed region (eastern vertisols) of the Sudan," Ph.D. dissertation, Purdue University (unpubl.).

Lindner, R.K. and Jarrett, F.G., 1978. Supply shifts and the size of research benefits. American Journal of Agricultural Economics 63:685-699.

M.Ahmed, Mohamed A/Wahab, 1990. "Economic evaluation of new sorghum production technologies and policy implications for the northern Gedaref region of eastern Sudan," M.S. thesis, Purdue University (unpubl.).

Peterson, W.L., 1967. Return to poultry research in the United States. Journal of Farm Economics 49:656-669.

Scobie, G.M. and R. Posada, T., 1978. The impact of technical change on income distribution: the case of rice in Colombia. American Journal of Agricultural Economics 60:85-92.

Yousif, O.A.F., 1989. Final report: pilot project for hybrid sorghum seed production, distribution, and utilization, 1984-1988. National Seed Administration, Sennar, Sudan (unpubl.).

Wicker, F.R., 1989. Commercial demonstration to produce composite flour by co-milling wheat and sorghum. Report prepared for the Government of Sudan and the USAID Mission to Sudan, Khartoum, Sudan. Unpublished.

World Bank, 1987. Sub-Saharan Africa: From Growth to Sustainability, World Bank, Washington, DC.

The Impacts of New Sorghum Cultivars and Other Associated Technologies in Honduras

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Introduction

In Honduras, maize is the main staple and is increasing in importance for industrial uses and as a feed. Sorghum can substitute for maize as a feed and is also an important substitute for maize as human food in poor rural areas. In this latter function, it enables small farmers in erratic rainfall regions to diversify their portfolios. By producing both maize and sorghum, small farmers ensure an adequate "tortilla" and "tamal" supply. Thus, sorghum has an important role in helping eliminate rural malnutrition, especially in adverse rainfall years. But the principal future role of sorghum is expected to be for feed as the demand for meat rapidly increases with income growth.

Three new sorghum cultivars were chosen from adaptation trials in Honduras by the INTSORMIL representative. These cultivars came from the breeding operations of ICRISAT and Texas A&M University. This selection process from materials developed worldwide is a substantial potential benefit to developing countries. The main costs are to belong to the international agricultural scientific community, to be qualified to select material for a region-specific environment, and to plant international nurseries or send for material with specific characteristics. These three new cultivars were released as Honduran cultivars in the mid-'80s. Two of them are now in the beginning stages of diffusion with an estimated 12% (Sureño) and 1% (Catracho) of the Honduran sorghum area in 1989.

In this paper, the role of sorghum in Honduras will be discussed first. Then the development of these new cultivars and other new technologies, and their potential impact on the income of small farmers in southern Honduras, will be reviewed. Then the rates of return for the development of these new cultivars are calculated. Finally, some factors influencing performance, implications, and conclusions are presented.

Sorghum and Maize Production in Honduras

Sorghum in Honduras is a low-rural-income-sector food[2] and a substitute feed for maize (Table 1). Average (miniscula) sorghum production and area over the period 1970-1989 were 45,884 Metric Tons (tons) and 53,414 ha as compared with maize production and area of 408,894 tons and 332,565 ha. Sorghum production was only 11% of maize production over the period. From 1970-1989, sorghum yields have been decreasing at a 2.3% annual rate, whereas maize yields have been increasing at a 1.2% annual rate[3]. Mean sorghum and maize yields over the period 1980-1989 were 849 kg/ha and 1,337 kg/ha, respectively. There have been substantial maize imports in the last five years but minimal sorghum imports since 1976. The biggest difference is in human consumption with sorghum averaging 5,118 tons (1976-1989) and decreasing slightly over time, whereas maize averaged 242,611 tons (1970-1984). Human consumption of maize has been increasing at a 1.8% rate. Sorghum human consumption was 2% of that of maize on the average over the two periods.

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[2] The human-consumption estimates were based on several household surveys in urban and rural areas. These estimates were then adjusted for the impact of weather on maize yields. See the references in this paper and Garcia et al., 1988, for these sources.

[3] These are geometric growth rates for the period 1970-1989. The "t" values were 1.84 and 2.88, respectively.

A recent consumption study indicates the importance of maize for low-income consumers. In the poorest rural income group, maize accounted for 56% of calorie availability, whereas it provided for only 13% of calorie availability for the urban high-income sector. In the urban areas and especially for higher-income sectors, wheat and rice are the principal cereals[4]. Of the principal grains consumed in Honduras — wheat, rice, and maize — only maize had a negative income elasticity[5]. Clearly with economic growth, there are taste or convenience factors associated with the shift away from maize and sorghum. Price distortions favoring wheat also accelerate this shift in consumption patterns away from maize.

Maize and, to a lesser extent, sorghum still have important roles to play in low-income rural and urban diets and in eliminating the caloric deficits among the poor. Nevertheless, the main expansion area for demand growth for both cereals will be the increasing feed demand as qualitative shifts in diets accelerate with income growth. The relative importance of feeds in utilizing sorghum and maize can be seen in Tables 1 and 2. Over the period 1976-1989 feed use of sorghum was 88% of total utilization.[6]

Potential Impact of New Sorghum Cultivars and Associated Technologies

Fifty-two percent (52%) of the sorghum produced in Honduras from 1983-1988 came from the south (Table 4) and 95% of the sorghum from the south was produced by small farmers, principally those on the hillsides. In 1988 and in a follow-up visit in January 1990, intensive farm interviews were undertaken in southern Honduras. One hundred nineteen (119) farmers were interviewed and 67 were classified as small farmers. Small farms were defined as having access to less than 5 ha. This type of farm comprises 56% of the farms in southern Honduras, an estimated 17,000 small farms (López-Pereira, 1990, p.10). Most of these farms were located on the hillsides with one-half having slopes of more than 50%, 5% between 15 and 50%, and 45% less than 15%. The first pressing problem of technology development for these farmers is to prevent the farm from washing down into the valley. Once the farm is stabilized, other new technologies can be introduced, including new sorghum cultivars and chemical fertilizer, which show substantial yield increases (Table 5).

The average annual small farmer family income in southern Honduras is $792 (U.S. dollars). Of this income 39% comes from the sales and the value of home consumption of the cereals, 37% from off-farm labor, and 15% from the sale of farm animals. These farmers often have to sell their cereals at harvest time when prices are lowest and rebuy grain later at a higher price. Twenty-nine percent (29%) of their cash expenses are for cereals. Given the slopes of these hillsides, the first technology requirement is a soil-conservation technique (SCT). Stone walls are constructed and supplemented with trees or bushes. The labor has been paid through governmental food-for-work programs.

The potential income effect of these technologies for the small farmers in the south was estimated. A whole-farm mathematical program was used in which a utility function of net income was maximized subject to labor, land, and capital constraints (López-Pereira and Sanders, 1992). Although the SCTs are extremely labor-intensive and their potential farm income effect would only be 7% (Table 6), they stabilize the agricultural system, making an itinerant agriculture into a permanent one. In southern Honduras 2,400 hectares have been put into these terraces. The adopting farmers (52% of the sample) put on the average 0.4 ha into these stone walls. Ditches (31%) and permanent legume tree barriers (25%) are also utilized on an average of 0.3 ha (López-Pereira, 1990, p.49). The potential income

[4] The income-elasticity estimates for wheat and rice are 0.39 and 0.18 to 0.2, respectively. Garcia U. et al. (1988), pp. 63, 126.
[5] Ibid, p. 63.
[6] The predominant industrial use of maize is for processed feeds. However, starch production from maize also is important. The feed and industrial use of maize increased by 3.8% annually over the period 1970-1984. The "t" value was 2.9. In the previous case of the increase in human maize consumption, the "t" value was 1.9.

effect of combining the SCTs with the new sorghum technologies is a 16% increase. As well, the risk of income variation measured by the Coefficient of Variation, is reduced by 31%, and total expected grain production is increased by 65% when the SCTs and the new sorghums are available (Table 6)

With the food aid, the internal rate of return (financial) of the SCTs to the farmer over a 10-year lifetime was estimated at 39% (López-Pereira, 1990). Besides soil conservation, the SCTs increase water retention, thus reducing the risk of fertilization not being profitable. Once permanent crop production is attained with these conservation devices, the farmer introduces Sureño or Catracho with fertilizer (Urea) on 25% of his crop area in the first season and all of it in the second season, for an average of 64% for the year, according to model results (Table 6). The new cultivars will substantially outyield traditional varieties; however, they require more purchased inputs and better management than the traditional cultivars. In the sample taken in 1988-1989 in the south, 28% of the farmers had planted Sureño and 15% Catracho. These cultivars were released in 1985 and 1984, respectively, by the Honduran Ministry of Natural Resources (MNR) and INTSORMIL. Farmers in the sample introduced the new cultivars only when they had already adopted the soil-conservation technologies. Forty-three percent (43%) of the farmers sampled had adopted both the SCTs and the new cultivar technologies (López-Pereira, 1990, p.48).

Farmers with the SCTs are expected to be the most progressive small farmers. Only 13% of the Honduran sorghum area was estimated to be in improved sorghum cultivars in 1989-90. Five percent (5%) of the small farm crop area in southern Honduras is planted to these new cultivars (López-Pereira, 1990, p.102). Given the substantial yield advantage of this new cultivar technology, why is profitability low and diffusion still limited? One principal problem in cereal production is the price collapse in good rainfall years, especially at harvest. With increased storage, animal fattening, or price supports, this price collapse can be avoided. If one or more of the above changes reduce the cereal price decline in good rainfall years, then the expected net farm income from the combination of SCTs, new sorghum cultivars, and associated technologies would increase by 60% (see Table 6). Modeling results indicate that expected farm income from sorghum production increases from $263 without new technologies and with the price collapse, to $415 with both the new technologies and the avoidance of the price collapse. Total grain production would also increase by 82% The greater potential effect on farmer income and production, and greater adoption of the new technologies resulting from eliminating the sorghum price collapse in good rainfall years, indicates the importance of further policy initiatives in this area.

These levels of minimum prices are already officially maintained by the Honduran marketing agency (Honduran Institute of Agricultural Marketing or IHMA) but small farmers are not presently able to take advantage of them (López-Pereira and Sanders, 1992). IHMA purchased an average of only 2.8% of total production between 1978 and 1984. Minimum prices established by IHMA do not significantly affect farmgate prices or supply quantities (MNR, 1986, p.14). The combination of technologies and effective policies then can substantially raise small-farmer income. These combined activities could increase cereal production by almost 100% and reduce the riskiness of the new agricultural system, according to these results. The SCTs stabilize the agricultural system and allow more intensive agriculture. Sureño and Catracho are then introduced on these farms. These are short-season cultivars maturing in approximately 100 days; hence, they can be fit into either the first or second season of this bi-modal rainfall regime. Their introduction often implies a shift to mono-culture. As in developed countries, Honduran small farmers need to be protected from price collapses when the weather is favorable.

In the '80s, the southern region produced slightly over half the sorghum in Honduras with production concentrated on the small hillside farms. The principal production problem of these farmers is to prevent the farm from washing down into the valley. The combined SCT/new sorghum cultivar technologies make possible a permanent, sustainable agricultural system in contrast with the itinerant hillside farming. The potential farm-level impact of these new technologies with supporting agricultural policy would be a 60% income increase for these farmers. Next to be considered is the potential national impact of these new technologies.

The Returns to Society: Methodology

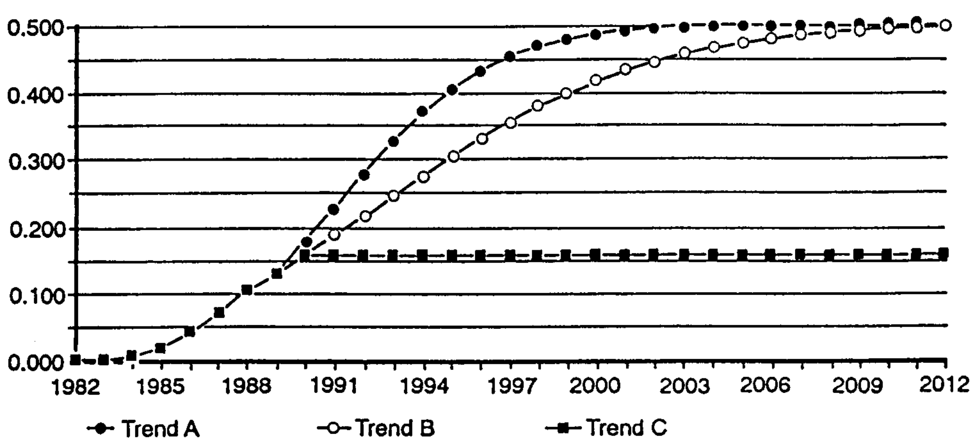
One critical variable in estimating the rate of return to new technologies is diffusion. In 1988 and 1989 the estimated diffusion of Sureño and Catracho was on 13% of the sorghum area, or an absolute area of 8,131 ha. Assuming that all those who have already tried the new sorghum cultivars would continue growing them over the next 20 years is the most conservative projection of future adoption. Total area in sorghum in 1989-90 had jumped up to 65,310 ha with the high sorghum prices of 1988-89. The sorghum area was projected to stay constant at the mean levels from 1980-1990 or at 54,046 ha. Thus, present diffusion would be at 15% with the same absolute area in the new sorghum cultivars and a slightly reduced total sorghum area.

With the rate of adoption of the new cultivars since their introduction in the mid-'80s, a continuing increase in their diffusion along the typical logistic curve is for the two cultivars to reach 50% of the sorghum area after 12 years, in 2002. Alternatively, with a slower diffusion rate, the same ceiling would be reached in 2012 (Fig. 1). The returns on investments for all three levels of diffusion will be given.

In Honduras, small farmers on the hillsides invest only in new cultivars and other associated technologies after stabilizing the farm with the soil-conservation technologies. The SCTs are very large investments in family labor; however, they not only prevent the farms from washing down into the valleys but also increase water retention. Water retention reduces the risk and increases the returns to fertilizer. It was estimated that one-half of the sorghum production of the new cultivars would come from the south and that all these producers would use the SCTs. The investment and maintenance costs, including the opportunity costs of the labor, for construction of these SCTs were included in the cost calculations. Thus, the costs of the new cultivar introduction also requires the SCT construction and are therefore consistent with field observations of adoption in the south (López-Pereira, 1990).

The yield advantage of the new cultivars depends upon the level of inputs utilized. From

Figure 1. Observed and projected extent of adoption of the new sorghum cultivars Sureño and Catracho in Honduras. 1982-2012.



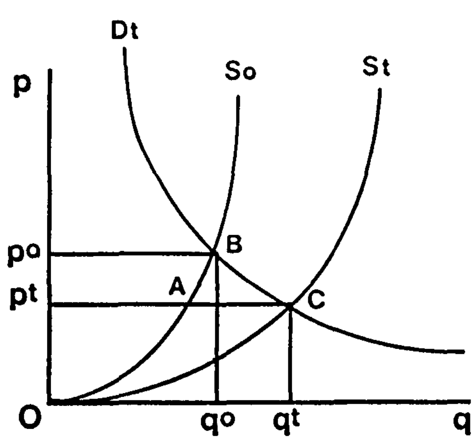
Trend A: 50% area in new sorghum cultivars by 2002.
Trend B: 50% area in new sorghum cultivars by 2012.
Trend C: Same absolute area in new sorghum cultivars as observed in 1989, with a reduction of total area in sorghum.

farm-level trials conducted in 1988, two yield levels were utilized. The first yield difference (1 and 2 in Table 5) included only the yield increase from the new cultivars but assumed that the soil-conservation techniques were already in place. The second yield difference included the new cultivar, seed treatment, and fertilization as well as the soil-conservation technique (1 and 4 in Table 5). These two yield levels were calculated for the three different diffusion rates.

With a new technology, the supply curve is shifted to the right and the price declines, as in Figure 2. Society benefits with OAC plus ABC. The increase in consumer benefits is P_oBAP_t + ABC. The increase (decrease) in producer benefits is OAC - P_oBAP_t. There are three basic components besides P_t and Q_t (observed prices and quantities) for calculating the impacts of technological change on society and the distribution of gains between producers and consumers. These components are the price elasticities of demand and supply (η and γ) here assumed to be constant, and the shift in the production function (K).

The price elasticity of demand for basic grains in Honduras was estimated to be between -0.2 and -0.3 presently. The elasticity estimate for grain sorghum at mean values was -0.26 (calculated from Garcia et al., 1988). The supply elasticity was estimated to be between 0.2 and 0.4 from other studies (Akino and Hayami, 1975; Scobie and Posada, 1978). Initial values utilized were -0.2 and 0.4 for η and γ, respectively. As the demand for feeds increases, the price elasticity of demand for sorghum is expected to increase. With a lower production cost from technological change in sorghum production, sorghum should be able to substitute up to a technical limit for maize in feed. Hence, a demand elasticity of -0.8 for sorghum was also used.

Figure 2. Supply shift with a new technology.



The shift of the production function (K) will be determined by the yield advantage of the new technology and the extent of the diffusion.

$$K_t = \Sigma \, [1 - y_{pt} / y_{at}] * L_{at}$$

where

t :the year,
y_{pt} :average yield present varieties in time t,
y_{at} :average yield of improved variety a in time t,
L_{at} :proportion of total area planted in variety a at time t (Ayer & Schuh, 1972).

The areas in Figure 2 to estimate these various benefits have been shown to be:

$$Area\ ABC = (1/2\, p_t q_t) \{ [K_t (1 + \gamma)]^2 / (\gamma + \eta) \}$$

$$Area\ OAC = p_t q_t K_t$$

$$Area\ P_oBAP_t = [p_t q_t K_t (1 + \gamma)/(\gamma + \eta)] * \{1 - [1/2 K_t (1 + \gamma)\eta)/(\gamma + \eta)] - 1/2 K_t (1 + \gamma)\}$$

Results

With the conservative assumption that only the present absolute area is planted to the new cultivars until 2012, the internal rate of return (IRR) is a respectable 32% for the combined technologies of SCTs, seed treatment, and low fertilization. If diffusion were to increase to 50% of the sorghum area by either 2002 or 2012, the IRR would increase to 40% and 37% respectively (Table 7). The present value of the returns, if the present area only is cultivated with the new sorghums, is \$4.6 million or an annuity of \$699,000 for 30 years. These are substantial returns already from the new cultivars with the potential for continuing increase as the diffusion proceeds. The annuity itself could finance a major part of the locally financed agricultural research in Honduras.

The more elastic demand substantially reduces the returns, as indicated in Table 7. The available empirical estimate for the elasticity of demand was -0.2. However, over time with increased demand for feeds, this demand is expected to become more elastic. For an elasticity of demand of -0.8, the IRR is 20%, with a net present value of $1.1 million, equivalent to a 30-year annuity of $172,000 if the present level of adoption is maintained until 2012. Table 8 shows that when the construction and maintenance of the SCT are included as costs and fertilization is not utilized, the returns to the new technology introduction discounted at the opportunity costs of capital (15%) are negative with demand elasticity of -0.8. If diffusion is increased to 50% at the present price elasticity of demand (-0.2), then the returns do become positive.

For the new sorghum cultivars to transform the agricultural system by making the southern hillsides into permanent systems, farmers need to accompany the SCTs and new cultivars with moderate levels of fertilization. Paying for the capital investment in the SCTs is a large burden for the sorghum technology evaluation. However, this is a necessary development cost for these southern valleys. If the hillsides with the SCTs stay in sorghum production, then the evaluation of new sorghum technology would appropriately include these investment costs. The best estimate for the returns is considered to be the diffusion of 50% by 2012 at the more elastic demand (-0.8). This would be a 26% internal rate of return, a present value of $4.6 million, or an annuity value of $706,000 (Table 7). With some governmental or private sector development enabling adequate seed and fertilizer to be available, these returns to the public investment seem to be reasonable.

Factors Influencing Performance and Implications for Other Regions

The first technology requirement for farmers in the south is to prevent the hillside farms from washing down into the valley. The LUPE program adapted the soil-conservation technology of stone terraces and living barriers and then promoted it among farmers in southern Honduras. This was the key innovation to create a sustainable agriculture in a difficult environment of itinerant agriculture. Once these labor-intensive improvements are in place, farmers demonstrated a substantial increase in demand for other new technologies, including improved cultivars and a moderate level of chemical fertilizer. Without the soil-conservation technology, these other improvements are not sustainable. Once the environment is stabilized, the farm must be sufficiently profitable to keep the farmers involved in agriculture. New sorghum cultivars and moderate fertilization have done that. The diffusion of Sureño and Catracho is now accelerating with the introduction of the SCTs. When utilized with moderate fertilization, they substantially increase yields over local cultivars, from 1.08 tons/ha to 2.55 tons/ha (Table 5).

Over the next decade, there will be a rapidly increasing demand for sorghum (and maize) for animal feed. Sorghum and maize are expected to be the preferred crops on these southern hillsides during the decade. Profitable alternatives, such as fruits and vegetables, would be expected to substitute for sorghum in the second decade. Moreover, with overall economic development, the opportunity costs of labor will be increasing. Then the returns to the labor-intensive terracing will probably not justify this investment. Hence, the diffusion process of the SCTs is expected to slow and crop production will gradually withdraw from the hillsides to the valleys, and the rate of growth of this intensive hillside technology is expected to decline over the next two decades. Meanwhile, it is an important income support for a large number of small farmers. Nevertheless, approximately 37% of the total income of the farmers interviewed already comes from off-farm sources (López-Pereira, 1990).

In spite of all these qualifications about the temporary nature of the new technologies, the public rates of return are still substantial to this research. Rates of return of 20% to 40% are above the estimated real cost of capital of 15% to 20%, which is then a proxy for the return to the marginal investment project. It is necessary, however, to utilize moderate fertilization. Without fertilizer at the more inelastic demand, these combined technology investments have only a marginal rate of return of 15% to 20%.

Conclusions

Sorghum in Honduras is principally a feed grain, 88% of utilization. However, it also serves as a food-security and income-generation device for small-scale maize producers in the erratic rainfall regions on the hillsides of southern Honduras. As such, it is important to the welfare of these small farmers. In combination with soil-conservation techniques, it makes the shift from an itinerant to a permanent, sustainable agriculture both feasible and profitable. Private and public returns were high on the new combined technologies of soil conservation, new cultivars, and moderate fertilization. Without the fertilization, these are not profitable investments.

At the present time, sorghum serves as an emergency food supply, a feed, and a source of income for a large number of small farmers in Central America and Mexico. Hence, this technology combination and institutional collaboration serve as a model for small-farmer development programs in rainfall-erratic regions. The model of first stabilizing the hillsides with soil conservation and then introducing new sorghum cultivars with moderate fertilization is an important one. Rates of return to this public investment in applied research are favorable and the benefits are concentrated among small farmers.

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References

Akino, M. and Y. Hayami, (1975). "Efficiency and Equity in Public Research: Rice Breeding in Japan's Economic Development," American Journal of Agricultural Economics 57:1-10.

Ayer, H.A. and G.E. Schuh, (1972). "Social Rates of Return and Other Aspects of Agricultural Research: The Case of Cotton Research in Sao Paulo, Brazil," American Journal of Agricultural Economics 54:557-569.

Escuela Agrícola Panamericana (EAP), 1988. "Producción de Semillas y Granos," (Internal Report), El Zamorano, Honduras.

Food and Agricultural Organization (FAO), United Nations, 1990. 1989 Commerce Yearbook, Rome.

Garcia, M., R.D. Norton, M.P. Cambar, and R.V. Hoeften, (1988). "Agricultural Development Policies in Honduras," Tegucigalpa, Honduras, U.S. Dept. of Agriculture and U.S. Agency for International Development.

Gómez, F., D. Meckenstock, E. Oviedo, and M. López-Pereira, (1989). "Transferencia de Tecnología de Sorgos: Lotes Demostrativos, Reporte Técnico, No. 1, Choluteca, Honduras.

International Monetary Fund, IMF, (1990). International Financial Statistics, Washington, D.C.

International Sorghum and Millet CRSP (INTSORMIL), Escuela Agrícola Panamericana (EAP), and Ministry of Natural Resources (MNR), (1990). "Tropical Sorghum Conservation and Enhancement in Honduras: Contracts and Grants," USAID Title XII, Sorghum/Millet PROGRAM, AID/H, and GOH, Honduras.

International Sorghum and Millet Program (INTSORMIL), (1989). 1988 Annual Report, University of Nebraska, Lincoln.

_____, (1990). 1989 Annual Report, University of Nebraska, Lincoln.

López-Pereira, M.A., (1990). "Economics of Sorghum and Soil-Erosion Control Technologies for Small Hillside Farmers in Southern Honduras," unpublished Ph.D. thesis, Dept. of Agricultural Economics, Purdue University, West Lafayette, IN 47907, 230 pp.

____ And J.H. Sanders, (1992). "Market Factors, Government Policies and Adoption of New Technology by Small Honduran Farmers: A Stochastic Programming Application," Quarterly Journal of International Agriculture, forthcoming.

____, J.H. Sanders, F. Gómez, and D. Meckenstock, (1989). "Presupuestos Económicos como base para la Evaluación de Nuevas Tecnologías Agrícolas en Honduras: El Caso de Nuevas Tecnologías de Sorgo," paper presented at the XXXV annual meetings of the PCCMCA, San Pedro Sula, Honduras.

Ministerio de Economía, (1990). Dirección General de Estadística y Censos, "Consolidación de Validación: Granos Básicos de Primera y Postrera," Tegucigalpa, Honduras.

____, (1986). Programa Nacional de Granos Básicos a Mediano Plazo: 1986-1990, Tegucigalpa, Honduras.

____, (1989). Informe Sobre la Situación de Abastecimiento de Granos Básicos, Tegucigalpa, Honduras.

Ministry of Natural Resources (MNR), (1990). Precios de Venta al por Mayor y Menor de Productos Agropecuarios: Enero 1985 - Diciembre 1989, Choluteca, Honduras.

Scobie, G.M. and R. Posada T., (1978). "The Impact of Technical Change on Income and Distribution: The Case of Rice in Colombia," American Journal of Agricultural Economics, 60(1):85-92.

Secretaría del Consejo Superior de Planificación Económica (SECPLAN), (1990). "Encuesta: Pronósticos de Cosecha," Tegucigalpa, Honduras.

Secretaría Permanente del Tratado General de Integración Económica Centroamericana (SIECA), (1984). Elasticidades Precio-Ingreso de los Principales Productos Alimenticios en Honduras, Tegucigalpa, Honduras.

Table 1. Sorghum production, area, yields, imports, human consumption, and animal feed in Honduras, 1970-1989.

Year	Total Production (tons)	Total Area (ha)	Yield (tons/ha)	Net Imports (tons)	Human Consumption (tons)	Animal Feed and Others (tons)
1970-71	46,047	36,155	1,274	-	5,603	40,444
1971-72	47,640	37,780	1,261	-	5,548	42,092
1972-73	49,234	39,405	1,249	-	5,500	43,734
1973-74	40,624	52,802	769	-	5,445	35,179
1974-75	52,420	42,655	1,229	-	3,773	48,447
1975-76	52,271	55,605	940	-	5,335	46,936
1976-77	43,753	60,702	721	15	5,280	38,488
1977-78	35,236	65,799	536	4	6,782	28,458
1978-79	52,995	73,920	717	20	5,162	47,853
1979-80	38,178	63,000	606	9	6,639	31,548
1980-81	52,208	61,810	845	1	5,044	47,165
1981-82	41,859	54,670	766	25	4,989	36,895
1982-83	48,845	34,640	1,410	0	4,926	43,919
1983-84	46,618	51,030	914	4	4,863	41,759
1984-85	52,841	59,640	880	1	6,240	46,242
1985-86	29,141	40,950	712	25	4,745	24,421
1986-87	60,681	77,820	785	43	3,277	57,447
1987-88	11,959	35,350	338	N/A	6,005	5,954
1988-89	53,640	59,780	897	N/A	4,556	49,084
1989-90	61,854	65,310	947	N/A	3,145	58,709
Averages:						
1970-79	45,840	52,782	930			
1980-89	45,929	54,046	849			

Note: Human-consumption estimates were made according to rural population in the southern region and rainfall variability. Population data were taken from MNR, "Programa Nacional de Granos Básicos," Honduras, 1989. The data are reported as agricultural years from May 1 to the following April 30.

Sources: 1970-71 to 1977-78: Garcia M., et al., "Agricultural Development Policies in Honduras," USDA/OICD, Feb. 1988, p. 149. 1978-79 to 1989-90: Ministerio de Economía, Dirección General de Estadística y Censos, "Consolidación de Validación: Granos Básicos de Primera y Postrera," Tegucigalpa D.C., Honduras, 1990.

Table 2. Maize production,area, yields, imports and utilization.

Year	Production (tons/ha)	Area Harvested (ha)	Yield (kg/tons)[a]	Net Imports (tons)[a]	Human Consumption (tons)[a]	Industrial Use (tons)[a]	Direct Feed Use (tons)[a]	Difference (Other)
1970-71	338,591	282,546	1,198	-14,564	202,938	57,743	17,095	46,251
1971-72	339,576	283,261	1,199	-13,252	211,156	51,366	17,333	46,469
1972-73	340,563	283,977	1,199	- 8,187	212,553	55,569	17,566	46,688
1973-74	342,561	287,011	1,194	1,294	211,008	67,341	17,815	47,691
1974-75	343,557	286,284	1,200	155	221,067	57,729	18,112	46,804
1975-76	358,129	330,532	1,083	44,091	264.937	55,488	18,537	63,438
1976-77	388,566	380,705	1,021	-16,710	218,018	56,958	18,574	78,306
1977-78	419,002	430,878	972	12,297	219,057	110,694	18,890	82,658
1978-79	519,248	419,860	1,237	37,101	241,420	137,744	19,119	159,006
1979-80	326,423	333,130	980	7,014	390,705	49,255	19,481	-126,004
1980-81	388,214	339,780	1,143	48,284	208,056	116,327	19,802	92,313
1981-82	404,368	344,260	1,175	17,329	246,434	87,113	19,651	68,499
1982-83	423,599	298,690	1,418	-697	313,233	86,294	19,466	3,909
1983-84	459,185	308,770	1,487	10,360	230,379	89,654	19,771	129,741
1984-85	507,844	368,690	1,377	7,494	248,200	92,705	19,986	154,447
1985-86	541,980	376,040	1,441	12,000				
1986-87	347,919	285,040	1,221	15,900				
1987-88	347,919	327,040	1,335	21,400				
1988-89	436,449	333,900	1,322	30,000				
1989-90	510,712	350,910	1,455					
Average								
1970-79	371,622	333,900	1,128					
1980-89	446,167	350,910	1,337					

[a]This was principally processing for feed concentrates but it also included starch.

Source: 1970-71 to 1977-78: Garcia, M., et al., "Agricultural Development Policies in Honduras, USDA/OICD, Feb. 1988 p. 149. 1978-79 to 1988-90: Ministerio de Economía, Dirección General de Estadística y Censos, "Consolidación de Validación: Granos Básicos de Primera y Postrera," Tegucigalpa D.C., Honduras, 1990. FAO, Food and Agriculture Organization, United Nations, 1989 Commerce Yearbook, 1990.

Table 3. Nominal and Real Prices of Sorghum and Maize in Honduras, 1970-1989.

	Farmgate Prices (lempiras/ton)		Real Prices (1989 lempiras)		
Year	Sorghum	Maize	Sorghum	Maize	GDP Deflator (1978 = 1000)
1970	167	134	567	455	550
1971	167	136	557	454	560
1972	168	136	537	435	584
1973	169	152	507	456	623
1974	187	167	503	449	695
1975	216	211	531	519	760
1976	214	207	485	469	824
1977	236	242	471	483	935
1978	252	238	471	445	1,000
1979	259	231	450	401	1,076
1980	282	288	443	452	1,189
1981	312	277	466	414	1,250
1982	329	286	458	398	1,341
1983	352	343	462	450	1,424
1984	352	370	450	462	1,495
1985	365	402	440	484	1,551
1986	449	431	518	497	1,620
1987	532	476	598	535	1,662
1988	607	442	652	475	1,740
1989	607	442	607	442	1,868

Sources: 1970-71 - 1983-84: Garcia M., et al., "Agricultural Development Policies in Honduras, "USDA/OICD, Feb. 1988, p. 163. 1984-85 - 1989-90: Ministry of Natural Resources of Honduras (MNR), Precios de Venta al por Mayor y Menor de Productos Agropecuarios: Enero 1985 - Diciembre 1989, Choluteca, Honduras, 1990. GDP Deflator: International Financial Statistics, IMF, Washington, DC, 1990.

Table 4. Sorghum and Maize Production in the Southern Region and Importance in Honduras.

	Sorghum					Maize				
	Production		Area		Yield	Production		Area		Yield
Year	South. Region (tons)	Share Total (%)	South. Region (ha)	Share Total (%)	South. Region (tons/ha)	South. Region (tons)	Share Total (%)	South. Region (ha)	Share Total (%)	South. Region (tons/ha)
1978	27,804	52	40,320	55	0.69	27,445	5	53,340	13	0.51
1979	18,573	49	29,540	47	0.63	33,118	10	50,540	15	0.66
1980	26,822	51	28,140	46	0.95	35,050	9	43,960	13	0.80
1981	21,032	50	26,040	48	0.81	27,304	7	40,180	12	0.68
1982	30,722	63	15,750	64	1.95	17,613	4	35,140	12	0.50
1983	26,277	56	26,670	52	0.99	14,627	3	27,230	9	0.54
1984	32,927	63	35,700	60	0.92	33,695	7	47,390	13	0.71
1985	14,804	51	23,240	57	0.64	15,841	3	36,740	10	0.43
1986	23,472	39	35,280	46	0.67	10,909	3	22,330	8	0.49
1987	6,918	58	20,090	57	0.34	16,218	4	34,230	10	0.47
1988	23,650	44	26,110	44	0.90	24,627	6	31,850	10	0.77
1989	N/A	N/A	N/A	N/A	N/A	26,850	5	33,390	10	0.80
Average	23,005	52	27,898	52	0.86	23,313	6	38,424	11	0.60

Source: Ministerio de Economía, Dirección General de Estadística de Censos, "Consolidación de Validación: Granos Básicos de Primera y Postrera," Tegucigalpa, D.C., Honduras, 1990.

Table 5. Farm-level performance of Sureño and Catracho compared to traditional varieties and practices, 1989.

		Sureño (tons/ha)	Catracho (tons/ha)
1	Traditional varieties and practices	1.08	1.20
2	Improved varieties and traditional practices	1.33	1.65
3	Improved varieties and seed treatment	1.48	1.96
4	Improved varieties, seed treatment, and fertilizer	1.81	2.55
		(n=33)	(n=14)

1 - Includes soil conservation techniques in place
2 and 3 - Seed treated with systemic insecticide
4 - 60 kg/ha of Nitrogen
n - Indicates the number of farms on which trials gave these recorded data

Source: Gómez, F., D. Meckenstock, E. Oviedo and M. López-Pereira, "Transferencia de Tecnología de Sorgos: Lotes Demostrativos," Reporte Técnico No. 1, Choluteca, Honduras, 1989.

Table 6. Potential effect of the new sorghum and related technologies for risk-averse farmers in southern Honduras, with and without prevention of the price collapse with the new sorghums.

	Traditional farm with:		
Description	No New Technologies	SCTs Only	SCTs and New Sorghums
With no price collapse prevention			
Expected total income (US$)	259	277	301
Percentage increase	-	7	16
Coeff. of Variation (%)	13	12	9
Total grain production (kg)	2361	2066	3894
Percentage increase	-	-12	65
New sorghum area (%)	0	0	64
With price collapse prevention[a]:			
Expected total income (US$)	259	374	415
Percentage increase	-	44	60
Coeff. of Variation (%)	13	6	12
Total grain production (kg)	2361	2735	4290
Percentage increase	-	16	82
New sorghum area (%)	0	0	73

[a]Minimum price of maize and sorghum in the model is increased from US$ 0.04 and 0.02 per kg to US$ 0.10 and 0.07 per kg, respectively. These were the prevailing minimum prices offered by the official marketing agency in 1990

Note: Results presented here correspond to an extremely risk-averse farmer.

Source: López-Pereira and Sanders, 1991

Table 7. Present and potential returns to the introduction of new sorghum cultivars (Sureño and Catracho) and associated technologies with different diffusion rates and elasticities of demand (η = - 0.2 and - 0.8).

	Internal rates of return (%)	Net present value of returns (1989 US$)	Annual flow of returns (1989 US$)
Elasticity of Demand = - 0.2			
Present returns:			
Present diffusion,[a] low fertilization, seed treatment and SCTs	32	4,588,467	698,824
Potential returns:			
50% diffusion by 2002, low fertilization, seed treatment and SCTs	40	14,397,921	2,192,806
50% diffusion by 2012, low fertilization, seed treatment and SCTs	37	11,110,294	1,692,100
Elasticity of Demand = -0.8			
Present returns:			
Present diffusion,[a] low fertilization, seed treatment and SCTs	20	1,129,028	171,951
Potential returns:			
50% diffusion by 2002, low fertilization, seed treatment and SCTs	29	6,489,243	988,314
50% diffusion by 2012, low fertilization, seed treatment and SCTs	26	4,637,230	706,251

Note: The price elasticity of supply was 0.4; discount rate of 15% for last two columns; exchange rate was the street rate in 1989 — 4 Lempiras/U.S.$. The low fertilization was 60 kg/ha of Urea.

[a]13% in 1989-90 and 15% thereafter until 2012. See discussion in the text.

Table 8. Present and potential returns to the introduction of new sorghum cultivars without fertilization, including the SCT investments (γ = 0.4) and two elasticities of demand.

	Internal rates of return		Net present value of returns (1989 US$)		Annual flow of returns (1989 US$)	
	η = - 0.2	η = - 0.8	η = - 0.2	η = - 0.8	η = - 0.2	η = - 0.8
Present returns:						
Present diffusion,[a] no fertilization or seed treatment. SCTs included	15	7	9,839	-1,544,843	1,498	-235,287
Potential returns:						
50% diffusion by 2002, no fertilization or seed treatment. SCTs included	21.5	13	2,400,161	-861,446	365,545	-131,198
50% diffusion by 2012, no fertilization or seed treatment. SCTs included	20	11	1,590,416	-1,136,531	242,221	-173,094

[a]13% in 1989-90 and increasing to 15% in 1990-91 until 2012. See discussion in the text.

Session III - Opportunities for Mutual Benefit through Interaction

- Opportunities for Mutual Benefit through Interaction: A U.S.A.I.D. Perspective
- The Power of the CRSPs
- CRSP Council - Honduras Concept Paper Towards a Sustainable Agriculture in Southern Honduras

Session Chair: John Yohe

Speakers: John Mitchell
Dan Meckenstock

Opportunities for Mutual Benefit through Interaction: A U.S.A.I.D. Mission Perspective[1]

John J. Mitchell[2]

"Agricultural research must be **bold** if it is to contribute significantly to the evolution of a fragile ecosystem whose development requires many integrated actions. Audacity, tempered by a basic-though imperfect understanding of Sahelian agrarian and economic systems, also helps to identify the major objectives for agriculture so that it can contribute significantly to economic growth."[3]

InterCRSPing: The Evolution of an Idea

During 1990, the Agricultural Development Office(ADO) in the U.S.A.I.D. Mission to Niger, conducted a review of its existing Agricultural Research program and its plans for the future. At that time, in addition to a major project involved exclusively with agricultural research, the Niger Applied Agriculture Research Project (NAAR), there were three Collaborative Research Support Programs (CRSP) working in Niger. These were INTSORMIL, TROPSOILS and Peanuts. Each of these CRSPs had an individual Memorandum of Understanding with the National Agriculture Research Institute (INRAN) and had been working in Niger for several years. At the same time, the Bean/Cowpea and Small Ruminant CRSPs expressed an interest in exploring possible programs in Niger. This led ADO staff to consider linking CRSP programs in what came to be called InterCRSPing. TROPSOILS work within Niger has provided an important impetus for the idea of interCRSPing. Their multi-disciplinary work on agropastoral production in the Hamdallaye watershed, approximately 40 kilometers north of Niamey, including work stemming from an Indigenous Knowledge Survey, has greatly influenced both the TROPSOILS/Niger program and USAID's thinking about the idea of InterCRSPing.

During our review, it was noted that CRSPs were working independently of each other, and little information and data were being exchanged in Niger except for annual reports. As this review progressed, the Mission was visited by staff of both the Small Ruminant and Bean /Cowpea CRSPs. The idea of a CRSP grouping was discussed with them and their suggestions taken into account. In October the mission was visited by a group concerned with the formation of a CRSP Council at the Washington level. This group included representatives from several CRSPs working in Niger, as well as Human Nutrition and Fish Pond Dynamics. This visit confirmed to the Mission the importance of its original idea to have a group of CRSPs working collaboratively in Niger. Additionally, this CRSP Council group recognized the work of TROPSOILS at Hamdallaye and the possibilities of using this site as the first area in which an InterCRSP group could begin and test the ideas of CRSP integration.

WHY InterCRSPing ?

In the prepublication edition of "Toward Sustainability" by the National Research Council, there is a statement which is very close to being the basis for the idea of InterCRSPing,

> "Knowledge of all relevant components and their interactions is fundamental to understanding the functioning and management of agroecosystems. However, this knowledge is often inadequately integrated or lacking altogether."[4]

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[1] This paper does not represent the views or opinions of the U.S. Agency for International Development or of U.S.A.I.D./Niger.
[2] Agriculture Development Officer, U.S.A.I.D./Niger, Department of State, Washington, D.C. 20521-2420.
[3] Revitalizing Agricultural Research in the Sahel, A Proposed Framework for Action, Synthesis Document": Institut Du Sahel/SPAAR Task Force, May 6, 1991, p1, in draft, p 1.

With integration as a key concept, we can proceed to define an overall goal for the InterCRSP program. Using an A.I.D. Logical Framework Matrix, one could select a goal such as, "Integrate multi-disciplinary agricultural research to benefit farmers." The goal achievements would be measured by indicators such as increased agricultural production, better use of natural resources available and the development of sustainable methods of agricultural production.

The next step in the Logical Framework is identifying the Project Purpose to be attained during the life of the project. One could foresee a two-part purpose such as, (1)"To strengthen, direct, and conduct multi-disciplinary agricultural research, and (2); "to develop strong effective linkages between INRAN, local institutions, International Agriculture Research Centers and CRSP university affiliates." Indicators of success could include the number of integrated experiments conducted, results which can be applied by farmers, and adoption (adaptation) of these results by the farmers.

We suggest three important reasons for InterCRSPing. These are:

1. The need to FOCUS research support on PRIORITY targets.

2. A desire to support earlier investments in training to enhance human capacity building.

3. The importance of supporting ongoing linkages between Sahelian researchers and their professional mentors and colleagues at US universities.

These are not the all inclusive reasons for InterCRSPing. They are, however, representative of our experience with research and provide the basis of our interest to continuing our involvement.

Integration in itself will not be an easy task to accomplish. Note that the title of this presentation concerns interaction, not integration. Interaction can be viewed as many institutions or organizations providing inputs of various kinds, be it funds, staff or research ideas. Interaction is a prerequisite for the integration of research efforts. We have all seen reports that were from either "integrated projects" or "multi-disciplinary groups" which were only compendia, with each section or discipline represented and not at all integrated with the other sections or disciplines. We must avoid repeating this kind of pseudo-integration. Integration to us means having all researchers presenting their research ideas to their colleagues and having their colleagues agree how the research will be conducted collaboratively so as to produce results that may be useful to several other disciplines, and more importantly, of direct relevance to the farmer and/or agropastoralist. Integration is not a goal in and of itself, but rather a condition for more effective, farmer-relevant research.

We would like to challenge the CRSPs to demonstrate how they will develop "integrated" research programs and how these programs will directly address farmers key constraints. Alternatively, if you do not feel that this is the best method with which to proceed, we look forward to your suggestions.

Research Agenda and Priorities

To establish the research agenda and priorities for an InterCRSP program will probably be the most difficult area in which to reach a consensus. The basis for its establishment will be influenced by numerous factors. These include the ideas of donors, ranging from the World Bank to governments to PVOs, past and current research of IARCs, NARS and regional organizations and farmer recognized constraints. To distinguish priorities will require significant liaison among those concerned with InterCRSPing. The one thing we can be sure of is that there will be many opinions.

We have neither a reference library nor the time to cite many authors and colleagues who

[4] "Toward Sustainability, A Plan for Collaborative Research on Agriculture and Natural Resource Management"; National Research Council, National Academy Press, Washington, D.C., 1991, p. 4.

have examined the finer points of establishing research agendas and priorities. Instead, since this paper in entitled "... A U.S.A.I.D. Mission Perspective", we will present our concerns about their establishment.

Our most serious concern is who will propose the research, researchers in the U.S., researchers in Niger or a committee of both? As simple as this sounds, we are sure that the varied interests represented by the varied disciplines will require firm, collaborative leadership if the research is to directly benefit the farmers, and not only the researchers.

The relevance of the research to the farmer is a major reason for instigating the idea of InterCRSPing. Recognizing the need for this relevance is but one step. The selection of areas or disciplines to conduct research is another. We then have to be concerned with the research methods. Do we begin or continue with station research, or go immediately to on farm trials? In Niger, we have had and currently have ongoing agricultural research projects. Do we accept the key farmer constraints that these projects have identified as a starting point, or do we develop "our own"? Should we accept the idea that food self sufficiency is a major goal of the country, and do we pursue this goal at the expense of maximizing the economic return in agriculture? There are many questions of this type that need to be carefully examined.

Niger presents several unique production systems in which research could be conducted. These include rainfed agropastoral, irrigated perimeters, *contre saison* agriculture and northern agropastoral sites. Our experience with TROPSOILS at the Hamdallaye watershed has shown the production system approach working on a single site to be a strong basis for InterCRSPing. Within the sites an understanding of the full farming system is readily obtainable. Problem/constraint analysis lead to the identification of research priorities upon which the program can be built. We do not limit ourselves to this idea, however, and as before, will be interested in your input.

At the recent Special Program for African Agricultural Research (SPAAR) meeting held in Abidjan May 13-14, 1991, "A Proposed Framework For Action" was presented. This Framework for Action proposes two strategic objectives:

"a. Increase agricultural production as much for improving food security as for generating surpluses for local and export markets; and,

b. Improve capacity to sustain the natural resource base as much for safeguarding the environment as for effectively managing the factors of rural production."[5]

It continues with a section on research methods with the following proposed actions:

"a. Develop capacity for analyses and proposals on the economic future of the Sahel...;

b. Enable a better understanding of local ecosystems and the biological processes best adapted to these systems....;

c. Promote "sub optimal" research which takes into account the actual conditions faced by farmers whose requirements for stability weigh more importantly in their decisions than yield increases and their associated risks;

d. Develop procedures for multi-disciplinary research which takes into account the diversity in the region's agrarian and farming systems.

e. Develop procedures for participatory research involving different economic actors in research design, trials and technology testing...."[6]

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[5] "Revitalizing Agricultural Research in the Sahel, A Proposed Framework for Action, Synthesis Document": Institut Du Sahel/SPAAR Task Force, May 6, 1991, in draft, p 2.
[6] Ibid, pp. 2 3.

Implementing InterCRSPing, Some thoughts, some questions

Field Implementation

As noted, there are currently three CRSPs which work in Niger. We foresee up to six CRSPs within the InterCRSP; INTSORMIL, TROPSOILS, Peanuts, Bean/Cowpea, Small Ruminants and Human Nutrition. Additionally, the ICRISAT Sahelian Center, IFDC, ILCA, IFPRI, ICRAF, IMMI and the University of Niamey are potentially very important cooperators. A wealth of on ground experience and data is represented and has been collected by staff of these organizations.

There are existing relationships between these organizations and some of the CRSPs. TROPSOILS personnel have established excellent, productive working relationships with ICRISAT and ILCA staff. The University of Niamey has provided a botanist to work with the TROPSOILS watershed project just outside of Niamey. INRAN has worked in many sites in Niger with ICRISAT input, sharing both plots and research results.

An enlarging of the current relations and expansion into new relations between these organizations is foreseen. Through regular meetings and discussions, it is expected that long term relationships will be established. A Memorandum of Understanding signed between INRAN and the InterCRSP management entity will be the cornerstone of the project. This management entity will then have as many Memoranda of Understanding as is necessary to include all the other organizations which have expressed interest in this project. Through the Memoranda, each signatory will know exactly what is expected of it and what its responsibilities are. A peer review committee would be responsible for the overall research plan.

We also foresee a major training component in which all organizations will be able to participate, both in having its people trained and in the training of local staff. The benefits are thus to all members of the project, with the Nigerien staff receiving both local short term and U.S. based degree training, and graduate students from the U.S. preparing thesis research in Niger and bringing their experience back to the U.S. campus.

Since we are currently in a pre-design phase, we do not have an established implementation plan. Our thinking now revolves around a small office being established in Niamey, with one expatriate project coordinator and a local staff of 4-5. The coordinator would be responsible for the day to day project implementation, arranging training and meetings, and overseeing the research agenda. Recognizing the importance of communication between the U.S. and Niger, there could be regular conference calls between Principal Investigators in both countries. Bi-annual visits would be made by Principal Investigators from the U.S., most likely once for annual research programming and then once more at a time mutually agreed upon between Niger and U.S. investigators. All investigators would attend their individual CRSPs annual meeting to exchange ideas with colleagues.

We are not bound by the ideas presented above for field implementation. They have not yet been put down on paper, but only discussed among several organizations and some of you here today. An alternative may be to have someone representing each CRSP working in Niger to be assigned there permanently, as is the case of TROPSOILS. A third alternative would be to have only organizational representatives for each signatory to the Memorandum of Understanding, and not have a U.S. expatriate presence. Each one of these options needs to be discussed more fully, and we look forward to your input.

U.S. Implementation

This side of the implementation must be sorted out in our usual Handbook-bound way. We have explored Cooperative Agreements, Direct Cost Reimbursable Contracts, Collaborative Design, and many other possibilities for employing the services of the CRSPs. To date, no method has emerged which is clearly more preferable. In discussions with INRAN and the CRSP Council team, we considered that one CRSP would be the lead institution, with the others as subcontractors. This has advantages, as well as disadvantages. As with field implementation, we have not yet decided on a particular contracting mechanism.

What we do know we want is ease of communication between all the members of the InterCRSP team and U.S.A.I.D., and for ease of U.S.A.I.D. management and implementation that we deal contractually with one organization. This may be a consortium established by the CRSPs, it could possibly be a contract with the CRSP Council. The alternatives are many, and we again seek your comments on this element of implementation.

Some Questions

Though we believe that the novel idea of InterCRSPing is sound, we still have several questions which need to be answered. These include:

1. What is the role of the CRSP Council in InterCRSPing? How will the CRSP Council participate? Will the CRSP Council have oversight, supervisory or management input into the InterCRSP?

2. Where does the Sustainable Agriculture CRSP fit into this InterCRSP idea? The InterCRSP may compete with the Sustainable Agriculture CRSP, which we understand seeks to integrate many disciplines in agriculture. Who will resolve the potential points of overlap?

3. Do the CRSPs interested in InterCRSPing in Niger have any existing formal links to relevant IARCs already? Can these be broadened to be utilized by the InterCRSP, or will they be defended by the individual CRSP which established the linkage?

4. What will be the contributions and commitments of US Universities to InterCRSPing?

5. How committed are CRSPs and U.S. Universities to developing language skills, not just in French but in other languages as well?

6. How will the InterCRSP work to assure adequate coordination with the various regional programs already working within a country. For example, in Niger CILSS, INSAH, SAFGRAD, ICRISAT and IITA are all working through networks and other means to support agricultural research. SPAAR is developing detailed plans for coordinated agricultural research across the Sahel. How will the InterCRSP ensure that it will be a constructive participant and not a duplicating participant in these regional efforts?

Conclusion

The opportunity available to conduct integrated farmer-relevant research in Niger through the liaison of several of the Collaborative Research Support Programs is unique. Employing the specialists and disciplines represented by the various CRSPs could provide Niger with significant new applied agricultural research. The approach of integrating research before research begins, monitoring the integration during the research phase and then producing truly integrated results is exciting in the possibilities of what can be discovered and applied through InterCRSPing.

USAID/Niger is poised to begin the documentation for an Agricultural Research InterCRSP program, and requests your input and thoughts. We believe that this may well be a precursor to a new type of agricultural research through which many aspects of the lives of Sahelian farmers may be positively affected.

The Power of the CRSPs

Dan H. Meckenstock[1]

The "Next Five Years" was the theme of the INTSORMIL conference in Scottsdale Arizona in 1984. At that time the concept of a CRSP Council was not yet born. Presently, we have a CRSP Council and many of its members are here with us today. The formation of the CRSP Council is perhaps the most significant event in recent CRSP history. In short, the CRSP Council is a sign of the times—and the times they are a' changing.

As the focus on how we conduct our agriculture changes so have the CRSPs. The purpose of the CRSP Council is to integrate CRSP activities to address global concerns of agricultural sustainability, natural resource conservation, and environmental quality. A change in focus is also apparent in individual INTSORMIL projects. With the new INTSORMIL grant, 12 of 29 INTSORMIL projects incorporated the term "sustainable" into their titles.

I find the goal of natural resource conservation the most challenging. Invariably, wherever man goes, he replaces nature's ecosystem with his own. Most of the dry tropical forests in Honduras have succumbed to slash and burn agriculture. In the Third World, conservation of natural resources does not mean putting your farm into the "Land Bank". Third World governments are too poor and land is too scarce. Instead, conservation means using your resources wisely. Granted, rural families in Honduras probably should not be farming on steep hillsides as they often do, but the reality of the Third World is that more and more marginal land is being pressed into service as populations increase. Countless hillside fields in Honduras are rocky and highly eroded. Thanks to technology, U. S. farmers have forgotten the days when they boasted of 40 bushel corn. However, many Honduran subsistence farmers still dream of the day when they will harvest half that. Many of you international students will face similar realities when you return home. Imagine your new boss saying, "Good morning, Mr. bushy tailed PhD, your job, should you decide to accept it, is to stabilize that system". Will you be ready for the challenge?

It is because of the growing importance of marginal land in sustaining populations that I make the following prediction,

"Just as maize and wheat research dominated the 20th Century, so will sorghum and millet dominate the 21st Century".

However, I see a dilemma in our development policies. The need to improve production on acid soils or drought prone areas is very real. In spite of this need, the size of the third world debt keeps donors thinking in terms of non-traditional export crops. The AID mission in Honduras, for example, has set its goal to increase export earnings by 250 million-dollars over the next five years. Most of the rural development portfolio is directed towards that goal. Investment in subsistence crops contribute very little to the success of their program. Consequently, sorghum research has a low priority. It is within this mind set, that we as sorghum and millet researchers must work.

The CRSP Council represents eight Collaborative Research Support Programs. Two are resource oriented, Soil Management CRSP and Nutrition CRSP, and the others are commodity oriented—Bean/Cowpea CRSP, Fisheries/Stock Assessment CRSP, Peanut CRSP, Pond Dynamics/Aquaculture CRSP, Small Ruminant CRSP, and Sorghum/Millet CRSP. Working with other CRSPs in an integrated approach to resolve todays agricultural constraints—developing a "systems science" if you will—is the best alternative I see for achieving individual project goals on sustain-

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ability, resource conservation, and environmental protection.

In his book Powershift, Alvin Toffler writes, "anything that can fulfill someone else's desire is a potential source of power". I submit to you that information is the CRSPs source of power. Our business is generating information. Unlike arms and wealth which are the property of the strong and the rich, information is a more versatile source of power that can be grasped by the weak and poor as well. Just as "smart bombs" helped win the 1991 Persian Gulf War, "smart farming" will determine how well a nation will eat and how well it competes in international markets.

The CRSPs are a vast research network that link over 700 experienced scientists from 34 U.S. universities and 80 International research institutions in addressing agricultural problems. This intellectual resource is unmatched in the agricultural world!

Because the CRSPs are designed to share information via collaboration, they have a special advantage in resolving agricultural problems. Collaborative research not only directs U.S. research capabilities at solving village level problems in the Third World, but it lets information flow both ways. Likewise, advanced degree training not only develops tomorrow's scientists, but it is another way in which CRSPs share state of the art information. These two methods of information sharing not only develop the human capital that builds institutions on both sides of the equation, but the CRSPs are a cost effective way for the Third World to develop its agriculture.

To test the Inter-CRSP concept, the CRSP Council chose four regions in the world, where two or more CRSPs are working, to examine the possibilities of integrating research activities. Team visits to West Africa (i.e., Niger, Mali, and Burkina Faso) and Central America (i.e., Honduras) have been made. Visits to Egypt and Indonesia are planned. Six CRSPs participated in the team visit to Honduras. Three of these, the Bean/Cowpea, Pond Dynamics, and INTSORMIL CRSPs already have projects based in Honduras. Other team members represented the Peanut, TropSoils, and Stock Assessment CRSPs. I was the INTSORMIL team member and, together, we identified Southern Honduras as a zone of work that has research needs that all eight CRSPs can address.

There are three important agro-ecological regions in Southern Honduras. These are hillside subsistence farming, shrimp farming in the Gulf of Fonseca, and production of cash crops on the coastal plain. Each region has interrelated problems that must be overcome before a sustainable agriculture can be achieved.

Two public sector and three private sector collaborative institutions are working in southern Honduras. Of these, the Ministry of Natural Resources and the Panamerican Agricultural School have signed MOUs with some of the CRSPs. The Land Use and Enhancement Project (LUPE) is a small farmer extension project funded by GOH/AID that works informally with INTSORMIL. In addition, the Honduran Foundation for Agricultural Research (FHIA) and the Federation of Agricultural and Agro-Industrial Producers and Exporters (FPX) are private sector projects funded by AID/H that focus on export crops. Although all these institutions have different objectives, they address many problems that have a common environmental concern. The CRSPs could bridge technical gaps between these groups and provide leadership in forming a systems approach to sustaining agricultural production and environmental quality.

Agriculture is the motor that drives the Honduran economy. More than 80 percent of Honduras' foreign exchange comes from agricultural products like bananas, coffee, seafood, and forest products. Since the 1950s, the agricultural economy of Southern Honduras has been driven by a series of boom and bust cycles of export commodities. Cattle, cotton, and sugar have each risen to a brief period of dominance only to dissipate in the face of declining productivity and adverse world markets. Much of the depreciation in productivity and inability to compete in the world market with these crops has been self-inflicted through degradation of the natural resource base. At present, non-traditional export crops like cantaloupe and shrimp are experiencing the great expectations and up-swing of this cycle.

Throughout the 1980s, production of cantaloupe and shrimp expanded at a brisk 22 percent per year and, by 1990, conjointly contributed 25 million-dollars to the Honduran economy. By 1995, these two crops are projected to generate 155 million-dollars in annual export earnings with the lion's share—126 million-dollars—coming from shrimp. Needless to say, achieving and sustaining this kind of production is on everyone's mind. The power of the CRSPs to fulfill these desires is a front door to the future.

In a more detailed look at the problems of maintaining agricultural production in Southern Honduras, migration of small scale marginal farmers onto fragile hillsides has destroyed the tropical dry forests and produced environmental consequences like flooding, erosion, seasonal drying up of streams and aquifers, and depletion of soil nutrients. In turn, this degradation of the natural resource base has resulted in reduced yields, production, and income for farm families. Although, these small farm families produce over 75 percent of the countries basic grains—beans, maize, and sorghum. Seasonal food shortages, unbalanced diets, contaminated water, poor sanitation, and intestinal parasites are important nutritional constraints that limit the quality of life and human function of rural households. Approximately 70 percent of preschool children in rural families in Choluteca suffer from some form of malnutrition with 30 percent manifesting second and third degree malnutrition. LUPE is presently focused on these families and research opportunities with TropSoils, Nutrition, Peanut, Bean/Cowpea and Sorghum/Millet CRSPs can significantly enhance LUPE's impact.

On the coastal plain, increased production of cantaloupe has come about through increased acreage and continuous cropping. Accompanying this expansion has been a growing problem with soil degradation and aphid-borne viruses. Farmers have responded to aphids with calendar spraying of two to three applications per week. Use of broad spectrum pesticides have exacerbated the problem by killing beneficial insects, which, in turn, has brought on secondary insect pests like leaf miners and white-fly. In 1990, melon crop loss due to these insect pests was 56 percent of the preplant projection. As with cotton, which was a major export player from the 50s through the 70s, the overuse of pesticides now threatens the sustainability of melon production and off-farm environments like community drinking water and estuaries.

Rapid expansion of shrimp farming has led to conflict between environmentalists, shrimp producers, and the fish capture industry over the use of land, estuarine, and gulf resources. Shrimp production depends on the availability of natural stocks found in the estuaries. The need to stem the decline in water quality and estuarine habitats is recognized as key to sustaining shrimp production. The nascent shrimp industry is presently threatened by pollution from upstream agriculture, siltation due to deforestation, destruction of mangroves, extensive pumping of estuarine water by shrimp farmers and over-harvest of post-larvae shrimp.

Stabilizing agricultural production in these three agro-ecological regions in southern Honduras will indeed be a challenge. It will require an integrated effort among producers, extensionists, researchers, policy makers, and donors to develop a delicate balance between conservation and utilization of natural resources. Some of the constraints to production, environmental quality, and natural resource conservation have been identified in the Honduras concept paper "Towards a sustainable agriculture in Southern Honduras" and many of the CRSPs and host country collaborative institution have begun discussing ways for finding solutions.

Honduras Concept Paper
Towards a Sustainable Agriculture in Southern Honduras

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Executive Summary

Agriculture generates more than 80 percent of Honduras' export earnings and is widely considered the motor that drives the Honduran economy. Since the 1950s, the agricultural economy of southern Honduras has been dominated by a series of boom and bust cycles of export commodities. Cattle, cotton, and sugar have each reached their zenith only to dissipate in the face of declining productivity and adverse world markets. Much of this instability has been self-inflicted through degradation of the natural resource base which has reduced productivity and profitability. At present, non-traditional export crops like melon and shrimp are experiencing the great expectations and up-swing of this cycle; however, signs of limitations and stress on production are becoming apparent.

This concept paper explores ways in which agricultural research expertise from the CRSPs can be united with expertise from five private and public agricultural institutions in Honduras to resolve production constraints and to develop sustainable agricultural systems in Southern Honduras. This area encompasses three agro-ecological regions—hillside subsistence farming, melon production on the coastal plain, and shrimp production in the Gulf of Fonseca—that have interrelated problems that must be overcome before a sustainable agriculture can be achieved. The production of shrimp has the most economic importance to the region with an estimated 126 million-dollar annual earnings by 1996. However, shrimp production depends on the availability of natural stocks found in the estuaries which not only are threaten by an expanding shrimp industry but also by deforestation and excessive use of pesticides by melon farmers on the coastal plain. This concept paper takes a look at these interrelated problems and proposes joint research initiatives to overcome them. Many of the experiences and technologies resulting from this endeavor would have application to other countries in the region.

The goal of sustainable agriculture is to develop agricultural resources and production systems that maintain and enhance environmental quality and that can become a permanent part of the economy and society. Shifting towards sustainable agricultural systems requires modifying conventional agricultural practices believed responsible for causing environmental and social problems.

The Collaborative Research Support Program Council (CRSP Council) is an integrated initiative that addresses the global concerns of agricultural production and sustainability, natural resource conservation, and environmental quality. The CRSP Council unites the resources and capabilities of scientists from 32 U.S. universities and over 80 international research institutions to form a powerful international research network. The purpose of the CRSPs is to provide direct access to cutting-edge technology for resolving agricultural production problems that face third world farmers each day. The CRSPs are a cost effective means for tapping into existing technologies and developing new ones. Also, they help train third world scientists, build permanent institu-

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tional linkages, and provide continuity in agricultural research.

CRSP Council

The Collaborative Research Support Program Council (CRSP Council) is an integrated initiative that addresses the global concerns of agricultural production and sustainability, natural resource conservation, and environmental quality. The goal of the Council is to integrate CRSP research activities into a systems science that addresses sustainable agricultural production issues which face third world farmers each day. The CRSP Council unites the resources and capabilities of the following eight CRSPs which provide direct access to cutting-edge technology through 700 experienced international scientists from 32 U.S. universities and over 80 international research institutions:

Bean/Cowpea CRSP
Pond Dynamics/Aquaculture CRSP
Fisheries Stock Assessment CRSP
Small Ruminant CRSP
Human Nutrition CRSP
Soil Management CRSP (TropSoils)
Peanut CRSP
Sorghum/Millet CRSP (INTSORMIL)

The CRSP Council has determined that Egypt, Honduras, Indonesia, and Niger possess excellent opportunities for implementing a systems approach to agricultural development. At present, the Bean/Cowpea CRSP, Pond Dynamics CRSP, and Sorghum/Millet CRSP are working in Honduras. The Fisheries Stock Assessment CRSP, Human Nutrition CRSP, Peanut CRSP, Small Ruminant CRSP, and Tropical Soils CRSP all have opportunities to work in Honduras.

The CRSP Council provides a successful, long-term, interdisciplinary, whole-farm, holistic research approach to enhance the quality of life in developing countries through alleviation of the major constraints to food production, nutrition, and natural resource conservation. It creates a powerful international research network that can service and support the Government of Honduras (GOH) in its agricultural development. Many of the technologies which can be developed also would have application in neighboring Central American counties. Special advantages to involving CRSP resources in the agricultural development of Honduras are: 1) link research conducted in high-tech U.S. laboratories, to the "ground level" problems of Honduras; 2) provide advanced degree and short term training to Honduran scientists as an integral part of a collaborative research thrust which builds and sustains permanent institutional linkages; 3) provide continuity in agricultural research; and 4) cost effectiveness.

General Constraints to Agricultural Development in Honduras

A recent USAID agricultural development strategy for Honduras identified the following five constraints to agricultural development in Honduras: "1) a heritage of statist, paternalistic policies; 2) inadequate infrastructure development; 3) distorted relative prices of goods and factors of production; 4) a deteriorating natural resource base; and 5) inadequate development of human capital, characterized by low literacy rates and malnutrition in large segments of the labor force." The CRSPs are uniquely poised to address segments of those constraints pertaining to the deterioration of the natural resource base, inadequate development of human capital, and malnutrition and food security.

Zone of Work

Southern Honduras is the zone of work identified during a six member inter-CRSP team visit to Honduras in January, 1991. This zone encompasses hillside subsistence farming on the Choluteca, Nacaome, and Negro watersheds, export crops on the coastal plain, and aquaculture in the Gulf of Fonseca. All eight CRSPs have opportunities to work together in this area to develop a highly productive agriculture that can become a permanent part of the Honduran economy and society.

Background

Southern Honduras is a semi-arid region distinguished by a six month dry season (November through April) and a bimodal rainy season. Historically, this region has lagged behind other sections of the country in agricultural development. Since the 1950s, the agricultural economy of southern Honduras has been driven by a series of boom and bust cycles of export commodities. Cotton, sugar, and cattle industries each have risen to a brief period of dominance, only to dissipate in the face of declining productivity and adverse world markets. Much of the depreciation in productivity and inability to compete in the world market has been self-inflicted through degradation of the resource base. At present, non-traditional export crops—*e.g.*, cantaloupe and shrimp—are experiencing the great expectations and up-swing of this cycle. Throughout the 1980s, cantaloupe and shrimp production expanded at a brisk 22 percent per year and conjointly contributed 25 million dollars to the Honduran economy in 1989-90. By 1996, these two crops are projected to generate 155 million dollars in annual export earnings, with the lion's share, 126 million-dollars, coming from shrimp.

Statement of the Problem

A high population growth rate (3.0 percent) and a finite land base have forced many farmers to intensify the use of existing cropland and others to occupy fragile hillside land which is less productive. Sustaining agricultural production in both these instances rests on a delicate balance between conservation and utilization of natural resources. The high rate of growth in cantaloupe and shrimp production is attributed to their profitability relative to traditional export crops and basic grains. As more farmers are drawn into the lucrative production of non-traditional crops and as others move onto marginal lands, resulting changes in the ecosystem induce a general degradation of the natural resource base which, in turn, not only promises to reduce productivity, but threatens to stifle production.

Hillside Agriculture

Migration of small scale marginal farmers onto fragile hillsides is the product of a rapidly growing population faced with few alternatives and an increasing scarcity of available arable land. These farm families, which represent a significant proportion of the rural population, produce over 75 percent of the country's basic grains—beans, maize, and sorghum. Extensive use of slash and burn agricultural practices employed by these farmers plus their increasing inability to rotate cropping sites are beginning to impose limitations on agricultural production. Deforestation (10,000 ha/yr, USAID estimate), which is largely attributed to commercial logging, also accompanies hillside agriculture and produces environmental consequences like flooding, erosion, seasonal drying up of streams and aquifers, and depletion of soil nutrients that result in reduced yields, production, and income for farm families. Malnutrition, stunting, and wasting—resulting from seasonal food shortages, unbalanced diets, contaminated water, generally poor sanitation, and intestinal parasites—are important nutritional constraints for improving the quality of life and human function of these rural households. Malnutrition falls principally on the women and children in these rural populations. Approximately 70 percent of preschool children in rural families in Choluteca suffer from some form of malnutrition with 30 percent manifesting second and third degree malnutrition. The limiting nutrient in these families appears to be energy rather than protein. Also, subsistence diets are periodically deficient in vitamin A, ascorbic acid, and riboflavin. Dysentery is the major cause of death in preschool children.

The cattle industry, which also has contributed significantly to deforestation, rose to an export peak of 70 million pounds in 1979, but since, has fallen off to a mere 17 million pounds. Scarcity of water and drying up of pastures are the production constraints most often cited for southern Honduras.

Agriculture on the Coastal Plain.

Increased production of cantaloupe has come about through increased acreage (4,500 ha in 1990) and continuous cropping. Accompanying this expansion—which is expected to reach 9,000 ha by 1996—has been a growing problem with soil degradation and aphid-borne viruses. Farmers have responded to aphids and other insect pests with intensive pesticide spray programs in which calendar spraying of 2 to 3 applications per week is common. Not only has continuous spraying of broad spectrum pesticides exacerbated the virus problem by creating resistant insect biotypes, but it has eliminated the resource of beneficial insects which, in turn, has brought on secondary insect pests like leaf miners and white fly. Melon crop loss due to these insect pests in 1989-90 was 56 percent of the preplant harvest projection. In spite of these losses, producers discounted the insect-pesticide problem because a higher than usual market price compensated for lost production. Clearly, melon producers have jumped on an "insecticide treadmill" which may take them to the brink of disaster.

The plight of the melon growers is reminiscent of an earlier generation of farmers who brought cotton production to a peak in 1965 (14,000 ha) in southern Honduras only to see that crop disappear in the early 1970s due to a spiraling cost of production coupled with declining world prices. Not only does overuse of pesticides threaten the sustainability of melon production itself, but it also has hidden and delayed off-site effects. Because melons are produced on a coastal plain with coarse textured soils and shallow groundwater, insecticides pose a threat to off-farm environments like community drinking water and estuaries in the Gulf of Fonseca. Recent post-larval recruitment samples taken from shrimp farms in Choluteca showed relatively high levels of DDT which dropped below minimum standards by the time adults were harvested. Presumably, the DDT came from the cotton producing era in which applications escalated to as many as 30-40 per crop and were depositing 40 kg DDT/ha annually.

Aquaculture in the Gulf of Fonseca

Rapid expansion of shrimp farming has led to conflict between environmentalists, shrimp producers, and the capture fisheries industry over the use of land, estuarine, and gulf resources. Little baseline data exists by which guidelines can be formulated for the management of this complex system. Shrimp production in the gulf depends on the availability of natural stocks found in estuaries. The need to stem the decline in water quality and estuarine habitats is now recognized as key to sustaining shrimp production which reached 2,600 metric tons on 4,770 ha in 1989-90 and achieving the 1995-96 production and productivity goals of 16,300 metric tons on 15,000_ha. The shrimp industry in Honduras, which is already a major export earner and could serve as *the* model for Central America, is presently threatened by pollution from upstream agriculture and possibly the shrimp farmers themselves, siltation due to deforestation, destruction of mangroves by salt farmers seeking a ready source of firewood for evaporating saltwater, extensive pumping of estuarine water by shrimp farmers, and improper capture fisheries techniques in the gulf. One example concerning the need for better management practices which the team came across was the common use of one-half inch mesh gill nets in artisinal capture fisheries of shrimp. This mesh is far too fine and threatens the environmental integrity of the estuary by removing everything in its path, including immature shrimp, small fish and mollusks. Use of three inch gill nets would better serve ecological stability.

Other potential constraints to shrimp production which may need to be addressed later are the planned irrigation project for the Choluteca river and release of raw sewage into the gulf. Effectively, the irrigation project would reduce the supply of fresh water to the estuaries. Salinity will rise and reduce the productivity of shrimp. Also the groundwater level will rise which, in turn, would hasten the migration of contaminants. The present epidemic of cholera in, which has been exacerbated by infected shell fish, has induced local health workers to question the feasibility of dumping raw sewage into the Gulf of Fonseca. Both situations require research before prudent policy decisions can be made.

Collaborative Institutions and Linkages

The inter-CRSP team identified the following five private and public institutions which could commit collaborators and resources to the zone of work:

- Escuela Agricola Panamericana (EAP)
- Federation of Agricultural and Agro-Industrial Producers and Exporters (FPX)
- Honduran Foundation for Agriculture Research (FHIA)
- Land Use and Productivity Enhancement Project (LUPE)
- Ministry of Natural Resources (MNR)

All of these institutions have recognized aspects of the production constraints mentioned and are working on them to some degree. Although they are addressing different problems, many with a common environmental concern, no attempt has been made to tie these efforts together into a comprehensive program. The aggregate expertise of the CRSPs could be used to bridge technical gaps and provide leadership in forming a systems approach to sustaining agricultural production and environmental quality in southern Honduras.

Escuela Agricola Panamericana (EAP)

The EAP is widely recognized as the agricultural college with the highest standards in tropical America. It is a four year non-profit private college with an enrollment of 650 and an annual budget in excess of 9.7 million dollars. Thirty-one members of its faculty have Ph.D. degrees—mostly from U.S. universities. The EAP offers a B.S. equivalent degree and has strong educational programs in agricultural economics, agronomy, animal science, fish culture, food processing, forestry, horticulture, plant protection, post harvest technology and utilization, rural development, soil fertility and microbiology. It is presently developing a natural resource management and conservation biology program. The EAP plays an important role in Honduran agricultural research because of its significant quantum of scientific expertise, a student research requirement for the Ingeniero Agronomo degree, publication of the scientific journal Ceiba, and affiliation with a network of international research institutions. At present, the EAP has a standing memorandum of understanding (MOU) with the Bean/Cowpea CRSP and Sorghum/Millet CRSP and serves as their base of operations in Honduras. Potential collaborator and graduate student linkages also exist for other CRSPs. In general, the EAP has well equipped laboratories and field facilities. Excellent facilities for conducting short course training, regional workshops, and seminars—plus housing for participants—further enhance collaborative prospects with CRSPs. The integrated pest management project (MIPH) at the EAP is internationally recognized for its technical capability and, currently, is implementing integrated pest management programs with APRDEXME (Asociacion de productores y export tadores de meln), LUPE, and Sorghum/Millet CRSP in southern Honduras. In 1990, MIPH began a regional technical assistance program to create and implement IPM for cantaloupe.

Federation of Agricultural and Agro-Industrial Producers and Exporters (FPX)

FPX, project (522-0207), is a non-profit private association sponsored by USAID and GOH for the purpose of developing and promoting competitive, non-traditional agricultural and agro-industrial exports. Principal commodity interests are: cacao, cardamom, cashew, cucumbers, melons, pineapples, plantains, shrimp, tomatoes, tropical flowers, and ornamental plants. FPX has a 36 member staff—16 professionals and 20 support staff—and a 690,000 dollar annual budget. In addition, its has seven full-time technical advisors, two of which provide technical assistance to shrimp producers. FPX pursues a variety of activities including: policy development, information and technology development, export promotion, product quality control, investment promotion, training, consulting, and trading and investment financing. It has both extension and research elements in the technology development component and these provide direct access to farmers for identifying research priorities and a modest capability for resolving production constraints firsthand. Presently, an MNR technician and the Pond Dynamics CRSP, are evaluating the effect of different management strategies on production at the "Granjas Marinas" farm, San Bernardo Choluteca. Equally important to the FPX research posture is its ability to serve as a catalyst in involving local research institutions—*e.g.*, EAP and FHIA—in solving production constraints. The previously mentioned FPX-MNR-Pond Dynamics CRSP initiative is one example. MIPHs integrated pest management program on melons is another. It is important to note that this latter effort is jointly financed by EAP, FPX, ROCAP, and producers. Not only has FPX successfully motivated producers to provide limited support for research in shrimp and melons, but beneficiaries of these efforts have been so pleased with results that a "check-off" system on the number of boxes sold is being considered as an equitable way to augment producer support for research. FPX has shown that Honduran producers are willing to support research when it is perceived as needed and results enhance profitability. FPX has expressed interest in setting up a water quality laboratory in Choluteca and has offered to supply part of the equipment and laboratory personnel including a chemist and assistant.

The new AID/H Investment and Export Development Project (IED) 522-0312, which is phase II of the FPX project, is scheduled to start in July, 1991. This project supports an array of activities, one of which commits two million-dollars to FPX research initiatives. This support is intended to encourage the development of new products and production technologies, and will position FPX in a more active role in research by giving it the ability to contract special research and development services. Conceivably, research priorities would include crop rotation-tillage interactions, tradeoffs in achieving production versus environmental objectives, and other issues of natural resource management integral to sustainable farming systems.

FPX has strong collaborative opportunities with the Pond Dynamics CRSP and Stock Assessment CRSP, provided national research collaborators are available. With IED assistance, it would be possible to place long-term scientists in local research institutions which, in turn, would be backstopped by the technical expertise of the CRSPs. Other CRSPs like the Peanut CRSP, INTSORMIL, and TropSoils also have opportunities to work with FPX and MIPH in developing rotation crops for melons. The objectives of these linkages would be to establish rotation crops that would break melon insect pest life cycles and increase melon productivity through improved soil fertility and soil structure. One simple technology that MIPH is promoting to control aphid-borne viruses is the use of sorghum borders and sorghum rows interspersed throughout melon fields. As aphids move across these borders into other sections of the field, they probe the sorghum plants with their stylet. This action cleans the virus—which is not non-persistent—from the stylet and reduces the rate of dissemination of viral disease in the field.

Honduran Foundation for Agriculture Research (FHIA)

FHIA, Project (522-0249), is a private research foundation established by USAID and the GOH for the purpose of generating and transferring technology for export crops. Its staff includes some 8 PhDs, 13 M.S., and 37 support personal. FHIA's annual operating budget is in excess of 2.7 million-dollars. Its principal research interests rest with bananas, plantain, and cocoa; but, it also works with mango, palm hearts, black pepper, tomatoes, small squash, and soybeans. Although FHIA's predecessor is credited with introducing melons and peanuts to southern Honduras in the mid-70s, its prospect of addressing production bottlenecks on these crops, as well as shrimp, is contingent upon acquiring additional funding for contracting scientists and providing their support. FHIA has a record of excellence for the work it has undertaken. Also, it has laboratories capable of running conventional soil and tissue analyses as well as determining the amount of pesticide residues and other contaminants in water, soil and agricultural products.

Land Use and Productivity Enhancement Project

LUPE, Project (522-0292), is a USAID technical assistance project implemented under the Ministry of Natural Resources of the Government of Honduras. It is an eight year, 50 million dollar project that has just completed its first year of operation. LUPE's dual directives are to enhance agricultural productivity on hillsides and to improve resource conservation. Stone wall terraces and alley cropping with fast growing, deep rooting leguminous trees such as *Leucaena leucocephala* and *Gliricidia sepium* are LUPEs technological monarches. Principal technical thrusts are: "1) Improved cropping systems—enhancing and diversifying technologies for producing maize, sorghum, beans, some cowpeas and peanuts, cassava, fruits, squash, vegetables, tree crops, and fish while conserving and improving the natural resource base; 2) Improved animal systems—enhancing animal health, grazing and range practices, and small animal management; 3) Post-harvest processing and storage—small silos, pest management, basic handling, processing and packaging at farm and community levels; and 4) Marketing—including assistance to farmers to secure market information and credit." The role of women also is an important component. Over its lifetime, LUPE is expected to reach 50,000 farm families which are generally eking a subsistence from small hillside plots of up to 5 hectares with slopes greater than 15 percent. Once geared up, LUPE will staff approximately 225 technicians, the majority of whom will be stationed at some 80 field sites. At present, LUPE has fielded some 150 frontline extensionists (both men and women) in approximately 40 agencies. These extensionists are supported by 32 technical specialists, 13 of whom have M.S. degrees. This network of extensionists facilitates rapid and direct dissemination of research results. Other components built into LUPE to support its initiatives are training and special services contracting.

Although LUPE was designed as an impact-oriented extension project, applied research is becoming an important concern, particularly, with regard to: developing new appropriate technologies; evaluating the effect of transferred technologies on natural resource conservation; and measuring the impact of introduced technologies on farm income. All CRSPs have research expertise that can be integrated with LUPE initiatives—specific research opportunities are discussed in Section VIII. One area of common interest that can be activated to bring LUPE and the CRSPs together immediately and at present funding levels is long-term training in U.S. universities. LUPEs training plan calls for 8-10 scholarships for advanced degrees in the U.S. with specialties in: agronomy/soils, agricultural economics/farm management, agricultural extension administration, small animal production, home economics extension, agricultural engineering, agronomy/crop diversification, and range/pasture management. These scholarship recipients could be placed with CRSP principal investigators at U.S. universities. Because of the international focus of the CRSPs, these students would conduct their research in Honduras on problems of high priority to LUPE. Not only would this add to the publishable results of LUPE by which similar development programs could benefit, but it would build collaborative scientist-to-scientist relationships that could be continued after the trained technician is reintegrated into LUPE.

Ministry of Natural Resources (MNR)

The MNR is currently being restructured for the purpose of reducing its size. Effectively, this restructuring will place the focus of the MNR on agricultural policy and reduce its agricultural services—including research. Although the MNR intends to maintain involvement in basic grains research which is considered vital for national food security, the private sector will be expected to address production constraints for other agricultural commodities. Nascent agricultural industries—*e.g.,* shrimp and melons—require technology and knowledge in order to develop their potential. Whether these industries meet their 1996 production and productivity goals (see Section V) depends on how they go about their growth and development. Research is needed—particularly in initial stages of development—to ensure that these industries get off to the right start, one that is capable of sustaining agricultural production. However, the need for research comes at a time when financial resources are limiting, before their potential has been developed. Intensification of CRSP involvement in Honduras not only would add to the scientific expertise needed to resolve important agricultural production constraints, but it would be a cost effective means for tapping existing technologies and developing new ones. One way MNR could assist the development of a sustainable agriculture systems is through the endorsement of research proposals to international donors that address these issues.

Although MNR does not play a direct role in research on some agricultural commodities, it plays a fundamental role in shaping the health and operation of agricultural systems. It does this through the formulation and reform of agricultural policy. Examples of policies in which the MNR is involved include: credit and financing, land transfers and acquisition, farm tenancy, marketing of commodities, regulating agrochemical imports, facilitating formation of businesses, protecting soil and water resources, and protecting the nation's food supply. Any effort to alter conventional agricultural systems means that agricultural policy will be integrally involved. Specifically, MNR policy involvement should encourage producers to adopt sustainable practices and minimize injurious conventional methods. Important issues on sustainable agriculture which the MNR may have to address include: funding research of alternative methods to identify their role in promoting sustainability; promoting sustainable shrimp production by wise use of water, nutrient inputs, and land; protecting estuaries from unnecessary farm discharge and agrochemical contamination; protecting water from agricultural chemical contamination; preventing soil erosion; nutrient management to limit contamination of water supplies from fertilizers; promoting the diversification of agricultural production; promoting the use of integrated pest management; integrating water quality protection standards into farm programs, determining individual liability for environmental contamination; and resolving conflicts between conventional and sustainable producers. Research contemplated in this concept paper would play an integral role in providing public information on which prudent policies could be formulated.

Program Concept

A succinct profile of the primary institutions conducting agricultural research in southern Honduras is presented above in Section VII. Each institution has complimentary strengths that can be pulled together into a systems approach to enhance agricultural sustainability and productivity in southern Honduras. For instance, the EAP has the bulk of the scientific expertise, but its outreach in southern Honduras is limited; FPX has extensive contact with medium and larger scale farmers on the coastal plains, but its research capability is limited, FHIA has adequate analytical laboratories for the task at hand, but limited scientific staff; LUPE has extensive contact with small scale farmers on hillsides and can field vast manpower, but it has little research expertise; and MRN has the mandate to formulate and implement policy which will guide agricultural development, but relies on the private sector for developing technology. Specific areas in which CRSP expertise can be brought to bear to bridge these institutions are: 1) develop a research program with LUPE that will fine tune its recommendations for hillside agriculture that not only will optimize productivity and resource conservation, but alleviate malnutrition; 2) develop rotation and alternative crops for melon producers on the coastal plain that not only will break insect life cycles and reduce the use of pesticides, but will improve melon production through improved soil physical and chemical characteristics; and 3) promote improved management practices in shrimp production and obtain base line information for formulating prudent policy which would conserve the natural estuarine resource base.

Bean/Cowpea CRSP

The Bean/Cowpea CRSP has been working in Honduras since 1983. It is the only CRSP project worldwide emphasizing the improvement of small red seeded bean germplasm, one of the two most largely consumed seed types in Central America. During the last years, two commercial bean varieties, 'Catrachita' in 1987 and 'Dorado' in 1990, were released in collaboration with the MNR and ProFrijol (Central American and Caribbean Bean Research Network). 'Dorado' was released in response to the widely and rapidly spread white fly-transmitted bean golden mosaic virus disease. Yield reductions by major bean diseases in Honduras have been quantified and recommendations based on integration control practices have been issued by the CRSP project.

The Bean/Cowpea CRSP would interact principally with LUPE and other CRSP programs on hillsides were beans and cowpeas are intercropped with sorghum and maize on small plots with soil/water conservation improvements. Both beans and cowpeas produce grain with high protein content and are an important nutritional source. High N-fixing bean and cowpea lines—inoculated with effective *Rhizobium* strains—are capable of deriving most of their N plant requirement from the air thru symbiotic N_2 fixation; these plants also contribute to the N balance in the soil. TropSoils could collaborate to determine how much N is available and its rate of mineralization; *i.e.*, conversion of organic nitrogen to ammonium and nitrate. Cowpeas are adapted to drought conditions and are being used at lower elevations in southern Honduras where common beans are difficult to produce. Additional funding would be required for testing cowpea lines introduced (large red seed lines would be better accepted by farmers) from other Bean/Cowpea projects. Interspecific *Phaseolus* hybrids which recombine desirable characteristics from *Phaseolus vulgaris* with *P. acutifolius* tolerance to drought are being developed at the EAP. Promising interspecific lines are available for on-farm testing in southern Honduras. These lines will extend the cultivation of beans into dryer areas and intercropping systems with short stature photoperiod sensitive sorghum. Selected beans or cowpea lines could be recommended for regional on-farm testing with LUPE personnel. Bean and cowpea plants can be used as fodder for cows and goats after grain harvest. Green pods of both cowpeas and beans can be consumed as a vegetable or sold at a good price in the market. The Bean/Cowpea project at the EAP could assist the Peanut CRSP with germplasm evaluation at the EAP and on-farm trials with LUPE.

Fisheries Stock Assessment and Pond Dynamics/Aquaculture CRSPs

The Fisheries Stock Assessment and Pond Dynamics/Aquaculture CRSP would collaborate with FPX in assisting the shrimp industry become more efficient and competitive in the international market. It would also work with the MNR in dealing with multiple use of riverine, estuarine, and gulf resources. Specific areas of research could include: 1) generation of baseline data about adult and larval shrimp population structure in the major estuaries of the Gulf of Fonseca; 2) establishment of a data base for climatic and water characteristics that might influence shrimp populations; 3) water quality determination of farm supply and discharge water; and 4) delineation of the effects of different management strategies on shrimp production. Information generated from some of these research initiatives could be used in formulating zoning laws to protect shrimp reproduction areas in the estuary.

<u>Training and Networking</u> - Implementation of the whole project in an integrated ecosystem approach would require a professional scientist be placed in-country. Fisheries Stock Assessment or Pond Dynamics/Aquaculture CRSP could place a temporary scientist in Honduras while one or two Hondurans complete their Ph.D. degree programs at a CRSP university. Upon completion of their education, these individuals could return to work with FPX and/or FHIA. Intensive short course training in methods of stock assessment and optimizing management strategies could be provided to a small core of shrimp farmers at CIMAR in Costa Rica. Training of a larger group of producers could be conducted in Honduras at the EAP and/or on-site in Choluteca. All these initiatives would require outside dollar funding.

Human Nutrition CRSP

The Human Nutrition CRSP would target small-scale farm families living in the area of influence of LUPE. This provides the opportunity to study marginal malnutrition in its natural context. In addition, the proliferation of new food crops induced by LUPE, presents the opportunity to develop and monitor appropriate intervention strategies for marginal malnutrition. The Human Nutrition CRSP could also interface with the women outreach component in LUPE and blend human nutrition concepts with food processing technologies developed in other CRSPs. There are a host of activities that the Human Nutrition CRSP could undertake. Those concerning the alleviation of dietary constraints are:

<u>Seasonal food shortages</u>. Improve storage of food grains and legumes. Introduce techniques for drying fruits and vegetables to preserve b-carotene.

<u>Inadequate supply of fruits and vegetables</u>. Increase home gardening activities in connection with vitamin A programs to improve b-carotene rich vegetable and fruit supplies. Improve caloric generation activities of women through horticulture.

<u>Young child malnutrition</u>. Develop concepts of diet balance. Analyze commonly used weaning foods and develop improved mixed weaning foods based on availability of food stuffs. Conduct field trials following growth and health of young children on improved diets. Determine impact on diet intake quality and quantity and growth of children. Provide health and nutrition education through women's groups at the household and community level on timing of introduction, preparation, and ingredients of weaning foods and feeding sick children.

<u>Poor diet quality</u>. In cooperation with the Small Ruminants CRSP, increase household utilization of meat and milk products from small ruminants. In concert with the Pond Dynamics CRSP, introduce fish with simple food processing and storage techniques.

<u>Vitamin deficiency</u>. Monitor vitamin A, riboflavin, and ascorbic acid deficiency and provide improved efforts at vitamin A nutrition.

Promote dark green leafy vegetables and b-carotene containing foods. Introduce malting or fermentation techniques of cereals to improve caloric density and B-vitamin content.

High infection rates. Direct linkages to child survival programs of diarrheal disease management, growth monitoring efforts, and immunizations to reduce infection incidence. Link water resources activities to safe water supplies and iodination of water supplies.

Networking. Linkage with the Ministry of Health could be established in order to extend results to rural families nationwide.

Peanut CRSP

The Peanut CRSP could work with LUPE to extend peanut production and utilization on hillside farms. Presently, subsistence farmers plant peanut on more than 100 ha in arid areas near Soledad, El Paraiso. Peanut is the preferred crop in this area due to its drought tolerance. Utilization projects in the Peanut CRSP could collaborate with LUPE in developing value-added products like salted peanuts, cleaned roasting stock (in shell), and peanut brittle. Not only would these enterprises usher peanuts—an important source of high protein and energy for humans—into the daily diet, but they would increase small farm income in areas where inadequate purchasing power is considered the primary cause of hunger. Also, utilization projects could work with women groups and the Nutrition CRSP in improving diet balance and weaning foods. Peanut CRSP interaction with LUPE and the Pond Dynamics/Aquaculture CRSP is also conceivable since green leaves from peanut plants can be used to feed grass carp or in a compose to enhance pond productivity. Introduction of improved peanut germplasm for testing on-farm by LUPE extension agents could be accomplished at present funding levels. Basic seed of adapted varieties could be maintained at the EAP.

Coastal Plains. The Peanut CRSP could work with FPX in developing alternative cropping systems for melons which include rotation and strip intercropping. Cultivation of peanut does not damage the environment, but rather enhances it. As a legume, peanut fixes atmospheric nitrogen through bacterial symbiosis and thus returns nitrogen to the soil. Integration of peanut into present cropping systems would improve soil fertility and soil structure plus help break life cycles of melon insect pests. The irrigation infrastructure used with melons, also could be used with peanut to obtain yields of 3000 kg/ha or higher. Resulting production would satiate local demand for commercial peanuts.

Training and Networking. Peanut CRSP could provide short course training in peanut husbandry and utilization at the EAP. The food processing section at the EAP could become involved in developing local capabilities for making peanut butter and other commercial food stuffs including confections and oil. The microbiology section at the EAP could collaborate in developing and maintaining effective nodulation strains of *Rhizobium* that are adapted to southern Honduras. This involvement is important, particularly when introducing peanut into soils where legumes have not been grown for several years. Once good *Rhizobium* nodulators are established, application of inorganic nitrogen fertilizers on peanut is not necessary. Also, application of inorganic nitrogen fertilizers on rotation crops like peanut could be reduced. This works in favor of public health because it minimizes the contamination of groundwater with nitrates from excessive use of inorganic fertilizers.

Pond Dynamics/Aquaculture CRSP (PD/A CRSP)

The PD/A CRSP has an MOU signed with the MNR and is based at the El Carao National Aquaculture Research Center in Comayagua. The Collaborative Research Support Program in Pond Dynamics was established in Honduras in 1983. Since that time, research has been conducted in the use of inorganic and organic fertilizers, artificial diets, and combinations of fertilizers and artificial diets for fish production. The goal of this work has been to increase the profitability of fish production by small and mid-size commercial producers using a technology that relies heavily on enhancement of pond natural productivity. Research on the use of organic and inorganic fertilizers for reducing feeding costs on semi-intensive shrimp farms has been conducted in Choluteca. A system for greatly increasing the efficiency of tilapia fingerling production in

Honduras was developed by the PD/A CRSP. Recently, a program for screening indigenous fish species for pond culture was initiated with El Carao personnel. FPX is interested in promoting the culture of fish for export and at least one farm is being built to supply fish for this market. The internal market for fish is good, but the quantity of fish that the market can absorb is unknown. Aquaculture has been integrated into LUPE, but little has been done in this area during its first year. The major constraint to expansion of aquaculture at all levels in the country is transfer of technology and information. LUPE extensionists have received little, if any, training in aquaculture. In country, short term training—1 to 2 weeks—for LUPE extensionists could be given in various aspects of aquaculture such as pond construction, production systems, and fingerling production. Short term assistance from the U.S. would be necessary. Intensive long term training in the U.S. for selected extensionists is also available. Auburn University offers an annual 4-month aquaculture training course that would be ideal for this purpose. Similar training could be provided to FPX for the purpose of developing an extension service capable of assisting in the design of aquacultural facilities and transfer of technology related to semi-intensive aquaculture. Specific training in water sample collection and water analysis for the FPX water laboratory could also be provided.

Because LUPE is directed toward the hilly, dry lands of southern Honduras, integration of aquaculture would be site specific. The major constrains would be a supply of gravity fed water, and an appropriate site for pond construction. However, the potential benefits from water harvesting integration with other farming enterprises, production of a high quality protein, and income generation make aquaculture an under developed resource to small farmers.

Small Ruminant CRSP (SR-CRSP)

The (SR-CRSP) has the opportunity to improve the meat and milk production from goats on hillside farms and dryer areas of the coastal plain in southern Honduras. Specifically, the SR-CRSP could work with the EAP in broadening the genetic base and gene pool of goats in Honduras. Also, it could interact with LUPE in developing more productive mixed-farming systems; particularly, those combining goats and tree crops. For marginal areas on the coastal plain, it could collaborate with other MNR sponsored projects in developing sustainable agro-pastoral systems.

Sorghum/Millet CRSP (INTSORMIL)

INTSORMIL has designated Honduras as its prime site in Central America and has operated there since 1981. INTSORMIL has a MOU signed with the MNR, EAP, and the Honduran Institute of Anthropology and History (HIAH). The MNR contributes the equivalent of $90,000 annually in local currency to cover counterpart costs in sorghum research. These funds are provided through the USAID PL480-Title I program and are administered by the EAP. Also, INTSORMIL works with LUPE in developing and testing new sorghum cultivars for alley cropping systems on hillsides. Twelve INTSORMIL projects have collaborated with MNR, EAP, and HIAH to form a multi-disciplinary approach to resolving local sorghum production constraints.

The collaborative research network put in place in Honduras by INTSORMIL serves as a model for integrating other CRSPs into a systems approach for developing sustainable agricultural in southern Honduras. Much of INTSORMIL's research in Honduras has been carried out by graduate students—many of whom are from Honduras—and Honduran collaborators. A Texas A&M University (TAMU) scientist is stationed at the EAP to coordinate sorghum research activities in Honduras. The socioeconomic project at the University of Kentucky (UKY) has collected base line information on farming systems in southern Honduras. Nutrition projects from UKY and Mississippi State University (MSU) have collected base line information on the nutritional status of rural families in southern Honduras. Based on their findings, three breeding programs at Texas A&M University, and one in Honduras, introduced and released conjointly with the MNR three sorghum cultivars—'Tortillero,' 'Sureño,' and 'Catracho'—in the mid-80s. Both Sureño and Catracho are high yielding dual purpose cultivars that can be used by both large and small farmers. Sureño's intermediate height and sweet stem also makes it suitable for making silage for cattle. Its superior tortilla grain quality and resistance to head molds makes it a favorite with subsistence farmers and they use it as a relay crop with maize. combination of improved sorghum varieties and soil conservation techniques promoted by LUPE increase net farm income by 25 percent.This breeding effort is backstopped by the cereal quality laboratory at TAMU which assists in the selection of cultivars with improved cereal properties for making tortillas; the pathology project at TAMU which assists in the identification of genes that confer disease resistance and development of efficient screening techniques; and two entomology projects at TAMU and MSU which work with MIPH on integrated pest management of sorghum and maize insects in southern Honduras. Predominant soil insect pests have been identified and the effect of slash and burn vs slash and mulch, and tillage vs non-till cultural practices on these populations have been determined. Present IPM research is directed at a complex of lepidopterous defoliators called "langosta." Biological control agents, host plant resistance, cultural practices, and chemical seed treatment are all elements in the IPM approach. Economic impact studies of Sureño and Catracho have been conducted by the economics project at Purdue University.

Hillsides. INTSORMIL would continue to work with LUPE by developing photoperiod sensitive sorghum varieties and hybrids for hillsides. These cultivars are essentially improved local landrace sorghum populations which are adapted to intercropping with maize and have intermediate height (2 m), increased levels of disease and insect resistance, and higher yield potential than local cultivars. These cultivars also would have application to El Salvador, Guatemala, Haiti, Nicaragua, and parts of Africa.

Coastal Plains. INTSORMIL could open a new initiative with FPX to promote high yielding tropically adapted sorghum hybrids for the coastal plain. These commercial hybrids not only offer a cash crop rotation alternative for melons, but they would help break melon insect pest life cycles which, in turn, would reduce the use of pesticides and thereby increase profitability and diminish environmental damage. Also, production of sorghum hybrids would help meet increasing demand for feed grains resulting from expansion of the cultivated shrimp industry and intensification of land use in livestock operations. Greater reliance on feed grains and silage enhances the efficiency of land use by making high quality land now in pasture available for crops. Also, it would improve the productivity of the livestock sector and make more dairy and beef products available to satisfy increasing demand. Broomcorn is another alternative that could be introduced and used in border rows with melons. Sorghum border rows interspersed in melon fields have been shown to reduce the dissemination of aphid-borne viruses.

TropSoils CRSP

TropSoils can play an integral role in research in each of the three agro-ecological zones—hillside, coastal plain, and estuaries.

Hillsides. Soils research can address various aspects related to soil/water conservation, soil fertility and crop production. Water is in limited supply about six months out of the year. Improved water conservation and reduced erosion during the wet season may be attained by improving the soil physical and chemical status. The use of rotation crops such as bean, cowpea and peanut may provide soil physical and chemical benefits in addition to alternative food sources. Soil and water conservation not only maintains or improves soil productivity, but reduces the occurrence of peak hydrologic events and sediment loads in the downstream areas of the watershed, especially in the shrimp-producing estuaries. Estimation of nitrogen availability from organic N sources such as rotation crops and leguminous trees is required to optimize the fertility status of such soils.

Coastal Plains. Concerns exist about the effect of agrichemicals on water quality in the watershed. Of particular concern is the use of insecticides and their effect on shrimp larva populations. Opportunities exist for reduction of agrichemical use through the use of rotation crops (*e.g.* peanuts, beans) which can break insect pest life cycles, provide additional cash income and organic sources of nitrogen, and improve soil physical conditions. Soils research can focus on nitrogen dynamics and soil structural improvement. In addition, solute transport processes can be studied to determine the quantities of pesticides/fertilizer chemicals lost to the environment and the pathways along which they reach groundwater.

Estuaries - TropSoils research can include analyses of soils and land use in the watershed which can be used to identify potential sources of contaminants and estimate the adverse effects of land use practices on water quality in the watershed. The feasibility of alternative management practices and their effects on the watershed in general and the estuary in particular can be evaluated through the use of geographical information systems. Subsequently, a watershed management plan can be developed which considers land resources, environmental quality, and economics.

Banquet

Master of Ceremonies: George Teetes

Address

International Agricultural Research Collaboration - Coordination and Integration

presented by

W.T. Mashler, Chairman

ICRISAT Governing Board

International Agricultural Research Collaboration - Coordination and Integration

W.T. Mashler[1]

The twentieth century has the dubious distinction of having witnessed more bloodshed, violence and misery than any other, and, some say, more than all preceding centuries together. Having lived through much of the misery, and having suffered through some of it myself, I hope that these years will stand as a powerful lesson to coming generations of what humanity is capable of contriving and what civilization has a duty not to repeat.

Yet, this is the same century that has seen remarkable advances in the area of science and technology, which has changed and improved the material quality of life more so than at any time before. And lately, we are also seeing with growing gratification, changes in attitudes that are bringing about improvements in the political life of many countries - the liquidation of colonialism; the emphasis on human rights, and the concomitant need for creating, safeguarding and maintaining conditions of freedom which is the major prerequisite for enabling people, through the free exercise of creativity and self expression, to enjoy a better life and to look to the future with confidence and courage.

This is not to say that there will not be lapses and setbacks, but I believe that there is a growing vigilance among people and their governments to seek to maintain and to expand newly won freedoms wrested from their oppressors at the cost of great suffering and sacrifice. In short, freedom is a central precondition for progress.

Why do I allude to these issues at a conference on sorghums and millets? Because research on these and other commodities depends, as in all other areas of human endeavor, on precisely the conditions that make it possible to achieve improvements in the objectives which are the focus of our attention. I need not tell you, Ladies and Gentlemen, that agriculture is and will remain, for as long as we can gaze into the future, one of the most essential elements in human survival. It is a fact easily overlooked in a world increasingly fascinated by more exciting and novel research activities with seemingly greater immediate impact.

In other words, in our part of the world, agriculture has come to be taken for granted, except when prices, subsidies and regulatory issues affect our pocketbooks; or when environmental factors threaten our sources of nourishment. I therefore believe it is imperative to draw attention to our obligation to sustain agriculture, if agriculture is to sustain us.

In the international area particularly in those countries which until the middle of the century had been under colonial rule, the emergence of the international agricultural research centers, was an essential response to the need to feed a rapidly growing populations and to ward off starvation. During the post-war years the threat to food production grew at an alarming rate. Food crop failures were on the rise and weakened the economies of the colonial powers in the post-war period did not hold much promise for investment in subsistence agriculture. Furthermore, during the colonial era, investments in export crops, benefitted the colonial powers at the expense of indigenous farming communities. At the time of independence, the governments of the newly formed nations took over the production of export crops. They had little experience or training for operating them, and their operation added yet new burdens of many of the newly independent countries.

At the same time, subsistence agriculture dealing with "subsistence" food crops did not even remotely resemble the well established

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agricultural market economies of developed countries. Hence many newly independent countries were forced to import food from the west to make up for local shortages with the concomitant loss in foreign exchange already in short supply. They were increasingly forced to borrow funds from abroad to pay for their imports.

It is against this background that we recall with pride and admiration Dr. George Harrar, President of the Rockefeller Foundation, and Dr. Forrest (Frosty) Hill of the Ford Foundation, for their the vision for setting up the first two international agricultural research centers. CIMMYT and IRRI's successes in developing high yielding varieties led to the creation of CIAT, IITA and CIP, and subsequently to the creation of the Consultative Group on International Agricultural Research in 1971. The CGIAR sought to benefit the developing countries by concentrating research on basic food crops and farming systems. Today, the CGIAR encompasses sixteen centers, with more to be added in the near future. Those of us who played a role in creating and shaping the CGIAR take pride in the knowledge that this great endeavor was based on practical as well as humanitarian considerations. It produced the strong support, both material and scientific, of donor countries, international organizations, foundations and other organizations which were caught up in the enthusiasm emanating from the truly exciting potential of well-organized and focused research.

It should also be recognized that the strong foundations that had been laid by organizations and scientists in the US, Canada, Australia and other countries and their cooperation in this new effort were essential elements in this novel operation. Thus from the start, the coordination and integration of agricultural research assumed a truly international character. It is amazing, to see how many scientists from developing countries were trained in institutions in developed countries significantly those in the United States, Canada and Australia. These countries each had a colonial past and having used their great natural resources, had become important bastions of agricultural production, research and reservoirs of institutions and knowledge which would become crucial elements in backstopping the emergence of new institutions in the developing world. In the case of India, our Land-Grant Universities played an important part in organizing the country's Agricultural Universities. At the same time, training agricultural scientists transcended national boundaries on a large scale with great benefit to all concerned.

In short, from the beginning of the organized international agricultural research effort, many new important bridges were going to be built, in addition to those that already existed. And unlike real bridges, those built through agricultural research have been and continue to be maintained admirably. They are the most basic network made up of people who out of scientific curiosity, and the desire to further and promote knowledge in their chosen profession to strengthen the cause of science, are cooperating with each other across national boundaries, continents, and oceans. In other words, science itself and by definition is inherently a cooperative endeavor.

When I listen, as a non-scientist, to the many discussions on the need for forming networks and co-operative links, I hear virtually no mention of these crucial links that have little formal character, but which I suspect are the strongest element in collaboration - and the deepest. To illustrate the point, as Chairman of the Search Committee to select a Director General for ICRISAT, I discovered that the largest number of addresses from whom nominations were solicited turned out to be individuals and collaborating scientists of ICRISAT. It was from that large segment of international agricultural collaboration that the core of our candidates were nominated and ultimately chosen. The three finalists were nominated by individuals. Hence, I want to stress that collaboration and coordination in agricultural research has strong and firm foundations.

I represented a donor agency, UNDP, at the founding of the CGIAR, and for the next 14 years I attended all of its discussions. Today, the recurrent theme about the need to work closely with national agricultural research systems and universities has reached a level of deja vu. Now that I am a Board member, I see even more clearly than before that the international centers have only one prime objective imposed upon them by their mandates, to conduct quality research on food production using all the available knowledge, expertise and institutional support to benefit the widest spectrum of their target populations in the developing countries.

I now move specifically to the Center which amongst its five mandate crops has two - sorghum and millets - which are the focus of your attention. The International Crops Research Institute for the semi-Arid Tropics, the first Center to be created in 1972 by the CGIAR itself. The Center was created to serve the peoples of the semi-arid tropics, an area encompassing one fifth of the world's land mass and an equal portion of its population. ICRISAT is the only center that from its inception has had a dual mandate: one being its crops mandate involving chickpeas, pigeonpeas, sorghum, millets and groundnuts; the other being a geographical mandate covering the semi-arid tropics. Implicit in these mandates is ICRISAT's objective to use all facilities within and outside the SAT to achieve its goals.

Just recently ICRISAT completed its 10-year Strategic Plan entitled "Pathways to Progress". The Plan represents the Institute's vision of its challenges in research and education strategy during the 1990s. We concluded that if present trends of production and population growth continue, net food production shortfall in the Third World will be 100 million tons by 2000. Africa will be the major victim of this deficit, but Asia also will experience severe shortages. At the same time, global growth and demand for cereal feed in the SAT will escalate.

The productivity of ICRISAT's mandate crops must therefore be increased in the SAT to guarantee adequate supplies of food for the small-scale farmer and to ensure that grain surpluses will provide food for urban populations and income for the farmer. ICRISAT must fit its mandate crops into different farming systems while addressing a range of ecologies and demands and providing an array of options to the farmers.

To meet this challenge, ICRISAT is determined to make agriculture more sustainable and profitable in the SAT and other resource-poor regions. Only then can the people improve their lives, achieve greater food security and contribute effectively to national development.

Some major elements of ICRISAT's mission over the coming years will be to use natural and human resources more judiciously. We will undertake this mission in partnership with national agricultural research systems and other institutions. At the same time we will encourage the NARS to accept research responsibilities to solve their problems and quickly provide technologies to their farmers.

Finally we will adjust our research to meet shifts in research responsibilities within this partnership. ICRISAT's mission is:

- to foster, facilitate, and conduct research on mandate crops, resource management, technologies, and institutions.
- to aim to increase the productivity, versatility, and stability of ICRISAT's mandate crops and suggest appropriate ways of fitting our crops into existing and improved farming systems.
- to emphasize a more judicious use of natural and human resources
- to undertake our mission in partnership with National Agricultural Research Systems (NARSs) and other institutions.
- to encourage NARSs to accept research responsibilities to solve their problems and quickly provide technologies to their farmers.
- to adjust our research to meet shifts in research responsibilities within this partnership.

The mission statement within our strategy is not novel. Rather it is an expansion of an emerging dynamic policy that has been part of ICRISAT's work since its inception.

Indeed from the start, ICRISAT focused on two major areas:

The first was the center's relationship with the Indian Council of Agricultural Research (ICAR). ICAR evolved into an important Indian Agricultural Research institution with a track record of excellence. It was seen by ICRISAT as an institution which could complement ICRISAT's work rather than compete with it. The record of cooperation between these organizations has been outstanding and is an enviable one to be emulated by others elsewhere. This is an extremely important development because looking back over 18 years of collaboration between these two institutions I find few other examples where collaboration and complementarity have nurtured both partners and achieved such salutary results. In addition, complementarity of economies of scale have been achieved making it possible to expand our respective efforts and making impact more telling.

The other area where ICRISAT took an early initiative was Africa where already at the creation of ICRISAT's mandate it was expected to play an important role in looking in its huge semi-arid areas. As early as 1975 plans were made to lay the foundation for ICRISAT's African program for the improvement of sorghums and millets. The rationale for the start of such a program at a time when ICRISAT was only 3 years old was the realization that if meaningful research on mandate crops was to take place it had to be undertaken in all parts of the SAT in different ecological and climatic conditions and cultures.

I recall that when we began to discuss a program for African SAT there was considerable doubt whether ICRISAT might not get ahead of itself too fast to the detriment of its mission. As it turned out, our decision to move ahead was justified. It imposed upon ICRISAT early in its life a wider responsibility for expanding research in support of its global mandate. At the same time it gained valuable experience and knowledge in the research was carried out in response to the diverse conditions to be addressed in the huge area that is the SAT. ICRISAT also initiated cooperative research with and in support of many NARS in the Sahelian area, where no formal regional institution previously existed which could serve as a bridge between international research centers and NARS. Here much valuable work was done together with the French institutions with which ICRISAT maintains to this day close relations, particularly with CIRAT.

The fledgling program of 1975 has now become an important institution. The ICRISAT Sahelian Center in Niamey, serves the Sahelian area in close collaboration with the regional NARS. This regional Sahelian research effort of ICRISAT was followed in 1984 with the establishment of the SADCC/ICRISAT Program for the Southern African region which now serves 10 countries in the semi-arid tropics of southern Africa in close collaboration with the Southern African Center for Cooperation in Agricultural Research (SACCAR). Close links are also being maintained in developed countries, particularly, the United States. It is to be hoped that once the problems in South Africa are finally resolved, this country will, with its own considerable experience in dryland agriculture, play a role in the development of that region. Finally, and most obviously, ICRISAT has many collaborative arrangements with ICARS within the CG System and with some of the non-associated centers.

In addition to these major collaborative efforts, ICRISAT has recognized the importance of developing networks dealing with specific crops and commodities which will associate developing countries, institutions in regional and global organizations to promote the development of research and the transfer of technology. In West Africa several networks unite research activities on improvement programs, pests and diseases and abiotic constraints. These are principally the SAFGRAD and WCASRN networks into which ICRISAT provides important inputs. In eastern Africa the EARSAM network unites the work of six national programs with ICRISAT. In southern Africa the SMIP activities promote the cultivation of both cereals throughout the 10 countries of the region, and in Latin America LASIP involves work of seven countries with that of ICRISAT scientists.

Linkages between ICRISAT and regional and international organizations as well as between ICRISAT and national programs were greatly strengthened in the 1980s by the establishment of these networks and other programs. We expect to strengthen these linkages through closer partnership in research. As national programs improve, we encourage them to assume an increased leadership role in the technical cooperation framework designed to:

- upgrade research and technical skills,

- identify problems and set priorities for research,
- allocate resources to support research aimed at generating sustainable agricultural systems,
- channel the flow and analysis of information between national programs, mentor institutions, and IARCs, and
- identify research and development activities of IARCs that can eventually be taken over by national systems.

Partner scientists in the national programs and mentor institutions work in close collaboration with ICRISAT scientists on many research projects. We have more than 70 collaborative projects under a formal agreement with the Indian Council of Agricultural Research alone. Most of our research in the SADCC region is undertaken in cooperation with national program scientists. This collaboration is a major contribution to building research capacities on our crops in southern Africa.

A fund has been established under the control of ICRISAT's Deputy Director General to initiate new research projects with national program scientists in SAT Africa. This has resulted in cooperative studies on sorghum pathology in Rwanda and Kenya, on sorghum grain quality in Kenya, Ethiopia, and Sudan, and on land and water management on Vertisols in Ethiopia. We hope to involve more women scientists in these projects.

In western Africa, we work closely with scientists in regional organizations in Mali, Niger, Burkina Faso, and Nigeria.

A major Regional Sorghum Research initiative is being planned by ICRISAT and will be the subject of discussion at a Consultative meeting to be held at ICRISAT Centre in mid-September of this year. The goal of this meeting is to consider the need to initiate a regional sorghum research network for Asia with the following objectives:

(a) Exchange of improved genetic material, germplasm lines, research methodology, and screening techniques between ICRISAT Centre and the national programs and among national programs;

(b) Improved inter-country interaction through workshops and monitoring tours;

(c) Initiate co-operative research activities for one or more economic products or sorghum among scientists;

(d) Effective initiation of a human resources development program with emphasis on sorghum for the benefit of national researchers and technicians.

These are examples of the kind of cooperation that has been and remains to be one of the central functions of ICRISAT; it has always been ICRISAT's policy to achieve early transfer of technologies that could benefit the farmers in its client countries. Here again collaboration with partners is a fundamental precondition for success. You will be interested to know that ICRISAT is the only center within the CG system that has had a Technology Transfer Committee within its Governing Board. It advises on appropriate ways and means of maximizing research output to the benefit of agricultural development. Technology transfer obviously must take place by making optimal use of national institutions in user countries, and we expect this practice to be enhanced and accelerated in the years to come. I am pleased to acknowledge here the important link and cooperation which ICRISAT has enjoyed with INTSORMIL over many years, and I wish to express our gratitude to INTSORMIL for the important and fine contribution it has made to ICRISAT in our collaborative programs.

You may well ask how effective are we and how can we become better? There's no easy answer, but I will give you my views of how I see the output of ICRISAT, and for that matter of other centers, in terms of its usefulness and potential. The stress on strengthening NARS is a logical step in an effort to promote change. What is not so obvious is the effectiveness on the transfer of technologies from all centers to NARS to achieve improvement in agricultural production. It needs to be recognized that strengthened research alone is not a guarantee for improvement in agricultural production. Improved agricultural production depends on a country's willingness to invest in its total agricultural system, of which research is only one part, albeit an important one. If we isolate agricultural research from all the other elements that are essential to the creation of an improved agricultural climate, we will simply have brought the output and the potential benefits of international agricultural research down to the level of national agricultural research organizations from whence it may not reach farmers' fields because the rest of the system is not in place. In Asian countries such as India, Pakistan, and others, large investments began to be made in agriculture in the 50's and 60's. This trend still continues and for that reason the output of agricultural research in these countries, was capable of being optimized. Where these conditions are absent, and they still are in many other countries, particularly, in Africa, no amount of good research can remedy the situation. This is an important fact to remember.

International centers have directed their efforts toward conducting meaningful research within their mandated crop areas. They are not intended to be instruments of change in agricultural policy. Neither can they become instruments for providing technical assistance. What they can do best is what they are good at doing: to improve by research and to make available germplasm and technologies, and help through training of scientists to strengthen the NARS.

To sum up: as you will see the quality and quantity of collaborative research at all levels has been quite satisfactory and has on the whole been remarkably successful. It has grown over the years and the linkages that have been established are firmly in place and holding. It seems to me, however, that there is one area where international cooperation and collaboration has not been sufficiently developed, and on which we will need to focus more sharply. It is the creation of a greater awareness amongst parliamentarians who have control over the allocation of the funds that support our several research efforts the essential need to support research. I fear that at this time when so many other issues preoccupy the attention of governments and legislatures, agriculture is beginning to take a back seat. Indeed, at a time when much additional research needs to be mounted to safeguard the health and nutrition of rapidly growing population, it is surprising that questions are being asked about the need for so much continued research in agriculture. Addressing an audience such as this I need not elaborate on why it is necessary. We all know the answer, but if we are to succeed in protecting food production we must augment our scientific preoccupations by keeping contact with and an eye on those on whom we depend for the funds that enable us to do our job. And I submit that in years to come we had better build bridges with politicians and legislatures in order to inform and convince them of the efficacy of our work. More than that, we need to articulate clearly that the role played by research is totally out of proportion to its cost.

We need also to concentrate in the future on meeting the challenges that are posing problems which we must address with vision and with determination if the gains that have been made are not to be lost. Agriculture is an important part in mankind's survival, but only one part. Modern life has brought changes which in their application and development require constant vigilance, if they are not to become detrimental to life and the environment. We cannot afford to take for granted what the good earth offers us. If we do we are inviting disaster and we are well on the way to it. If we are to save the resources we have, we must face up to our responsibilities to use them wisely and stop paying lip-service to the issues, as I fear too often we still do. We need to select better leaders in all walks of life and be prepared to pay the bill. We cannot demand what happens to be desirable without considering the consequences. If we fail, all the gains that have been achieved at such high cost will ultimately be lost. Beware of lethargy and neglect.

Let me finish with the reflection that political revolutions are in abundance - I wish there were only a fraction of their number in the areas of health, nutrition, education, and a better environment for the benefit of all mankind.

Session IV: Networking

- SADCC/ICRISAT Sorghum and Millet Network
- The IRAT Sorghum Program Highlights and Areas for Interaction with INTSORMIL

Session Chair: Timothy Schilling

Speakers: Lovegot Tendengu
Alain Ratnadass

SADCC/ICRISAT Sorghum and Millet Network

Lovegot Tendengu[1]

Introduction

ICRISAT Centre has two dominant networks consisting of the cooperative cereals research network and technology transfer network. The Cooperative Cereals Research Network (CCRN) was initiated at ICRISAT Centre in 1988 to work towards providing support to national programmes. Through the CCRN, international sorghum trials and nurseries are organized to provide the NARS in Asia, Africa and Central America access to improved cultivars in the world for their use in breeding programmes and the ultimate transfer to farmers. Elite material originating from the NARS are evaluated over a wide range of agroclimatic conditions.

In Asia, the activities comprise exchange of genetic material, visits, joint evaluation of trials and nurseries, and training. In West and Central Africa, the network was formalized in September 1987 by forming the following:

a) a steering committee consisting of six representatives of the NARS;

b) a coordinator from ICRISAT and

c) three observers from SAFGRAD, ICRISAT and INSAH/CILSS (Institute du Sahel, Mali/Comite permanent inter Etats de lutte contre la Sechresse dans le Sahel, Mali).

The East African Regional Cereals and Legumes (EARCAL) has been further strengthened by the placement of a pigeon pea agronomist/breeder.

SADCC/ICRISAT/SMIP Network

The SADCC/ICRISAT/SMIP network is unique in that it is not as formalized as other networks which are characterized by a coordinator, steering committee and observers. This leads some people to question whether SMIP is a network or not.

SMIP is indeed a network characterized by a high level of collaborative work geared towards responding to the needs of NARS which are in turn a reflection of the farmers' needs in the ten SADCC countries. Because of the very high level of communication and cooperation between NARS and SMIP, some of our activities tend to be country specific and thus it becomes difficult for us to devote uniform resources and effort to each country.

For example, *Striga* studies and research on photosensitive materials is prominent in Tanzania while food technology research is prominent in Botswana. Station development and management is prominent in Zambia, while forages research stands out in Botswana, Swaziland, Mozambique, and Zimbabwe. Marketing and policy features are prevalent in Zambia and Tanzania, while in Namibia, pearl millet research is dominant.

In all countries, Human Resource Development features top on the agenda as we strive to develop national research capabilities. Education and training have been tailor-made to meet the specific needs of respective NARS. Also outstanding with the SMIP network is that each NARS scientist whom we work with is a colleague or a working partner. This democratic and informal approach to collaborative networking ensures sustainability of the national programmes as we gradually work ourselves out of the programme.

Having given that scenario, one can now look at the components and mode of operation of the SADCC/ICRISAT network.

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Components and Operation

The main objective of the SADCC/ICRISAT network is to strengthen research capabilities of NARS through the following activities:

1) collaborative research

2) assistance to NARS by provision of physical facilities and station development, and

3) human resource development.

The project or programme, established in May 1984 in response to the invitation by Heads of SADCC states, is viewed as a SADCC Sorghum and Millet Improvement Programme executed by ICRISAT. Thus, there is a very close working relationship between the programme and SACCAR (Southern African Centre for Cooperation in Agricultural Research and Training). The SACCAR Director chairs the annual meeting of the Technical Advisory Panel while the SMIP Project Manager presents an annual report to the SACCAR Board.

Collaborative Research Activities.

SMIP scientists have a component of their activities in development research while the other component is for evaluation and adaptation of research accomplishments. About 30% of each SMIP scientists' time is spent with NARS scientists.

<u>Breeding</u>. Breeding is confined to sorghum, pearl millet, finger millet and forages. After evaluating introductions, the best go into national programmes and into regional programme nurseries and crossing blocks. Selections from these are eventually included in preliminary trials and their regional trials.

Through joint effort between SMIP and NARS, the network has made significant contributions to the region as exemplified below.

- In Zambia, two sorghum varieties, Kuyuma and Nzima, plus the hybrid WSH 287 have been released, while the pearl millet variety Kaufela has been released. Finger millet variety Lima has been released.

- In Zimbabwe, our Ph.D. INTSORMIL participant, who happens to be the national breeder, has released SV-1 and SV-2. Also, pearl millet variety RMP-1 has been released. One hundred and thirty farmers have collected, from Matapos, Banna Grass (pearl millet X Napier) for forage production.

- In Botswana, six varieties of sorghum SDSL 87019, SDSL 87020, SDSL 87021, SDSL 87013, MP 623 and Macia and one hybrid (SDSH 19) have been identified in Pandamatenga for use in a weaning food project with Foods Botswana.

- In Namibia, pearl millet variety Okashana-1 was released three years ago. In 1990, SMIP sent about eleven tons of seed to Namibia for distribution to farmers.

- In Swaziland, two brown varieties of sorghum have been released while fifteen farmers have, to date, collected cuttings of Banna grass.

- In Mozambique, two white varieties of sorghum Macia and Mamonhe have been released but civil strife has prevented meaningful production and marketing of seed.

- In Malawi, two varieties of white sorghum have been released.

- In Tanzania, efforts are being made to select long season material coupled with concerted efforts on striga research.

- In Lesotho, sorghum demonstrations have been carried out for two years.

<u>Agronomy</u>. Collaborative research is being carried out on stand establishment, growth variability, plant density, spacial arrangement, moisture, fertility, effects of planting dates, nematodes and various cultural methods. Interaction with national scientists has led to site specific research.

<u>Pathology</u>. Seven diseases have been listed to be of major concern. They are ergot and downy mildew in pearl millet. In sorghum

they are downy mildew, leaf blight, sooty stripe, anthracnose and ergot.

Resistance has been found for ergot and downy mildew in pearl millet, while in sorghum it is for leaf blight and downy mildew.

Entomology. Specific networking efforts have been initiated in Zimbabwe, Botswana, and Zambia where the collaborating scientists are also research scholars working on country problems.

The Botswana candidate is doing Ph.D. research on the sugar cane aphid; the Zimbabwe candidate who is also head of entomology is doing research on the effect of stem borers on yield reduction while the Zambian participant is working on armoured ground cricket.

Food Technology. The Food Technology Programme has embarked on collaborative consultation on interests in Zambia and Botswana to blend sorghum flour into that of wheat and soybean respectively. The networking is unique in that it deliberately collaborates with both NARS and the private sector. For example, there has been collaborative work with the Carlsberg Laboratory in Copenhagen on malting and diastatic power, and on the use of internode chips to make construction boards.

Economics. In its networking, our Economics Programme focuses its research on the following pertinent issues:

1) Marketing constraints affecting sorghum and millet.

2) Options and constraints for expanding utilization of sorghum and millets.

3) Factors influencing the substitution in production and consumption of sorghum, millets and maize.

Networking is taking place through collaborative research and training in Botswana, Lesotho, Zambia, Tanzania, and Zimbabwe.

Assistance to NARS

One of the reasons contributing to the success of our networking has been the availability of funds to enable offering of assistance to NARS. Major contributions have been to Zambia with modest assistance to the remainder of the NARS except Angola.

Assistance has included land survey, land shaping, provision of farm implements, vehicles, construction of houses, seed stores, and provision of lab equipment and computers.

Human Resource Development (HRD)

The most significant and visible contribution from the SADCC/ICRISAT/SMIP to the region is in Human Resource Development. While this is expensive ($1.3 million per year), the project has a strong conviction that, at the end of the project, we will be judged not so much by the increase in the production of our mandate crops but the numbers of indigenous scientists, technicians and station managers who can truly, capably, and confidently carry out sustainable research when we are gone.

Thus the main objective of the Human Resource Development Programme (HRD) is to strengthen research capabilities of the ten SADCC countries NARS.

This is achieved through the following strategies:

1. Advanced degree education. Initially this was wholly subcontracted to INTSORMIL but now we have developed the capability of enrolling some candidates into regional universities. For example, to date, we have made the following effort: one Ph.D. in entomology at the University of Zimbabwe; one Ph.D. in pathology at the University of Zimbabwe; three M.Sc. at the University of Zambia commencing in 1992; one B.Sc. at the University of Lesotho commencing in 1992; and, four B.Sc. in food technology at the University of Nairobi in 1992.

If all participants complete studies on time, by the end of the project in 1994, about 120 degrees will have been conferred (combining INTSORMIL and regional effort).

2. Post doctoral support at Matopos. We have the capacity to work with national scientists who have just completed their PhD's. At present, we have one postdoc in Pathology.

3. Research internship support at Matopos has been reserved for those nationals in the network who have completed their first degrees and now wish to be attached to SMIP for two years. They are attached in staff positions but do research contributory to their next higher degrees.

4. Research associate in the region. By 1994, when all the 120 degrees have been conferred, there should be a critical mass of scientists to enable NARS to release some of them for a season (4 months) to work with SMIP regional scientists before returning home. They can then apply for a project grant to enable them to carry out research in their home station.

5. Research scholarship support. Some scientists prefer to attend university coursework and then return home or to SADCC to carry out research. Notwithstanding costs, this is an approach that heads of NARS prefer mainly, because the research remains relevant. Also, it can be cost effective in that the scholars can work on a real national problem as opposed to a theoretical problem. Recently, scientists from Botswana, Lesotho, and Zimbabwe have utilized regional facilities for such.

6. Undergraduate internship at Matopos. Final year agricultural undergraduates from national programmes come to us during the growing season for 3 to 4 months and are attached to a scientist for training. About 12 nationals are trained in this manner per year. While this internship is open to all countries, only Zimbabwe and Zambia have taken advantage of it to date.

7. Technical In-service in SADCC. With the obvious scarcity of scientists in the region, most research operations are executed by technicians and farm managers. Hence, it is important to continually give them in-service training. To date, 294 technicians and farm managers have been trained. By 1993 (end of PACD), we will have trained 410 participants (Table 1).

Major courses have been in station management, nursery management, pest management, land development, and pollination techniques.

8. Technical In-service at ICRISAT Centre in India. In responding to the high demand for in-service training from NARS and also realizing our limited resources at Matopos, we send technicians and farm managers to our Hyder-

Table 1. SADCC/ICRISAT in-service training for technicians and experiment farm managers 1985-1993.

	Training by SADCC/ICRISAT Matopos						ICRISAT Center
Course	Station Management	Apprentice	Nursery Management	Pest Management	Pollination Techniques	Land Management	Various
Year							
1985							18
1986			9				14
1987	16		7				25
1988	15						21
1989	15	4		15	8	9	32
1990	15			17			15
1991	19						20
Total	80	4	16	32	8	9	145 (43*)
Planned						Sub Total	294
1992		2**	15	15	6		21
1993	15			15	6		21
Total Combined	95	6	31	62	20	9	187
				Phase I & II		Grand Total	410

Notes: 294 Participants were trained between 1985 and 1991
410 Participants will have been trained by end of Phase II
* Funded by SADCC/ICRISAT
** To be attached to entomology

Table 2. 1985 to 1991 (June) Combined training effort of technicians by SADCC/ICRISAT (Matopos) and ICRISAT Centre (India).

	Angola	Botswana	Lesotho	Malawi	Mozambique	Namibia	Swaziland	Tanzania	Zambia	Zimbabwe	SADCC/ ICRISAT Staff	Total Technicians
Training Effort by SADCC/ICRISAT Matopos												
	3	16	13	19	2	2	14	22	19	25	7	142
ICRISAT Centre, India												
	1	13	1	23	18	2	6	28	29	24*		145
Combined Total Effort												
	4	29	14	42	20	4	20	50	48	49		287

*Includes SADCC/ICRISAT Staff

Observations:

Tanzania, Zibmabwe, Zambia and Malawi have benefitted most while Angola and Namibia have benefitted the least from the combined training effort of SADCC/ICRISAT and ICRISAT Centre.

Peace permitting the inbalance will be redressed in Phase III and IV.

abad Centre in India for training. To date, 145 participants have been to India. Of these, 43 were sponsored by SADCC/ICRISAT. Another 42 will benefit from Centre training between now and November 1993 (Table 2).

9. Human Resource Development through workshops. This is one of the most important components of our network. The success of our networking depends to a large extent on live communication and close contact with NARS scientists. As such, we have a number of strategies that we implement.

(a) Regional workshop. We hold annual regional workshops where collaborating and SMIP scientists meet. It is an important relevant interactive reporting and planning meeting where workplans for SMIP and the region are finalized. The number of participants has risen over the years from 40 to 80 and in duration from three to five days; thereby making the workshop both expensive and requiring considerable coordination effort.

It has since been resolved that the workshop will in future be held biannually. In between will be disciplinary group consultative meetings.

10. Group consultative meetings. Disciplinary group consultative meetings will comprise NARS and SMIP scientists of a specific discipline; e.g., pathologists. Recent graduates, the already participating NARS scientists, and SMIP scientists will review current work before mapping out a joint strategy for future joint effort and joint publication. The approach gives more meaningful interactive networking.

11. Conferences. To stimulate scientific paper writing and generally further new ideas, our networking mounts one international workshop per year. Collaborating scientists are invited to participate.

12. Monitoring tours. One crop monitoring and evaluation tour is mounted every year where SMIP and NARS scientists visit several stations in SADCC. They jointly evaluate material and discuss strategy.

13. Visitations. SMIP scientists spend 30% of their time at NARS research stations working with national scientists. This is an important aspect of both collaboration and HRD.

14. Provision of information. NARS scientists are in need of up-to-date information. SMIP is developing a comprehensive information base to cope with the needs of NARS for abstracts, extracts, journals, reference texts, etc. To that extent, a documentalist/librarian is being hired to serve SMIP and NARS. Already, the Semi Arid Tropics Information Service (SATCRIS) is working on the needs of NARS.

The Future of the Network

Originating from SMIP's success over a short period of time, an in-house debate is going on regarding the future of the SADCC/ICRISAT/SMIP Network. Should we remain a sorghum and millet network or capitalize on our successes and broaden our base to cater to a wider array of activities concerning the semi-arid tropics? Should we develop into a Regional Research Centre managed by SACCAR? Should we assist SACCAR in developing a Regional Seed Centre, a Regional Station Development and Management Project, etc? These questions I cannot answer and therefore call upon you to give some responses for consideration.

Conclusion

From the discussion above and the statistics herein appendixed, the SADCC/ICRISAT Network has been successful in meeting its objectives. This has been due mainly to good management, generous donor support, and excellent collaboration from NARS. SADCC/ICRISAT has earned credibility from SACCAR as a sincere, effective, and hard-working project. It is our intention to continue working hard in strengthening research capabilities of NARS. I thank you.

List Of References

House, L.R. 1991. Improved Varieties and Hybrids of Sorghum and Millets in SADCC countries. (In-house paper)

House, L.R. 1990. Overview SADCC/ICRISAT/SMIP. (In-house publication)

House, L.R. 1991. July Oral Communication Proceedings of the Sixth Regional Workshop On Sorghum and Millets for Southern Africa. 1989, Bulawayo, Zimbabwe.

Tendengu, L. 1990. Annual Report Human Resources Development Programme.

Gupta, S.C. 1991 July Oral Communications.

Leuschner, K. 1991 July Oral Communications.

Rohrbach, D. 1991 July Oral Communications.

Osmanzai, M. 1991 July Oral Communications.

The IRAT Sorghum Program Highlights and Areas for Interaction with INTSORMIL

A. Ratnadass and P. Salez[1]

Structure of IRAT Sorghum Program

General presentation of CIRAD/IRAT

The Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières (IRAT), was established in 1960, in order to respond to the African states' demand for assistance in food crops research. It later became CIRAD/IRAT, as a member of CIRAD (Centre de Coopération Internationale en Recherche Agronomique pour le Développement), in 1984.

CIRAD is a French state-owned organization (roughly a staff of 2000 and a turnover of US $ 184 million), devoted to agricultural research with emphasis on tropical and subtropical areas. This center, with 11 departments, has been mandated to contribute to the development of the mentioned areas through research, experiments, training and information dissemination. One of its major activities is the assistance, on request, to National Agricultural Research Systems (NARSs).

Within CIRAD, CIRAD/IRAT is the most important department, with 160 scientists. It is in charge of the improvement of food crop production in order to contribute to the success of food self sufficiency policies claimed by most of the third world countries. It is also deeply concerned by carrying out appropriate techniques to achieve the conservation and the optimum use of natural resources without which the first objective could not be reached sustainably. In addition, a long experience in its intervention area has convinced CIRAD/IRAT of the importance to extend more and more its activities at farm level.

To reach its targets, CIRAD/IRAT's activities are managed within two divisions. One is an environmental division called the Division of Natural Resources which leads various activities in the fields of soil science, remote-sensing, mapping, soil management, climate-soil-crop relationship, hydraulics, etc. The second division is devoted to crop programs, namely five major crops (rice, maize, sugarcane, sorghum and vegetable crops), and miscellaneous crops.

The IRAT Sorghum Program

IRAT has supported research on sorghum since its inception, aiming at the optimum utilization of this cereal potential. These activities encompassed the fields of plant breeding, agronomy, crop protection, and grain technology. They were mainly carried out in West and Central Africa.

At present, with nine scientist positions, the IRAT Sorghum Program is organized as shown in Table 1. The four scientists in Mali are posted in the ICRISAT/WASIP regional

Table 1. Organization of IRAT Sorghum Program.

Discipline	No. scientist positions	Locations
Breeding	3	Burkina Faso[1] Mali[2] Senegal[3]
Agronomy	2	Mali[2] - Togo[3]
Weed Science	1	Mali[2]
Entomology	1	Mali[2]
Technology	1	Montpellier
Biotechnology	1[4]	Montpellier

[1]posted in NARS
[2]posted at ICRISAT/WASIP
[3]posted in a SAFGRAD project
[4]=2 research scholars

[1] Respectively, IRAT Entomologist and IRAT Agronomist, Head of IRAT Sorghum Program, ICRISAT/WASIP, B.P. 320, Bamako, Mali.

Table 2. Major varieties of IRAT sorghum breeding programs.

	From landraces evaluation carried out in the sixties
Traditional sorghums for rainfed cultivation:	
Senegal	Ngor Gatna (IRAT 1), Congossane SH 60 (IRAT 4)
Mali	SH2D2 (IRAT 5), Tiemarifing
Burkina Faso	S 29, Gnofing, Ouedezoure
Niger	Jan Jare, Hamo Kire (IRAT 2), El Dele
Cameroon	Makalari (IRAT 55)
Dune sorghums:	
Niger	Bogoba, Babadia ja, Babadia Fara
Flood recession cropped sorghums:	
Senegal	RT 13, RT 50
	From crosses dating back to the sixties
Burkina Faso	IRAT 6, IRAT 7, IRAT 8
Mali	IRAT 74, IRAT 75, IRAT 76
Niger	C1-13-1-1, C6-4-1-3
	From crosses dating back to the seventies
Early lines (90 days)	IRAT 10 (CE 90), IRAT 202 (CE 145-66), IRAT 204 (CE 151-262)
Medium cycle lines (110 days)	IRAT 11 (L.30), IRAT 16 (CE 111-6)
Late maturing lines (130 days)	IRAT 174
Hybrids	
for rainfed cultivation	IRAT 325
for irrigated conditions	IRAT 179, IRAT 180, IRAT 181

center at Samanko, which is indeed a joint venture between ICRISAT and CIRAD/IRAT. The agronomist acts as the head of IRAT Sorghum Program. The breeders in Burkina Faso and Senegal are integrated to NARSs, (INERA and ISRA, respectively), on a bilateral basis. The agronomist in Togo is working on the SAFGRAD project.

Other activities related to sorghum although not implemented within the sorghum program which should also be considered, are: genetic resources management (Montpellier); agroclimatology and water balances (IER, Mali; Niger); and cereals mineral nutrition (IER, Mali).

The program is thus very much West Africa oriented, although expert missions can also be carried out in other regions.

Major achievements and current strategy

Plant breeding

The sorghum breeding program at IRAT dates back to the 1960's, when activities started almost simultaneously in Senegal, Mali, Burkina Faso, Niger, Benin and Madagascar. Initially it involved mass selection and pure line isolation from West and Central African local varieties. Later on, it incorporated various other breeding methodologies. These include the use of exotic varieties as sources of dwarfism genes, the creation of hybrids using a *cms* system, the creation of composites bringing together numerous parental sources, and the application of induced mutagenesis. The major varieties obtained from the selection work carried out in the sixties and seventies are presented in Table 2.

These experiences led to placing the present breeding emphasis on grain quality and yield stability, and on improving our knowledge of available genetic resources for the rationalization of hybridization strategies.

A second part, more methodological, has been carried out mainly in Burkina Faso and in Montpellier.

Varietal creation and evaluation

The IRAT Sorghum Breeding program aims at obtaining two types of fixed material for human consumption in the tropical zones:

- one related to local varieties which are generally tall, photoperiod sensitive, hardy, with low yield but high quality grain;
- one similar to high yielding sorghums that are to be found in developed countries, short stalked, photoperiod insensitive, with heavy and compact panicles, large grains, but often not appreciated for food consumption in West Africa.

Concerning the first type, we are trying to improve their yield potential, while maintaining their own particular qualities. We therefore are looking for a better balance between vegetative and reproductive parts of the plant (by means of straw shortening and tillering limitation), using breeding methods that modify local varieties for only the desired (and limited) changes. We use methods such as:

- back crossing and mutagenesis in Burkina Faso;
- recurrent selection with ms_3 male sterility gene, from a population coming from a mixture of local landraces in Mali.

Varieties obtained, though looking very much like traditional material, valorize better cropping intensification. At the same time, they do not drastically change the farmer habits, and could therefore constitute a transition towards the introduction of better yielding, but also more labor and input demanding varieties.

Concerning the second type (high yielding varieties), we are mainly looking for a better adaptation to tropical conditions. With this aim in view, we are looking at resistance to main leaf diseases and insect pests (notably panicle feeding ones), yield stability and improvement of grain quality.

Our main breeding method is that of crosses between parents with complementary qualities followed by pedigree selection of progenies showing interesting combinations of parental characters. It is used in Senegal, Mali and Burkina Faso. In Mali, recurrent selection is applied to a *caudatum* population to obtain fixed varieties with grain mold resistance (character controlled by several genes).

Our varietal creations are capable of high yields but require more labor intensive farming care than traditional varieties. They are aimed at farmers with a minimum technical background.

On a limited scale, the IRAT sorghum breeding program works on the exploitation of heterosis in order to obtain original hybrid formulas, to respond to the demand for cost efficiency of irrigated plots (which are still not many in West Africa).

A large part of the material is still in the breeding process. At present, certain lines or composites are promising and are likely to have a significant impact in the tropical rural world. In Burkina Faso, the first recurrent selection cycle was successful and improved the composite created in 1987, which became as good as variety IRAT 277. In Mali, out of 160 accessions of *guineense* and 111 accessions of caudatum that were evaluated at Samanko, 23 and 19 were selected, respectively, to create random-mating populations. Out of 232 germplasm accessions, 12 were selected for use in the pedigree breeding program to develop full-season varieties adapted to the Northern Guinean Zone.

In terms of varietal creation in Senegal, priority is given to medium cycle varieties, high yielding, with good tolerance to grain molds and good grain quality from *guinea* and *caudatum* material. In varietal evaluation tests conducted in 1989 and 1990, the best varieties under rainfed conditions were: CE 180-33, CE 196-7-2-1, CE 145-66 (IRAT 202) and F2-20. F2-20 was included in SAFGRAD Sorghum Network regional nurseries. The best variety for irrigated cropping during the rainy season was CE 151-262 (IRAT 204), and for irrigated cropping during the dry season, 75-14 (IRAT 207).

Biotechnology

The evaluation of genetic diversity was conducted with concurrent morpho-agronomic (in collaboration with INERA, Burkina Faso) and isozyme analyses, as part of an EEC funded project.

Three groups could be identified on the basis of multivariate analysis of 25 morpho-agronomic traits in a representative sample of 157 traditional *Sorghum bicolor* varieties. This scheme verified the panicle and grain traits as classification criteria, as had already been found by Harlan and de Wet.

From the analysis for 11 enzymes of a representative sample of 348 traditional varieties, it was found that the variation observed in Africa included all the variation found in the species. Three groups, roughly corresponding to three broad geographical areas, namely Western, Eastern/Central and Southern Africa, were resolved by multivariate analyses of multi-locus associations.

A second series of analyses focused on the Guinea group. Three groups could be identified on the basis of multivariate analysis of 30 morpho-agronomic traits in a sample of 55 traditional varieties. This scheme was again close to the key developed by Harlan and de Wet. Three groups were defined by multivariate analysis for 8 enzymes of a sample of 167 traditional varieties. The agreement between the morpho-agronomic and the isoenzymatic analyses was stronger in this guinea sample than in the first sample which represented the whole species.

As a result of these investigations, a global scheme of the domestication and subsequent migrations of sorghum, and a simplified scheme of its genetic variation, could be proposed. Conceivably, this can then be used to identify trends in the breeding behavior of combinations within and between groups, and thus to formulate guidelines as to which type of cross should help in obtaining specific objectives.

At present, a genetic diversity study using RFLPs (Restriction Fragment Length Polymorphism) is in progress in Montpellier. Its objective is to assess whether additional markers will modify the relative differentiation between the groups identified so far, and further resolve differences within these groups.

Plans to undertake marker-assisted genetic analysis of grain quality traits are being considered. The grain quality data and the RFLP diversity analysis will provide a basis for selecting parents for relevant crosses. The three plant breeders located in Burkina Faso, Senegal and Mali, and the grain technologist at Montpellier will be involved.

In other respects, research has continued aiming at directly obtaining pure lines by ways of haploid production. Three approaches were explored: gynogenesis induced after an intergenera crossing or pollination with irradiated pollen, and in vitro androgenesis. None of the approaches has been completely successful so far.

Grain technology

The IRAT grain technology laboratory has been helping sorghum breeders to screen varieties suitable for first and second processing, for several years now. A sorghum grain hardness measurement test based on the evaluation of particle size after grinding (Particle Size Index Method) was set up in the laboratory. It allows the prevision of sorghum grain decortication ability from 20 g samples.

A second test was developed, at the request of breeders aware of problems linked to the acceptability of improved new varieties, to assess tô (a traditional West African stiff porridge) texture, using an INSTRON texture tester. This method can also be used as a screening tool for varieties under selection: it allowed us to sort out 20 varieties in 12 groups. It is also used in the laboratory to identify biochemical characteristics linked to tô quality.

A multiple regression analysis, based on the results of a preliminary study established the importance of starch characteristics on tô consistency. Sorghums with high amylose content, whose starch swells little and solubilizes in water at tô cooking temperature, would give firmer porridges. Some proteins can have an indirect role on tô texture, particularly through grain hardness and therefore particle size and rate of damaged starch.

In other respects, a statistical study clearly established the influence of grain physicochemical characters on tô quality. These characters are, in decreasing order of importance: vitrosity, protein content and per cent recovery at decortication.

Twenty sorghum varieties from Mali, France and from the IRAT catalog were decorticated using the TADD (Tangential Abrasive Dehulling Device). Decortication rate appears to play an important role in tô stability. Research on factors affecting tô quality is being carried out jointly with the IER/SRCVO Cereals Technology Laboratory in Mali. Studies on milling (flours characterization, development of a suitable laboratory technique) are also underway.

Agronomy

Earlier work

Before the sixties, the technical bases for improved sorghum cultivation, from either local or improved varieties, were known from earlier work carried out in a range of situations in Francophone West Africa. In the sixties, experiments continued in Benin, Burkina Faso, Cameroon, Mali, Senegal and Togo, on land preparation, fertilization, sowing and weeding. For rainfed cultivation, they recommended deep plowing, so as to improve the soil physical properties, in connection with better root development for sorghum. The major role of nitrogen was established. The problem of crop succession, especially toxic effects of sorghum on the following crops (allelopathy) in sandy and clayey soil was also investigated.

During this period, research efforts were also devoted to flood recession cropped and transplanted sorghums.

Due to drought problems in the seventies, studies on water requirement were carried out, and techniques of improved irrigated sorghum cultivation were developed. Results from a study conducted for five years in Burkina Faso suggested that water-saving technology implementation at the plot level (soil-scarification, plowing, ridging, earthing-up, tied ridges and weeding, taken separately or as combinations) could play a role on sorghum production as important as breeding for drought resistance. Techniques of irrigated cropping were improved, and an interesting experiment was carried out on 8500 ha in the Sarir desert in Libya, which was a success.

Current activities and main results

Mali

The current agronomy program in Mali aims at developing sorghum based cropping systems efficiently using natural resources and maintaining soil fertility as well as long term productivity ("sustainability"). It has two components:

- Agrophysiology: study of the functioning of sorghum-legume intercrop systems and their efficiency in using nitrogen; study of sorghum yield determinism in connection with nitrogen nutrition;
- Cropping systems: improvement of cropping techniques used in sorghum-legumes intercrops (farm level); study of production evolution and soil fertility maintenance in diverse agrosystems including sorghum (long run study).

At our partners' (NARSs) request, the second component is given major emphasis.

With respect to response of sorghum cultivars to nitrogen, it was found that N fertilizer significantly increased grain yields, mainly due to an increase in number of seeds per panicle. Root:shoot ratios were also increased. Sorghum/soybean systems were found to be globally more efficient than sorghum/groundnut ones, which suffer from an early inter-specific competition. Promising results have already been gained in the fields of optimum combinations for sorghum/legumes intercropping systems, varieties, fertilization, sowing, rotations, weeding, etc. Specifically, the system consisting in alternate paired rows of sorghum and cowpea (2S:2C) proved to be particularly relevant.

As for weed control in sorghum/legume intercrops, it was found that intercropping, particularly sorghum/cowpea, depressed weed emergence between 0 and 70 DAS, because of rapid covering of the soil surface, and only two weedings were thus required in intercrops, compared to three in the sorghum sole crop. Mean fresh mass of weeds was also lower in the sorghum/cowpea system. Intercropping also reduced total labor time required for manual weeding and enabled a savings of about 10% in labor charges.

A legume, as a sole crop, was the best preceding crop for sorghum, with average sorghum yield increase of 20 to 30% as compared to sorghum-sorghum rotation. Legume/sorghum intercrops had no effect on succeeding sorghum yield compared to that of sorghum as a sole crop. However, the intercrops had an important preceding effect on cotton production when no fertilizer or a mineral fertilizer was applied; a combined fertilization (organic + mineral) confounded the effects of all preceding cropping systems. When sorghum-legume intercrops succeed to themselves on the same plot, their yield advantage compared to sole crops succeeding to themselves was maintained after two years (LER between 1 and 1.4). However, these rotations of sorghum-legumes intercrops have no comparative advantage with sole crop rotations of legume on year 1 and sorghum on year 2.

Togo

Research on sorghum based intercropping systems (including groundnut, cowpea and pigeonpea) are also carried out in Northern Togo, and comparisons are being made with maize based cropping systems. Among the systems tested in on-farm trials, it was found that the sorghum/pigeon pea intercropping system with respective densities of 62,500 and 31,250 plants ha^{-1} gave the best yields, namely 74% over that of sole crops.

Crop protection

General aspects

Until recently, few activities had been devoted to this research area. Earlier work, dating back to the sixties, mainly consisted in inventories of main sorghum diseases and insect pests. Particular attention was then paid to grain molds.

With the development of WASIP in Burkina Faso and in Mali, crop protection research within the IRAT Sorghum Program took a new start. Besides some aspects that are tackled by breeding programs (such as grain molds) or agronomy programs (weeding), special programs are now devoted to parasitic plant control (particularly *Striga*), from an agronomic approach, and to insect pest control, with major emphasis on host plant resistance.

Crops parasitic plants

The program has three main research components: a bio-ecological study, a village-level survey, trials in farmers fields (on the pair *Striga hermonthica* and sorghum only, jointly with IER).

Surveys undertaken in Burkina Faso were extended to Mali (southern, northern and northwestern regions). It allowed the census of 21 parasitic species belonging to 9 genera and 4 families; 10 species are recorded in genus *Striga* alone. In the cultivated fields of these regions, the most important *Striga* species are *S. hermonthica* on millet and sorghum and *S. gesnerioides* on cowpea. In the Sudano-Guinean Zone of Mali, where the ecological conditions are more favorable to crops and where the farmers are more progressive due to cotton cultivation, *Striga* is rarely a problem. On the other hand, in the Sudanian Zone (north and northwest) the climatic conditions and the farmers' lack of resources have favored the spread of *Striga*, which is a major yield reducer in this area. Detailed investigations conducted in three villages resulted in mapping at the parcel level, with the indication of parasitic species in one of them. *Striga hermonthica* was the most harmful species.

A manual for identification of the main crop parasitic species was prepared, and computer software developed, for the analysis of data, thus aiming at diagnosing the importance of these parasites and the farming practices that favor their spreading. An experiment showed that covering the wet soil for 35 days with black polyethylene sheet in April, when temperatures were high, reduced *Striga* emergence significantly and doubled grain yield of sorghum variety 'Tiemarifing'. This method could possibly be used to obtain different levels of *Striga* infestation in experimental plots.

The integrated control tests conducted in a farmer's field heavily infested with *Striga* showed that an improved *caudatum* variety

ICSV 1063 BF was relatively less attacked by *Striga* and produced higher grain yields than Seguetana and Tiemarifing, the two local guinea varieties under test. Of the control methods tested, an early 2,4-D herbicide application (70 DAS) was the most effective in reducing numbers of emerged *Striga* plants; however, low concentration used did not completely eliminate *Striga*. The grain yields were nearly doubled with this treatment. Weeding by late hand pulling (85 DAS), preferably when the soil is dry also reduces *Striga* emergence and increases sorghum yield. Straw mulching reduces vegetative development of *Striga* but does not hamper its fructification as the two other techniques do. Integrated *Striga* management research is implemented jointly with IER/SRCVO.

Entomology

The entomology program is giving priority to two major groups of sorghum pests in West Africa, namely stem borers and head bugs. Some activities are also devoted to sorghum midge, storage pests, and insects of flood recession cropped sorghum.

The noctuid *Busseola fusca* was identified as the main stem borer at Samanko, where its incidence, however, is pretty low. It was reared on an artificial diet in the laboratory for several generations during the dry season without undergoing diapause.

Losses due to head bugs (*Eurystylus immaculatus*) were quantified. Susceptible varieties suffer from oviposition and feeding punctures an important decrease of thousand grain mass, grain density, vitrosity, germination power, decortication rate, and tô quality.

The efficiency of the cage technique to screen sorghum for head bug resistance was confirmed. Malisor 84-7's high level and stability of resistance was confirmed, and promising selections were made among progenies of a cross between this source of resistance and high yielding improved varieties.

Losses due to stored-product insects in a sample of 27 traditional sorghum granaries distributed in four villages of Mali were assessed and found to be generally very low (about 1% weight loss for a six month storage period).

Future activities envisaged are:

- *Busseola fusca*: solve rearing problems (namely elucidate diapause phenomenon and develop a suitable artificial diet) so as to be able to mass produce this insect for screening under artificial infestation at Samanko.
- *Eurystylus immaculatus*: study of its biology and population dynamics; investigation on factors (physical, physiological or chemical) in sorghum imparting resistance to head bugs; determination of the genetics of inheritance of this resistance so as to be able to advise breeders on the best breeding strategies; simplification of screening techniques for use by breeders in NARSs.
- Storage pests: develop a suitable technique for screening sorghum grain for resistance to Rhyzopertha dominica, its major storage pest in West Africa; screen local material and lines at the pre-releasing stage on a routine basis, so as to be sure not to release supersusceptible varieties.

Genetic resources

Photoperiod insensitive varieties are being produced at Montpellier. A new edition of the varietal catalog was published in 1988.

Future strategy and areas of interaction with INTSORMIL

Future strategy of IRAT Sorghum Program

At present, the IRAT Sorghum Program is concentrating its efforts on West Africa. It is unlikely that it will in the near future significantly extend to other areas (with the possible exception of the Mediterranean area, where its hybrids can be cultivated).

However, it could logically be strengthened by scientists from CIRAD/IRHO (oil department) and CIRAD/IRCT (cotton department), as, as it is likely to happen, CIRAD programs shift their emphasis from plants to cropping systems (such as cropping systems based on sorghum, groundnut and cotton, for the sudanian zone).

Areas of common interest with INTSORMIL

The objectives and activities of the IRAT Sorghum Program and INTSORMIL are in several respects very similar, in most of the fields encompassed by both institutions, notably in their common countries of intervention (namely Mali and, to a lesser extent, Senegal), and in terms of technical thrusts, as well as training, which is becoming one of the major emphasis of the IRAT Sorghum Program. Sustainability has become a priority for both institutions.

IRAT operates within the national agricultural research organizations and conducts cooperative programs with them. It also participates in WASIP and SAFGRAD sorghum network. INTSORMIL has always coordinated and collaborated with ICRISAT regional activities located in West Africa, in order to avoid duplication of activities. ICRISAT/WASIP provides an opportunity for closer interaction.

In the field of plant breeding, the IRAT sorghum breeder posted at CNRA Bambey, Senegal, (ISRA) is involved on a more or less formal basis in a collaborative project with University of Nebraska (UNL-115). In agronomy (Mali), there is no joint project between IRAT Agronomist posted at ICRISAT/WASIP and IER scientists involved in INTSORMIL projects on nitrogen uptake and cropping systems, however, only unofficial scientific relationships do exist at the moment.

In entomology (Mali), collaboration with Texas A&M University is underway, notably to determine the mechanisms and genetics of inheritance of head bug resistance in sorghum (Projects TAM-121 and TAM-122).

In Mali again, support is provided to IER/SRCVO Cereals Technology Laboratory by both INTSORMIL and IRAT. Both institutions address problems such as factors affecting tô quality in Mali. Although coordination exists (through meetings between Texas A&M, IRAT, ICRISAT and IER scientists), the IRAT food technologist is not a collaborating scientist in Project TAM-126.

In other respects, we feel that much benefit could also be gained from coordination between Purdue University and IRAT on support of *Striga* research (although countries covered are not the same) and on biotechnology (Projects PRF-103A, PRF-107 and PRF-104B).

We strongly think that the type of collaboration that currently exists, (namely, with a NARS when an IRAT scientist working in a NARS is involved, or with ICRISAT when IRAT scientists working with ICRISAT/WASIP are involved), does not suffice and should be structured and enhanced in order to more efficiently use available funds.

If direct collaboration between IRAT and INTSORMIL could pose problems because of institutional difficulties, at least a better coordination is needed, in order to avoid duplication of activities, so as to best serve the interests of NARSs.

As a first step, a joint meeting between INTSORMIL, IER and ICRISAT/IRAT scientists and representatives could be proposed to be held soon in Mali, with the objective of discussing possible ways of cooperation on themes such as nitrogen uptake and utilization, sorghum based cropping systems, sorghum resistance to head bugs, sorghum technology and food quality.

Recent Publications

Books

Chantereau J., Nicou R. (1991) Sorghum (in French). Le Technicien d'Agriculture tropicale, Maisonneuve et Larose Eds, Paris. In press.

Sapin P. (1985) Sorghum in Burkina Faso and its improvement by IRAT (in French). Mémoires et Travaux de l'IRAT N$ 11, Montpellier, CIRAD-IRAT, 98 p.

Vandevenne R., Bono M. (1987) Sorghum seeds production and control in the tropics (in French). Mémoires et travaux de l'IRAT, Montpellier, CIRAD-IRAT, 369 p.

Journal Articles

Chantereau J., Arnaud M., Ollitrault P., Nabayaogo P., Noyer J.L. (1989) Study of morphophysiological diversity and classification of cultivated sorghums (in French). Agron. trop. 44(3), 223-232.

Nicou R., Ouattara B., Some L. (1990) Effects of the plot water saving technology on cereals crops (sorghum, maize, millet) in Burkina Faso (in French). Agron. trop. 45(1), 43-57.

Ollitrault P., Escoute J., Noyer J.L. (1989) Polymorphism of enzymes in sorghums. I - Description of 11 enzymatic systems, genetical control and linkage(In French). Agron. trop. 44(3), 203-210.

Ollitrault P., Arnaud M., Chantereau J. (1989) Enzyme polymorphism in sorghum. II - Genetic and evolutionary constitution of cultivated sorghum (in French). Agron. trop. 44(3), 211-222.

Ollitrault P., Noyer J.-L. (1990) Enzyme polymorphism in sorghums. III - Identification and classification of IRAT improved varieties (in French). Agron. trop. 45(1), 59-66.

Proceedings and Presentations

Chantereau J., Kondombo C. (1991) Allogamy rate estimate of Guinea race sorghums (in French). Paper presented at the SAFGRAD/IITA/ICRISAT Inter-Network Conference on Food Grain Research and Production in Semi-Arid Africa, Niamey, Niger, March 7-14, 1991.

Fliedel G., Grenet C., Gontard N., Pons B. (1989) Sorghum grains hardness, physico-chemical characteristics and decortication ability (in French), 187-201 In: Céréales en régions chaudes AUPELF-UREF, John Libbey Eurotext Eds, Paris (Proceedings of an International Technology Colloquium: Cereals in Warm Areas: Conservation and Processing, N'Gaoundere, Cameroon, February 22-27, 1988).

Glaszmann J.C., Dégremont I., Deu M., Gonzalez de Leon D. (1991) Use of genetic markers in the sorghum breeding program at CIRAD (in English), Paper presented at the Rockefeller Foundation RFLP Conference, Bellagio, Italy, May 6-10, 1991.

Hoffmann G. (1990) A new approach of the study of parasitic plants of Mali (in French). Poster presented at the CILSS Workshop on Integrated Management of Food Crop Pests in the Sahel, Bamako, Mali, January 4-9, 1990.

Hoffmann G., Diarra C. (1991) A new approach of the study of parasitic plants on crops: Field diagnosis (in French). Paper presented at the SAFGRAD/IITA/ICRISAT Inter-Network Conference on Food Grain Research and Production in Semi-Arid Africa, Niamey, Niger, March 7-14, 1991.

Luce C. Hamada M.A. (1991) Comparative study of the incidence of grain mold and its effect on seed viability of some sorghum varieties (in French). Paper presented at the SAFGRAD/IITA/ICRISAT Inter-Network Conference on Food Grain Research and Production in Semi-Arid Africa, Niamey, Niger, March 7-14, 1991.

Ratnadass A., Ramaiah K.V.R., Sharma H.C., Cissé B. (1991) Reaction of some sorghum varieties to the attacks of the head bug Eurystylus immaculatus Odhiambo (Heteroptera, Miridae) in West Africa (in French). Paper presented at the SAFGRAD/IITA/ICRISAT Inter-Network Conference on Food Grain Research and Production in Semi-Arid Africa, Niamey, Niger, March 7-14, 1991.

Reneaud H., Toky P. (1991) Study of three intercropping techniques in Northern Togo in controlled and real environments: Maize/Cajanus cajan; Sorghum/Cajanus cajan; Millet 5 months/Millet 2 Months/Cowpea (in French). Paper presented at the SAFGRAD/IITA/ICRISAT Inter-Network Conference on Food Grain Research and Production in Semi-Arid Africa, Niamey, Niger, March 7-14, 1991.

Salez P., Traoré K., (1991) Preliminary results obtained on different types of crop rotations including sorghum, legumes and cotton (in French). Paper presented at the SAFGRAD/IITA/ICRISAT Inter-Network Conference on Food Grain Research and Production in Semi-Arid Africa, Niamey, Niger, March 7-14, 1991.

Trouche G., Samb S. (1991) Sorghum improvement in Senegal (in French). Paper presented at the SAFGRAD/IITA/ICRISAT Inter-Network Conference on Food Grain Research and Production in Semi-Arid Africa, Niamey, Niger, March 7-14, 1991.

Session V - Utilization, Quality and Product Development

- The Prolamins of Sorghum: Their Role in Protein Digestibility
- Progress and Change in Sorghum Utilization as a Result of Policy Reform in Nigeria
- Uses and Food Potential of White Sorghum Grain in Mexico
- The Use of Sorghum and Millet in the Sudan
- Utilization and Quality: A Seed Industry Perspective

Session Chair: Lloyd Rooney

Speakers:
Julia J. Watterson
D.S. Murty
Fernando Martinez Bustos
S.M. Badi
Ted Givens

The Prolamins of Sorghum: Their Role in Protein Digestibility

Allen Kirleis, Julia J. Watterson and Jeannette M. Shull[1]

Introduction

The most common way of classifying cereal proteins is on the basis of their solubility in alcoholic or aqueous solvents. The cereal protein fractionation procedures used today are derived from the sequential extraction technique developed for maize by Osborne and Mendel (1914). In their extraction procedure the water-soluble protein fraction is regarded as albumin, and the proteins extracted with dilute salt solutions from the remaining residue are referred to as globulins. Prolamins, the major storage protein are next extracted sequentially with aqueous alcohol. The other proteins remaining insoluble are referred to as glutelins and can be extracted with dilute alkali or acid.

Many workers have used the Osborne-Mendel procedure or variations of it to examine sorghum proteins. Johns and Brewster (1917) were the first to report that the aqueous alcohol protein fraction from sorghum made up over one-half of the total proteins in the kernel. These workers call the prolamin fraction from sorghum "kafirins" because they were extracted from grain of the race *Kaffir*. One of the problems associated with the Osborne-Mendel fractionation procedure when used to extract sorghum kernel proteins is that very different protein yields have been reported by different workers. Skoch et al. (1970) subjected five sorghum cultivars to sequential extraction with saline, aqueous alcohol, and alkali solutions, but managed to extract only 26-40% of the total protein in the grain. While Haikerwal and Mathieson (1971) reported extracting 89% of the total sorghum kernel proteins when they sequentially used saline, 70% ethanol, and sodium hydroxide.

In 1970 Landry and Moureaux (L-M) proposed a more efficient fractionation protein extraction procedure for maize. With this procedure, five protein fractions are sequentially extracted as follows: Fraction I - albumins and globulins, extracted with 0.5 M NaCl; Fraction II - prolamins, extracted with 70% isopropanol; Fraction III - prolamin-like, extracted with 70% isopropanol plus 0.6% 2-mercaptoethanol (2-ME); Fraction IV - glutelin-like, extracted in pH 10 borate buffer plus 0.6% 2-ME; and Fraction V - glutelin, extracted in pH 10 borate buffer, 0.6% 2-ME, plus 0.5% sodium dodecyl sulfate (SDS).

The prolamines (L-M Fractions II and III), are the principal storage protein fractions in sorghum, maize, and millet. These storage proteins are called prolamins due to their high concentration of the amino acids proline and glutamine. Prolamin proteins are synthesized in the endosperm of the developing seed in an insoluble form to form organelles called protein bodies. The prolamin or storage proteins of sorghum, maize, and pearl millet are called kafirins, zeins, and pennisetins, respectively.

The distribution of nitrogen in the five L-M fractions of sorghum, maize, and pearl millet are shown in Table I. An examination of the distribution of storage proteins between the two L-M prolamin fractions shows that sorghum contains about twice the quantity of prolamin-like as it does true prolamin nitrogen. Whereas both maize and pearl millet contain much more true-prolamin than prolamin-like nitrogen. Thus sorghum is unique among the three cereals due to its high level of prolamin-like fraction, which indicates that more disulfide bonds must be broken in order to extract

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Table 1. Nitrogen distribution in the Landry-Moureaux fractions of sorghum, maize, and pearl millet normal whole seeds.[a]

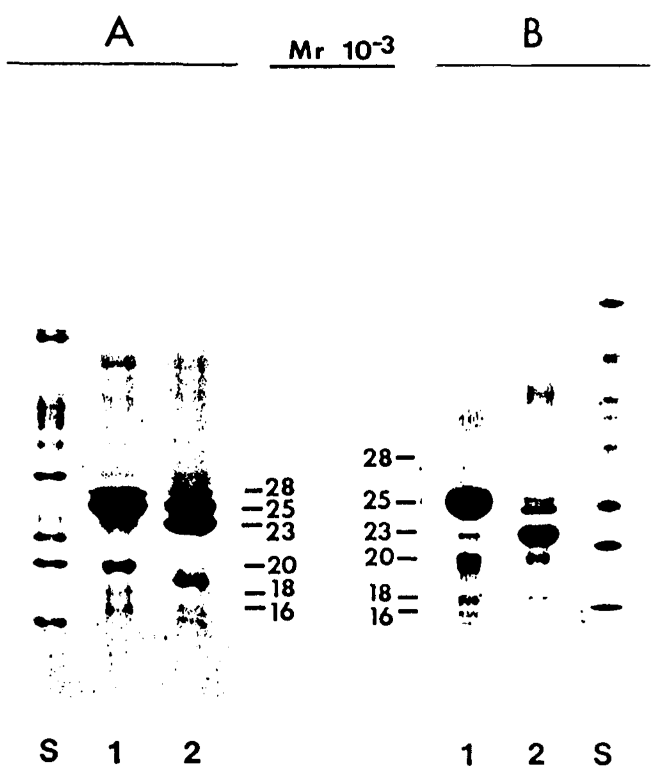
L-M Fractions		% of total N Sorghum	Maize	Millet
I	albumins-globulins	10.0	16.6	22.3
II	true-prolamin	15.7	38.6	41.4
III	crosslinked-prolamin	31.3	10.1	6.8
IV	glutelin-like	4.5	10.0	9.3
V	true-glutelin	29.3	20.2	20.9
Total N	extracted	90.8	95.5	100.7
% protein in seed		13.5	10.7	14.3

[a]Source Nwasike et al. 1979.

the majority of the sorghum storage proteins compared to maize and pearl millet. Hence this has lead to the prolamin-like fraction of sorghum to be sometimes called "crosslinked prolamins" or "crosslinked kafirins."

Analysis by gel electrophoresis of the kafirin and zein proteins from sorghum and maize, respectively, reveals that these proteins are very similar (Fig. 1). Both the kafirins and the zeins consist of a mixture of polypeptides that have been designated as alpha,

Figure 1. SDS-PAGE profiles of total kafirin (lane 1), total zein (lane 2) and molecular weight standards (lane 5) using (A) a linear 8-18% polyacrylamide gradient gel without urea and (B) a linear 10-15% polyacrylamide gel without urea (Shull et al., 1991).



beta, and gamma types (Esen 1986 and Shull et al. 1991). The major types of proteins in both sorghum and maize are called alpha-kafirins and alpha-zeins, respectively. These are a complex group of closely related polypeptides which are soluble in aqueous alcohol. The beta-types are soluble in alcohol containing a reducing agent. The gamma-type proteins are soluble in both aqueous and alcoholic solvents with strong reducing conditions. When separated by SDS-PAGE, sorghum storage proteins are resolved into polypeptides of Mr 28, 25, 23, 20, 18, and 16 kD (Shull et al. 1991). The protein groups designated alpha-, beta-, and gamma-, kafirins, correspond to the Mr 25,000 and 23,000, the Mr 20,000, 18,000 and 16,000, and Mr 28,000 components, respectively.

Identification of the Undigested Proteins from Sorghum

Using a pepsin digestibility method to determine *in vitro* protein digestibility, work in our laboratory has shown that sorghum proteins are much less digestible than cooked maize and pearl millet proteins (Table 2). Animal bioassay and *in vitro* pepsin techniques have clearly shown that cooking sorghum in excess water adversely affects sorghum protein digestibility (Axtell et al. 1981; Eggum et al. 1983; Mitaru et al. 1985). The above cited animal studies report a negative relationship between protein digestibility and biological value (BV). As BV measures the efficiency of utilization of the nitrogen absorbed, this variable is dependent on the amino acid composition of the digested protein. This finding led Bach Knudsen and Munck (1985) to hypothesize that BV of cooked sorghum increased, because the lysine poor kafirin proteins became indigestible after cooking. Accordingly, by removing the poor quality kafirins from sorghum the remaining digested proteins had a better balanced amino acid profile and an improved BV compared to sorghum flour.

Table 2. In vitro protein digestibility of uncooked and cooked sorghum, maize, and pearl millet.

	% Protein digestibility	
Cereal	Uncooked	Cooked
Sorghum	83	56
Maize	86	79
Pearl Millet	89	85

Work by Hamaker et al. (1986) showed that when sorghum is cooked the solubility of the proteins is altered, in particular the alcohol-soluble kafirins. The amount of alcohol-soluble proteins (L-M Fractions II and III) in sorghum was reduced from 42 to 6% by cooking. An examination of the pepsin-indigestible proteins from both uncooked and cooked sorghum by polyacrylamide gel electrophoresis revealed that the predominant proteins in the indigestible residue were alpha- and beta-kafirins. Recently Rayas and Kirleis, unpublished, showed that the kafirin proteins were also the least digestible protein when cooked sorghum was fed to rats. These findings thus confirmed the hypothesis that kafirins became less digestible after cooking.

Improving Sorghum Protein Digestibility with Reducing Agents

Identification of the kafirins as the least digestible proteins in sorghum prompted additional work on these proteins to obtain a better understanding of how these proteins are altered by cooking. As mentioned above, sorghum contains about twice the quantity of crosslinked kafirin (L-M Fraction III) proteins as it does kafirin (L-M Fraction II) proteins. Whereas maize and pearl millet, cereals that show only a slight decrease in protein digestibility after cooking contain more L-M Fraction II than crosslinked L-M Fraction III prolamin proteins. Thus the high level of crosslinked kafirins might be responsible for the low protein digestibility of sorghum following cooking. This hypothesis led to examining the effect of adding reducing agents to sorghum and maize for improving protein digestibility. It was found that treating sorghum with 2-ME improved *in vitro* protein digestibility (Hamaker et al. 1987). The reducing agent treatment was used to improve the protein digestibility of both uncooked (flour) and cooked sorghum, and resulted in increasing pepsin digestibility by 11 and 25% respectively, compared with sorghum that was either soaked or cooked in water. An identical reducing agent treatment on maize gave only an 8 and 5% increase in protein digestibility compared to soaked and cooked in water treatments (Table 3).

Table 3. Effect of 2-mercaptoethanol on the pepsin digestibility of sorghum and maize.

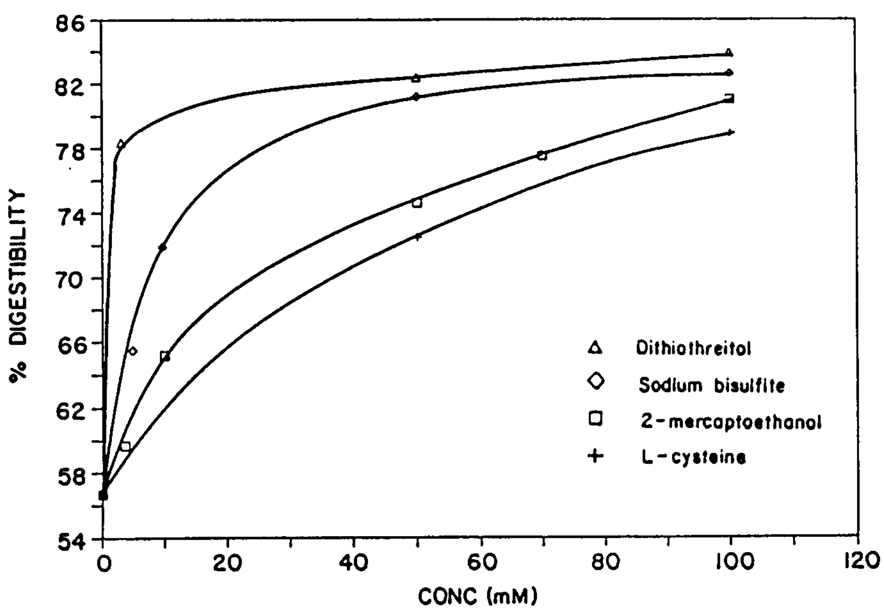
	% protein digestibility			
	Soaked[a]		Cooked[b]	
	NT	2-ME	NT	2-ME
Sorghum	83.2	94.3	56.7	81.8
Maize	86.4	94.8	78.0	83.1

[a]Uncooked flours were soaked either in water (NT) or a solution containing 100mM 2-ME for 12 hr.
[b]Cooked gruels were prepared with water (NT) or a solution containing 100mM 2-ME.

Other reducing agents also enhanced protein digestibility of sorghum (Fig. 2). When sorghum was cooked in 100 mM solutions of dithiothreitol, sodium bisulfite, or L-cysteine, pepsin digestibilities increased by 27.3%, 25.0%, and 20.3%, respectively, over sorghum cooked in water alone. Dithiothreitol was most effective, followed by bisulfite, 2-mercaptoethanol, and L-cysteine, in increasing pepsin digestibility at low concentrations. At 100 mM, however, the effect of the reducing agents on digestibility was nearly equal.

Using gel filtration chromatography, Hamaker (1986) showed that cooking sorghum caused the formation of high molecular weight (Mr 10-20 million D) disulfide linked protein polymers. This protein polymerization did not occur when sorghum was cooked in the presence of a reducing agent such as 2-ME. These protein polymers formed by cooking may be associated with the protein body proteins and thereby limit kafirin digestion. It was observed, using scanning electron microscopy, that sorghum cooked with water and an aqueous solution containing a reducing agent caused no visible disruption of the protein body structure (Leonard 1990). When changes in the *in vitro* pepsin digestion of uncooked and cooked sorghum (with or without a reducing agent) were observed by scanning electron microscopy, it was found that the protein matrix (non-kafirin protein) surrounding the protein bodies was more readily digested than protein body proteins or kafirins (Leonard 1990). It was found that the mode of

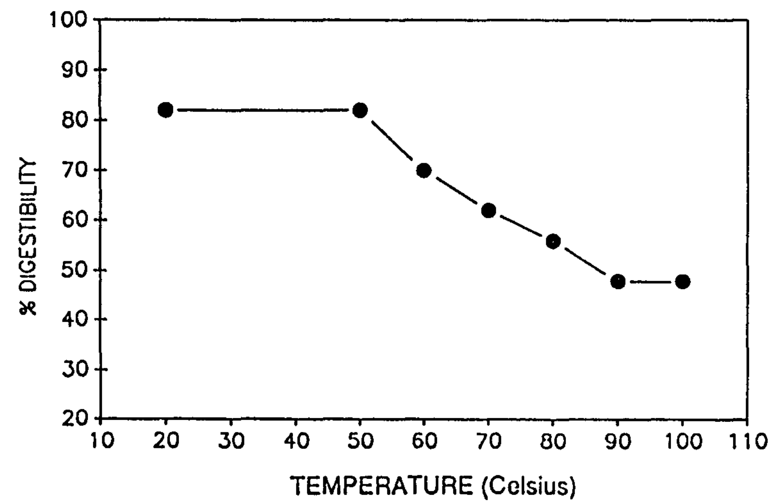
Figure 2. Effects of different reducing agents on the pepsin digestibility of cooked sorghum.

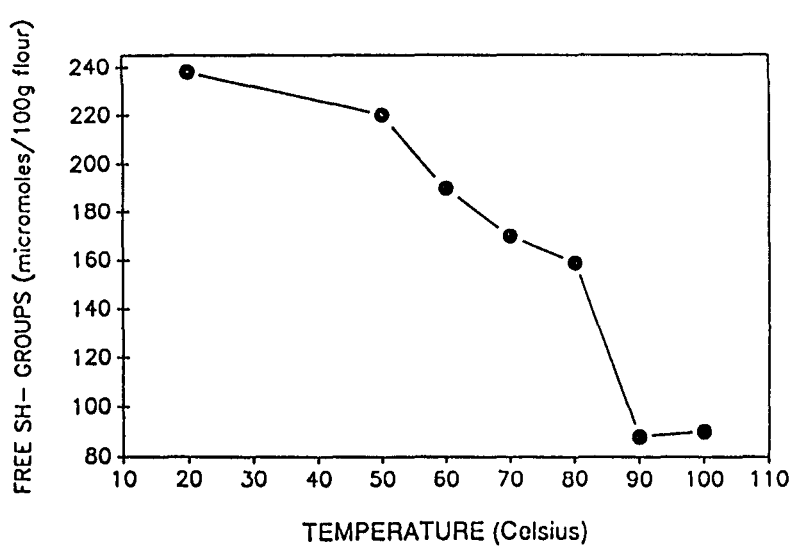


protein body digestion with pepsin was similar in uncooked and reducing agent cooked sorghum, i.e. protein body pitting was first observed after 15 and 30 minutes of digestion, respectively. Whereas the digestion of protein bodies cooked in water proceeded by decreasing in size and losing their spherical shape without any observed pitting even after 120 minutes of pepsin digestion.

Sorghum proteins react differently than proteins of other cereals. Their digestibility is most negatively affected by the cooking process and most improved by the addition of reducing agents. As cooking in the presence of a reducing agent makes sorghum proteins more digestible and prevents the formation of high molecular weight polymers, oxidative formation of disulfide bonds during the cooking process must play a role in creating the less digestible proteins in sorghum porridges. In fact, an *in vitro* study done in our laboratory showed that as cooking temperature increases from 20° C to 100° C both the digestibility of sorghum flour and the amount of free sulhydryl groups in the flour, were greatly re-

Figure 3. The percent digestibility and the amount of free sulfhydryl groups contained in sorghum flour after cooking at 20°C to 100°C.



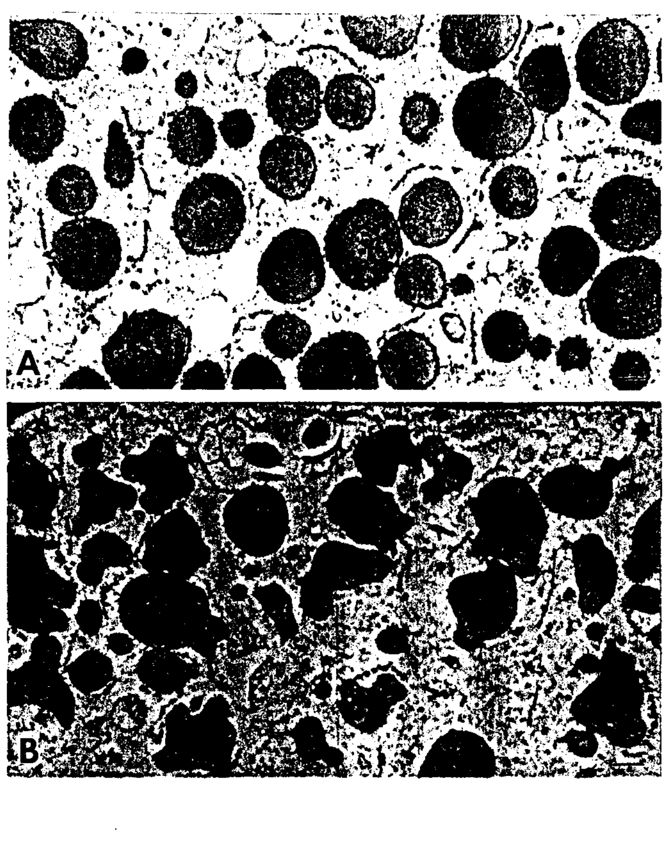


duced (Fig. 3). As we know that kafirin proteins are the least digestible protein fraction, it appears that these proteins are in some way involved with this formation of disulfide linked polymers during cooking. Likely candidates for this involvement are gamma-kafirin and beta-kafirin, which contain as much as 7 and 5.4 mole percent of cysteine, respectively (Taylor et al. 1989 and Watterson et al. 1990). Alpha-kafirin involvement is less likely since it contains very little cysteine.

Localization of Kafirins in Sorghum Protein Bodies

The staining patterns observed in sorghum protein bodies prepared for electron microscopy suggest that there are differences in protein composition within the protein bodies. Sorghum protein bodies have concentric rings with dark inclusions. Many of the protein bodies have darkly staining cores (Fig. 4). To determine the organization of kafirins within the protein body: alpha-, beta-, and gamma-kafirins were localized using immunocytochemical methods. Alpha-kafirins were localized only in the light staining regions of the protein bodies. Beta-kafirins were primarily localized in the dark staining regions, however, a minor portion was present in the light staining regions. Gamma-kafirin was localized in the dark regions of the protein body. Similar staining patterns were observed between protein bodies from the peripheral and central endosperms. However, protein bodies in the central endosperm had a higher proportion of darkly stained material than those in the peripheral endosperm so beta- and gamma-kafirin stained in a larger area of the protein bodies from the central endosperm.

Figure 4. Protein bodies in 20 day sorghum, prepared for electron microscopy, and stained with lead citrate and uranyl acetate. (A) Protein bodies from the peripheal endosperm region. (B) Protein bodies from the central endosperm region. (Bar=0.5μm).



Our research shows that the staining patterns of alpha- beta- and gamma-kafirins in sorghum protein bodies are similar to those observed for zeins in maize (Lending et al. 1988). The distribution of beta-kafirin and gamma-kafirin through the protein body may provide a mechanism for the formation of disulfide linked polymers throughout the protein body during cooking thereby leading to poor digestibility. Currently, immunolocalization techniques are being used to investigate how the alpha-kafirin, beta-kafirin and gamma-kafirin regions of the protein bodies are altered by both cooking and digestion. Also, enzyme-linked immunosorbent assays (ELISA) have been developed for the quantitation of alpha-kafirin, beta-kafirin and gamma-kafirin. These assays will be used to discover how the relative percentages of alpha-kafirin, beta-kafirin and gamma-kafirin of sorghum flour are altered by protein digestion both before and after cooking.

Conclusions

These results demonstrate that sorghum proteins are considerably less digestible after cooking than other cereal proteins. Using both *in vitro* and *in vivo* techniques, cooking reduced the digestibility of the alcohol-soluble sorghum storage proteins or kafirins. A variety of reducing agents have been used to significantly improve the *in vitro* digestibility of uncooked and cooked sorghum proteins. The addition of a reducing agent brought protein digestibility to the level of maize.

Scanning electron micrographs showed that the kafirin-containing protein bodies, present in sorghum endosperm, retained their structural integrity during cooking. It was shown that the mode of protein body digestion with pepsin proceeded by a pitting mechanism in both uncooked and reducing agent cooked sorghum. Whereas the digestion of protein bodies cooked in water proceeded by decreasing in size and losing their spherical shape without any pitting.

Since cooking in the presence of a reducing agent makes sorghum proteins more digestible and prevents the formation of high molecular weight protein polymers, oxidative formation of disulfide bonds during the cooking process may play a role in creating the less digestible proteins. Likely candidates for this involvement are the high-cysteine gamma-kafirin and beta-kafirin. Both gamma-kafirin and beta-kafirin are associated with the darker staining areas of the sorghum protein bodies. Immunolocalization and ELISA studies of sorghum flour both before and after cooking and with and without digestion are underway to determine the effects of alpha-kafirin, beta-kafirin and gamma-kafirin on protein digestion.

Literature Cited

Axtell, J.D., A.W. Kirleis, M.M. Hassen, N. DeCroz-Mason, E.T. Mertz, and L. Munck. 1981. Digestibility of sorghum proteins. Proc. Natl. Acad. Sci. USA. 78:1333-1335.

Bach Knudsen, K.E. and L. Munck. 1985. Dietary fiber contents and compositions of sorghum and sorghum-based foods. J. Cereal Sci. 3:153-164.

Eggum, B.O., L. Monowar, K.E. Bach Knudsen, L. Munck and J. Axtell. 1983. Nutritional quality of sorghum and sorghum foods from Sudan. J. Cereal Sci. 1:127-137.

Esen, A. 1986. Separation of alcohol-soluble proteins (zeins) from maize into three fractions by differential solubility. Plant Physiol. 80:623-627.

Haikerwal, M. and A. Mathieson. 1971. Extraction and fractionation of proteins of sorghum kernels. J. Sci. Food Agric. 22:142-145.

Hamaker, B.R. 1986. The indigestible sorghum proteins and improvement of digestibility using reducing agents. Ph.D. Thesis, Purdue University.

Hamaker, B.R., A.W. Kirleis, L.G. Butler, J.D. Axtell, and E.T. Mertz. 1987. Improving the *in vitro* protein digestibility of sorghum with reducing agents. Proc. Natl. Acad. Sci. USA 84:626-628.

Hamaker, B.R., E.T. Mertz, A.W. Kirleis, and J.D. Axtell. 1986. Effect of cooking on the protein profiles and pepsin digestibility of sorghum and maize. J. Agric. and Food Chem. 34:647-649.

Johns, C.O. and J.F. Brewster. 1917. Kafirin, an alcohol-soluble protein from kafir, andropogon sorghum. J. Biol Chem. 28:59-66.

Landry, J. and T. Moureaux. 1970. Heterogeneite des glutelines du grain de mais: Extraction selective et composition en acides amines des trois fractions isolees. Bull. Soc. Chim Biol. 52:1021-1037.

Lending, C.R., A.L. Kriz, B.A. Larkins, and C.E. Bracker. 1988. Structure and immunocytochemical localization of zeins. Protoplasma 143:51-62.

Leonard, D.L. 1990. Microscopic study of *in vitro* pepsin digestibility of sorghum proteins. M.S. Thesis, Purdue University.

Mitaru, B.N., R.D. Reichert, and R. Blair. 1985. Protein and amino acid digestibilities for chickens of reconstituted and boiled sorghum grains varying in tannin content. Poultry Sci. 64:101-106.

Nwasike, C.C., E.T. Mertz, R.C. Pickett, D.V. Glover, B.A.K. Chibber, and S.W. VanScoyoc. 1979. Lysine level in solvent fractions of pearl millet. J. Agric. Food Chem. 27:1329-1331.

Osborne, T.B. and L.B. Mendel. 1914. Nutritive properties of proteins of the maize kernel. J. Biol. Chem. 18:1-6.

Shull, J.M., J.J. Watterson, and A.W. Kirleis. 1991. A proposed nomenclature for the alcohol-soluble proteins (kafirins) of Sorghum bicolor (L. Moench) based on

molecular weight, solubility and structure. J. Agric. Food Chem. 39:83-87.
Shull, J.M., J. Watterson, and A.W. Kirleis. 1990. Localization of gamma-kafirin in Sorghum bicolor endosperm. Cereal Fd. World 35:830.
Skock, L.V., C.W. Deyoe, F.K. Shoup, J. Bathurst, and D. Liang. 1970. Protein fractionation of sorghum grains. Cereal Chem. 47:472-481.
Taylor, J.R.N., R. Von Benecke, and F.H.H. Carlsson. 1989. Distribution, purification and N-terminal amino acid sequence of sorghum reduced-soluble protein. J. Cereal Sci. 9:166-177.
Watterson, J., J.M. Shull, A.A. Mohamed, V. Reddy and A.W. Kirleis. 1990. Isolation of a high-cysteine kafirin protein and its cross-reactivity with gamma-zein antiserum. J. Cereal Sci. 12:137-144.

Progress and Change in Sorghum Utilization as a Result of Policy Reform in Nigeria

D. S. Murty and J.O. Akingbala[1]

Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is the most important staple food grain cultivated between 8°N to 13°N in northern Nigeria. It is commonly known as guinea corn and is also called *dawa* and *oka baba* in Nigerian local languages. Nigeria is the foremost country in Africa, in total area cultivated with sorghum as well as in its production (4.86 million t/a^{-1}, Doggett, 1988). Local cultivars grown by the farmers mostly belong to the races *durra-caudatum, guinea-caudatum* and *guinea*, whose maturity could range from 120 to 180 days. Yellow endosperm types called *kaura*, and white grain types called *farafara*, are popular. Average grain yields under local conditions rarely exceed 2.0 t/ha^{-1} and are normally below 1.0 t/ha^{-1}.

Until very recently, sorghum has been used in Nigeria exclusively for human consumption, in the form of traditional foods such as *tuwo* (thick porridge), *ogi* (thin fermented porridge), *kunu tsamia* and *massa*. In some parts of Nigeria, sorghum has been used for the production of traditional alcoholic drinks such as *burukutu, pito* and *otika* and domestic breweries of small cottage industry level are common.

Since their inception, the modern food and beverage industries of Nigeria were dependent entirely on imported wheat, barley malt, maize and other cereal products. The sudden decline of foreign exchange earnings during the early eighties led the Government of Nigeria to introduce a "Structural Adjustment Programme" (SAP) with emphasis on the use of local raw materials for industrial purposes. Importation of wheat, barley malt, maize and other cereal grains has been banned. Local production of wheat is small, while barley production is still under experimentation in a small area. It has therefore become imperative for the food and beverage industries to search for locally produced cereals to substitute imported wheat and barley malt. Local research and development efforts on the prospective use of local cereals have been going on since the mid-seventies, but came into the light during the late eighties. Sorghum grain which is locally abundant was the natural choice. During the last five years, Nigerian industries have made a highly successful and strong effort to substitute imported cereals, with local sorghum, which has resulted in a tremendous boost to industrial utilization and value of sorghum in commercial grain markets (ICRISAT, 1990).

Sorghum grain is currently used in Nigeria, for the production of lager beer, non-alcoholic malt drinks, weaning foods, bread, biscuits, confectionaries and feeds. Some of the important industrial products, processes and problems related to sorghum utilization in Nigeria are briefly reviewed below.

Lager Beer

By far the largest proportion of sorghum grain currently used by Nigerian industries goes to the lager beer sector, followed by the non-alcoholic malt beverages sector. The consumption of traditional alcoholic drinks was drastically reduced in Nigeria after the introduction of barley-based lager beer (Illori, 1991). The first brewery, Nigerian Breweries Ltd., Lagos, was commissioned in 1949 and since then the number of industrial breweries increased rapidly. Currently, there are 29 companies operating 24 breweries which have a

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total installed capacity of 19.61 million hL/a^{-1} of lager beer production (Malomo, 1990). During the year 1985, about 161,042 t of barley malt was imported into Nigeria and used by the breweries which then operated at an average efficiency of 50% of their installed capacity (Ilori, 1991).

With the objective of producing lager beer from local cereals, the Federal Institute of Industrial Research, Oshodi (FIIRO), Lagos, conducted a series of investigations on the production of sorghum malt and its substitution for barley malt (FIIRO, 1976). Promising results were reported by Skinner (1976) and Okafor and Aniche (1980) in their experiments with sorghum brewing. Meanwhile, the Institute for Agricultural Research (IAR), provided several improved cultivars of sorghum, mostly derived from local germplasm (Curtis, 1967; Andrews, 1970, Obilana, 1985). One cultivar, Short Kaura 5912 (SK 5912) was found by FIIRO as the most promising for malting quality. Trials using blends of barley malt and sorghum malt (25% and 50%) resulted in the production of lager beers on experimental basis (Olaniyi, 1984). The ban on the importation of barley malt into Nigeria came into effect from January, 1988. Since then, the breweries are obliged to utilize locally available sorghum and maize as raw materials in beer production, and have considerably modified their brewing process and equipment. Several brands of lager beer such as "Double Crown", "Rex", "Monarch", "Masters", "Bond", "Trophy", "Class", "Kronenburg", "Mayor", "Gold", "Kings" and "Premier" with a major portion of their cereal extract derived from sorghum are in the market. Other beers such as "Harp" and "Star" are being produced with a major portion of their cereal extract derived from maize and a small portion from sorghum.

Raw Materials

Preferences in the form of sorghum for use in beer production vary among brewers. It is used in the form of either raw grain (broken pieces from whole grain or grits from dehulled grain) or malt. Different breweries use different proportions of sorghum malt, sorghum grits and maize grits as their raw material. There is a shortage of sorghum grits for brewing. Most milling companies are able to achieve only 50% extraction of grits after dehulling whole grain.

The sorghum malting technology in Nigeria is in its infancy and is under improvement. Floor malting and other less sophisticated techniques are in use. There are only three companies which supply sorghum malt in commercial quantities and they can cater for only a fraction of the country's needs (Ikediobi, 1990). A few breweries have acquired small box malting facilities to serve their own needs, while most breweries still depend upon the local market for the purchase of sorghum malt.

Problems encountered during industrial malting of sorghum in Nigeria include molds, cyanogenesis, high malting losses (up to 20%), insufficient modification and nonuniform germination (Ikediobi, 1990). The byproduct of sorghum malting, namely sprouts (shoots and roots) is used as organic fertilizer. The sprouts could be a rich source of dhurrin. Ilori et al (1990) observed differences among two sorghum cultivars in their malting response to grain bed thickness. They also determined 18 h steeping time and 96 h germination period at 28-30°C as optimal for sorghum malting (Table 1).

Although the cultivar SK 5912 has been recommended for malting, there is insufficient supply of its grain. Consequently, the brewers and maltsters are using grains of SK 5912 and the local white grain cultivar, *farafara* (Aisien, 1990). The grains of SK 5912 have a yellow endosperm while *farafara* has white endosperm. The brewers are not satisfied with the grain lots available in the local market, because they frequently represent a mixture of different cultivars with similar grain color, and impurities are high. Some breweries have invested in large agricultural farms, where they could grow sorghum and maize cultivars of their choice and obtain uniform and dependable raw material.

The qualities of sorghum malt available to brewers in the market vary from lot to lot (Chukwura, 1990). Non uniform grain lots and malt affect their corresponding brew house performance. The milling of sorghum malt using equipment normally used for barley might require suitable modifications.

Table 1. Malting properties of SSV3 and SSV12 sorghum varieties at different grain bed thicknesses.

	SSV3 sorghum variety Initial grain bed thickness (cm)			SSV12 sorghum variety Initial grain bed thickness (cm)		
	2	4	6	2	4	6
Malting loss*	25.0a	17.4b	10.9c	25.3a	26.0a	26.4a
Moisture content*	10.4a	10.6a	10.4a	10.8a	10.3a	10.4a
Diastatic power (°IOB)	44.0a	30.0c	20.0d	33.0b	32.3b	34.0b
Total soluble sugars*	27.4a	24.8c	20.4d	23.6d	23.6b	20.1b
Cold water extract* (°EBC)	38.8a	26.4c	22.4d	30.6b	30.5b	31.1b
Hot water extract (L°/kg)	229.6a	186.6c	156.8b	198.8b	198.3b	199.0b
Malt colour	5.5a	4.5b	3.0c	5.5a	5.0a	5.5a
Ash*	1.17b	1.38a	1.44a	1.20b	1.19b	1.18b
Fat*	2.39b	2.81a	2.88a	2.19c	2.06c	2.01c
Protein*	11.4d	12.1c	12.7a	13.3a	12.8a	12.8a

*Values were expressed in percentage of the dried malt after 180 h germination.
IOB = Institute of Brewing

Means with the same letter along the same row are not significantly different at 5% level of significance.

Source: Ilori, et. al., (1990)

Brewing

In contrast to barley malt, sorghum malt contains low levels of amylases, particularly, *b*-amylase (Table 2). During the mashing operations, it is necessary to add external heat-stable enzymes such as *a*-amylase, neutral protease, *b*-glucanase, cellulase and amyloglucosidase to obtain complete saccharification (Aisien and Muts, 1987; Aisien, 1990). The peripheral corneous endosperm of the grain frequently poses problems of incomplete modification, although the floury endosperm undergoes complete modification (Palmer, 1989, 1991). Barley malt, with its husk, facilitates mash filtration, whereas the application of naked sorghum grain requires the use of special mash filters during wort separation. The gelatinization temperature of sorghum is relatively higher (70°-80°C) than that of barley and therefore malt and enzymes can be added only after cooling the starch gel. However, use of heat-stable enzymes and other mashing techniques could circumvent this problem. Arri (1990) listed several problems in brewing a 100% sorghum beer of acceptable quality, while Ogundiwin, et. al., (1990) studied the properties of 100% sorghum beer produced without the use of external enzymes and claimed encouraging results.

Table 2. Analytical properties of sorghum and barley malt (dry weight basis).

Parameter	Sorghum	Barley
Moisture (%)	5-8	5-8
Starch (%)	70-72	58-60
Soluble sugars (reducing) % power	4-5	4-5
Extract a.i. (%)	78	75
Extract (%)	85	81
Diastatic power (WK)	80	220
TSN (total soluble N) mg/L	301	1022
FAN (Free Amino N)	150	350
Homogeneity (%)	37	75
Modification Index (%)	40	90
Colour EBC	5.0	6.5

Source: Aisien, 1990

Selection of Cultivars

Different brewers emphasize different quality parameters desired for sorghum as a raw material in brewing and malting. These differences are mainly due to the form in which the respective breweries apply sorghum in their brewing process. Selection parameters for cultivars suitable for lager beer production can be broadly categorized under two groups:

A)Grain quality parameters for brewer's grits:

i) hard endosperm suitable for dehulling and gritting
ii) high percentage of extract and soluble protein
iii) low polyphenol/tannin content
iv) low fat content
v) low gelatinization temperature

B) Grain quality parameters for malting:

i) high water absorption and germinability
ii) higher levels of enzyme activity, particularly *b*-amylase
iii) high malt extract (80%)
iv) soft endosperm with easily accessible protein bodies
v) low levels of mold growth, and rootlet production
vi) low polyphenol/tannin content
vii) high level of proteases

It is apparent that brewers would require corneous endosperm grain types while maltsters might require soft endosperm grain types. In addition, higher productivity (grain yield t/ha^{-1}) is universally desired. However, new analytical techniques might be required to assess the malting and brewing potential of sorghum grain and malt, since the use of analytical techniques developed for barley and barley malt are unlikely to give a realistic indication of sorghum quality (Palmer, 1989).

Non-Alcoholic Malt Drinks

A variety of non-alcoholic malt drinks with different brand names such as "Maltina", "Evamalt" "Malta", "Maltonic" and "Vitamalt" are being successfully marketed in Nigeria by some of the breweries. The production process is similar to that of lager beer until the separation of wort and fermentation is avoided. The wort is further boiled and caramalases, flavor and coloring agents are added before bottling. Malt drinks are highly popular and are liked by one and all across all religious communities. These drinks have great potential in the African market in general.

Since the ban of barley malt importation came into effect in Nigeria, the breweries have substituted barley malt and other adjuncts used in malt drinks with sorghum grain and malt much in the same way as they dealt with lager beer production without barley malt. There seem to be no major problems in consumer acceptability and marketing of these malt drinks, and thus sorghum usage in the production of non-alcoholic drinks, has been very successful.

Weaning Food-Drinks

Malt-cocoa based weaning food-drinks are highly popular in Nigeria. The industries in this sector were using barley malt extract as base material. However, since 1988, they have been using sorghum as raw material for malt extraction. The production process involves the preparation of a clear wort, concentration of the wort to a syrup, addition of cocoa, whey and other agents, preparation of a dry cake, followed by packaging in a granulated form. Sorghum malt can be a source of the extract; alternatively sorghum grits can be converted and saccharified using external enzymes. Food Specialities (Nigeria) Ltd., are manufacturing such a malt-cocoa drink with the name "Milo" while Cadbury Nigeria Ltd., are manufacturing a similar product, "Bournvita". The granulated powder can be instantly mixed with hot milk, dilute milk or even warm water. It has been estimated that the current sorghum malt requirement in these Nigerian industries is about 25,000 t/a^{-1} and will increase rapidly. The qualities of sorghum malt extract are generally similar to barley malt extract and thus sorghum malt extract can be substituted for barley, at a cheaper price, in a range of weaning foods (Solabi, 1990). Some Nigerian companies are selling sorghum malt extract.

Nutritive value, sweetness, malt flavor and taste are the desired properties of a malt extract intended for use in weaning foods and drinks. Recently baby food formulations are also being supplemented with sorghum malt extract. FIIRO has devised methods to produce sorghum-soy *ogi* and also sorghum - cowpea *ogi* (Olanji and Daodu, 1990).

Bread, Biscuits and Confectionery

Sorghum Flour

Industrial milling of sorghum is new to Nigeria. Until the importation of wheat into Nigeria was banned in January 1987, the bakeries and biscuit manufacturers were using conventional wheat flour supplied by the local mills. In the year 1985, the installed capacity of the Nigerian wheat milling industry was about 4.6 million t/a^{-1}. Currently, most of the existing 22 large wheat flour mills in Nigeria are running at < 10% capacity (Ngoddy, 1990). As the demand for milled sorghum and maize products increased in the food and brewery sectors, some wheat flour mills were partly modified to suit maize and sorghum milling. For example, the Northern Nigerian Flour Mills, Kano, uses a decomatic decorticator for dehulling sorghum. A combination of roller stand with two passages and a hammer mill have been adapted to grind the pearled sorghum. The Pioneer Milling Co., Jos, is using a United Milling Systems (UMS) dehuller which can process 5 t/h. Recently about 15 to 20 new medium scale plants with horizontal dehulling devices were installed. These are versatile and flexible and can mill a range of grains such as sorghum, maize and legumes. In spite of low extraction rates, these mills have been successful. The milled products are mainly brewer grits and flour. Poor extraction rates, high fat content in the product, and coarse flour particle size are some of the sorghum milling problems generally encountered. There is an urgent need for improvement in the sorghum milling techniques being used, as well as the product standards, because the consumer industries are not satisfied with the milled products. However, the flour products which have less shelf life are probably satisfactory for domestic uses.

Wheat-Sorghum Composite Bread

Considerable research has been carried out by FIIRO and IAR on the substitution of wheat flour with sorghum flour in bakery products (Olatunji, et. al., 1982; Aluko and Olugbemi, 1990). As in other countries, the specific loaf volume of the composite bread was found to decrease with increased level of substitution for wheat. Bread made from 70%wheat: 30% sorghum (dehulled) composite flour has been tried by the bakeries (Idowu, 1990). The proximate composition of composite bread showed reduced protein and increased fibre content when compared to 100% wheat bread. Bakers complain that the composite bread required a relatively higher quantity of flour to obtain a unit volume and that the texture and shelf life of the composite bread is poorer than 100% wheat bread. It is widely recognized that the bread in the Nigerian market now has up to 20% of maize or sorghum content and that there is some consumer resistance to the change in bread quality. However, much higher levels of substitution for wheat have been achieved in cakes and other local snacks.

Biscuits

Substitution of sorghum for wheat in biscuit manufacture has been relatively more successful in Nigeria. Breakage of composite flour biscuits during processing and packing has been reported to be the most important problem. A leading biscuit manufacturing company, NASCO, found that substitution with 25% sorghum flour in production of short and hard dough biscuits and wafers was cost effective without affecting quality, breakage and plant efficiency (Priyolkar, 1990).

Feeds

Till recently, very little sorghum was used as raw material in the manufacture of feeds in Nigeria. However, the importance of sorghum in the feed industry has increased many fold due to the ban on the importation of cereal grains and the acute demand for maize in various industries. It was estimated that the feed industries requirement of maize and sorghum in 1995 will be about 1.7 million tons (Esiemokai, 1990). It is even likely that in the next few years sorghum will replace maize in various feed formulations. However, the processing of sorghum for feed uses would require additional technological efforts by the respective industries.

Future Research Needs

The Raw Materials Research and Development Council (RMRDC) of Nigeria estimated that the current demand for sorghum in Nigeria is about 4 million t/a^{-1} while the projected potential demand through the year 2000 is about 8 million t/a^{-1} (Aribisala, 1990). If the anticipated potential industrial uses are realized in the near future, the deficit of cereal grains in Nigeria is likely to further increase. In spite of substitutability among the available cereal grains, there is already a general shortage of cereal grains in the country due to low productivity and high demand. A situation such as this could soon lead to competition for the available cereal grains between industrial users and traditional consumers. Therefore, there is an urgent need for sorghum improvement programs to aim at higher productivity and cultivars for different end uses. Specific attention should be paid to improvement in sorghum milling and malting technologies.

Literature Cited

Aisien, A.O. 1990. Utilization of sorghum in brewing lager beer in Nigeria. p.24 In Industrial Utilization of Sorghum: Summary proceedings of a symposium on the current status and potential of industrial uses of sorghum in Nigeria, 4 - 6 Dec., 1989, Kano, ICRISAT, Patancheru, 502 324 (AP) India.

Aisien, A.O. and G.C. Muts. 1987. Microscale malting and brewing studies of some sorghum varieties: J. Inst. Brew. 93: 328-331.

Aluko, R.E. and L.B. Olugbemi. 1990. Sorghum as a raw material in the baking industry p21, In Industrial Utilization of Sorghum: Summary proceedings of a symposium on the current status and potential of industrial uses of sorghum in Nigeria, 4 - 6 Dec., 1989, Kano, ICRISAT, Patancheru, 502 324 (AP) India.

Andrews, D.J. 1970. Breeding and testing dwarf sorghums in Nigeria. Expl. Agric. 6 : 41-50.

Aribisala, A.O. 1990. Industrial utilization of sorghum in Nigeria, p. 13 In Industrial Utilization of Sorghum: Summary proceedings of a symposium on the current status and potential of industrial uses of sorghum in Nigeria, 4 - 6 Dec., 1989, Kano, ICRISAT, Patancheru, 502 324 (AP) India.

Arri, B.K. 1990. Problems associated with the use of sorghum for lager beer production. p. 29 Ibid.

Chukwura, E.N. 1990. Brewhouse performance of sorghum grain and malt: Problems and prospects. pp 30 - 31 Ibid.

Curtis, D. L. 1967. A review of the sorghum breeding programme in Nigeria. Samaru Miscellaneous Paper No. 18, p. 14, Ahmadu Bello University, Samaru.

Doggett, H. 1988. Sorghum, 2nd ed, pp 512, Longman Scientific and Technical, Longman Group UK Limited.

Esiemokai, A.O. 1990. Sorghum: Feed grain of the future in Nigeria. p.45 In Industrial Utilization of Sorghum: Summary Proceedings of a symposium on the current status and potential of industrial uses of sorghum in Nigeria, 4 - 6 Dec., 1989, Kano, ICRISAT, Patancheru, 502 324 (AP) India.

FIIRO (Federal Institute of Industrial Research, Oshodi), 1976. Production of Malt from Nigerian sorghum. Technical Information Bulletin for Industries (FIIRO) 1976 (5) 1 - 4.

ICRISAT (International Crop Research Institute for the Semi-Arid Tropics), 1990. Industrial Utilization of sorghum: Summary proceedings of a symposium on the current status and potential of industrial uses of sorghum in Nigeria, ed. D.S. Murty,4 - 6 Dec., 1989, Kano, ICRISAT, Patancheru, 502 324 (AP) India.

Idowu, A. 1990. Bread from composite flour, p. 22 Ibid.

Ikediobi, C.O. 1990. Industrial production of sorghum malt in Nigeria, p32, Ibid.

Ilori, M. O. 1991. The use of sorghum for beer brewing in Nigeria. Technovation Vol. 11 (1) 27 - 37 Elsevier Science Publishers Ltd.

Ilori, M. O., J.O. Akingbala, G.B. Oguntimein and J.O. Ogundiwin. 1990. Effect of grain bed thickness, duration of steeping and germination on the malting properties of improved Nigerian sorghum varieties. Food Science and Technology - Lebensm - Wiss. U. Technol. 23, 505 - 512.

Malomo, O. 1990. Sorghum in lager beer production: Progress and prospects. p. 30. In Industrial Utilization of sorghum: Summary proceedings of a symposium on the current status and potential of industrial uses of sorghum in Nigeria, 4 - 6 Dec., 1989, Kano, ICRISAT, Patancheru, 502 324 (AP) India.

Ngoddy, P.O. 1990. Sorghum milling in Nigeria: A review of industrial practice, research, and innovations P. 14. In Industrial Utilization of sorghum, Ibid.

Obilana, T.A. 1985. Sorghum breeding and selection for brewing industry in Nigeria. National Symposium on the brewing industry - Now and in the 21st century. Problems, challenges and prospects. 29 May - 1st June, 1985, Owerri, Nigeria.

Ogundiwin, J.O., M.O. Ilori and A. Okelaye. 1990. Brewing of clear lager beer from sorghum grains of SK 5912 variety without addition of external enzymes to achieve saccharification: A case study. p. 31 In Industrial Utilization of sorghum: Summary proceedings of a symposium on the current status and potential of industrial uses of sorghum in Nigeria, 4 - 6 Dec., 1989, Kano, ICRISAT, Patancheru, 502 324 (AP) India.

Okafor, N. and G.N. Aniche. 1980. Brewing a lager beer from Nigerian Sorghum. Brewing and Distilling International 10, 32 - 35.

Olaniyi, O.A. 1984. Cereal in brewing industry. A paper presented at the 8th Annual Conference of the Nigerian Institute of Food Science and Technology. Obafemi Awolowo University, Ile-Ife, November, 1984.

Olatunji, O., I.A. Akinrele, C.C. Edwards and O.A. Koleoso. 1982. Sorghum and millet processing and uses in Nigeria. Cereal Foods World. 27 (6) 277 - 280.

Olatunji, O. and A.M. Daodu. 1990. Potentials of using sorghum in the production of weaning foods. p. 37 Industrial Utilization of sorghum: Summary proceedings of a symposium on the current status and potential of industrial uses of sorghum in Nigeria, 4 - 6 Dec., 1989, Kano, ICRISAT, Patancheru, 502 324 (AP) India.

Palmer, G.H. 1989. Cereals in malting and brewing pp. 61 - 242, In Cereal Science and Technology ed. G.H. Palmer, Aberdeen, Aberdeen University Press.

Palmer, G.H. 1991. Enzymic degradation of the endosperm cell walls of germinated sorghum. World Journal of Microbiology and Biotechnology 7: 17 - 21.

Priyolkar, V.S. 1990. Use of sorghum flour in biscuit and wafer production: The NASCO Experience. p.23. In Industrial Utilization of sorghum: Summary proceedings of a symposium on the current status and potential of industrial uses of sorghum in Nigeria, 4 - 6 Dec., 1989, Kano, ICRISAT, Patancheru, 502 324 (AP) India.

Skinner, K. 1976. Tropical lager beer brewing with sorghum malt. Brewing and Distilling International 6, 26 - 27.

Solabi, G.A. 1990. Uses of sorghum in malted and fermented foods and drinks. p.37. In Industrial Utilization of sorghum:

Summary proceedings of a symposium on the current status and potential of industrial uses of sorghum in Nigeria, 4 - 6 Dec., 1989, Kano, ICRISAT, Patancheru, 502 324 (AP) India.

Uses and Food Potential of White Sorghum Grain in Mexico

Fernando Martinez Bustos[1]

Introduction

In 1987, Mexico produced approximately 4.5 million tons of sorghum grain with an average grain yield of between 3.5 and 4.0 t/ha on an area of between 1.5 and 2.0 million hectares. This yield is considered among the highest in the world. However, in the last few years, the country has been importing 1.5 million tons per year to satisfy its internal demand . Since sorghum was introduced to Mexico it has been destined principally to feeding animals (INEGI 1988) with a small proportion being used as an adjunct in brewing (Canales 1976) and in making tortillas and atoles in southern Mexico (Almeida-Dominguez et al 1991). White sorghum introduced to Mexico by ICRISAT (International Crops Research Institute for the Semi-arid Tropics) has permitted INIFAP (National Institute of Research in Agriculture, Forestry and Livestock) to liberate approximately eight varieties of white sorghum with good agronomic characteristics and grain quality (Hash y Clará 1990). Also, private seed companies have introduced white-seeded hybrids with potential as food and with better efficiency for feed since many feed factories prefer white sorghum. The availability of cheaper white sorghum on the market compared to maize and wheat makes sorghum more attractive and more profitable as a food .

Alkaline-cooked Foods and Atoles from Sorghum

White sorghum with tan glumes, intermediate grain texture, thick white or light yellow pericarp without testa, and with a normal proportion of amylose-amylopectin in starch, produces staple Mexican foods such as tortillas and instant sorghum flours of acceptable sensory characteristics. Alkali concentration and the length of alkaline cooking are critical parameters in obtaining whiter products. Sorghum requires one third the alkali concentration and approximately one fourth the cooking time necessary for maize. Mixtures of 10% to 50% white sorghum with maize improve technological and sensory characteristics of alkaline products (Table 1). Because sorghum requires less cooking time than maize, sorghum should be added when the maize has been cooked, keeping the sorghum-maize mixture together during steeping and later steps of tortilla preparation (Martínez et al 1982, Silva y Martínez 1984). Atoles from white sorghum flours or white sorghum flours obtained through the hydrothermal process present acceptable sensory and technological characteristics (Ramirez y Martínez 1983).

Sorghum in Brewing

Sorghum is utilized as an adjunct in brewing (Canales 1976). However, it is important to characterize the sorghums that present appropriate sugar content during the fermenting stage in brewing. Sorghum's potential for the preparation of sorghum malt is associated with sorghums that present an adequate enzymatic amylolitic potential, low tannin content and considerable extract yield during the malting process (Table 2). To predict the malting quality of sorghum, conditions followed for barley must be modified since sorghum presents low germinating energy as compared with barley (Figueroa and Martínez 1991).

Extrusion Cooking of Sorghum

The extrusion-cooking process presents many alternatives for producing diverse food and industrial products from whole sorghum flour, sorghum grits or sorghum starch. The versatility of the process permits the production of extruded products with different grades

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Table 1. **Sensory characteristics[a] of tortillas preparated with instant sorghum[b] flours and maize-sorghum instant mixtures.**

	Sorghum								
	Genotype 9A				Genotype 145				
	WSF[c]	MMSF[d]	RSF[e]	MMSF	WSF	CIMF	DSF[f]	MMSF	CIMF[g]
Color	4.62b[h]	5.47b	3.96b	4.36b	3.76b	3.86b	5.05b	6.19a	6.96a
Aroma	4.77b	5.75a	4.35b	5.40a	5.32b	5.78a	5.99a	6.36a	6.54a
Flavor	5.96a	6.53a	3.90b	4.62a	6.29a	6.07a	5.99a	6.54a	6.09a
Texture	5.39a	6.50a	6.97a	5.24a	7.28a	7.18a	6.83a	7.02a	6.37a

Source: Martínez 1988

[a]A 9 point Hedonic scale with scores 1 to 9 was used. Ten Mexican consumers rated each tortilla-treatment.

[b]Obtained with a single screw Brabender extruder.

[c]WSF: Whole sorghum flour.

[d]MMSF: Mixture commercial maize flour (10%) with instant sorghum flour (90%).

[e]RSF: Sorghum flour with particle size smaller than 0.420 mm.

[f]DSF: Decorticated sorghum flour.

[g]CIMF: Commercial instant maize flour (control).

[h]Values with the same letter are not significantly different within each row at $\alpha = 0.05$.

Table 2. Malting characteristics[a] in some commercial sorghum hybrids and varieties.

	Endosperm		Tannin	Diastatic	Extract
Type	Type	Color	C.E.	Power °L	%
Perlita	Nonwaxy	White	0.00	6.22	74.3
Blanco-86	Nonwaxy	Yellow	0.00	6.19	76.3
Pacifico	Nonwaxy	Yellow	0.00	5.39	74.9
W 823-A	Nonwaxy	Yellow	0.00	8.27	77.9
M-62641	Nonwaxy	White	0.00	6.20	70.6
Car-1099	Nonwaxy	Red	0.12	6.20	64.0
Purepecha	Nonwaxy	Yellow	0.00	2.49	81.5

Source: Figueroa and Martínez 1991

[a]Values are means of three repetitions

C.E.: Cathequin Equivalent

°L: Lintner Grades

of gelatinization, expansion, density, texture, format and functional properties. Scaled pilot tests have confirmed the positive results obtained with experimental equipment (Table 3).

However, the availability of enough sorghum on the market has limited the implementation of the process at an industrial level (Martínez y Paul 1991). The traditional method of preparing tortillas or producing tortilla flour is time and energy consuming and produces waste effluents. The extrusion cooking process offers appropriate technology for the production of instant sorghum flours with less alkali, water, process area, and without waste effluents since solids are not lost in the process (Martínez 1988).

Milling of Sorghum

A good way to increase the use of sorghum for food is through the production of acceptable quality flour with low fiber, ash, lipid, and pigment contents. The production of this type of flour basically include the following steps : decortication using commercial rice attrition equipment to remove approximately 12% of its original weight (mainly pericarp and germ tissue), and grain milling using conventional wheat milling equipment (Table 4). Sorghum flours can be used in the preparation of cookies, cakes, snacks, extruded products, pre-gelatinized flours and mixtures of sorghum and wheat to produce breadmaking products (Martínez 1990, Rivera et al 1985). Another

Table 3. Effect of moisture content on color, expansion and density of extruded products[a] from decorticated and whole sorghum variety Blanco-86.

	Color[b]			Expansion[c]	Density g/cm^3
	L	a	b		
Whole sorghum					
12%	70.6a[d]	0.6	15.0	2.81b	0.305b
15%	69.6b	0.4	15.2	3.20b	0.561a
18%	69.3b	0.4	14.4	3.70a	0.221c
Decorticated sorghum (20%)					
12%	76.1b[d]	0.5	14.7	3.38b	0.114c
15%	72.8c	0.6	14.5	3.76a	0.375a
18%	78.3a	0.7	12.4	2.46c	0.253b

Source: Martínez y Paul 1991

[a]Single screw cooker extruder Mapinplanti, screw velocity 150 rpm, temperature of extrusion 110°C, die of 2mm, values are means of three repetitions.

[b]Hunter-Lab Colorimeter.

[c]diameter extruded product/internal die diameter.

[d]Values with the same letter are not significantly different within each row at $\alpha = 0.05$.

Table 4. Experimental milling[a] of sorghum in roller mills, Brabender Quadrumat Senior and Buhler Automatic 202.

Milling fraction	Buhler 202 Moisture content		Brabender Quadrumat Moisture content		Brabender Quadrumat
	12%	13.5% (5h rest period)	12%	13.5% (5h rest period)	Decorticated sorghum[b]
Break	15.02	14.96	30.10	29.01	16.02
Reduction	38.91	40.05	45.14	40.01	63.88
Total flour	53.93	55.00	75.24	69.02	79.90*
Shorts	29.61	28.00	11.15	13.71	8.35
Bran	16.45	17.00	13.60	17.26	11.75

Source: Martínez 1990.

[a]Values are means of two repetitions.

[b]Commercial rice attrition equipment to remove approximately 12% of its original weight.

*0.35% lipid content, 0.54% ash content, 0.30% fiber content.

potential for use is sorghum starch which can be used "in natura" or modified for different uses (Salinas et al 1990).

Conclusions

White sorghums offer broad perspectives for food and industrial uses and can be used efficiently in feed. Several studies in Latin America and the United States have shown their viability in the preparation of traditional foods as well as of several non-conventional products with new presentations which could probably be easily introduced into the market. New national policies have managed to reduce the price of sorghum to 50% that of corn and to make its cultivation more extensive in critical areas. Probably due to lower prices on the market and greater production, white sorghum will be more attractive for utilization. Also, countrywide advice to small farmers for efficient use of sorghum for food will raise its status as food. Up to now, intensive research by national and international institutions has been focused on searching for new strains resistant to grain mold and rot which are frequent problems of white sorghum under the warm and wet conditions that prevail in the sorghum growing areas of Latin America.

Literature Cited

Almeida-dominguez, H. D., Serna-saldivar, S. O., and Rooney, L. W. 1991. Properties of new and commercial sorghum hybrids for use in alkaline-cooked foods. Cereal Chem. 68:25.

Canales, A. M., and J. A. Sierra. 1976. Use of sorghum. Technical Quarterly, Master Breweries Association of America. 13:114.

Figueroa, C. De Dios. J., and Martinez, B. F. 1991. Quality malting characteristics of commercial sorghum hybrids and varieties (in preparation).

INEGI. 1988. Abasto y comercialización de productos básicos.Sorgo. Instituto Nacional de Estadística Geografía e Informática.

Martinez, B. F. 1988. Obtençao de farinhas instantâneas de sorgo para tortillas pelo processo de extrusao. Tese de Doutorado. Faculdade de Enghenaría de Alimentos, Universidade Estadual de Campinas, So Paulo, Brasil.

Martinez, B. F. 1990. Molienda y usos potenciales del sorgo para consumo humano. VII Taller de la Comisión Latinoaméricana de Investigadores en Sorgo. CLAIS. 24-27 de abril, CIMMYT, El Batán, México.

Martinez, B. F., Cejudo, G. H. E. y Guiragossian, V. 1982. Análisis y selección de variedades de sorgo para elaboración de tortillas. XXVIII Reunión anual del Programa Cooperativo Centroaméricano para el Mejoramiento de Cultivos y Animales.26-30 de marzo, San José, Costa Rica. C. A.

Martinez, B. F. y Paul, C. L. 1991. Extrusión de sorgo integral y decorticado. XXXVII Reunión anual del Programa Cooperativo Centroaméricano para el Mejoramiento de Cultivos y Animales. 17-23 de marzo, República de Panamá, C. A.

Ramirez, B. R. F. y Martinez, B. F. 1983. Elaboración de harinas pre-gelatinizadas de sorgo por proceso hidrotérmico. Características químicas y usos. Revista Chapingo, No 41 Universidad Autónoma Chapingo. México.

Rivera, M. V., Martinez, B. F., Calderon, D. G. y Guiragossian, V. 1985. Utilización de harinas de sorgo en panificación. XXXI Reunión anual del Programa Cooperativo Centroaméricano para el Mejoramiento de Cultivos y Animales. 26-30 de marzo, San Pedro Sula Honduras, C. A.

Salinas, M. Y., Martinez, B. F. y Compton, L. P. 1990. Efecto del proceso de decorticado de sorgo en el rendimiento y color del almidón. XXXVI Reunión anual del Programa Cooperativo Centroaméricano para el Mejoramiento de Cultivos y Animales. 26-30 de marzo, República del Salvador, C. A.

Silva, P. M. y Martinez, B. F. 1984. Elaboración de harinas instantáneas de sorgo para tortillas. Características químicas y tecnológicas. Revista Chapingo, No 43-44 Universidad Autónoma Chapingo. México.

Hash, T.CH. y Clara, R. V. 1989. Reporte final LASIP. Latin-American Sorghum Improvement Program. ICRISAT. CIMMYT, El Batán, México.

The Use of Sorghum and Millet in the Sudan

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Introduction

Sorghum and millet are important cereals in many Asian and African countries. They are a major source of dietary energy and protein sources especially in areas where temperature, low rainfall and limited irrigation do not allow for cultivation of other cereals.

The importance of sorghum and millet has recently increased due to the rapid growth of the population, drought and desertification which has affected some of the African countries. In the Sudan, sorghum is the most extensively cultivated cereal; occupying approximately 40% of the entire cropped area. According to the official statistics of the Ministry of National planning it was estimated that 15 million feddans (1.037 feddans = 1.0 acre) will be planted in sorghum and millet respectively by the end of the three year national development plan.

Recently, sorghum was introduced as a main crop in the irrigated areas to account for rainfall failure. Research programs have introduced high yielding varieties and hybrids (Hageen Dura I) and are progressing to improve nutritional value of the improved cultivars.

Millet is grown mostly in the arid western part of the Sudan where climatic conditions permit only millet production. The annual production is estimated to be 500,000 tons.

Sorghum and millet are considered the food of the people in Sudan. The traditional importance of these crops is due to their use in local dishes. These dishes include whole cooked grains, porridges (thin and thick) and baked products (Kisra). Sorghum and millet are also incorporated into the formulation of new foods such as snack foods, biscuits and composite bread; and they are used in producing different types of drinks, including alcoholic and non alcoholic beverages.

Food Uses

Sorghum and millet are staple foods in the Sudan. The two grains are usually processed and used in many different types of dishes. This involves many steps and complicated techniques that were developed by the consumers through their understanding and awareness of their needs. These methods of processing have been modified to overcome nutritional factors or to improve the acceptability, digestibility and storage stability of sorghum and millet food products.

Various dishes which have some important social, economical, chemical, biochemical or microbial benefits will be presented in this paper. These will include some special recipes which have been designed to solve problems of hunger and malnutrition.

Whole grains

Balila is whole sorghum and millet grains boiled in water, salted and served with sugar, milk or consumed plain. Balila plays an important role in some religious and traditional ceremonies[2]. Served with milk, sugar and ghee, it contributes significantly to the nourishing process.

Fermented foods

Fermentation of sorghum grains tends to increase the available lysine in the final product[3]. It also it helps in enhancing the flavors

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[2] Badi, S. and L. Monawar (1987). Sudanese Sorghum and Millet Directory. Khartoum: Food Research Centre, Sudan.
[3] Eggum, B.O., L. Monawar, K.E. Bach Knudsen, L. Munck, J. Axtell. (1983). Nutritional Quality of Sorghum and Sorghum Foods from Sudan. J. Cereal Sci 1:137

and improves protein digestibility. The sorghum and millet fermentation involves lactic acid and alcohol.

Kisra

Kisra is a creppe like product prepared from fermented whole or refined sorghum or millet batter. In some areas it provides more than 80% of the energy intake. In spite of the belief of the poor people that Kisra is a nutritious and healthy product, many studies and modifications were done to change the composition to make it more nutritious. The addition of chick pea or peanuts to Kisra increases the protein content. The addition of milk powder and sugar increase the energy density (Table 1).

The Food Research Center in Sudan played an important role in upgrading the traditional technology of Kisra making and developed many recipes to cope with some nutritional problems in the country.

The way Kisra is baked on a hot iron plate for 20-30 seconds has some nutritional advantages. Accordingly the mechanization of Kisra uses this mode of processing. The machine is composed of a gas or diesel heated drum where the batter comes in contact with the hot surface. When the drum rotates, the Kisra sheet is dropped on a moving belt and collected at the other end. The time of the batter contact with the hot surface is the same as that in the traditional method.[4]

The established Kisra parameters for evaluation are light color, along with fine, smooth and soft texture. Kisra should also have minimum elasticity to keep it as one sheet. Shelf life is another important parameter. Kisra that retains its quality for more than 48 hours is essential for commercial production.

Asida

Asida is a fermented thick porridge. It is cooked like Ugali in Tanzania or tuwo in Nigeria or Sanakati in India. Asida is popular for breakfast and is usually eaten with meat stew, milk, honey, yoghurt or tomatoes. In the villages, Asida is considered the "food for guests" because it is easier to prepare than the Kisra. Asida is also used as a breakfast meal at weddings and other social ceremonies. Table 1 shows an analysis of Asida.

Nasha

Nasha is prepared from fermented batter cooked with continuous stirring in boiling water. It is usually sweetened with sugar and seasoned with cardamon, cinnamon and with preserved apricots.

The traditional Nasha was found to be low in protein, fat and caloric value but high in moisture content (Table 2). The dry matter content was 5%. To improve the nutritional quality of Nasha, the research results recommended supplementation with milk and groundnuts. Drum drying or extrusion processes were used to produce this product at the commercial level.

Table 1. Kisra and Asida Analysis

Protein	Ash %	Fat %	Crude fibre %	Starch %	Energy Cal/g
K. from whole Fetarita					
14.1	1.59	5.1	2.4	68.8	4601
K. from Decorticated Dabar					
12.6	1.23	4.2	1.1	74.8	4485
Asida from Decorticated Dabar					
Deco Dabar	0.68	2.3	1.0	75.9	4445

[4] Badi, S., P.L. Bureng, L. Monawar. (1987). Kisra Upgraded Technology. Khartoum: Food Research Center.

Whole millet porridge

Whole millet porridge is usually cooked like Nasha with milk and ghee. It has high calorie and high protein values.

Non-alcoholic beverage

Hulu murr, Abery and Huswa are good examples of non-alcoholic beverages in the Sudan.

Hulu murr

Hulu murr has a sweet astringent taste. It is prepared from a fermented, spiced slurry of malted sorghum or millet and baked like Kisra. The sheets are baked brown and dry. They are stored and used as desired. The flakes are soaked in water for 2-3 hours and then strained with a filter. It is usually used during the fasting period for Muslims (Ramadan).

Abery

Abery is very thin white flakes that are made from a fermented, cooked slurry of sorghum flour and spices. It is baked the same way as Kisra and hulu murr. The flakes are sour in taste.

Huswa

Huswa is made from malted flour. It is cooked in fat until brown in color and is then left to ferment for about 24 hours.

Alcoholic beverages

Fermented beverage are often made from darker sorghum varieties. To make beer the grains are germinated, dried, pounded and fermented. Sprouted millet is also used to make beer.

Merissa

Merissa is well known in Sudan and is equivalent to Bantu beer. It is opaque in color due to the presence of suspended starch. Merissa is not pasteurized and is consumed in active fermentation. The viscosity and taste are the important quality parameters for good Merissa.

Merissa beer contributes significant amounts of protein to the diet of the consumer (Table 3). Usually when it is sieved the sieved material has a much higher protein quality and biological value than the unsieved material.

Merissa is consumed mainly in the southern and western parts of the Sudan. Although Islam prohibits the consumption of any alcoholic material, it is socially accepted in those areas.

Unfermented Dishes

In Sudan many dishes are prepared from unfermented batter, dough or flour.

Suksukania

Suksukania is similar to North African Couscous made from durum wheat. When making suksukania, flour is wetted with cool water and agglomerated into small particles by hand. The Suksukania is usually used in wedding's breakfasts and some other ceremonies.

Table 2. Traditional Nasha

Moisture %	Ash %	Crude Fibre %	Protein %	Starch %	Fat %	Energy Cal/g
95	0.37	0.32	1.3	3.23	0.16	230

Table 3. Chemical composition of Merissa

	Protein	Ash	Fat	Crude fibre	Starch	Energy/Cal/g
Unsieved	19.1	1.54	4.5	3.2	55.4	4628
Sieved	13.3	2.58	4.5	2.0	61.3	4619

Sorghum and Millet processing

Traditional and new technology

The processing of sorghum and millet includes dehulling, grinding, flaking etc. For human food the grains are customarily milled before being cooked.[5]

Traditional milling

Traditional milling of sorghum and millet includes a pestle and mortar made from carved wood. During hand pounding, the grains are poured into the mortar and water added. Then the grains are stamped by the pestle for five minutes, winnowed and re-stamped. At the end of pounding, about 20% water (of the original grain weight) is used.

The product produced by traditional milling is white and fine. There are considerable losses from the mortar and pestles because some grains are thrown out of the mortar during pounding. Heat generated by the mortar also causes some loss of thiamine and B - Vitamins.[6]

The whiteness of the flour is one of the major criterias for acceptability in sorghum and millet. Generally the nationals prefer the whiteness of the flour over the nutritional quality.

Traditional milling is a tedious process and time consuming. As a result of drought and desertification many social changes have happened in Sudanese Society. The people's shift from sorghum to wheat added an economical burden on the government as imported wheat requires hard currency. This situation promoted the industrial milling of sorghum.

Industrial milling

Industrial milling has started in Sudan by implementing a pilot mill at the Food Research Center. To gain acceptability, the mill started by providing the people flour similar to that produced by the traditional milling process. At the beginning a 75% extraction rate was used to produce white flour but after that a 80% extraction rate was found to be the most suitable for sorghum to avoid great losses of nutritious embryo and aleurone layer.

Wet milling

Sorghum grain ranks second behind corn in the amount of total available energy. Sorghum and corn are valued for their high content of carbohydrates mostly in the form of starch (60-75%). The endosperm of sorghum may be soft and floury (Fetarita) medium in texture (Dabar) or hard (Safara). All white varieties proved to produce high quality starches.

The physical, chemical and rheological results have shown close similarities between raw sorghum starch and market corn starch (Fig. 1-4).

Traditional starch (Geeria in Arabic) is produced from fermented sorghum and millet and used in Nasha and Asida. Starch can easily be used in Kisra making as a pasting agent (Madida). In Sudanese houses wheat flour is mixed with sorghum flour to produce some elasticity to Kisra; gelatinized sorghum starch can be used instead.

Composite flour (Baked products)

Sorghum flour is incorporated with wheat to produce different baked products. The quality of the products depends on the wheat flour strength (gluten quality and quantity). Sorghum can be added in the range of 10-40% depending on sorghum variety and the percentage of decortication. The technology of preparing different types of bread is similar to that of normal wheat bread. When sorghum is added, the mixing and fermentation times are shortened by 5-10 minutes.

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[5] Hulse, J.H., E. Laing and D.E. Pearson. (1980). Sorghum and the Millets: Their Composition and Nutritive Value. Academic Press. New York. U.S.A.

[6] Munck, L., K.E. Bach Knudsen and J.D. Axtell (1981). Sorghum and Millet Milling Technology, I Quality of Locally Milled Sorghum Products as Related to Kernel Morphology in "Proceedings of the International Symposium on Sorghum Grain Quality", ICRISAT. October 28-31, 1981. Patancheru, India.

Sorghum New Food[7]

All sorghum new foods are made of 100% sorghum flour.

Pearl dura: Dehulled and polished sorghum grains which are used similar to rice. The large grains can be used in soups.

Snack food

Many different types of snack foods were prepared from sorghum and millets. Such as:

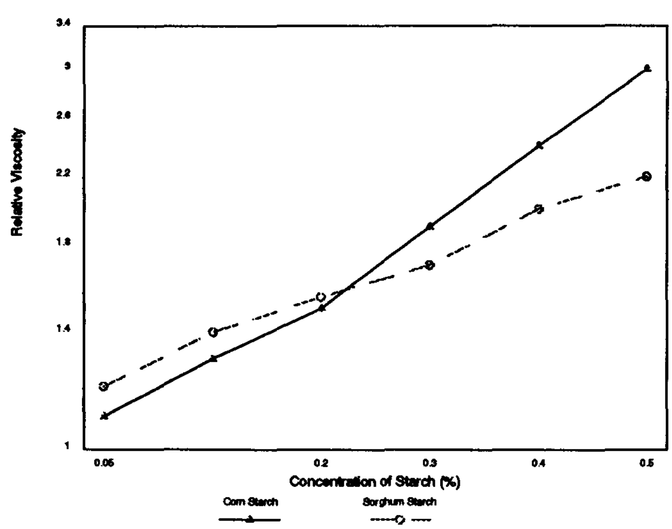
- Gham dates
- Crisp and chips
- Biscuits
- Calces

Also macaroni and spaghetti were made from sorghum.

Baby Food[8]

The traditional Nasha was upgraded to improve its nutritional quality by adding groundnuts, milk, vitamins and minerals and processing by drum drying (Table 3). Nasha was also improved by the addition of malt which gives Nasha a higher solids content and lowers its viscosity. The formulation and way of processing is well suited for commercial production of sorghum and millet based baby food. The product has been found to be highly acceptable.

Figure 1. Relative Viscosity of sorghum and corn starches.



[7] Badi, S. and L. Monawar. (1986). Sorghum New Foods. Khartoum: Food Research Center. Sudan.
[8] Monawar, L. and S. Badi. (1987). Instant Nasha. Sorghum and Millet Baby Food. Khartoum: Food Research Center. Sudan.

Figure 2. Swelling power of sorghum and corn starches.

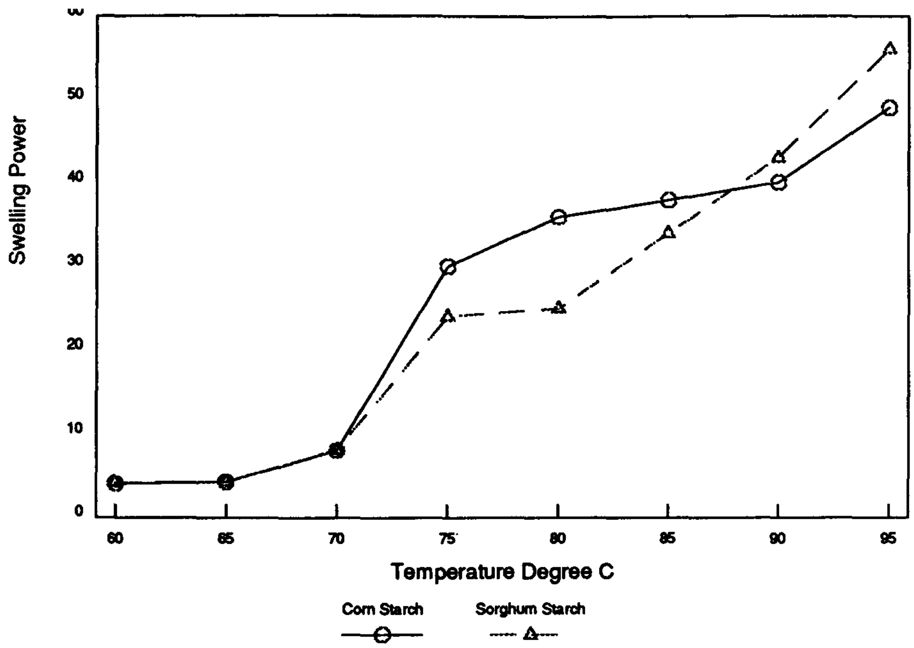


Figure 3. Solubility curves for sorghum and corn starches.

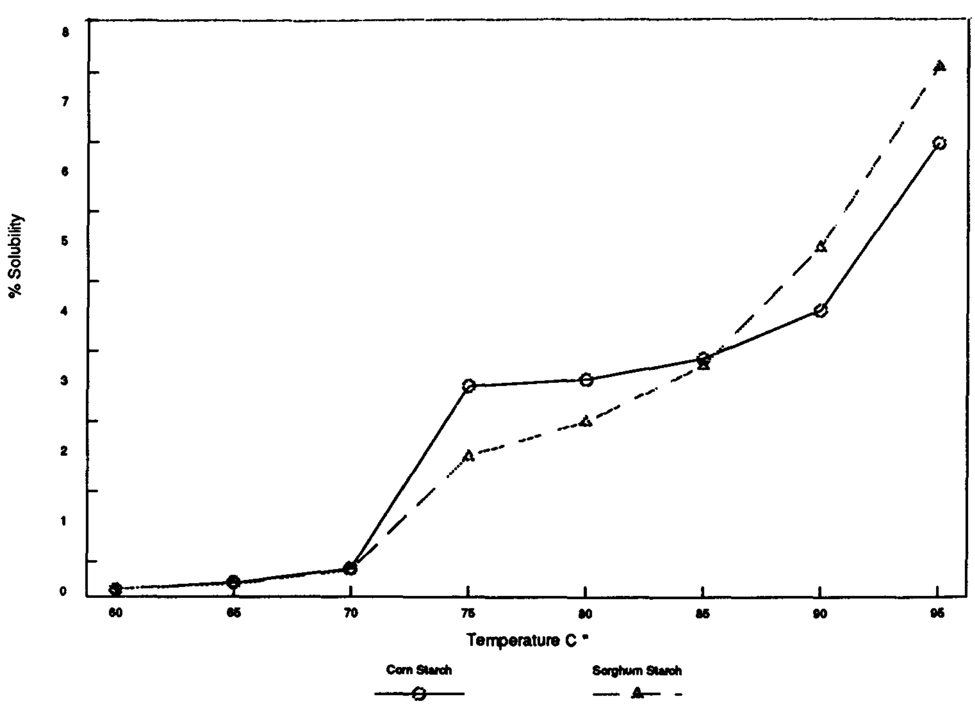
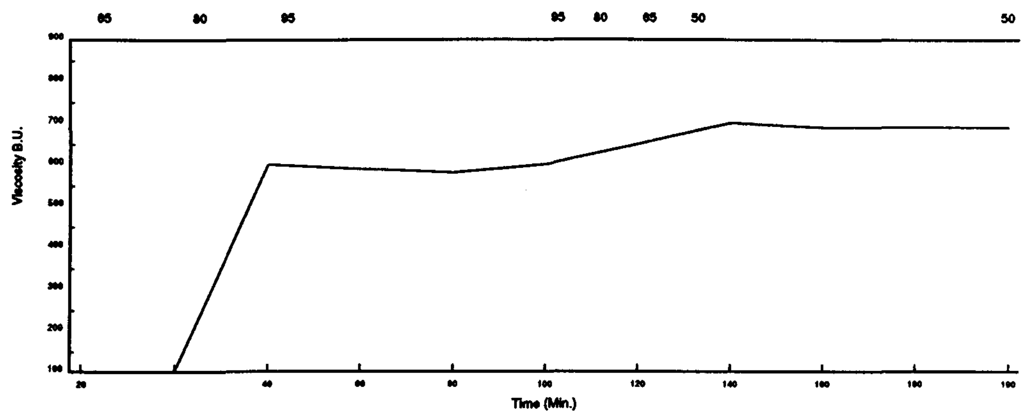


Figure 4. Visco-Amylogram of sorghum starch (40 grams).



Utilization and Quality: A Seed Industry Perspective

Ted Givens[1]

The definition of quality is our number one problem. It is unfortunate that the definition depends on the end user application. Little breeding progress will be made unless we learn to narrow quality down to specific traits so products can be packaged in sets of traits needed for a specific end user target. It is difficult to make breeding headway using a general overall rating for quality since it means different things to different markets.

How do you define food quality? Is it the attributes or characteristics of the grain that give better nutritive value or is it the characteristics of the grain which people want and prefer in the food they consume? As I review the literature, it is obvious that in many cases the two can be negatively correlated. It is much more important to a person consuming the local food preparation, that it has the right taste and consistency, rather than whether it has high lysine or reduced tannins. Even in the developed world, you must have a product that tastes good, no matter how nutritious it may be, or it will not succeed. Although, some progressive groups of people will now give up some taste in order to consume a more nutritious, healthy diet. I will not try to list all the many foods made from sorghum such as Kisra, Injera, Tô, Roti, etc. All of you are much more familiar with these local foods and the manner in which they are prepared than I am. I claim no expertise in this area. The point is that the people in each geographical niche have their own special food preparations which do require special grain characteristics. In times of famine, these special types may not be available, and obviously, the people will consume any type available, but this is surely not the case if they have a choice. The many different types of food preparations made from sorghum in Third World countries might be broadly categorized as follows: 1) bread (leavened and unleavened), 2) porridge (thick, thin, 3) fermented beverages (alcoholic, non-alcoholic), 4) boiled whole grain, and 5) roasted grain. In the U.S., we use sorghum as an animal feed. I would hope we will generate other uses for sorghum in the U.S., but I am unaware of any commercial available food product made from sorghum other than sorghum molasses.

What kind of research will an international seed company be willing to invest the shareholder's money. Most, if not all, commercial seed companies with bona fide research programs are interested in selling hybrid sorghum seed. Our programs will be set up to produce elite male and female inbreds which combine to make hybrids that give high and/or stable grain yields. We will have much interest in any desirable grain quality characteristics for which we can practice visual selection in the field. Field breeders can have real problems trying to make progress selecting for quality variables which are based on a preference rating. These are floating targets based on subjective ratings and the variation is usually too high to allow breeders to make progress.

Field breeders have less interest in traits which require lab analysis or long turn around time for the analysis. If the lab analysis is a very simple and cost efficient process, we become much more interested. I propose to stick with a basic core of traits that bear on quality and screen for the desirable hybrids suited to end user markets. In this case, the final product selection will not be made by the seed company but by Kellogg Company, The Quaker Oats Company or other feed/food companies. These companies have cereal chemists and nutritionists on staff and will evaluate the grain of the hybrid for acceptability.

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[1] Pioneer Hi-Bred International, Inc., P.O. Box 1743, Plainview, TX 79072

I doubt that commercial seed companies will be able to carry the expense in-house to do basic research. We can make progress if traits can be identified that are recognizable in the field and are correlated to quality traits. This is an excellent opportunity for public and private workers to work as a team to solve the quality problem. The public sector is well equipped to search for the answers to the basic questions and once the solutions are found, the private sector can apply the technology and, hopefully, supply the improved hybrid seed to the farmer.

Is it practical or even possible for a commercial seed company to develop products that meet the taste requirements for each of the different food preparations found in India, Africa, Latin America, etc.? I think not. Due to the present economic climate in the seed industry, I know that Pioneer will not be funding sorghum research to meet this challenge. I believe it will continue to be the responsibility of public organizations such as INTSORMIL, ICRISAT and the national programs to provide improved products for these many local geographical niches. Even then I realize it is sometimes difficult to get the improved genotypes into the hands of the farmers. The research efforts of the public sector in the Third World countries are well recognized and appreciated. This is a function which is critical to the survival of many of these developing countries and would be difficult, if not impossible, for a private company to duplicate. An international seed company will check very thoroughly the political and economic climate of any country which might be a candidate for a seed venture. The leaders of any particular country must show enthusiasm for the endeavors of private enterprise and be willing to adopt policies and regulations which will allow a private seed business to survive. We must have this type climate or we have no interest in doing business in that country. The seed business is risky enough without taking additional risk.

We are and will continue to work on grain quality. We have two stations in India which develop hybrids that produce grain for human consumption. It took us several years for our stations in India to develop proprietary hybrids which produced grain that was acceptable in the market place without a tremendous dockage. Our first hybrid had chalky white grain and black glumes. Needless to say, it did not receive a premium in the market.

Our next entry had reduced pigment and corneous textured grain. Although much improved over our first hybrid, it still received much less than a premium in the market place and could only be considered as a stop gap hybrid. We finally released a pure tan, pearly white hybrid with straw glumes which was acceptable. But even then some local genotypes with bold seed size or other desirable attributes will draw a premium in the market. In the U.S., the breeder breeds for higher yielding types, but with the constraint that it must be of combine height or it will not be accepted by the farmer. In India, we breed for high yielding types but with the constraint that the grain must be of the type preferred for human consumption. In either case, if you ask the breeder to name his major breeding objective, he would probably list the development of a hybrid with 10% yield superiority over the competition. The breeder is well aware that the hybrid must be the agronomic type preferred by the farmer and the grain acceptable in the marketplace. We cannot sacrifice yield for any trait unless there is a "value added" opportunity to justify its lack of yield. If there is any trade-off of yield for any trait, the market must recognize the value added.

In India, we continue to breed for food quality and as a bonus, now these inbreds are making an impact on our other research programs both in the U.S. and other overseas projects. Of course, many of the inbreds must be converted to shorter types in order to be utilized by our U.S. breeders. But, every attempt is made to retain the excellent grain quality possessed by many of these inbreds.

Another major concern to me is the quality of the grain which reaches the consumer regardless of whether it will be used for human food or animal feed. I am appalled by the horror stories I heard concerning the quality of number 2 yellow milo which may finally reach some of our overseas consumers. If these stories are true, then we are cutting our own throat and the standards need to be revised. As a breeder, there may not be much I can do about the grain standard, but I can breed hybrids which produce a good quality grain that will at least reach the port of embarkation in reasonably good condition. In my mind, this means breeding for mold tolerance and/or weathering tolerance. These two terms are not interchangeable but for the sake of simplicity, I will refer only to mold tolerance. One of the biggest deterrents to obtaining harvestable yield is deterioration of the grain due to inclement weather conditions at or near harvest time. Unfortunately, as compared to corn, sorghum grain is exposed to the full force of mother nature. As a result, the grain can be in pretty poor shape by the time it reaches the elevator. In fact, the farmer may lose a goodly portion of the products of his labor as dust out the back of the combine. A good proportion of our research dollar will be spent trying to find resistance to grain mold without resorting to the use of high tannin brown genotypes. We have, for many years, selected for mold tolerance as the opportunity presented itself, but we now have in place a system to evaluate and select germplasm which is tolerant to grain mold each year. Since grain deterioration due to grain mold is a serious problem in most areas of the world, I believe the system we now have in place will prove to be a tremendous aid in improving grain quality.

I believe the private seed industry will continue to provide the type product that the customer demands and requires, at least in those countries where it is possible to get a return upon investment. If Venezuela wants and needs hybrids that produce high tannin grain, then we will supply that need. That is our job. We will try our best to come up with hybrids that are low in tannin but will perform and give the benefits of the high tannin hybrids without the harmful effects associated with high tannin. In many countries, rain at harvest rather than birds, is the reason they grow high tannin sorghum. Red hybrids or even white hybrids which produce good grain quality even under these harsh conditions will be our goal. In Venezuela, we have a case this year where a feed formulation company may offer a premium for a Pioneer hybrid which produces red grain instead of brown. This is surely a step in the right direction.

The many, many opportunities for Biotech should not go unmentioned. Just as one example, if we could have a gene or genes capable of fixing the lysine limitation inserted into the genome of a superior yielding hybrid without any detrimental side effects, this would open doors to us that have been inaccessible in the past. There is increasing interest in "Identity Preserved" products for which a premium is paid and a company like ours would enter this effort with vigor.

I am convinced that we must push for new uses for sorghum. Land area devoted to sorghum in many areas of the world is going down. As result, research dollars both public and private are becoming very hard to come by. At every opportunity we must search for specialty products that sorghum may be used for. The quality of the grain whether real, perceived or preferred will be the limiting factor in restricting the use of sorghum in these new products. As sorghum scientists, both public and private, I hope we will work together to enhance the future of our favorite crop.

Session VI - Sorghum and Millet as Sustainable Systems Components

- Niche and Role of Sorghum and Millet in African Agricultural Systems
- Sustainable Systems Approach to Sorghum/Millet Production
- Managing Natural Resources for Sustained Sorghum and Millet
- Role, Contribution and Direction of Biotechnology on a Sustainable Production Framework
- Plant Protection for Sustainable Agriculture in Sorghum and Pearl Millet Cropping Systems in Africa

Session Chair: Jerry Eastin

Speakers:

Yilma Kebede
Max Clegg
A.S.R. Juo
R.A. Frederiksen
Klaus Leuschner

Niche and Role of Sorghum and Millet in African Agricultural Systems

Yilma Kebede and Ouendeba Botorou[1]

Introduction

Africa accounts for about 40 % of the world's area under sorghum (*Sorghum bicolor* L. Moench) and millets[2] (*Pennisetum glaucum* (L) R. Br., *Eleusine corocana* etc.). The semi-arid belt (10-15°N lat.) of Africa that stretches from Senegal in the west to Somalia in the east is the main sorghum and millet growing region. Of the total area under sorghum (16.9 million ha) and millets (14.5 million ha) distributed in 35-40 countries, only a few countries account for 75-80% of the acreage in the continent (Table 1). In some countries, sorghum and millet occupy 75 to nearly a 100% of the area under cereals. There is usually more millet compared to sorghum or a higher proportion of sorghum and millets compared to other cereals as the environment gets drier.

Most of the sorghum and millet grain produced is for human consumption in the form of bread, porridge, and fermented products. The stalks are also an important source of feed, fuelwood, and building material. Despite the importance of sorghum and millet in the subsistence economy of the African farming system, grain yield levels are very low (890 kg/ha for sorghum and 680 kg/ha for millet). This is mainly due to the increasingly harsh and dry environment, poor and eroded soils, diseases and pests, weeds (especially *Striga*) and birds (*Quelea*).

Both crops are indigenous to Africa and thus there exists a wealth of genetic diversity. The wide range of sorghum and millet growing environments in the continent in terms of precipitation, elevation, temperature and length of growing season are testimony to the versatility and importance of these crops. In eastern Africa sorghum is more important than millet. In the west African semi-arid tropics millet is dominant between the isohytes of 250-650mm while sorghum is concentrated in areas of 650-1000mm (Matlon, 1983). Pearl millet is also grown in eastern and southern Africa, though in these regions other millets such as finger millet, *Eleusine corocana*, contribute to the total millet production. In eastern and southern Africa much of the sorghum growing area receives between 750-1000mm.

Table 1. Area under sorghum and millet in some major producing countries in Africa (1987-1989).

	Area		Cereal area	
	Sorghum	Millet	Sorghum	Millet
	- ('000 ha) -		- % -	
Senegal	128	940	10.2	74.6
Mali	572	921	30.9	49.7
Burkina Faso	1278	1241	45.9	44.6
Niger	1379	3304	29.2	67.8
Nigeria	3876	3360	39.9	37.7
Sudan	4206	1675	69.3	28.5
Ethiopia	867	215	17.6	4.4

Source: FAO Yearbook (1989).

[1] Dr. Yilma Kebede, Sorghum Program Leader, Institute of Agricultural Research, P.O. Box 436, Nazret Research Station, Nazret, Ethiopia. Mr. Ouendeba Botorou, Millet Breeder, INRAN, Kolo, Niger.

[2] The millet referred to in this paper is mainly pearl millet.

Evolution and Variation of Sorghum and Millet

Sorghum originated in tropical north east Africa some 5000 years ago and moved to other parts where climate, ethnic isolation, natural barriers have helped create distinct races and intermediate types which occupy various niches. Cultivated sorghums are believed to have arisen from the wild ancestor *Sorghum bicolor* ssp *arundinaceum* through introgression and selection (Doggett, 1965). Harlan and de Wet (1972) have classified the cultivated sorghums into five basic (bicolor, guinea, kafir, caudatum, durra) and 10 intermediate (hybrid) races on the basis of spikelet morphology. The characteristics and distribution of these basic races in Africa is presented in Table 2. Most of the basic races are widely distributed but some races like kafir and guinea, for example, have their greatest concentration in southern and western Africa, respectively.

Table 2. Characteristics and distribution of the basic races of *Sorghum bicolor* L. Moench in Africa.

Race	Characteristics	Major area
Kafir	short glume, grain elliptical	S. Africa
Guinea	loose panicle, open glumes, flattened grain	W. Africa
Durra	compact & recurved panicle, glumes with crease, round grain	N.E. Africa (Ethiopia)
Caudatum	grains asymmetrical, short glumes	Cent/E.Africa
Bicolor	long glumes, grain elongate	Wide distribution

Harlan (1972); Harlan and de Wet (l1972)

A good portion of the variability in the cultivated sorghum is preserved in the world sorghum collection at ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). About 65% of the accessions in the sorghum gene bank trace to African origin (ICRISAT, 1986). Among these, the durra types along with *hegari* and *zera-zeras* (caudatum) from eastern Africa, the yellow endosperm *kaura* (durra-caudatum) and *fara-fara* (guinea) from west Africa, and the kafirs from southern Africa have been valuable germplasm resources. Researchers both in Africa and elsewhere have drawn upon germplasm accessions for various plant, grain, and stress resistance characteristics.

Farmers have consciously maintained diversity, practiced selection and preserved their own types. In most parts of Africa because of the long and close association of sorghum with the farmers, it figures prominently in the folklore, songs and local traditions. This strong association is best exemplified by the names assigned to the local landraces based on either morphological characteristics, suitability for food or brewing, quality, resistance and adaptation traits. An example from Ethiopia is presented in Table 3 (Brhane Gebrekidan, 1982; Yilma Kebede, 1991).

Table 3. Examples of farmers designation of sorghums in Ethiopia.

Group	Local name	Meaning
End use	Fendisha	Pop sorghum
	Tenkish	Sweet stalk
	Yshet Ehil	Consumed green
Quality	Sinde Lemine	Equals wheat
	Gan Seber	Good ferm'n
	Wotet Begunche	Mouthful of milk
	Marchuke	Oozing honey
Morphology	Alequay	Faba bean size
	Dirb Keteto	Twin seed
Resit. traits	Wof Aybelash	Bird-tolerant
	Kitgn Ayfere	Unafraid of syphilis (*Striga*)

Adapted from Brhane (1982).

Special purpose sorghums with specific adaptation occupy different niches:

Transplant sorghums - In the Chad basin the *Mouskouari* sorghums are adapted for transplant purposes. The seedlings of these durra or caudatum type sorghums are raised on seed beds and transplanted on Vertisols to grow on residual moisture (Westphal et al., 1981).

Irrigated sorghums - The pastoralists of southern Ethiopia and northern Sudan cultivate guinea-caudatum sorghums on residual moisture. As floods gradually recede, some 4-10 seeds are planted in a hole and the planting may spread for 2-3 months.

Rattoon sorghums - In Eastern Africa, in places where the rainfall is bimodal, a second crop of sorghum is obtained by cultivating the regenerating stubble of the first crop. In southern Ethiopia the *Konso* farmers obtain two harvests from one planting while in Uganda several rattoons could be obtained from a rattooning sorghum such as *Namatare*. Often times the rattoon crop results in higher grain and biomass yield than the seeded crop (Doggett, 1988).

High altitude sorghums - These cold tolerant, durra-bicolor type sorghums are found mainly in the highlands of Eastern Africa (Ethiopia, Uganda and Burundi) and are especially adapted to elevations above 1900m.

Other important adaptations include photoperiod sensitivity, which enables grain matures after the end of the rainy season, and drought and water logging tolerance which ensure the survival and production of the crop under extremes of environmental conditions.

It is commonly accepted that pearl millet originated in the dry sub-Saharan region of west Africa. Pearl millet landraces reached their greatest importance and diversity in the semi-arid regions between Senegal and Western Sudan (Brunken, 1977) and later spread to other regions like India where they have evolved over the past four or five centuries (Rachie and Majmudar, 1980).

The wild progenitor, *Pennisetum glaucum* ssp *monodii* (Maire), is found in isolated niches in the northern regions of the Senegal-Sudan zone. Wild millet is also found along roads and on borders of cultivated fields. The wild form exhibits little morphological variability (Marchais and Tostain, 1984). When growing side by side, wild races can freely cross with cultivated millet. The hybrid plants (*shibras*) that spontaneously occur in farmers' fields are not easily distinguishable from pearl millet during the vegetative stage. *Shibras* (*Pennisetum glaucum* ssp *stenostachyum* (Klotzsch) Stapf and Hubb) usually mature earlier than the millet landraces, and they are harvested before shattering. This "weed" has been an important source of food for farmers a time when they have emptied their granaries and are anxiously waiting for the harvest. Wild and weedy species (*Pennisetum monodii* and *Pennisetum stenostachyum*) have been valuable sources of genes for disease resistance (Hanna, 1985), for improving growth rate, and grain yield (Bramel-Cox et al, 1986.).

In West Africa, farmers generally distinguish two groups of pearl millet based on the number of days from planting to harvest:

early millets (*gero, souna,* and *iniadi*) - These millets are cultivated in marginal regions with low annual rainfall and are harvested between 75-90 days.

late millets (more than 120 days) - These millets are grown in regions of adequate moisture during growing season and are known under a variety of names such as *maiwa,* (Nigeria and Niger), *sanio* (Senegal and Mali) and *dauro* (Nigeria). *Dauro* is unique as it is a type raised in nursery beds and transplanted after four to six weeks (Labe et al., 1987).

Pearl millets are also characterized by their diversity in head length which may vary between 20 cm and more than 150 cm. Millet heads are often subdivided into short (<30 cm), medium (30 to 50 cm), and long (>50 cm) head types and are distributed in early and late maturity groups. The longest millet heads are found in the northern region of Nigeria and southern region of Niger where the rainfall averages 700 mm.

Sorghum and Millet Production Systems

Variations in the farming systems of the subsistence farmer are a function of the production constraints he is faced with (Norman, 1982). In subsistence system of cultivation yields of sorghum and millet are low (< 1 t/ha). Most farm equipment is traditional and by necessity land holdings are small (< 2 ha). Cultivation is done by family members and most of the production is for food use in the home though some may make its way to the market for cash generation. For the most part, production activities are determined by rainfall pattern since very little sorghum or millet in Africa is produced under irrigation. Field preparation, wherever it is practiced, starts with the onset of rains using either animal traction or hand tools. To reduce wind erosion in the arid regions, land preparation may often be avoided unless millet is the first crop following a long fallow (Rachie and Majmudar, 1980). High seed rates are common to offset loss of seed to insects, diseases, soil temperature and soil crusting. The tedious process of hand weeding followed by bird and animal scaring put a heavy strain on the resources of most farmers. To minimize the loss of valuable top soil and organic matter and also conserve moisture especially on slopes, farmers build elaborate terraces. Terraced cultivation of sorghum is common throughout Africa.

About 80% of the cropped area in the west African semi-arid tropics is intercropped (Fussel and Serafini, 1985). The seeds of sorghum or millet and the intercrop are mixed and broadcast or planted separately on hills. In many areas sorghum and millet are intercropped with other cereals (maize and sorghum or millet), legumes (cowpea, common bean) and other crops (sweet potato, peanuts). Pearl millet and cowpea intercropping is the most prevalent system in the Sahelian region of West Africa (Spencer and Sivakumar, 1987). The socioeconomic rationale for intercropping has been risk aversion and provision of food before sorghum or millet harvest. For example in the Chercher highlands of Ethiopia by intercropping sorghum, maize, and beans a farmer is able to harvest the beans early followed by maize and finally sorghum (Brhane Gebrekidan, 1977).

Where a farmer grows a number of crops, sorghum is allotted to the poorer areas and is hardly fertilized. This is mainly as a result of a realization that sorghum is able to withstand stresses better than most crops. Similarly, pearl millet is generally grown on poor sandy soils with low water holding capacity and tillage is not a common practice. Low income and uncertainties do not encourage farmers to purchase inputs. Application of manure appears on the decline due to a decrease in grazing land, the decimation of livestock as a result of intermittent droughts, and its use of manure as cooking fuel as wood becomes scarce.

Role of Sorghum and Millet

The range in plant types and growth duration reflect not only adaptation but also preferences on how the crops are put to use. The grain characteristics range from vitreous to floury endosperm, small to large seed size, and shades of color which in some way reflect the multiplicity of uses and requirements both in food and beverage preparation and other various uses.

Foods

Most sorghum and millet grain is used for food . Food is prepared from whole or decorticated grain or from flour (Doggett,1988; Vogel and Graham,1979). Boiled sorghum is prepared from whole grain and sometimes mixed with other grains or legumes. Corneous grains which do not stick after cooking are preferred. The *marchuke* and *wotet begunche* sorghums from Ethiopia have sugary taste and often the grain is roasted on the panicle at the soft-dough stage. The grains appear shrunken at maturity. Pop sorghum is also a common snack food among sorghum farmers. Early maturing millet heads are often roasted (*moumi* or *girmeye* in Niger) and used as snack.

The most popular and common use of sorghum and millet grain are products from flour. Flour is obtained either using grindstone, mortars or machine grinders. Thick and thin porridges, leavened and unleavened bread, and *couscous* (steamed flour) are prepared from sorghum and millet flour.

Thin porridge - Sorghum flour is boiled in water to make a smooth batter and allowed to ferment, e.g., *uji*-Kenya, *oji*-Nigeria. Porridges such as *fura* and *koko* are made from millet in west Africa.

Thick (stiff) porridge - These are very popular throughout Africa and are prepared by adding flour steadily to boiling water but with slight variations in preparation. *Ugali* (eastern Africa), *mafo* (Somalia), *nsima* (Malawi), and *tuwo* are of neutral pH. Tô from Burkina Faso is acidified by adding lime, while in Mali alkaline tô is prepared by adding wood ash. Another variation that is popular in West Africa is *couscous* made by steaming sorghum or millet flour.

Leavened bread - Injera (Ethiopia) and *kisra* (Sudan) are made from fermented dough. In West Africa *masa* (Nigeria and Niger) and *ghalet* (Burkina Fasao) are also fermented products made from either millet or sorghum flour.

Unleavened bread - These are thick flat breads made from unfermented batter, e.g., *kitta* (Ethiopia), *waina* (Nigeria).

Beverages

Beverages from sorghum and millet are an important dietary constituent. This includes mostly beer (*chibuku*-Zambia), non-alcoholic (*abrey*-Sudan), and distilled products (*warangi*-Uganda). Sorghum beer is produced mostly from red and brown sorghums (Doggett, 1988; Vogel and Graham, 1979). For brewing purposes, sorghum is commonly soaked, germinated, dried and coarsely ground before mixing with water to produce malt. At times the difference between preparations for food and drink is less distinct as some of the drinks may have a substantial amount of solids. Commercial beer is produced from sorghum malt in some countries (Nigeria, Uganda, Rwanda, and Zambia)

Other Uses

Sorghums with sweet stalks are sparingly planted across many areas in Africa. Though there are dual types used for grain and sweet stalks, some like the *tinkish* in Ethiopia are specifically planted for chewing like sugar cane while the stalks are green and tender.

Stalk and leaves of sorghum and millet are used for animal feed. Tall types with juicy stalk are preferred. For instance it is common in the Ethiopian highlands for farmers to progressively strip the lower leaves of sorghum and feed their cattle. During the long dry season, livestock rely on sorghum and millet stover when grazing pastures are not available. The frequent droughts have underscored the importance of integrating crop and livestock production. In addition, the stalks are used as building material for thatching huts and fencing compounds.

Farming communities attach some spiritual and medicinal properties to some types of sorghum and millet. Gifts of grain are exchanged at child birth, marriage, death, and at some religious festivals. In addition some food preparations are used as weaning food, for lactating mothers, and in treating some ailments, i.e., diarrhea, measles and broken bones. (Graham and Vogel, 1979).

Sorghum and Millet Research

Considerable research efforts have been geared to improve and stabilize sorghum and millet production in Africa. The expansion of sorghum and millet research capacity of national programs has benefitted from increased posting of graduates and the establishment of regional and international research centers. In some countries this has been accompanied by increased government commitment to research. Ultimate success is measured by the impact of technical solutions that will be reflected on overall production levels. The road to success is being paved by collaboration at regional and international levels, and an increased appreciation of farmer circumstances and interdisciplinary research on priority problems at the national level. However, inadequate infrastructure, meagre resources, unattractive policies, natural and man made calamities have kept research impact to a minimum.

In the face of changing weather patterns, a deteriorating resource base, and expanding population, sorghum and millet will continue to be important crops in Africa. This interplay of environment (often harsh and unpredictable), societal needs (extremely varied), and institutional setup and capabilities (at times poor and non existent) points to the problem of dealing with complex economic and social systems. Research into increasing and stabilizing yields, tackling severe problems such as drought and *Striga*, and alleviating widespread constraints of disease and insect damage would be helped by regional and international collaboration. The following issues figure prominently as we contemplate a regional or continental research agenda.

1. Considering the resource base (land, human resources and capital) and the institutional and physical environment, yield im-

provements will be slow. African farmers cultivate landraces with inherent capacity to survive the harsh environments not necessarily to give high yields. Thus the need to better utilize indigenous germplasm and related species to develop populations with useful genetic traits such as broad adaptation and stable yield become important.

2. Varieties that provide the food requirements of the population need to satisfy the necessary preference criteria. Besides antinutritional factors (tannins), poor digestibility causes problems in sorghum for human consumption. In addition, other uses in commercial brewing, composite flour technology, weaning foods etc. are needed to substitute imports and increase the market opportunity for these crops.

3. *Striga*, a serious threat in much of Africa, causes severe losses in sorghum and millet. Effective selection and testing have so far been difficult. Bird damage is becoming significant especially with a shift towards good food types sorghums and reduction in farm labor for scaring birds.

4. Equally limiting production are drought and nutrient stress. Drying weather patterns have severely affected production. Fallow systems have given way to increased population pressure on land leading to exhausted soils. Development of methodology to get suitable material and or appropriate technologies for these conditions is important.

5. Insect (stem borers, head bugs, shootfly, midge and storage insects) and disease (smuts, ergot, mold, anthracnose, downy mildew, blight and charcoal rot) resistances would be a priority.

6. Production systems often involve mixed cropping. Such systems by necessity would not only include crops but also feed and forage resources as animals would be a necessary component of the production equation.

7. An integrated research program that includes varietal development coupled with cultural practices, management systems that minimize moisture loss and pest damage, cropping systems and patterns that are compatible with the farming system of the area would benefit production.

Summary

The importance of sorghum and millet as food crops and their adaptation to harsh and varied environments reaffirms their significant role in the African agricultural system. Their roles in the preparation of different foods and brews from the grain and the use of the stalk and leaves as animal feed makes for a complete utilization of these crops. Efforts to improve the production of these crops would to a great extent improve the lot of the farmer.

References

Bramel-Cox. P.J., D.J. Andrews, and K.J. Frey. 1986. Exotic germplasm for improving grain yield and growth rate in pearl millet. Crop Sci. 26:687-690.

Brhane Gebrekidan. 1977. Sorghum-legume intercropping in the Chercher highlands of Ethiopia. Assoc. Adv. Agric. Sci. Africa J. 4(2):39-43.

Brhane Gebrekidan. 1982. Utilization of germplasm in sorghum improvement. p.335-345. In Sorghum in the Eighties: Proc. of International Symposium of Sorghum. Patancheru, A.P., India. 2-7 Nov. 1981. ICRISAT, Patancheru, India.

Brunken J., J.M.J. de Wet, and J.R. Harlan. 1977. The morphology and domestication of pearl millet. Econ. Bot. 31:163-174.

Doggett, H. 1965. The development of cultivated sorghums. p.50-69. In Sir J. utchinson (ed). Essays on crop plant evolution. Cambridge University Press, Cambridge

Doggett, H. 1988. Sorghum. Longmans Group UK Limited.

FAO (Food and Agriculture Organization). 1989. FAO production yearbook (Vol 43). FAO, Rome, Italy.

Fussel, L.K. and P.G. Serafini. 1985. Crop associations in the semi-arid tropics of west Africa: Research strategies past and future. p.218-235. In H.W. Ohm and J.G. Nagy (ed). Appropriate technologies for semi-arid west Africa.

Hanna, W.W., H.D. Wells, and G.W. Burton. 1985. Dominant gene for rust resistance in pearl millet. J. of Heredity 76:134.

Harlan, J.R. and J.M.J. de Wet. 1972. A simplified classification of cultivated sorghum. Crop Sci. 12:172-176

Harlan, J.R. 1972. A new classification of cultivated sorghum. p.512-516. In N.G.P. Rao and L.R. House (ed). Sorghum in Seventies: Proc. International Symposium of Sorghum. Hyderabad, A. P., India. 27-30 Oct 1971. Oxford & IBH Publ. Co., New Delhi, India.

ICRISAT. 1986. ICRISAT in Africa. ICRISAT, Patancheru, India

Mation, P.J. 1987. The West African semi-arid tropics. p.59-77. In J.W. Mellor, C.L. Delgado and M.J. Blackie (ed.) Accelerating food production in sub-Saharan Africa. Johns Hopkins University Press, Baltimore, MD.

Labe, D.A., P.N. Egharebva, J.Y. Yayock and S.A.Okiror. 1987. Effect of planting methods on the performance of Dauro millet. Maydica 32:287-299.

Norman, D.W. 1982. Socioeconomic considerations in sorghum farming systems. p.633-646. In Sorghum in the Eighties: Proc. of International Symposium of Sorghum.

Patancheru, A.P., India. 2-7 Nov. 1981. ICRISAT, Patancheru, India.
Rachie, K.O., and Majumdar, J.V. 1980. Pearl millet. The Pennsylvania University Press, University Park, PA.
Spencer, D.S.C. and M.V.K. Sivakumar. 1986. Pearl millet in African agriculture. p.19-31. In Proc. International Pearl Millet Workshop. 7-11 April 1986. Patancheru, A.P., India. ICRISAT.
Vogel, S. and M. Graham. 1979. Sorghum and millet: food production and use. Report of a workshop. Nairobi, Kenya. 4-7 July 1978. IDRC, Ottawa, Ont.
Westphal, E., J. Embrechts, P. Mbouemboue, M. Boyomo, And J.M.C. Westphal- Stevels. 1981. L'Agriculture Autochtone au Cameroun. Wageningen, The Nether lands.
Yilma Kebede. 1991. The role of Ethiopian sorghum germplasm resources in the national breeding programme. p.315-332. In J.M.M.Engels, J.G.Hawkes, and Melaku Worede (ed). Proc. International Symposium on Conservation and Utilization of Ethiopian Germplasm. Addis Ababa, Ethiopia. 13-16 Oct.1986. Cambridge University Press, Cambridge.

Sustainable Systems Approach to Sorghum/Millet Production

Max Clegg, Richard Vanderlip, and Stephen Mason[1]

Sorghum [*Sorghum bicolor* (L) Moench] and millet (*Pennisetum glaucum* (L) R.Br.] are two crops which are tailored for sustainable agriculture. The resources used to grow these crops are less than others. Yet, high grain yields can be obtained for use as food and feed. The stover also can be used for feed or cycled back into the soil.

This presentation will briefly describe the following: 1) conditions under which sorghum and millet are grown, 2) crop characteristics which can be manipulated by cropping practices and 3) management choices.

Conditions

Botswana and the United States will be used to demonstrate the conditions which may exist where these crops are grown.

Most of the agriculture in Botswana is located in the eastern region. The January mean temperature is 25°C. The soils are sandy but have some clay making them a better soil for growing these crops. Soil fertility is low and the soils also crust. Rain varies considerably from area to area and within an area. Rain averaged (30 year period) 430 to 590mm at the different areas. Also, within an area there is extreme yearly variation. For example, rain over a 30 year period varied from 347mm to 843mm at Gabarone. Rain occurs mostly during the growing season, therefore, there is very little stored soil moisture.

In the United States, what is known as the sorghum belt goes from southern Texas, north through Kansas, Nebraska and into South Dakota. Sorghum also is grown to some extent in California, New Mexico, Arizona, Oklahoma, Mississippi, Georgia, and other states. The soils vary in fertility and are susceptible to erosion. The growing season length is from 100 to 240+ days. Rainfall varies from 500mm to 1000mm. Sorghum generally is grown in the areas towards the low side.

Thus, sorghum is grown under conditions where rainfall can vary from almost no rain to 1500mm, temperature ranges from 5 to 45°C and the soil is very poor to good. Millet is usually grown under even more extreme conditions.

Crop Characteristics

Sorghum and millet are two crops that are somewhat different, yet they are somewhat similar in their general growth and physiology.

Grain sorghum is a perennial, but treated as an annual. It has the tendency to tiller and it is heat tolerant and probably drought avoidant. Pearl millet is an annual. It tillers freely and it is heat tolerant and resistant. Both sorghum and millet have C_4 photosynthesis, a tropical characteristic.

As mentioned earlier, these crops have good yield potential under optimum growing conditions (Table 1). Some may even be greater for some of the regions than has been indicated. We can agree they are greater than what the average farmer produces.

Management Choices:

Good varieties and hybrids are needed for high sustainable yield. However, in all cases where you have high yield and added stability, there also is good management. Many strategies can be used by a farmer to improve the chances of obtaining improved yields. Essen-

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Table 1. Indication of the grain yield potential of millet and sorghum.

Crop	(Country)	Yield (Mg ha^{-1})
Millet	(Botswana)	3.4
	(Niger)	1.5
	(U.S.A.)	5.0
Sorghum	(Zambia)	5.0
	(Zimbabwe)	4.0
	(U.S.A.)	12.0

tially, the crop can be fit to the environmental conditions using good management.

Two factors, water and nitrogen fertility, have been previously mentioned in the earlier sessions as main constraints. This is true or these two crops would not be grown. Also, the cropping practices that can be used to add stability involve fitting the crop to efficiently use these resources based on availability or possible availability.

Plant population: Plant population (and row spacing) can be used to manage water use. Plants transpire water through the leaves and depending upon knowledge of available soil moisture, rain patterns and variability it is possible to adjust the leaf area (i.e. evaporative surface) for an environment.

As was mentioned previously, millet and sorghum are tillering crops. This adds stability because in variable environments it is better to plant lower plant populations which results in lower leaf surface. Tillering will add more leaf surface and increase yield as environmental conditions improve. Data of M'Kaitir (1990) shows the tillering of millet and sorghum and that millet tillers considerably more than sorghum (Table 2). Therefore, yield of millet changes very little with an increase in plant population. With sorghum tillering less, an increase of plant population will result in higher grain yield especially in areas with better environments.

Rotation: Nitrogen is a main constraint for crop growth. Many soils are deficient and nitrogen may not be available. Rotation with legumes can be used to improve fertility and nutrient cycling. In most instances legumes are available for use in an area. Also, the legume seed can be of economic importance as it may be used as a food or an oil crop. In

Table 2. Effect of millet and sorghum X plant population on grain yield and number of heads per plant at St. John and Manhattan, Kansas in 1988 and 1989.

Crop and Year	St. John			Manhattan		
	Plant Pop.	Yield Mg ha^{-1}	Heads per plant	Plant Pop.	Yield Mg ha^{-1}	Heads per plant
Mllet						
1988	31000	1.8	6.5	15000	1.7	9.0
1988	55000	1.7	1.9	42000	2.2	4.7
1988	130000	2.9	1.1	95000	2.6	1.9
1989	18000	2.5	7.5	15000	1.2	
1989	47000	2.7	2.5	39000	1.6	
1989	120000	2.7	1.5	120000	2.1	
Sorghum						
1988	35000	1.8	1.5	12500	2.1	
1988	58000	2.0	1.4	53000	3.8	
1988	115000	2.9	1.1	104000	5.2	
1989	12500	2.0	1.4	12500	1.6	2.9
1989	35000	2.7	1.5	40000	2.5	1.9
1989	115000	3.7	1.1	104000	4.2	2.2

Table 3. Grain yield and grain protein of sorghum grown continuously or after soybean and with different levels of applied nitrogen.

Culture	Applied N (kg ha^{-1})	Yield (Mg ha^{-1})	Protein (%)
Continuous	0	3.6	6.5
	57	5.9	7.9
	114	6.6	9.9
	171	6.8	11.2
Rotation	0	5.8	7.9
	57	6.5	9.8
	114	6.7	10.4
	171	6.3	11.6

Nebraska, yield of sorghum following soybean is almost doubled (Table 3). The effect is equal to about 57 kg applied N ha^{-1}. Previously the importance of grain quality in relation to nutrition was mentioned by Dr. Kahn. Sorghum protein improvement is considerable with increased fertility. Protein was 6.5% for continuous sorghum with no added nitrogen and 7.9% when rotated with soybean. Application of 57 kg N ha^{-1} to the sorghum in rotation increased the protein to 9.8%. Total protein (kg ha^{-1}) is increased more as it is a function of a higher concentration and also it is linked to higher grain yield.

Residues: Crop residues are used to control erosion, retain moisture, improve soil structure and removed for animal feed. However, organic matter in the soil is a resource for benefitting soil structure and nutrients. Millet data from Niger (Verma et al., 1990) show the benefit of the addition of 0, 1, 2, and 3 Mg ha^{-1} residue (Table 4). Yield and total biomass were increased considerably with increased amounts of residue. The benefit of the residue was probably a result of nutrient cycling.

Weeds: In twenty years of attending international meetings, little mention has been made concerning weeds. The only exception is *Striga*. In some instances, weeds may even be considered a resource because if a crop is not established they are utilized as forage.

Weeds are very competitive with crops for water and nutrients. Their competitive effect is even more detrimental if these resources are low. This is shown in Table 5 (Maliro, unpublished). For Segaolane in Nebraska, both yield and total biomass were affected regardless of the fertility level. Resources (water, nutrients) were partitioned into weeds/grain/stover, with weeds making up as much as 42% of the total biomass in the treatment with the lowest management.

Nutrient cycling: Nutrients in many instances are limiting. As previously indicated rotation and residues can improve the nutrient status of the soil. Sorghum stover quality (as measured by protein) is improved by growing in rotation with a legume or applied nitrogen (Table 6). Thus, whether used for feed or left in the field, a greater benefit should occur. One would think over time there would be an accumulative benefit.

An interesting observation with maize grown after soybean is shown in Table 7 (Onyango, 1991). Maize flowering time was reduced by applied nitrogen as would be expected. However, growing maize after soybean reduced the time for flowering even more. This suggests a phosphorus cycling from the legume. As phosphorus will hasten maturity.

Table 4. Grain and total dry weights (Mg ha^{-1}) of millet in response to different amounts of crop residue left on the surface as a mulch (Ouallam, Niger, 1988).

Residue applied Mg ha^{-1}	Grain weight Mg ha^{-1}	% Increase in grain wt over 0 Mg ha^{-1}	Total dry wt Mg ha^{-1}	% Increase in grain wt over 0 Mg ha^{-1}
0	0.19	--	0.74	--
1	0.78	308	2.62	253
2	1.07	458	3.32	347
3	1.23	545	3.38	382
LSD 0.05	0.24		0.63	

Verma, et al., 1990

Table 5. The affect of applied nitrogen x weed control on sorghum stover and grain yield and weed yield and each as a percent of the total biomass.

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

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

Table 6. Stover yield and stover protein of sorghum grown coninuously or after soybean and with different levels of applied nitrogen.

Culture	Applied N (kg ha^{-1})	Yield (Mg ha^{-1})	Protein (%)
Continuous	0	4.4	2.6
	57	5.2	4.0
	114	5.3	5.9
	171	5.5	6.1
Rotation	0	5.2	3.6
	57	5.9	4.5
	114	5.8	4.6
	171	5.6	5.7

Table 7. The influence of nitrogen and soybean on the flowering of maize.

Treatment	Days to flowering
Continuous Maize (0 kg N ha^{-1})	75.0
Continuous Maize (114 kg N ha^{-1})	70.0
Maize after Soybean (0 N)	66.6

Onyango, 1991

Conclusion

Genetically, the grain and forage yield potential of millet and sorghum is much greater than the average productivity of farmers. Plant breeders are continuing to improve this potential. However, emphasis needs to be directed to management strategies to utilize this potential. Farmers in developing countries should be obtaining yield levels from 1 to 3 Mg ha^{-1} instead of 0.3 to 0.8 Mg ha^{-1}.

References

M'Khaitir, Y.O. 1990. Comparison of grain sorghum and pearl millet response to date and rate of planting. M.S. Thesis. Kansas State University.

Onyango, R.M.A. 1991. Maize-soybean rotation residue interaction on grain yield. M.S. Thesis. University of Nebraska.

Verma, P.K., M. Nouri, A. Alou, J.D. Eastin and K.C. Reddy. 1990. Effect of crop residue on millet production in Niger. Agron. Abst. p 64.

Managing Natural Resources for Sustained Sorghum and Millet Production

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Summary

In agricultural terms, natural resource conservation implies management of soil, water and vegetation resources for sustained land productivity. Land productivity is generally determined by inherent soil fertility, external input, and effectiveness of soil and water conservation practices used. Sorghum and millet are well-adapted to regions of limited rainfall. Sorghum is cultivated mainly on high base status and organic matter-rich Mollisols in the southern Great Plains of the United States, on high base status Alfisols in China and India, and on low base status Alfisols and Entisols in West and East Africa. Millet is primarily grown on sandier soils in the lower rainfall region of the Sahel. Phosphorus deficiency is a widespread soil fertility problem in sub-Saharan Africa. Current strategies and approaches to soil and water management for sustained sorghum production in North America give emphasis to reducing cost of external inputs, conserving groundwater storage and prevent groundwater pollution. For many developing countries, rejuvenation of degraded land and intensification of indigenous farming systems are more pressing issues. Future agricultural development needs to place more emphasis on managing all landscape units within a watershed.

Introduction

The impact of agriculture upon natural resources is a major concern throughout the world. A critical problem confronting both developing and developed nations is the long-term physical and chemical deterioration of the soil as a result of non-sustainable agricultural practices. Such degradation of the natural resource base magnifies shortfalls in agricultural production in a large part of the semiarid tropics where population exceeds estimated carrying capacity of the land under existing levels of technology and management (FAO/UNFPA/IIASA, 1982). Since sorghum and millet are important food and feed crops in the semiarid regions of the world, the development of viable and sustainable agriculture systems suitable for their production is crucial. Sorghum and millet are known for their ability to use soil, water and nutrients more efficiently than other cereals under drought conditions. If managed properly, these crops can contribute significantly to meet basic food needs and at the same time enhance the natural resource base in the semiarid regions of the world.

In order to adequately assess the role of sorghum and millet in natural resource conservation, it is necessary to characterize the climatic, edaphic and socio-economic conditions representative of a particular agroecological region. In this paper, we attempt to address important edaphic factors affecting sorghum and millet production with special references to regions where population has exceeded the land carrying capacities under traditional low input farming systems.

Soil Resources

Sorghum and millet are extensively cultivated throughout the drier regions of the world as human food and animal feed. There are seven important sorghum producing countries, namely, India, China, United States, Mexico, Argentina, Nigeria and Sudan. Together, they produce over 80 percent of the world's sorghum crop (Myers and Asher, 1982). Millet is generally cultivated in poorer soils and in areas with less rainfall because the crop uses water more efficiently than sorghum. The principal soils used for the production of sorghum are Vertisols, Alfisols and

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Table 1. Major grain sorghum producing countries and predominant soils used.

Country	% of world sorghum Production	Area	Predominant soils used (U.S. Soil Taxonomy)
India	17	31	Vertisols, Alfisols
China	16	16	(Alfisols, Mollisols)
United States	27	11	Mollisols
Mexico	6	3	Vertisols, Alfisols, Mollisols
Argentina	11	5	Mollisols
Nigeria	6	12	Alfisols
Sudan	4	5	Alfisols, Vertisols
Burkina Faso	1	2	Entisols, Alfisols
Niger	1	2	Alfisols
Ethiopia	1	2	Entisols, Alfisols, Vertisols
Australia	1	1	Vertisols
Total	91	90	—

Source: Myers and Asher, 1982.

Mollisols, however much diversity exists which encompasses a wide range of soil types (Table 1).

Large areas of Vertisols used for sorghum production are found in United States (mainly Texas), India, Sudan and Ethiopia (FAO, 1965; Sivakumar and Virmani, 1982; Myers and Asher, 1982). In semiarid regions, these cracking clay soils typically occupy lower topographic positions of inland valleys or depressions. These soils are composed of high activity clays, predominantly montmorillonite, and therefore have high cation exchange capacities (CEC). Other notable features of Vertisols include a high water-holding capacity, low hydraulic conductivity, and special management problems related to tillage and drainage (Wilding and Puentes, 1988).

Alfisols are a major soil group used for sorghum production in India, China and East and West Africa. Alfisols (mainly Kandiustalfs) found in subhumid and semiarid tropics are characterized by moderate clay contents in the subsoil horizons, low nutrient reserve, low organic matter content, and low to moderate water retention capacities (Abrol, 1988; Sivakumar and Virmani, 1982). Unlike the relatively fertile, high base saturation, and typically alkaline or calcareous Ustalfs of United States and China, Ustalfs in West Africa are acidic, poorly buffered soils with low inherent fertility and have a low cation exchange capacity. Kaolinite is the dominate mineral in the clay fraction. Moreover, phosphorus deficiency is a prevailing fertility problem in the sandy Alfisols and Entisols throughout the Sahelian region (Sivakumar and Virmani, 1982; Wilding and Hossner, 1987; Bationo, et al., 1986).

Pearl millet often replaces sorghum on sandier soils in Africa and India. It is cultivated predominantly on Entisols (Psamments) and Alfisols (Kandiustalfs) and Aridisols in the sub-Sahelian region of Africa and low rainfall areas in India (Norman et al., 1984). Sandy Entisols (Psamments) are common on the northern fringes of the Sahel in Africa where the growing period is short. The available moisture holding capacity of Psamments is very low, which places a severe limitation on millet production especially during the drought years.

Mollisols are well-structured, dark-colored soils rich in organic matter and calcium. In the Great Plains of United States, monoculture sorghum is cultivated on Mollisols (Ustolls). A high level of grain production is maintained through the use of high-yielding dwarf cultivars, nitrogen fertilization and supplemental irrigation. The crop is grown for export and consumed locally as cattle feed (Maunder, 1972).

Water Resources

In terms of agriculture, a great part of earth's land surface suffers from water deficiency. This is particularly true in sub-Saharan Africa where current population has already exceeded the region's land carrying capacity under traditional systems of food production (Harrison, 1983). Water resources in drier regions are generally limited. Data given in Table 2 indicate water availability in Africa for agriculture. The deficit is the difference between potential and actual evaporation. The availability, which can be positive or negative, assumes that the total runoff can be used to offset the deficit. All parts of Africa show negative availability, especially in the arid internal runoff areas (IAHS, 1984; Wright, 1986). These data indicate the limited renewable water resource in the continent. Consequently, agricultural development should make the best use of rainfed agriculture.

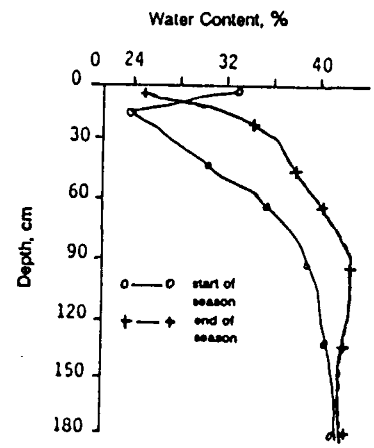
Table 2. Water resources availability in Africa (Wright, 1986).

	Runoff mm	Deficit mm	Availability +ve; -ve
Atlantic Ocean slope			
External runoff	241	980	- 739
Internal runoff	11	2160	-1969
Indian Ocean slope			
External runoff	84	1070	- 986
Internal runoff	46	1200	-1154
Continent	141	1300	-1159

Water resources include surface water and groundwater. With the exception of a few large perennial rivers (e. g. Nile and Niger), most rivers and streams in major sorghum and millet producing areas are seasonal, derived by local runoff. Irrigated agriculture in the fertile valleys along large perennial rivers have been an integral part of several ancient civilizations such as China and Egypt. But in modern times, efforts to develop large irrigation schemes in Africa and elsewhere have been very costly and in most instances, unsuccessful.

Because of large evaporation losses, developing surface water storage in lower rainfall areas is also economically disadvantageous. Soil management practices and cropping systems that can make more efficient use of rainfall and available soil moisture are probably the most desirable. A good example is the presence of substantial amount of available soil moisture in the subsurface layers of a Vertisol at the end of a short-cycle cereal crop (Fig. 1). To utilize the residual soil moisture, a longer duration deep-rooting legume, such as pigeon pea, may be planted as a intercrop or a relay crop with the main season cereal (sorghum or maize). Such a system, though labor-intensive, would increase total grain and biomass yields and help maintain soil fertility.

Figure 1. Water contents beneath a maize crop grown on a Vertisol at the start and end of the rainy season (ICRISAT, 1978 as cited by Onken and Wendt, 1989).



The use of groundwater for domestic and small-scale irrigation schemes offers an attractive alternative in the arid and semiarid lands. Shallow groundwaters are important sources for small holders because of the low cost of development. However, it is important to point out that usable storage of shallow groundwater in the semiarid regions is small and recharge is a critical factor to be considered when tapping shallow groundwater for domestic and irrigation uses.

There have been two approaches to developing surface and ground water resources for agriculture: (i) The development of large-scale, full water irrigation systems with supply from major perennial rivers or large fossil aquifers. (ii) The development of small-scale, supplementary irrigation systems using dispersed water sources integrated with traditional farming systems. The current thoughts of researchers and planners in the developing countries favor the second approach. However, its practical and economic feasibility for widespread development has yet to be established (Wright, 1986). For example, the most important components of water resources for small-scale development are extended river flow and shallow groundwater. Nevertheless, both of these sources are susceptible to deterioration which may be caused by degradation of land and vegetation within a catchment area. Rapid runoff and reduced infiltration of a degraded landscape would seriously affect recharge. Thus, an integrated land and water use based on topography, soil, hydrology and vegetation of an entire watershed area offers the best hope for agriculture and natural resource management in the semiarid regions.

Technological Options

The unique ability of sorghum and millets to endure long periods of soil moisture stress and other adverse climatic and edaphic conditions fosters their wide acceptance and use in semiarid environments. However, sustainability of sorghum and millet production in the dryland regions of the world is threatened by increased degradation of natural resource base. In the Great Plains region of United States, irrigation and nitrogen fertilization have caused significant depletion and contamination of groundwater resources. Thus, increased attention has now been given to re-introducing rainfed cultivation using soil and water conserving practices such crop rotation, furrow diking and conservation tillage practices to enhance soil moisture storage (Hons, 1988).

In the less developed countries, sorghum and millet are invariably intercropped with grain legumes and other cereals on small farms (1 to 3 ha) with little or no external inputs. Crop yields are low due to low soil nutrient and water availability. Farmers generally plant the crop at low density to minimize competition for nutrients and water. Such low input cropping systems are generally sustainable as long as the short cropping cycle (1-2 years) is followed by a long fallow phase (15 years or more). Nevertheless, increasing land pressure during the past decades has caused farmers to shorten the length of fallow. Consequently, land productivity declined rapidly due to soil erosion and loss natural vegetation.

There is ample evidence that in many areas of the semiarid regions of the world, efforts to fulfill the basic human requirements for food and fiber is resulting in a steady loss of long-term soil productivity. An appropriate question therefore is "how can the cultivation of sorghum and millet be incorporated into land management systems which can sustain crop yield and enhance land productivity?" The remainder of this paper will be focused on this concern.

Cropping Systems

Although sorghum and millet are best adapted to drought conditions, grain yield depends upon the amount of water available during the reproductive phase. In rainfed agriculture, adjustment in the time of planting, breeding short-cycle cultivars, and reducing evaporation losses are probably more practical measures to sustain optimum yield.

Both sorghum and millet are quite adaptable to various multiple cropping schemes which are employed primarily in the tropics (Ntare et al., 1989; Venkateswarlu, et al., 1981; Shetty, 1988). Due to preferential flow which occurs in Vertisols, antecedent moisture content is often the major factor controlling infiltration rates. Hence, intercropping systems which increase the utilization of soil moisture during peak periods of rain on these soils can contribute to reduced runoff and erosion rates (Mullins et al., 1987). It also reduces the risk of complete crop failure due to drought and pest damages. In regions where residue and vegetative cover is particularly sparse during highly erosive periods, sorghum or millet wind-barriers can be utilized to reduce wind erosion. In the southern Great Plains of North America. Such a practice can be used in conjunction with tillage practices to control wind erosion during the fallow period (Bilbro and Fryrear, 1988).

Cereal-legume rotation and intercropping was a common cropping system practiced in North America some years ago. But the practice was replaced by cereal monoculture since the introduction of large mechanical harvesters (Harvey, et al., 1961; Francis, 1986). Intercropping is however, still a common practice on small-holding farms in the semiarid tropics. Sorghum or millet is often intercropped with cowpea, beans, pigeon pea, and groundnuts. However, the choice of cropping system is determined by a combination of physical and socio-economic factors, such as soil characteristics, length of growing season, market, and local consumption preferences. For example, cowpea is often intercropped with millet on the sandy soils in Niger and northern Nigeria. The short rainy season and high insect pressure often result in low grain yield. However, cowpea fodder is a highly valued commodity which is sold at the local market as livestock feed during the dry season. Thus, farmers prefer to grow viney cultivars which can produce large quantities of biomass. Under such circumstances, the goal of improving a millet/cowpea intercropping system should be placed on increasing cowpea total biomass yield for fodder and green manure. On fertile soils with an adequate moisture supply, high-yielding, erect-type cowpea cultivars may be grown. Optimum rates of pesticides or other biological pest control methods are also needed to ensure acceptable grain yield.

In India and Central America, where soils and rainfall are more favorable, sorghum is intercropped with pigeon pea (redgram), mungbean (greengram), common beans and groundnuts. The efficient use of nutrient, water and light resources may be illustrated by the sorghum/pigeon pea intercropping on a Vertisol in the dryland region of India (Natarajan and Wiley, 1980). Using the respective sole crop population, 180,000 plants per ha for sorghum and 50, 000 plants per ha of pigeon pea, the intercrop sorghum produced as much grain yield as the sole crop (4.5 t/ha) and the total productivity or yield advantage of the system was 63 percent (LER = 1.63) higher than that of sole cropping (Table 3). Although pigeon pea growth was greatly reduced at first, it compensated in growth after the harvest of

Table 3. Yield and land equivalent ratio (LER) in sorghum/pigeon pea intercroppng (Natarajan and Wiley, 1980).

	Grain yield, kg/ha		LER
Crop	Sorghum	Pigeon pea	
Sole crop	4467	1017	1.00
Intercropping	4312	671	1.63

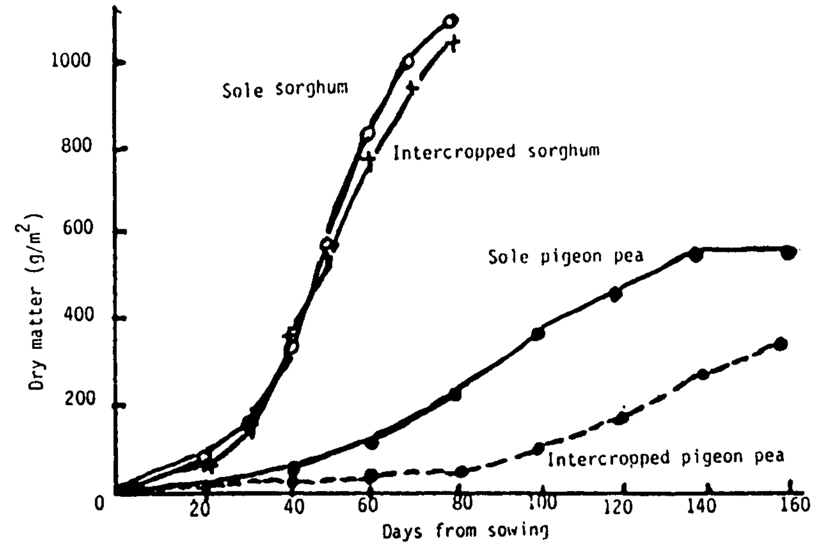
sorghum and produced 53 per cent of the sole crop dry matter (Fig. 2). Thus, the selection of a long duration legume intercropped with a short-cycle cereal such as sorghum on Vertisols and other fine-textured soils can make efficient use of residual soil moisture, produce high total yield, and improve soil productivity.

Soil Conservation Practices

Sorghum and millet are typically cultivated in regions which suffer from rainfall deficiencies which are often intensified by periodic droughts. A consequence of drought stress is a low level of residue production by crops which can result in severe wind and water erosion . Thus, in order to minimize soil erosion, effective soil and land management practices are required which maximize infiltration, ensure the safe disposal of excess rainfall and make efficient use of soil water. Crop management practices (e.g., residue management, multiple cropping) alone can make a significant contribution towards alleviating soil erosion, however in semiarid regions where vegetative and residue cover is difficult to maintain, mechanical soil and water conservation practices are often required.

Soil and water conservation techniques are well known (FAO, 1977; Barrow, 1987; El-Swaify, 1988; Nair, 1988), but their successful application and transfer to the farmer's fields is determined by many physical, biological and socio-economic factors. It should also be recognized that due to the complex physical and socio-economic factors and the long-term investments involved in carrying out soil conservation programs, success depends heavily upon government involvement and the active participation of communities and land users (Hauck, 1985). Contour tillage techniques aid in the storage of water and the reduction of soil erosion on gentle slopes in temperate climates, however in the tropics under higher rainfall intensities and on steeper slopes, this

Figure 2. Dry-matter production by sorghum and pigeon pea in sole cropping and 2.1 intercropping.



practice has often led to runoff concentration and severe gully erosion (Hudson, 1981). In the West African Sahel suitable alternatives which have proven to be effective include micro-catchment techniques and tied ridges (furrow diking). In the steep lands of Central America, rock barriers and tree legume (e.g. Leucaena spp., Gliricidia spp.) hedgerows and grass (e.g. Panicum) barriers are being tested in farmers fields. Although these practices have the potential to reduce soil erosion, such practices may also need to incorporate technologies which allow safe disposal of runoff (e.g. graded terraces and contour canals) and increase surface cover.

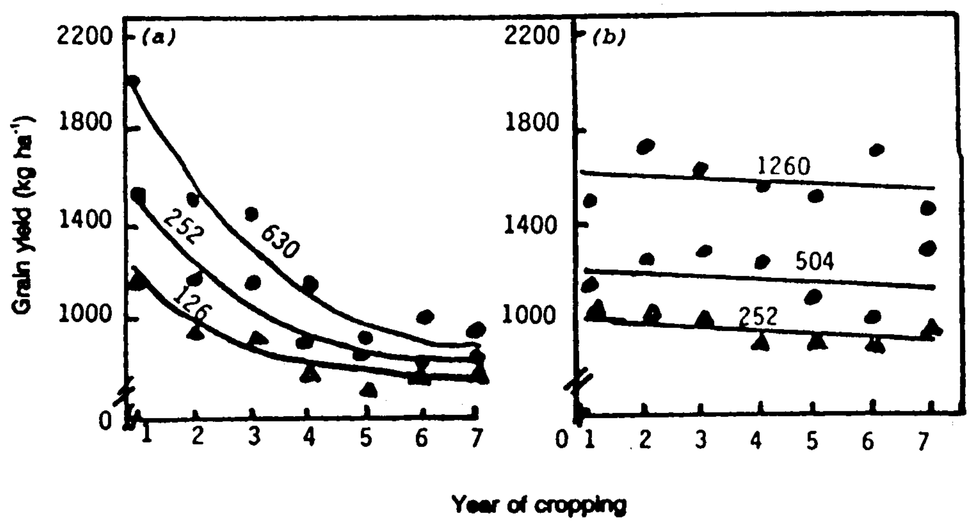
Plant Residue Management

Numerous publications have reported that the use of crop residue mulch improves soil organic matter and nutrient status, reduces erosion, regulates soil temperature and conserves soil moisture. On the other hand, it also may immobilize available nitrogen and harbor plant pests and diseases. In tropical and subtropical regions, the practice of conservation tillage and mulching with crop residues are generally beneficial on sloping lands and on well-drained soils. On poorly-drained, clayey soils, particularly under cooler climates, crop residue mulch may produce adverse effects, such as immobilization of inorganic nitrogen and increased risk of pest and disease infestation. Results on the use of crop residue mulch on well-drained, low fertility soils in the subhumid and semiarid tropics has been beneficial (Juo and Kang, 1987). Generally, slope, soil texture, soil structure and drainage condition are among the key factors determining whether crop residues should be removed, plowed-under or left on soil surface as mulch.

Maintaining crop residues on the soil surface is also a practical means for controlling wind and water erosion. Besides reducing surface sealing and maintaining higher infiltration rates, surface residues generally reduce cumulative seasonal evaporative losses of water from otherwise bare soil surfaces (Unger, 1988; Papendick and Parr, 1989). In general, however, residue maintenance is most effective in reducing evaporation over fine textured soils rather than soils with a sandy surface horizon.

In most parts of the semiarid tropics, however, the above-ground crop residues are harvested for fodder and other household uses. In the kaolin and quartz dominated soils in sub-Saharan Africa, the low level of organic inputs has resulted in serious soil compaction on farm land where ridging and mounding have become essential practices of seedbed preparation. Thus, future soil and crop man-

Figure 3. Grain yield of sorghum in successive years of cropping after initial applications of three levels (kg per ha) of (a) superphosphate and (b) rock phosphate to an Alfisol in northern Australia (Arndt and McIntyre, 1963 as cited by Norman et. al., 1984



agement strategies in the region should give more emphasis to increase total farm biomass production so that the demands for fodder, mulch material and household uses can be met at the same time (Juo and Kang, 1987).

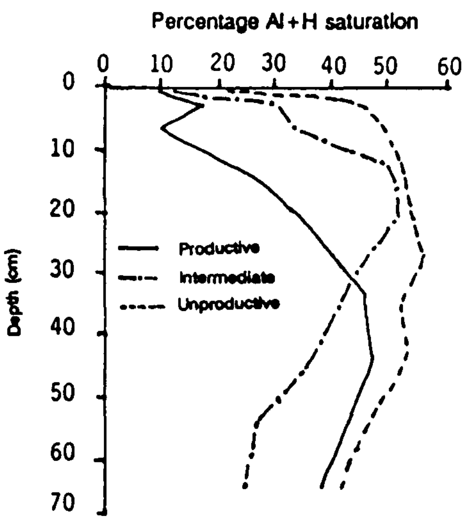
Soil Fertility Maintenance

There are two important soil fertility problems in the sorghum and millet growing areas in semiarid Africa: the widespread phosphorus deficiency on arable land and soil spatial variability.

Although phosphorus deficiency in the Sahelian soils are widespread, fortunately, the coarse-textured, kaolinitic soils have relatively low P-fixing capacity. Therefore, deficiency in most cases, may be ameliorated with applications of 20 to 40 kg of P per ha as superphosphates as demonstrated by a study where millet grain yield in a sandy soil in Niger was increased 3 to 5 fold (Bationo et al., 1986). Thus, to sustain crop yields and maintain soil fertility, phosphate fertilization becomes an essential input in the region. However, imported triple superphosphate fertilizers are expensive and beyond the reach of farmers in the region. Fertilizer subsidies are required initially until soil available phosphate has reached adequate levels. Alternatively, locally produced rock phosphates and partially acidulated rock phosphates can be cheaper sources of P for local farmers. A long-term field experiment conducted on a fine-textured Alfisol in tropical northern Australia reported that rock phosphate showed much greater sustained availability than superphosphate to seven successive annual crops of sorghum (Fig. 3).

It has been reported that marked variability in soil chemical properties over short distances in sandy Sahelian soils can cause significant yield reduction within a farmer's field (Wendt, 1986; Chase et at., 1987; Wilding and Hossner, 1987). Variability in KCl-extractable acidity in soil within short distances was related to the poor crop growth and yield reduction (Fig. 4). The randomly distributed productive and unproductive areas of the field are characterized by gradually declining millet growth. The plants in the most unproductive areas eventually die, leaving patches in the fields devoid of vegetation (Wendt, 1986).

Figure 4. Percentage Al + H saturation with depth along a transect from an unproductive to a productive region (Wendt 1986).



Spatial variability in other soil physical and chemical properties such as micro-relief, crusting, soil texture, organic matter, exchangeable bases and available phosphorus contents may also contribute to millet growth variability in these intensively used sandy soils. Causes of such widespread soil variability may be attributed to both pedogenic and anthropic factors and the potential crop yield loss in the Sahel region is yet to be quantified (Wilding and Hossner, 1987). Liming, phosphate application and addition of plant residue may help correct the problem over time. But economic and practical soil and crop management systems are yet to be developed and tested in the farmer's fields.

Integrated Watershed Management

In terms of natural resource conservation and enhancement, perhaps future agricultural practices should give more emphasis to a holistic approach to managing all landscape units within a watershed. Such an approach is of particular importance to countries and regions with inherent poor land and water resources. Moreover, successful watershed management for agricultural and forestry production is a multidisciplinary effort. Baseline data on climate, soil, hydrology, topography, natural vegetation, present and past land use systems and socio-economic conditions are needed to establish scientific criteria for designing sustainable land management and production systems (FAO, 1977; Barrow, 1887).

Few attempts have been made in developing countries to integrate modern technologies with indigenous knowledge on a watershed basis. The INRAN/TAMU/USAID collaborative project on Integrated Management of Agricultural Watershed (IMAW) in Niger may serve as an example for such an effort (Manu, et al., 1990). In this study, land management units within the watershed are delineated using geographic information systems (GIS). Promising land rejuvenation and crop production practices, including erosion control, water harvesting, agroforestry, phosphate application; alternative cropping systems, etc., are being tested and integrated into indigenous farming systems.

References

Abrol, I.P., 1988. Dryland farming - the Indian experience. In: P.W. Unger, W.R. Jordan, T.V. Sneed, R.W. Jensen (eds.) Challenges in Dryland Agriculture - A Global Perspective. Proc. Int. Conference on Dryland Farming. USDA/ARS, Bushland, Texas. pp. 50-53.

Barrow, C. 1987. Water resources and agricultural development in the tropics. Longman/John Wiley & Sons, New York. 356p.

Bationo, A., S.K. Mughogho and A.U. Mokwunye. 1986. Agronomic evaluation of phosphate fertilizers in the tropical Africa. In: A. W. Mokunye and P. L. G. Vlek (eds.), Management of N and P fertilizers in sub-Saharan Africa. Martinus Nijhoff, Dordrecht, Netherlands.

Bilbro, J.D. and D.W. Fryrear. 1988. Annual herbaceous windbarriers for protecting crops and soils and managing snowfall. Agric. Ecosystems Environ. 22/23:149-161.

Chase, R. G., J.W. Wendt and L. R. Hossner, 1987. A study of crop growth variability in sandy Sahelian soils. In: C. Renard, R. J. Van Den Beldt and I. F. Parr (eds.). Soil, Crop and water management in the Sudano-Sahelian Zone. ICRISAT, Hyderabad, India. pp. 229-240.

El-Swaify, S.A., 1988. Conservation-effective rainfed farming systems for the tropics. In: P.W. Unger, W.R. Jordan, T.V. Sneed, R.W. Jensen (eds.) Challenges in Dryland Agriculture - A Global Perspective. Proc. Int. Conf. on Dryland Farming. Bushland, Texas. pp. 134-36.

FAO, 1965. Dark clay soils of tropical and sub-tropical regions. FAO Agricultural Development Paper no. 83, ed. R. Dudal. FAO, United Nations, Rome, Italy.

FAO, 1977. Guidelines for watershed management. FAO Conservation Guide No. 1. FAO, Rome. 293p.

FAO/UNFPA/IIASA 1982. Potential population supporting capacities of lands in the developing world. Rome, Italy.

Francis, C. A. (ed.), 1986. Multiple cropping systems. Macmillian, N. Y. 383p.

Harrison, P. 1983. Earthwatch:land and people, growing pressure. People, 13:1-18.

Harvey, C., D.L. Jones and C.E. Fisher. 1961. Dryland crop rotations on the Southern High Plains of Texas. Texas Agric. Exp. Sta. Misc. Report no. 544.

Hauck, F.W., 1985. Soil erosion and its control in developing countries. In: S.A. El-Swaify, W.C. Moldenhauer and A. Lo (eds.) Soil Erosion and Conservation. Soil Conservation Society of America, Akeny, Iowa. pp. 718-728.

Hons, F. M. (ed.), 1988. Conservation tillage in Texas. Texas Agric. Exp. Sta. College Station, Texas. 84p.

Hudson, N., 1981. Soil Conservation. Batsford Academic, London.

Juo, A. S. R. and B. T. Kang, 1987. Nutrient effects of modification of shifting cultivation in West Africa. In: J. Proctor (ed.), Mineral nutrients in tropical forest and savanna ecosystems. British Ecological Society Special Publ. no. 9. Blackwell Scientific Publications, London. pp. 289-300.

Manu, A., S.C. Geiger, A. Pfordresher, E. Taylor-Powell and Saadou Mahamane. 1990. Integrated management of agricultural watershed in Niger: Land and vegetation characteristics and indigenous farming systems of the Hamdallaye watershed. TAMU/INRAN/USAID Project Report (memo), 113p.

Maunder, A. B., 1972. Objectives and approaches to grain and forage sorghum improvement in the Americas. In: N. G. P. Rao and L. House (eds.), Sorghum in the seventies. Proc. Int. Sorghum Workshop, New Delhi, India. Oxford & IBH Publ. Co. pp. 60-100.

Mullins, J.A., A.A. Webb and K.J. Coughlan. 1987. Approaches to erosion control on Vertisols in Queensland, Australia. In: M. Latham and P. Ahn (eds.) Management of Vertisols under Semi-Arid Conditions. Proc. First Regional Seminar, Nairobi, Kenya. IBSRAM, Bangkok.

Myers, R.J.K. and C.J. Asher. 1982. Mineral nutrition of grain sorghum: macronutrients. In: L.R. House, L.K. Mughogho, and J.M. Peacock (eds.) Sorghum in the Eighties. Proc. Int. Symp. on Sorghum. ICRISAT, Patancheru, A.P., India. pp. 161-178.

Nair, P. K. R., 1990. The prospect for Agroforestry in the Tropics. World Bank Technical Paper No. 131. 77p.

Natharajan, M. and R. M. Wiley. 1980. Sorghum-pigeon pea intercropping 1. Growth and yield. 2. Resource use. I. Agric. Sci. Cambridge. 95:51-65.

Norman, M.J.T., C.J. Pearson and P.G.E. Searle. 1984. The ecology of tropical food crops. Cambridge Univ. Press, Cambridge, U.K.

Ntare, B.R., P.G. Serafini and L.K. Fussell. 1987. Recent developments in pearl millet/cowpea cropping systems for low-rainfall areas of the Sudano-Sahelian Zone of West Africa. In: C. Renard, R.J. Van Den Beldt, J.F. Parr (eds.) Soil, Crop and Water Management Systems for Rainfed Agriculture in the Sudano-Sahelian Zone. ICRISAT, Hyderabad, India. pp. 277-290.

Onken, A. and C.W. Wendt. 1987. Soil fertility management and water relationships. In. C. Renard, R. Van Den Beldt and I. J. Parr (eds.) Soil, crop and water management in Sudano-Sahelian Zone. ICRISAT, Hyderabad, India. pp. 99-108.

Papendick, R.I. and J.F. Parr. 1987. The value of crop residues for water conservation. In: C. Renard, R.J. Van Den Beldt, J.F. Parr (eds.) Soil, Crop and Water Management Systems for Rainfed Agriculture in the Sudano-Sahelian Zone. ICRISAT, Hyderabad, India. pp. 183-190.

Shetty, S.V.R., 1988. Improving sorghum based cropping systems in the Sudanian zone of the West African Savanna. In: P.W. Unger, W.R. Jordan, T.V. Sneed, R.W. Jensen (eds.), Challenges in Dryland Agriculture - A Global Perspective. Proc. Int. Conf. on Dryland Farming, Bushland, Texas. pp. 724-27.

Sivakumar, M.V.K. and S.M. Virmani. 1982. The physical environment. In: L.R. House, L.K. Mughogho, and J.M. Peacock (eds.) Sorghum in the Eighties. Proc. Int. Symp. on Sorghum. ICRISAT, Patancheru, A.P., India. pp. 83-100.

Unger, P.W., 1988. Residue management for dryland farming. In: P.W. Unger, W.R. Jordan, T.V. Sneed, R.W. Jensen (eds.) Challenges in Dryland Agriculture - A Global Perspective. Proc. Int. Conf. on Dryland Farming, Bushland, Texas. pp. 483-89.

Venkateswarlu, J., N.K. Sanghi, Bhaskara Rao, U. M. B. and H. Ch. Rao. 1981. Maximizing production in a sorghum/pigeonpea intercropping system in the semiarid tropics. In: R.W. Willey (ed.) Proc. Int. Workshop on Intercropping (ICRISAT). Hyderabad, India.pp. 30-34.

Wendt, J. W., 1986. Pearl millet response to soil variability in sandy Ustalfs near Niamey, Niger. M.S. Thesis, Soils & Crop Sciences Department, Texas A&M University, College Station, Texas.

Wilding, L. P. and L.R. Hossner. 1987. Causes and effects of acidity in sandy Sahelian soils. In: C. Renard, R. Van Den Beldt and J. F. Parr (eds.), Soil, Crop, and water management in Sudano-Sahelian Zone. ICRISAT, Hyderabad, India. pp. 215-226.

Wilding, L. P. and R. Puentes. (eds.), 1988. Vertisols: Their distribution, properties, classification and management. Texas A&M University Printing Center. 193p.

Wright, E. P., 1986. Water resources for human, livestocks and irrigation in Africa. In: L. J. Foster, (ed). Agricultural development in drought-prone Africa. Overseas Development Institute, London. pp.25-37.

Role, Contribution and Direction of Biotechnology on a Sustainable Production Framework

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Generally, I will be referring to sub-Saharan Africa and sorghum and millet, as the crops. The other general assumption is that biotechnology is like any technology in that it has value in helping to answer questions about our environment and how we exploit that environment. A useful inventory of ideas regarding application of biotechnology can be found in a report prepared for the National Research Council (1990). Some 98 applications of biotechnology are suggested. This list represents, in my view, only a few of the probable applications possible over the next 2 decades. Sustainability has its rapidly changing roots in ecology and economics. While there are several sources of definitions, may I suggest we refer to Pearce et. al. (1990) who states, "emphasis ... implies a greater concern of the future". Leopold (1949) when addressing our understanding of relevant aspects of predator-prey relations in ecology said "Only the mountain has lived long enough—".

Changing views are bringing about newer approaches to sustainability. The idea that research information has been available and that it only need to be applied represented a view of the 1950's and 1960's. During the 1970's and into the 1980's there became a general awareness of the need for application of both indigenous information as well as technical transfer. Individuals in development also recognized the need for approaching a greater audience spectra. In every case self sufficiency or the amelioration of hunger was our goal. Today, I submit that we must think of agriculture and the technologies involved with economic development. The transfer of technology, such as in many developed countries, is extremely rapid. New ideas are eagerly accepted by receptive individuals within a framework of competing views and often these same individuals have an appreciation of the technology on sustainability. Amartya Sen, (1990), Lamont University Professor at Harvard argues, as well as others, that famines as we know and define them result from entitlement failures. Entitlements reduce differences among the rich and poor and tend to reduce the endemic deprivation that has so sorely affected sub-Saharan Africa over the past decades. Consequently he calls for sub-Saharan Africa to develop sources of income and growth outside food production and even outside agriculture. What we see is agriculture at times is its own enemy; particularly when agriculture is to be the source of foreign exchange. (See Pearce, et. al. 1990). The World Bank report (Anonymous 1989) in their comprehensive study on sub-Saharan Africa 1989, concludes that economic growth in this region of Africa will come principally from agriculture. Clearly, I believe that Professor Sen sees and understands that food production is one thing but producing food as a source of income for western societies would be another form of mining (exploiting) the already fragile ecosystems of Africa. Possibly these soils in sub-Saharan Africa are no more fragile than that of soils from other regions of the world, although I doubt that, but increasing populations of people and livestock directly affect the native fauna and flora of the countryside often with dire consequences. It is interesting to recall that sustainability in agriculture as a practice began in Africa as an idea to reduce damage caused by agricultural practices that tended to deplete soil nutrients, a direct inference to slash and burn approaches. While I have not witnessed slash and burn tactics, per se, in Sudan, burning to deter nomads from production fields has a similar effect. I recently read Bill Holm's extraordinary evaluation of agriculture in the developing world in "Coming Home Crazy". Bill comes from Mineota, Minnesota and asks what makes us think that because we grew up in an area where every time you gambled, you won, that you have all the an-

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swers to the world's food problems, sustainability, or even technology! He argued that agriculture in western Minnesota was so good that it was difficult to make a production mistake. In 1980, I had the opportunity to visit a mechanized scheme developed by GDZ in the Kordufan in central Sudan. When they began the project they introduced lightweight 40-50 horsepower tractors, and by the next season they were introducing 100 horsepower tractors. Any farmer from south Texas would have told you that you needed heavy and powerful equipment to work those cracking clay soils. Of course no one would have thought to ask a Texas farmer! But who asked the Sudanese? What was the philosophical discussion among the developing country farmers or scientists and donors as to the real objective of this development? Was there to be a cooperative with these tractors and implements? How were they to be maintained and what about spare parts? Have you seen the roads in that region? How was the crop to be moved to the population centers, marketed, stored? Who would this benefit? What were the problems of the area that needed addressing (before the mechanization). These are only a few of the questions that I had when I visited this show case of development! That list did not even begin to address the issues of collaboration. Was this appropriate technology under the circumstances and how does one arrive at a reasonable conclusion when much of development depends on your bias and background. After all, the discussion of the donors are important, correct? I serve on the Board of Directors of an NGO. Our major concern with partnership or collaboration, which constantly challenges us, is the role of the partners from the developing world. For INTSORMIL, these are USAID client countries. Is it possible to be equal partners when one partner has the financial resources and the other has all of the needs?

With this as a background, where do we stand with biotechnology or technology of any kind that we think could be transferred. Technology transfer can be rewarding or it could be frivolous (at best) as many attempts at technology transfer have been in the past. DeWalt, (1991) states that, "the way technology is created and implemented must have values, morals, ethics, and social justice issues incorporated from the beginning. Let us ask what we are doing. Development of cultivars with the ability to flourish on marginal soils would only promote the types of problems that have been created in the past. There are still those people who believe that only a well or two in the proper place will solve Africa's drought problems. There are those even with some "education" who believe that drought resistant plants will produce vast quantities of food in the arid regions. We (INTSORMIL) certainly do not want to promote this myth nor any other based on technical "miracles" (Again, see DeWalt, 1991). Over a decade ago, we were "chided" for believing that plants cannot develop without water, nutrients and in the presence of most of the world's damaging pests, pathogens and weeds and still produce extremely high yields (R. Nicou). Or as one of my colleagues likes to say, "Folks let's get real about this"!

What should we be doing

Actually we are doing some things quite well. INTSORMIL has always worked as a collaborative research organization. We involve our partners and some of our collaborative efforts have been reasonably successful. If I had my way we would do much more collaborative work! Drs. Brhane and Hulluka from Ethiopia, while participating in the first global conference on sorghum diseases in India, quizzed Dr. J. Betancourt about the yields of sorghum in Mexico since there was a 10-fold difference. (This was technology introduced to Mexico by commercial seed producers from the U.S.). I can still see the expression of doubt on the faces of the Ethiopian scientists on how sorghum grown at similar altitudes, under similar rainfall patterns could have such tremendous differences in yield. Progress of Global 2000 and as well as other projects have repeatedly shown that higher yields are not the problem. Greater production really becomes one of the simplest goals to achieve and it is possible to design a program for increased yields, from a desk or on a computer. It really becomes a matter of priority. Unfortunately, we have yet to develop the wisdom to picture future or potential problem scenarios for our models of increased yields. With disease management, we can design that component of management and generally improve the level of plant protection from disease to permit yields to be increased above subsistence levels. Generally it can be done without biotechnology except there are some important questions to ask before we embark on 5 or 10-year collaborative research studies. Some technology is being applied to look at questions that we think have merit. We have studies underway utilizing biotechnology from the sorghum-millet genomic mapping program to help design disease control strategies. These include techniques to genetically tag isolates of pathogens to better observe their behavior in the field, particularly in the presence of different host resistance genes or with different management schemes. The question is to determine whether some traits for disease resistance by their nature are more appropriate for controlling certain diseases than others. We have always believed so but before the development of this technology, we have not been able to test these hypotheses because we lacked research tools. We now have the potential to design plants and some of their pathogens, parasites and predators genetically. Remarkable cDNAs are being produced in response to specific stresses in plants from mRNAs. In many ways we can go directly after a gene that is responsible for an activity in a plant. Of course there are risks. In a recent issue of my professional journal, a paper was prepared announcing that there are risks associated with one of the heralded developments in biotechnology as applied to plant disease control (Zoeten, 1991). Zoeten argues that utilization of virus coat protein as a means of protecting plants form virus diseases could lead to the development of new virus diseases. The element of risk does not mean that we should not be involved with new technologies, we must be involved with new technologies. We are, however, obligated to use the technology wisely. But what are the goals and who calls the shots?

Our future depends on our ability to make differences and differences often lead to problems in the environment. I empathize with action rather than inaction even though there is the possibility of risk. This has to be a shared risk. Currently my concern is with who is doing what to whom! Recently USAID asked members of the National Research Council to design several new CRSPs. Unfortunately, not one person from the so-called developing world participated in the development of these new collaborative research initiatives. I know because I was there and asked! This is absolute nonsense. It is as much nonsense as expecting all of the agricultural research to be done for sub-Saharan Africa in some western or northern institution. Problems in Africa ideally need to be identified, visualized and solved by Africans. It may well be that these agricultural problems will need the assistance of and guidance of the farmers of Africa. There are millions of African farmers and most of them are women.

Jacopson (1990), in his testimony before a Congressional Committee on agricultural sustainability stressed that in alternative agriculture, we will look to integrated controls for plant disease. We cannot rely on a single strategy. Information exists, to solve many of these problems. There are however, few of us with the experience in enough regions with enough wisdom to be able to visualize the future impacts of the improved production. In the same manner, we must seek good sound collaboration that will permit broad based economic development. We can assist in improving plants and the value of these plants for agriculture. While most of us have specific collaborative research objectives we must carefully evaluate the impact of our work with our collaborators. The powerful tools of biotechnology ought not to be used irresponsibly. Together we con continue to use these tools wisely and successfully.

References

Anonymous, 1989. Sub-Saharan Africa From Crisis to Sustainable Growth. World Bank, Washington, D.C. 300 pp.

Anonymous, 1990. Sustainable Agricultural Development in Ethiopia. Hearing before the Joint Economic Committee Congress of the United States. February 27, 1990. (Y4 Ec 7:Ag 8/16).

Anonymous, 1990. Plant Biotechnological Research for Developing Countries. National Research Council. National Academic Press. Washington, D.C. 44 p.

Anonymous, 1991. The State of the Environment. Organization for Economic Cooperation and Development. Paris, 297 pp.

Browning, J. A., 1991. Conserving crop plant-pathogen coevolutionary processes <u>In situ</u>. In Press.

DeWalt, B. R., 1991. The cultural Ecologist concept of justice. p. 173-187. In: Thompson, P. B. and Stout, B. A., 1991. Beyond the Large Farm. Westview Press, Boulder, CO. 312 pp.

Jacopson, B. J., 1990. Alternative agriculture a plant pathologist point of view. pp 150-151. In: Alternative Agriculture: Perspectives of the National Academy of Sciences and the Council for Agricultural Sciences and Technology. Hearing before the Joint Economic Com-

mittee Congress of the United States. June 6, 1990. (Y4. Ec 7:Ag 8/17).
Leopold, A., 1949. A Sand County Almanac. Oxford University Press. 226 pp.
Nicou, R., 1982. Discussion on factors reducing sorghum yields environmental stress. Page 209 In: Sorghum in the Eighties. ICRISAT: Proceedings of the International Symposium on Sorghum. Nov. 1981. Patancheru, A. P. India.
Norton, B. G., 1991. Making the land ethic operational: Toward an integrated theory of environmental management. pp. 137-159. In: Thompson, P. B. and Stout, B. A., 1991. Beyond the Large Farm. Westview Pres, Bolder, CO. 312 pp.
Pearce, D., Barbier, E., and Markandya, A., 1990. Sustainable Development: Economics and Environment in the Third World. Elgar Publishing, London 217 pp.
Sen, A., 1990. Public Action to Remedy Hunger. Arturo Tanco Memorial Lecture Publication Series. Hunger Project, Washington, D.C. 39 pp.
Thompson, P. B. and Stout, B. A. (eds.) 1991. Beyond the Large Farm. Westview Press, Bolder, CO 312 pp.
Zoeten, G. A., 1991. Risk assessment: Do we let history repeat itself? Phytopathology: 81:585-586.

Plant Protection for Sustainable Agriculture in Sorghum and Pearl Millet Cropping Systems in Africa

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Summary

The paper tries to make an assessment of presently used control practices for sorghum and pearl millet insects and diseases in traditional and modern agricultural production in Africa. Based on literature and personal observations it was found that increasingly pesticides are used which leads to environmental pollution.

Based on experiences in developed countries, over use of pesticides can be avoided by the implementation of integrated pest management (IPM) strategies. Contributions of the different components of IPM are separately analysed and finally suggestions are made on how host plant resistance, cultural control and biocontrol could possibly be used in simple IPM strategies. The need to train scientists, extension people and farmers for successful development and implementation of IPM strategies is stressed.

Introduction

Sorghum bicolor (L.) Moench) and pearl millet (*Pennisetum glaucum* (L.) R. Br.) are the most important cereal crops in African Semi Arid Tropics where maize (*Zea mays* L.)is less competitive. Their yields in the communal sector are generally low (400 - 800 kg/ha). They remain primarily subsistence crops because they are grown in areas distant from the market and therefore tend to be uncompetitive on formal markets in comparison to maize due to higher marketing costs and lower yields. In order to increase competitiveness of these crops in the communal farming sector, yields have to be increased (Rohrbach, 1990). The large scale commercial farming sector in Zimbabwe, Botswana and South Africa already demonstrates that sorghum can compete favorably with maize. The yield increase in this agricultural sector has come from improved varieties and hybrids associated with improved management practices. For the communal sector the same trend of development can be predicted.

Yield increase due to improved cultivars certainly will not be without production constraints. Insects and diseases will constitute an important production constraint. In traditional agricultural systems they are of lesser importance but they will certainly increase parallel to increased sorghum and millet production, as already seen in the higher production commercial sector. Change of cultivars and cropping systems (monoculture) and fertilizer will create an environment that will increase the incidence and severity of existing insect pests and diseases and favour new ones. The higher obtainable yields will also increase the farmers income and permit him to use pesticides. Since pesticides are a relative simple solution to insect and disease problems, the African farmer, like the farmers in the developed countries, will use them as a regular production input. For example in Texas, only 2% of the harvested acreage was treated for insect control in 1965, while in 1976 approximately 60% of the total sorghum acreage was treated (Teetes, 1981). Commercial farmers in Botswana (Pandamatenga) already apply 3 - 4 insecticide treatments per season (Leuschner 1989).

Fortunately this trend up to now is not observed in the communal small farmers sector in Africa. However, improved technology is increasingly moving into this sector, particularly in Zimbabwe, Botswana, Zambia and Tanzania through global 2000 and other ex-

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tension agencies. It may therefore not be long until a similar situation of overuse and misuse of chemical pesticides could be visualized in sorghum and millet production similar to the developed countries.

The developed countries had realized the mistake they made and are intensively working towards more integrated control methods which are less dependent on pesticides. In Africa very little attention is paid to this area, although a lot of lip service is given to alternative integrated insect and disease control methods by National Agricultural Research Systems (NARS). The main reasons attributed to this failure are:

- Less developed NARS in terms of manpower and facilities.
- Inadequate extension services.
- Lack of awareness in end users (farmers).

With the above background this paper attempts to discuss means and ways towards pest control for sustainable agriculture in sorghum and pearl millet based cropping systems.

Important Insects and Diseases in Sorghum and Pearl Millet in Africa

The most important insects of sorghum and pearl millet in Africa based on reported and personally observed yield losses are listed in Table 1. Some of the yield loss figures were obtained from Seshu Reddy and Omalo (1985) and Nwanze (1985).

Among the major insect pests only one insect *Chilo partellus* was introduced into Africa from Asia. Other insects of minor and local importance in sorghum and pearl millet are of soilborne nature (white grubs, wireworms, termites and armoured cricket).

Similarly, major diseases of sorghum and millet and associated possible yield losses are listed in Table 2..

Traditional Insects and Diseases Control Practices used by African farmers

The traditional farming systems used by small farmers up to today are low input systems which created stable but low yields. In most cases no crop protection measures were taken for the control of insects and/or diseases alone. But a number of traditional agricultural practices based on cultivar features and management practices lead to a reduction of insect and pathogens populations (Matteson et al., 1984).

Traditional cropping systems of sorghum and pearl millet differ according to environments and socio economic constraints in the region throughout Africa. However, the main stabilizing factors to minimize the damages caused by insects and diseased are:

Cultivar traits: Resistance (Antibiosis, non preference, tolerance) and avoidance (Tables 3 and 4).

Cultural practices: Avoidance and suppression (Tables 5 and 6).

Biological control: Indigenous natural enemies (fairly undisturbed, except for reduction in flora diversity).

Modern Pest Control Practices

Modern agricultural production recommendations include, mainly:

- Use of improved cultivars
- Recommendations on crop rotation, land preparation, planting time, weeding/thinning and harvesting time.
- Fertilizer application
- Pesticide application

Little is mentioned about cultivar performance against major pests and diseases in relation to insect and disease suppression, cultural control practices and biological control. In Table 7 an attempt has been made to analyze to what extent components of traditional agricultural practices, which contributed to sustainable agriculture, have been incorporated into present insect and disease management practices.

The most obvious change to traditional systems is host plant resistance that has been neglected in the currently used cultivars. The general increase in insects and diseases is at least partially explained by negligence of host plant resistance. In addition, increased pesti-

Table 1. Major insects of sorghum and pearl millet in Africa.

Common name	Scientific name	Yield loss	Countries
Sorghum			
Shootfly	*Atherigona soccata*	10 - 40%	Botswana, Tanzania, Sudan
Stemborer	*Chilo partellus*	10 - 45%	Botswana, Zimbabwe, Malawi
	Busseola fusca	10 - 30%	Lesotho
	Sesamia sp	Not known	Not known
Aphids	*Rhopalosiphum maidis*	100%	Yield loss not clear
	Melanaphis sacchari	>50% infestation	Zimbabwe, Botswana, Malawi
Headbugs	*Calocoris spp*	Quality loss	
	Spilostethus sp	Quality loss	Botswana
	Nezara viridula	Quality loss	Yield loss not clear
	Calidea dregii	Quality loss	
Midge	*Contarinia sorghicola*	>25%	Mozambique, Tanzania, Sudan
Bollworm	*Heliotis armigera*	10 - 20%	Botswana, Zambia
Armoured cricket	*Acanthoplus speiseri*	10-30%	Zambia, Zimbabwe, Namibia, Botswana
Storage pests	*Sitophilus sp*		
	Sitotroga cerealella	>12%	Zimbabwe
Pearl Millet			
Shootfly	*Atherigona approximata*	>30%	Zambia
Stemborer	*Haimbachia ingnefusalis*	10 - 30%	West Africa
Head girdler	*Heliochelus albipunctella*	>10%	West Africa
Bollworm	*Heliotis armigera*	10 - 20%	Botswana

Table 2. Major diseases of sorghum and pearl millet in Africa.

Common Name	Scientific name	Yield loss	Region/Country
Sorghum			
Leaf and shoot diseases			
Anthracnose	*Colletotrichum graminocola*	15 - 30%	SADCC, East, West Africa
Leaf blight	*Excerohilum turcicum*	10 - 20%	SADCC
Sooty stripe	*Ramulispora sorghi*	10 - 20%	SADCC
Downy mildew	*Peronosclerospora sorghi*	10 - 15%	SADCC
Panicle diseases			
Grain mold	Several unspecified fungi	Quality loss	Tanzania, West Africa
Ergot	*Sphacelia sorghi*	Seed production	SADCC
Root and Stalk			
Charcoal rot	*Macrophomina phaseolina*	Lodging*	Botswana, West Africa
Anthracnose	*Colletotrichum graminicola*	Lodging*	Africa
Pearl Millet			
Downy mildew	*Sclerospora graminicola*	30 - 40%	Zambia, Zimbabwe, Senegal
Smut	*Tolyposporium pencillariae*	5 - 10%	Africa
Ergot	*Claviceps fusiformis*	5 - 10%	Africa

*Harvestable loss of the produce.

Table 3. Traditional cultivar traits contributing to lower insect populations.

Insects	Antibiosis	Non preference	Tolerance	Avoidance	Continents
Sorghum					
Shootfly	Glossiness	Glossiness	Tillers		India
Stemborer		Oviposition non preference	Thick stem Long internodes, Tillers		Africa
Aphids		Open head types			Africa
Headbugs		Open head, Long glumes		Long duration cultivars	India Africa
Midge				Long duration cultivars	Africa India
Heliotis		Open head		Long duration cultivars	Africa India
Storage insects	Hard grain				Africa/India
Birds	Tanins	Lacks, open heads			Africa
Pearl Millet					
Shootfly			Tillers		Africa
Stemborer		Hard stems	Tillers		Africa
Head girdler				Long duration cultivars	Africa
Storage insects	Small grain	Small corneous, grain			India Africa
Birds		Small grain, Tight heads, Brissels			Africa

Table 4. Traditional cultivar traits contributing to lower pathogen populations.

Diseases	Resistance	Tolerance	Avoidance	Continents
Sorghum				
Grain molds	Loose panicles long glumes Flavan - ols	-	Photo sensitivity/ long duration	India Africa
	Corneous hard grain	Brown seed		
Root & stalk rots	Non senescence or stay green	Thick, short stem	Early maturing	India Africa
Leaf diseases	-	Tall	Late maturity	Africa India
Downy mildew	-		Rapidly germinating seeds	India Africa
Viruses	-	-	Chemical vector control	-
Pearl Millet				
Downy mildew	-	Tillering	-	-
Smuts	-	-	-	-
Ergots	-	-	-	-

Table 5. Traditional agronomic practices contributing to lower insect populations.

Sorghum insects	Planting time	Weeding	Thinning	Field sanitation	Mixed inter-cropping	Manual control
Shootfly*	Early planting	Increases seedling growth	Removal of dead hearts	Grazing, removal of residues & regrowth		
Stemborer*	Early planting	Increases seedling growth	Removal of dead hearts	Grazing removal of residues, regrowth	Cereal/ legume	
Aphids**	Early planting	Increases seedling regrowth				
Headbugs**	Uniform early planting		Uniform plant growth			
Midge**	Uniform early planting		Uniform plant growth			
Heliotis*	Uniform éarly planting		Uniform plant growth			
Armoured* cricket		Removal of grass hosts				Collection of crickets
Storage* insects						Cleaning of seed before storage
Head girdler***	Early planting		Uniform plant growth			
Birds						Bird watching

*Common to sorghum & pearl millet **Specific to sorghum ***Specific to pearl millet

cide use tends to reduce natural enemies. Similarly, increased fertilizer use may also increase plant susceptibility to several insects and diseases.

Traditional mixed cropping and inter cropping systems are often replaced by monocropping. All these changes are increasing the vulnerability of the sorghum and pearl millet agro-ecosystems in Africa.

Possibilities in Pest Control for more Sustainable Agriculture

Based on what was said earlier (Table 7) it becomes obvious that crop protection in modern cereal production in Africa will become increasingly dependent on pesticides. It is our impression and supported by extension agency reference books in Zimbabwe which refer to insect control in cereals (Agritex, 1985) mainly insecticides, that this appears to be future trend.

In the developed countries public awareness of the potential danger of pesticide pollution to the environment and to living beings was created by Carson in 1962. Since then a rethinking process has started which resulted in the integrated pest management approach which became the leading principle in all FAO plant protection activities up till now (FAO 1968). "IPM is a pest management system that in the context of the associated environment and the population dynamics of the pest species utilizes all suitable techniques and methods in as compatible manner as possible and maintains the pest population at levels below those causing the pest population at levels

Table 6. Traditional agronomic practices contributing to lower pathogen populations and disease pressure.

Disease	Planting time	Weeding	Thinning	Sanitation	Mixed/inter-cropping/ *crop rotation	Manual
Sorghum/Millet						
Grain molds	Late planting?	-	-	Removal of residues	-	-
Leaf diseases**	Late planting?	Reduce favourable microclimate . Removal of wild and weed hosts	Enhances better air circulation	Removal of infected debris	Cereals and legumes; Reduce inoculum	-
Root & Stalk rots** (charcoal rot)	Early planting	Reduce favourable microclimate	Provides more soil moisture to lesser no. of plants	Reduces soil borne inoculum	Cereals and legumes	-
Downy mildew**	Late planting	Reduce secondary spread. Removal of wild and weedy hosts	Removal of infected plants reduce further spread	Removal of systemically infected plants	Cereals and legumes	-
Ergot**	-	Removal of wild and weedy hosts	-	Removal of sclerotia from the seed		
Smuts**	-	Removal of wild and weedy hosts	Removal of infected plant reduce further spread	Clean seed provides lesser infected plants		
Virus/bacteria	-	Removal of wild and weedy hosts	Remove earlier infected plants	Reduces inoculum	-	Proper drying and cleaning of seed before storage
Storage fungi	-	-	-	-	-	-

**Common to both sorghum and millet ? in certain regions and areas

below those causing economic injury". (FAO 1973).

For Africa the development and implementation of integrated insect and disease control systems would be ideal for the following reasons.

1. Pesticide use is still low and all the undesirable side effects like the development of insect and pathogen resistance to pesticides and environmental pollution could be minimized.

2. Africa has a unique situation because pesticide use is still comparatively low and agro ecosystems are still partially or com-

Table 7. Traditional control components and agricultural practices that are presently used in modern pest management in Africa.

	Cultural control*							Chemical control**				
Sorghum insects	Host plant resist.	Bio cont..	Crop rota-tion	Planting time	Sanitation	Inter/Mix cropping	Cultivar dependent avoidance	Soil	Seed	Folia	Other	Increase/ decrease of insect diseases
Shootfly	1	1	-	3	-	2	-	2	2	-	-	decrease
Stemborer	1	1	2	3	2	2	-	2	2	3	-	increase
Aphids	1	1	-	3	1	2	-	-	-	3	-	increase
Armoured cricket	-	1	-	3	-	-	-	-	-	2	3	increase
Headbugs	1	1	-	3	-	2	1	-	-	3	-	increase
Midge	1	1	-	3	-	2	1	-	-	3	-	increase
Heliotis	1	1	-	3	-	2	1	-	-	3	-	increase
Storage insects	2	1	-	-	-	-	-	-	-	-	2**	increase
Sorghum*** diseases												
Anthrac-nose	1	-	1	3	1	2	1	-	-	1	-	increase
Leaf blight	1	-	1	3	1	2	1	-	-	1	-	increase
Downy mildew	1	-	1	3	1	2	-	-	1	-	-	increase
Sooty stripe	1	-	-	3	-	2	1	-	-	-	-	increase
Grain mold	1	-	-	3	-	2	1	-	-	-	-	increase
Ergot	1	-	-	3	-	2	-	-	-	-	-	increase in hybrid production

*Control methods: 1 = Little or no use. 2 = Some use. 3 = Major use.

2**Chemical treatment in storage (sorghum and pearl millet).

***Similar insect and disease control componenets and agricultural practices are in use to control pest problems of pearl millet.

pletely intact which provides a unique study ground for scientists and possible trade offs for the development of new IPM systems (Matteson et al, 1984).

3. Africa plant protection scientists (entomologists, Pathologists and breeders), have only recently come up in numbers and most of them are familiar with the concept of IPM. These scientists will be able to accept IPM concepts fairly easily provided they are motivated, properly guided and supported.

The text book definition of IMP is usually complex However, it can be broken down into major components and under each component approaches and suggestions for more effective plant protection will be discussed.

- Host plant resistance
- Cultural control
- Biological control
- Pesticide management
- Education:Researchers
- Extension
- Farmers

Breeding for resistance

Host plant resistance, is the strongest plant protection component of the traditional agricultural system and will remain so in the modern IPM system, because it is:

- Safe to the environment
- Easily acceptable to farmers
- Economic to use

Recently various international institutes (ICIPE, ICRISAT, INTSORMIL), private, and national seed companies (Pioneer Seed, South Africa) have made impressive progress in developing varieties and hybrids resistant to major insects (sorghum midge, shootfly, stemborer, storage insects) (SADCC\ICRISAT 1986 - 89) and diseases (downy mildew, leaf blight, anthracnose, sooty stripe) (SADCC\ICRISAT 1986 - 90). Traditional cultivar traits, like open to semi open panicles (less susceptible to head insect and grain mold damage) and medium duration to maturity, which increases drought resistance and reduces impact of stemborers, are used as sources of resistance in various breeding programs. Lack of manpower and inadequate funding make it difficult for National Agricultural Research System scientists to enter into breeding for resistance efficiently. SADCC\ICRISAT is working closely with national scientists by providing them adequate germplasm, and segregating progenies derived from resistance breeding programs.

Plant breeding in general is still carried out in the traditional way in the region and may continue in years to come. Biotechnology and genetic engineering could accelerate the progress in breeding for better resistance in future. However, for the time being such research should be carried out in developed countries, and the end products could be tested under African environmental conditions.

Cultural control

Cultural control is the second important component of IPM that needs to be strengthened in Africa. Only recently intensive research has been directed towards the understanding of cropping systems in relation to insect and disease population dynamics. ICIPE is probably the leading institute in this area of research. Such studies certainly can enhance our knowledge and options for increasing its effectiveness. Promising areas of research would be:

Time of planting: Early planting: avoiding first generation of shootfly, stemborer.

Date planting: escape grain molds of sorghum.

Crop rotation: Reduction of carry over population of stemborer and primary inoculum of diseases such as downy mildew and leaf diseases.

Sanitation: Reduction of carry over populations of stemborer and midge and primary and soilborne inoculum of leaf diseases and ergot by removing plant debris.

Cultivation - Ploughing: Early ploughing, exposes soil insects like white grubs and egg pods of armoured cricket. Soil exposure to heat during the hottest months of the years in Africa reduces the population of the soilborne fungus flora. Thus can reduce the primary inoculum of several soil borne diseases.

Weeding: Enhances plant growth by removing competition. Thus seedlings grow quickly out of the susceptible shootfly, stemborer and downy mildew stage. Rouging of the primary diseased plants helps reduce the secondary spread of ergot and downy mildew.

Biological control

Very little experience and research is known to be carried out in the area of biological control in cereals. Attempts have been made to control stemborer by exotic parasites (Jotwani, 1982) but with only marginal success. Biological control in cereals is still a very underdeveloped field in Africa. The present focus is on:

- Identification of natural enemy complexes for major pests.
- Conservation of existing natural enemy fauna. National scientists are mainly involved in this area of research and ICIPE has a strong research program on identification conservation and enhancement of indigenous natural enemies for stemborers. Therefore, main focus in research should be in preserving the natural enemy fauna. Possibilities should be explored to find exotic natural enemies for stemborer and sugarcane aphid control.

Pesticide management

Indiscriminate pesticide use is on the increase in cereals. The main reasons for this are:

- Lack of information on economic threshold levels and insect monitoring techniques. Similarly, little is known about the biology of the pathogens and epidemiology of the diseases caused by them.

Additionally, little is known about the pathogen variability in Africa.
- Lack of forecasting systems.
- Poorly trained extension services.
- Low level of awareness among farmers.

Recently attempts have been made to develop procedures to determine the economic threshold levels of the most important insects and monitoring damage caused by them. For example the threshold level of sorghum stemborer is 15% of plants showing leaf feeding symptoms at 25 - 30 days after plant emergence (Sithole unpublished). Arbitrary levels for headbugs are 10 - 20 nymphs/head and for midge 2 - 3 adults/head during flowering (Leuschner (1989), personal observation). Research at present is being conducted on stemborer (*Chilo partellus* and *Busseola fusca*) population monitoring in the SADCC region. This may eventually lead to a forecasting system. However, more research input is necessary in these two areas to provide effective guidelines to farmers for insecticide application. Also we have started the monitoring of pathogen populations of various cereal diseases in collaboration with institutes such as Texas A&M University and the University of Reading, etc.

Farmers and extension workers need to be trained in the application of pesticides and maintenance of spraying equipment. Seed treatment for insects (soil insects, shootfly, stemborer) and diseases like downy mildew and smuts of sorghum and millet should have much wider application. It reduces the amount of pesticides used at later crop development, and is relatively economical and environmentally acceptable.

Other areas that need improvement are effective pesticide legislation acts including regulated registration, sale, distribution and use of pesticides. The Zimbabwe pesticide legislation is a good example. Pesticide labelling and user guide lines should be clear and easy to understand. Further to avoid build up of insect and pathogen resistance, chemicals need to be rotated. Pesticide formulations should be modified under the aspect of lower toxicity. Protective clothing and personnel hygiene should be introduced to those people handling pesticides.

Education

Scientists: Most scientists from the region are trained in developed countries. On returning home they often face culture shock, low salaries, and poor working conditions. Experienced colleagues who could give initial guidance in identifying and carrying out of relevant projects of national or regional importance are seldom available.

The situation needs improvement and therefore, expatriate entomologists and pathologists have a huge task in motivating the returning scientists. Bilateral and multilateral agencies should, as their first priority, work closely with NARS scientists. They should provide guidance, encouragement and incentives to motivate regional scientists. This can be done by developing relevant collaborative research projects, providing training on methodologies, helping them with publications, support them to participate in workshops and provide small funds which should be solely managed by the NARS scientists to carry out collaborative research at their location. Expatriate and NARS scientist should respect and accept each other as equal partners with all the responsibilities equally shared between them. SADCC/ICRISAT has initiated working along these guidelines with variable but in general good success.

Extension: Extension services are the vital link between research and farmers. It is surprising how little is done to improve this vital and most important sector of agriculture. Similar to trained scientists, extension workers are also poorly paid, face poor working conditions and often have no transport to communicate with farmers. In addition there is poor dialogue with NARS researchers and very little relevant information materials are available to them. In Africa informative extension bulletins are more appreciated and useful than journal publications to improve the production of sorghum, millet and other crops..

Generally most of the international agencies are very reluctant to assist this sector. They are probably scared about the magnitude of the problem. Global 2000 is one of the few agencies which is willing to work with farmers and extension services.

To improve the situation agricultural extension schools are needed, scientists have to provide extension information materials, and government policies in relation to extension support have to be changed before marked improvement can be achieved. Long term projects are needed to support and strengthen this sector so that products of research can reach the end users, the farmers.

Farmers: Education of the farmer, through whom the ultimate implementation of improved plant protection systems and technologies can be achieved, is the challenging task of governments, researchers and extension agencies.

Governments have to give the necessary production incentives and education to the farmers through extension and research support.

Researchers need to provide the necessary research back up for any control recommendations provided by extension to the farmers.

Extension has the ultimate task to implement control methodologies together with the farmers. Among the many experiences encountered in the implementation of IPM in small farms, is, that the IPM approach should not be introduced as new (Samsudin et al, 1985). As discussed earlier, many farmers are already practicing IPM unconsciously and should be encouraged to continue to do so. They should be taught about biological factors surrounding them, and integration with other methods of control should be viewed as a step by step modification of existing conditions. Teaching should be done through the experimental and empirical approach.

IPM

Integrated pest management in the modern sense, has already been successfully implemented in cotton production in Zimbabwe (AGRITEX 1985). Crop rotation, planting time, burning of residues, scouting procedures, thresholds and insecticide recommendations are standard practices taught by extension workers to farmers.

In sorghum and pearl millet it should be relatively easy to introduce similar guidelines. An attempt has been made in Table 8 to list some of the above mentioned guidelines as the main components of an IPM system in order of importance for various insects and diseases of sorghum. Similar models will be operable to control diseases and insects of pearl millet. The individual components have been discussed earlier. The table shows clearly that the prospective to develop IPM systems are feasible. For example if seed treatments and early planting are implemented, a fairly large number of insects and diseases can be controlled or avoided. Similarly with resistant cultivars it should be possible to reduce the impact of certain insects or diseases to a level that chemical control can be avoided. This should be the case in the near future since cultivars with resistance or levels of resistance to major diseases (DM, leaf disease) and insects (aphids, midge, storage insects) are in the advanced development stage. Chemical control can probably never completely be avoided but the development of economic threshold levels should eliminate over and misuse in future.

Conclusion

Over the next ten to twenty years, the dominant share of sorghum and millet grown in the SADCC region will be consumed on the farms where it is produced. They will remain important food security crops all over Africa. Maize is the major competitor to sorghum and millet production. In order to compete with maize, productivity of sorghum and millet has to be compatible with maize.

Improved crop protection practices will certainly help to increase competitiveness by increasing the yield of these two crops, but let us do it with utmost concern for the environment in which these crops are grown.

Table 8. IPM components in order of mportance to suppression or avoidance of insects and disease build up in sorghum.

Insect	Seed Treatment	Planting time	Resist./ tolerance	Biocontrol	Rotation Thinning Weedng Sanitat.	Chemical control	Econom. threshold
Shootfly	+	+++	+	+	+	-	-
Stemborer	+	+	+	+	+++	+	+++
Aphids	+	+	+++	+	+	+	+++
Headbugs	-	+++	+	+	-	+	+++
Midge	-	+++	+++	+	-	+	+
Heliots	-	+	+	+	-	+	+++
Armoured Cricket	-	+	-	+	+++	+++*	+
Storage	-	-	+++	+	-	+	-
Insects Birds	+	-	+	-	-	+	-
Rats	+	-	-	-	+	+*	+
Diseases							
Downy mildew	+++	-	+++	-	+	+	+++
Grain mold	-	+++	+++	-	+	-	+
Leaf diseases	+?	+	+++	-	+	+?	+
Stalk rot	-	+	+	+	+++	-	-
Virus and Bacterial diseases	-	+	++	+	+++	+***	+
Ergot	-	+	+	-	+	-	-
Smuts**	+++**	+	+	-	+	-	+

+ . Low importance ++Medium importance +++High importance *Bait

** . Lose and covered smuts of sorghum

*** Vector control in case of insect transmitted virus diseases

References

AGRITEX, 1985. Rapoko and sorghum. Pages 48 - 51 In: extension workers reference booklet, crop packages. Agricultural Technical and Extension Services (AGRITEX). Government Printer, Harare, Zimbabwe, 55 pp.

Carson, R. L., 1962. Silent Spring. Boston, Houghton Mifflin, 368 pp.

FAO, 1968. Report of the first session of the FAO panel of experts on Integrated pest control, Rome, 18 - 22 September, 1967, PL/1967/M/7. Rome: FAO 19 pp.

FAO, 1973. Report of the fourth session of the FAO panel of experts on integrated pest control, Rome, December 6 - 9, 1972. Rome: FAO 35 pp.

Jotwan., M. G., 1982. Factors reducing sorghum yields: Insect pests. Pages 251 - 255 In Sorghum in the eighties: proceedings of the International Symposium on Sorghum, 2 - 7 November 1981, ICRISAT Centre, India. Vol. 1. Patancheru, A. P. 502 324, India: International Crops Research Institute for the Semi Arid Tropics.

Leuschner, K. 1989. Trip report on insect survey at Pandamatenga, Botswana, SADCC/ICRISAT, P O Box 776, Bulawayo, Zimbabwe.

Matteson, P. C., M.A. Alturi, and W.C. Gagne. 1984. Modification of small farmer practices for better pest management. Ann. Riv. Entomol. 29: 383 - 404.

Nwanze, K. F., 1985. Sorghum insect pests in West Africa. Pages 37 - 44 In: proceedings of International Sorghum Entomology Workshop, 15 - 21, July 1984. Texas A & M University, College Station, Texas, USA.

Rohrbach, R. L., 1990. Sorghum and millet marketing in the SADCC region. Pages 373 - 393 In: proceedings of the 6th Regional Workshop on Sorghum and Millet in Southern Africa, 18 - 22 September 1989, SADCC/ICRISAT Sorghum and Millet Improvement Program, P O Box 776, Bulawayo, Zimbabwe.

SADCC\ICRISAT, 1986 - 90. Proceeding of Regional Workshops on Sorghum and Millet for Southern Africa, 1986 - 89. SADCC/ICRISAT, Sorghum and Millet Improvement Program, P O Box 776, Bulawayo, Zimbabwe.

Samsudin, S., S. Mazlanm, M.E. Yazid and T. Noorazimah. 1985. Implementation of integrated pest management programme for paddy in the Tanjung Korang Irrigation scheme. In Integrated Pest Management in Malaysia (ed. B. S. Lee et al) pp 283 - 293.

Seshu Reddy, K. V. and E. O. Omolo. 1985. Sorghum insect pest situation in Eastern Africa. Pages 31 - 36 In: proceedings of International Sorghum Entomology Workshops, 15 - 21 July 1984. Texas A & M University College Station, Texas, USA. International Crops Research Institute for the Semi Arid Tropics, Patancheru, P O Andhra Pradesh 502 324, India.

Teetes, G. L., 1981. Sorghum insect pest management. Pages 225 - 236 In: Sorghum in the eighties: proceedings of the International Symposium on Sorghum, 2 - 7 November 1981, ICRISAT Centre, India, Vol. 1. Patancheru. A. P. 502 - 324, India: International Crops Research Institute for the Semi Arid Tropics.

Session VII - Regional Prioritization of Constraints within a Sustainability Framework

- Sorghum and Millet Research in Botswana
- Current Status of Sorghum Production in Colombia
- Towards Sustainable Agriculture in Honduras with Inter-CRSP Collaboration
- INRAN/INTSORMIL Collaboration
- Priorities in the Sudan in the 1990s

Session Chair: Robert Schaffert

Speakers:
Lucas P. Gakale
Manuel Torregroza Castro
Roberto Villeda-Toledo
Moussa Adamou
El Hilu Omer

Sorghum and Millet Research in Botswana

L. P. Gakale[1]

Introduction

Botswana is a landlocked country in the heart of Southern Africa. It shares borders with Namibia, South Africa, Zambia and Zimbabwe. It has an average elevation of 1000m above sea level and except for a few rocky hills in the eastern part, the country has a general featureless topography of rolling savanna plains. This monotony is interrupted by the Okavango River in the north-west which ends in a huge inland delta and the Chobe River which flows northward to join the Zambesi just above the Victoria Falls.

The climate of Botswana is continental semi-arid. Four seasons are recognized, the dry cold winter (May - July), the dry warm spring (August - October) the rainy and hot summers (November - January) and the rainy warm autumn (February - March). These seasons are however, not that distinct and perhaps one should only talk of the rainy hot season and the cool-cold dry season. Although rainfall may start as early as September, dryland cropping usually begins towards the middle of November and the crop cycle is completed by April as it is within this period that there is a greater chance of rainfall. Crop production is solely depend on rainfall as there are very limited water resources to permit irrigation. Irrigation is limited to horticultural production and all cereals (sorghum, maize, millets) and other field crops are rainfed.

Rainfall is by far the main determinant of crop yields. The country ranges from 250 mm of rain in the southwest to 650 mm in the northwest. The rainfall comes during the hot months when day temperatures may reach 40°C and evapotranspiration may reach as high as 2000 mm per annum. These conditions, coupled with the fact that rainfall is very erratic and variable within and between seasons, results in extended drought spells within the growing season and any crop grown will face drought spells of varying duration and degrees of intensity.

About 80% of Botswana is covered by the Kgalagadi sands which are unsuitable for arable farming. Most of the arable soils fall into the FAO units arenosols, regosols, luvisols, cambisols and vertisols located in pockets in the eastern part of the country. These soils are marginal for crop farming and are texturally classified as sands, loamy sands and sandy loams. In the Okavango delta, silty clays are found in the flood plains and in the Pandamatenga area, some 100000ha of heavy clay soils (vertisols) have been identified. Most of the soils are shallow, have a low moisture holding capacity and are weakly developed.

Sorghum and Millet Production in Botswana

In order to appreciate the importance of sorghum and millet in Botswana, it is pertinent here to review the production statistics of these crops and compare them with those of other crops grown in the country.

Table 1 shows the total land area grown to various crops during the 1980 - 1989 cropping seasons. The table shows that over the 10 year period, over 60% of the land area was planted to sorghum alone while maize, millet and other crops (beans, pulses, sunflower, groundnuts etc) occupied 22.7%, 6.1% and 10.3% of the land area respectively.

Table 2 shows that over the same period, 70% of the harvested area was occupied by sorghum compared to only 16% and 6% for maize and millet respectively. These figures reveal the comparative advantage of growing sorghum and millets in Botswana because of

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Table 1. Crop area planted, 1980 - 1989.

Year	Sorghum	Maize	Millet	Other	Total
		ha x 1000			
1980	147.0	80.0	17.0	43.0	287.0
1981	141.0	87.0	20.0	42.0	290.0
1982	93.0	64.0	16.0	31.0	204.0
1983	126.0	61.0	17.0	25.0	229.0
1984	1.14.0	48.0	17.0	24.0	203.0
1985	125.0	49.0	16.0	21.0	211.0
1986	161.0	44.0	18.0	20.0	243.0
1987	210.0	46.0	14.0	20.0	290.0
1988	279.0	54.0	13.0	21.0	367.0
1989	266.1	88.4	20.4	34.5	409.4
10 Year Mean	166.2	62.1	16.8	28.2	
% Crop Area	60.8	22.7	6.1	10.3	

Source: Botswana Agricultural Statistics 1980 - 1989. Planning and Statistics Division, Ministry of Agriculture, Gaborone.

Table 2. Crop area harvested, 1980 - 1989.

Year	Sorghum	Maize	Millet	Others	Total	% of total planted
			ha x 1000			
1980	131.0	47.0	14.0	26.0	218.0	76.0
1981	123.0	59.0	13.0	27.0	222.0	75.5
1982	37.0	24.0	4.0	11.0	76.0	37.2
1983	35.0	20.0	6.0	5.0	66.0	28.8
1984	49.0	3.0	8.0	7.1	67.1	33.0
1985	83.0	8.0	10.0	5.0	106.0	50.2
1986	96.6	8.8	10.1	6.7	122.2	50.3
1987	113.9	5.4	5.5	4.7	129.5	44.6
1988	243.98	32.9	9.1	13.7	299.5	81.6
1989	201.2	52.3	11.5	18.8	283.8	69.3
10 Year Mean	111.4	26.0	9.1	12.5		54.6
% Crop Area	70.0	16.4	5.7	7.9		

Source: Botswana Agricultural Statistics, 1980-1989. Planning and Statistics Division, Ministry of Agriculture, Gaborone.

the marginal growing conditions imposed by low and poorly distributed rainfall. Maize usually never recovers from extended mid-season droughts and thus higher percentages of the planted area usually produce no yield.

Table 2 also reveals that over the decade of the eighties, on average only 54.6% of the planted area was ever harvested and that even in the best season of 1988, only 81.6% of the planted area was harvested. While pests, stray animals, late plantings, etc. may have accounted for some of the low harvest percentages, the dominant factor affecting this is insufficient moisture as can be seen by the most vulnerable crop, maize, which tended to suffer the most.

Table 3 shows the total crop production figures for sorghum, maize, millet and other crops. Again we observe that 67% of the total production came from sorghum compared to 23%, 4% and 6% for maize, millet and others respectively. Slightly higher average yields for sorghum were obtained even though all the yields were poor by any standard. This is

Table 3. Total crop production, 1980 - 1989.

Year	Sorghum	Maize	Millet	Others	Total
			Metric tons		
1980	29,000	12,000	3,000	4,800	48,800
1981	28,000	22,000	2,000	6,200	58,200
1982	4,000	13,000	500	1,500	19,000
1983	5,000	9,000	500	1,300	1,800
1984	6,000	500	700	1,400	8,600
1985	15,000	1,500	800	1,700	20,000
1986	16,000	3,600	1,300	1,000	21,900
1987	1,800	3,300	400	300	22,000
1988	94,000	7,300	3,700	2,700	107,700
1989	53,000	20,000	2,000	3,200	78,200
10 Year Mean	26,800	9,220	1,590	2,410	40,020
% Crop Production	67.0	23.0	4.0	6.0	
Average Yield	161	148	94	85	

further illustrated in Table 4 where average yields of the three main cereals are compared.

An interesting trend is shown by yield figures for the 1982 and 1983 cropping seasons. During these years, which were drought years, maize substantially outyielded sorghum. This would seem to contradict my earlier assertion that under drought conditions, sorghum performs better than maize. The reason I can offer for this apparent discrepancy is that at that particular point in time, much of the maize was being grown by big commercial farmers who tended to have better crop management skills and therefore they were able to get some "reasonable" yields even under those severe drought conditions. With the government raising the price of sorghum during the drought years from 1984, even these larger farmers started growing sorghum and this is reflected by slight improvement in sorghum yields and a large reduction in maize yields.

Table 4. Average yields of three main cereal crops based on area planted and production, 1980 - 1989.

Year	Sorghum	Maize	Millet
		Kg ha^{-1}	
1980	197	150	176
1981	199	253	100
1982	43	203	31
1983	40	148	29
1984	53	10	41
1985	120	31	113
1986	99	82	74
1987	86	70	26
1988	338	141	225
1989	199	224	97
10 year mean	161	148	94

Priority and Rank of Sorghum and Millet Research

As has been seen in production figures presented above it is perhaps an understatement to say that sorghum is the crop of Botswana. While millet is also an important crop, its production is limited to certain small areas and therefore from national production figures, one may not readily realize its importance. However, in those areas where it is produced, it reverses the trend seen for sorghum at the national scale, at times occupying as much as 90% of the land planted as is the case in the refugee settlement villages of Etsha in northwestern Botswana. In the main settlement and farming areas of eastern Botswana, sorghum is the main crop. As most research stations and sites are located in this area, sorghum has tended to dominate the commodity research programs and it is often the test crop in almost all areas of research including farm machinery, basic agronomy, soil and water management research, plant protection, etc. The work on millet so far has been limited to the crop improvement program although it is realized that this too needs to be expanded in both scale and scope.

Priority Sorghum and Millet Research

Breeding

The research objective is to generate high yielding cultivars (varieties, composites and hybrids) which are stable in terms of grain yield under various biotic and abiotic stresses. Of particular interest to us are genotypes that are tolerant to drought and heat stresses and have good grain quality for use as human food and for industrial utilization in milling and brewing of opaque beer.

Various crop improvement strategies are being pursued including:

a) evaluation of introduced commercial varieties and hybrids to identify locally adapted cultivars with acceptable commercial and agronomist attributes.

b) using various selection approaches in breeding programs.

c) Use of single row observation nurseries to screen hundreds of introduced and locally collected materials after which the promising ones are advanced to replicated trials for further evaluation and development.

Agronomy

The agronomy subprogram falls under the soil and water management research program whose major object is to identify suitable soil management techniques to address the problems of soil moisture deficits, poor plant stands and poor fertility.

The research strategy is to design and test suitable ox-drawn implements to manage different primary tillage, cultivation and planting systems, use of different tillage systems to increase rainfall interception and soil moisture storage and use of inorganic fertilizers and cropping systems to increase and/or maintain fertility. INTSORMIL's input has been provision of an in-country based PI with a small operation budget. We feel this has been a significant and important area of research collaboration.

Food Technology

The Department of Agricultural Research does not have a research program on food technology. However it is collaborating with other institutions within the country and in the region to develop a sorghum based baby food formulation. The department is expected to contribute in the identification and development of varieties with required grain quality.

Another area of emphasis is looking at grain quality for brewing and milling purposes. Despite the low domestic production, much of the grain produced locally does not enter the local brewing as brewers complain of the grain quality. Botswana's sorghum prices are distorted as they are much higher than in neighboring trading partners. It is also true that the current sorghum stocks are of poor quality as no procurement grain standards are used by the local produce marketing agent, the Botswana Marketing Board. It is therefore necessary for our breeders to work with the local users of grain sorghum to determine their specific requirements so that they can tailor their research effort towards satisfying those requirements.

Entomology

Until recently we have used a discipline approach in our research programs and projects. Our Entomology program has therefore been independent from the commodity research programs. In our new approach, we want to foster a more coordinated research approach, where disciplines such as Entomology will fall under a commodity program such as cereals program. We therefore see a situation where the entomologists will work hand in hand with the breeders, identifying sources of resistance and incorporating this into the breeding program so that there could be an accelerated pace towards meeting the objective of incorporating pest resistance in the finished product for improving stability of sorghum and millet production.

As of now, our research emphasis has been on stem borers, head bugs and aphids. This work, has however, been more or less on hold as the only trained entomologist in the department has been away on training for the last three years. Until he finishes his studies, and we review our whole entomology research topics, vis-a-vis the pest problems, I hesitate to single out topics that I may consider priority areas of research.

In some seasons, certain pests including corn crickets, locusts, become economically important but there is no research conducted for these.

Pathology

Priority on sorghum pathology research is placed on screening varieties and hybrids for major disease listed below in order of importance:

Certain areas such as the pandamatenga commercial farms in the Chobe District have proved to be hot spots for these diseases and close collaboration with the SADCC/ICRISAT Sorghum and Millet Improvement Project has proved useful in addressing these. It must be noted however that the prevalence of these diseases depends on the season and environment.

A very few minor pathological problems

Sorghum downy mildew	*(Peronosclerospora sorghi)*
Ergot	*(Sphacelia sorghi)*
Leaf blight	*(Exserolidum turcicum)*
Sooty stripe	(Ramulispora sorghi)
Anthracnose	(Colletotrichum graminicola)

have been found on millets and at the moment no pathology research is conducted on this crop.

Economics

So far our economic research has been confined to socio-economic studies connected to our on-farm research programs where the emphasis has been on understanding the farmers' circumstances and evaluating and monitoring the impact of various production packages.

It is felt that in future areas, such as pricing policies, trade and grain marketing will receive greater emphasis as we have earlier noted that the pricing structures currently in place tend to discourage the flow of grain into the local high volume markets such as the brewing and milling industries.

Others

The other area, which is not strictly research, but where we have to make an input, is in the seed industry sector.

In the absence of a developed private seed industry, we are charged with the task of making improved seed available to farmers. We also note that our breeding efforts will be fruitless if we do not follow through to the end product, i.e. the commercial variety or hybrid. We shall therefore be placing priority on ensuring that we play a more active role in multiplication of seed of those varieties/hybrids that have proved promising in our evaluation trials.

Non-INTSORMIL Funded Sorghum and Millet research

As pointed above, sorghum and millet research occupies a higher proportion of our whole research agenda in all disciplines. INTSORMIL input is but a small fraction of the funding that goes to these crops. Apart from government funding through its recurrent and development budgets, other bilateral donors including USAID, GTZ, SIDA, NORAD, USAID/CIDA/GTZ and through the SADCC/ICRISAT Sorghum and Millet Improvement Project provide significant financial and technical support that support sorghum and millet research. It is not easy to give a financial figure to this donor funding as part of it is not specific to these crop but comes in as general support to research.

Research and Training Needs for the Future

To date, we have collaborative research activities with INTSORMIL in the soil and water management areas for millets with emphasis on the development of early maturing composites adapted to heat and moisture stresses.

The second area of collaboration has been through joint research activities with INTSORMIL PIs and technical backstopping in the areas of Plant Pathology, Entomology and Plant Breeding. This type of collaboration has been associated with training of the country's PIs and we have found this very useful in developing the latters' research programs at home.

Regarding formal training, the SADCC Region has a graduate training program with INTSORMIL. A number of graduates from Botswana have or are still benefiting from this training. This has been very useful in training the required manpower to man the national sorghum and millet programs. To date 8 students are currently in the USA benefiting from this training and at least 3 others have already completed their training.

As for the future, we hope the existing types of collaboration will continue and perhaps research disciplines be expanded to other areas such as pricing and policy analysis so that expertise and capability can be developed within the region.

Current Status of Sorghum Production in Colombia

Manuel Torregroza Castro[1]

Introduction

Among the annual crops currently grown in Colombia, sorghum has had the fastest growth rate and expansion in area cultivated in the last three decades. Statistics indicate that area planted went from 2,800 ha in 1960 to 254,624 ha in 1990, for a total growth of about 9 thousand percent. Production figures were still more spectacular, going from 6,300 t of grain harvested in 1960 to over 760 thousand in 1990; these figures represent an increase of more than 12 thousand percent.

This grass, along with maize, rice, wheat, and barley, among other plant species, is a valuable source of energy and protein. This is one of the reasons why sorghum grain is used in Colombia as a basic raw material in the animal feed industry, particularly in aviculture. Thus the explanation for sorghum production having grown at the same rate of egg and fowl production. In 1970, 18,200,000 heads of fattening fowl and 1,357 million eggs were produced; while in 1990 these figures were 172 million and 5,100 million, respectively. The purpose of this document is to report the current status of this cereal in Colombia and its future perspectives.

Route of Dispersion of Sorghum from its Geographical Center of Origin to the New World

Sorghum, originating in the northeast of Africa, was introduced in America during the period of African negro slave trade to the New World around the end of the XVI Century and beginning of the XVII Century (Torregroza, 1991). In accepting the hypothesis that "the obliged african black immigrants" introduced milo seed to american agriculture, one infers that the route followed by the slave boats to arrive at previously established ports for trading their "human merchandise" is the same followed by sorghum in the past. This is the theory found in many publications on this subject (Patiño, 1969; Mellafe, 1973; and Del Castillo, 1982); the first dedicated to cultivated plants and domestic animals in Equinoctial America—primarily in Volume IV dedicated to plants introduced—and the last two related with the "history of slavery in Latin America" and "black slaves in Cartagena".

Milo seed was carried by the slaves in motets brought from their homeland in the depths of the African territory and thus it arrived to the localities where the tradesmen concentrated the slaves before being shipped to America. According to Del Castillo (1982), most slaves were shipped from the Cape Verde Islands to Lisbon and Seville in Spain and from here to the Canary Islands, before arriving at their final destination. Benzoni, cited by Patiño (1969) indicates that even before the slave trade became a regular activity, milo was already being planted in these islands, from where it could have been introduced to the American continent. Patiño (1969) states that milo was already known in the Spanish Island since 1650 and had been planted in Puerto Rico as late as 1647, while Sloan found it planted in Jamaica in 1689. Thus Patiño (1969) states that milo was a broadly known crop in the lower West Indies during the XVII Century.

It is possible that seed of this cereal arrived in Colombia via Cartagena in the beginning of the XVI Century (Torregroza, 1991), and was later grown not only in the Atlantic Coast but also in the interior of the country. Rosa, cited by Patiño (1969) records cultivation of this crop close to Santa Marta and in the Sierra Nevada; and Gili (also cited by Patiño) reports the crop in Orinoco.

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According to Quinby (1974), Milo Maize and Giant milo or Guinea kafir were the first two tropical varieties planted in the Western Hemisphere, the latter native genotype being the most used in the continent. Seed of Guinea kafir was introduced in South Carolina in 1880 from Barranquilla, Colombia (Quinby, 1974). In the agricultural regions of the states of Atlántico, Bolivar, Magdalena, and Santander seed of possibly Giant milo is still being cultivated; the plant is used as green forage for animal feed while the grain, of a popping type, is used to prepare a candy called "alegría" (Torregroza, 1989).

Paul (1990) has indicated that Guinea Corn and Chicken Corn, along with the Durra race from the tropics of North Africa and the Kafir types from South Africa, were introduced in the United States through the slave trade in the XVII and XVII Centuries. The sweet sorghum variety, Chinese Ambarino, arrived from China in 1853 and from South Africa in 1857 and was used to prepare syrup and as a forage grass. Other types introduced in the United States included the Durras, brown and white, from Egypt in 1884, the Kafir types from South Africa in 1886, milo from Northeast Africa in 1880, Shalú from India in 1880, and Ferita and Hegari from Sudan in 1908. As pointed out by Paul (1990), "even though sorghum arrived in Latin America through the slave trade route of Europe-Africa-Latin America in the XVI Century, the crop only became important during this century".

Importance of Grain Sorghum Production

Among the five socio-economically most important cereals in Colombia, during the decade of the 80's, sorghum occupied the third place in area planted and volume of grain harvested, being surpassed only by rice and maize. Out of 1,352,100 ha used, 18% (245,700 ha) was planted to sorghum. As indicated in Table 1, this cereal contributed also with 18% (611,200 t) of the total 3,406,400 t of grain produced. On average, sorghum produced yields of 2.49 t/ha, being excelled only by rice (4.43 t/ha).

The tremendous growth of the animal industry (particularly aviculture) in Colombia obliged manufacturers of feedstuffs to search for alternative sources of energy and protein which were cheaper than those used in the past. Among the plant species investigated, sorghum grain was found to be the best alternative as a raw material for the massive production of concentrates required by this agroindustry for its expansion.

Table 2 shows data for production of fattening fowl and eggs for the period 1970-1990. The increase in production of fattening fowl during this period was as much as 945%, growing from 18,200,000 head produced in 1970 to 171,900,000 in 1990 (this figure being even greater for 1988). In 1990, a total of 5,100,000 eggs were produced, an increase of 376% over the 1,357,000 figure for 1970.

The accelerated growth in Colombian aviculture accompanied the increasing importance of sorghum production. In 1970, an area of 54,000 ha were planted to this cereal in the country, for a total production of 118,000 t of grain. These figures increased in 1980 to 206,200 and 762,672, respectively. According to data from FENALCE, sorghum production

Table 1. Extension, production, and productivity of the five most widely grown cereals in Colombia. Average data for the period 1980-1989.

	Area Planted (ha)		Production (t)		
Cereals	(000)	%	(000)	%	Yields (t/ha)
Rice	379.9	29	1,761.3	52	4.43
Barley	38.4	3	68.9	2	1.80
Maize	629.1	47	898.0	26	1.43
Sorghum	245.7	18	611.2	18	2.49
Wheat	41.0	3	67.0	2	1.64
Total	1,352.1	100	3,406.4	100	2.52

Sources: FEDEARROZ, FENALCE

Table 2. Production of fattening fowl and eggs in Colombia. Data for the period 1970-1990.

	Chicken		Eggs	
Years	(000)	%	(000,000)	%
1970	18,200	100	1,357	100
1972	25,661	141	2,207	163
1974	37,396	205	2,798	206
1976	47,058	259	2,977	219
1978	64,774	356	3,659	270
1980	74,721	411	3,713	274
1982	78,119	429	3,600	265
1984	85,100	468	3,661	270
1986	94,100	417	3,964	292
1988	190,000	1044	4,200	310
1990	171,900	945	5,100	376

Sources: OPSA, Ministry of Agriculture, FENAVI

in 1990 increased by 8.1% over the previous year.

As can be observed in Table 3, the greatest growth in area planted to the five most used cereals in the country during the last two decades corresponds to sorghum. Of the average increase of 191,000 ha, this species contributed with 61%, followed by rice with 44% and maize with 10%. On the other hand, area planted to barley and wheat decreased. In terms of production, of the additional 869,000 t harvested in the periods compared, rice participated with 55%, followed by sorghum (35%) and maize and wheat, in that order. Barley production decreased by 3%. These data indicate the current importance of sorghum production in the national agricultural economy.

Having established the excellent adaptation of this species, it is used in rotation with crops such as cotton, rice, soybeans, and maize; in other agricultural regions sorghum has replaced these other crops, where ecological conditions make them unsure and economically not as attractive as sorghum.

Evolution of the Crop

Table 4 presents statistics on area and production which reflect the way sorghum cultivation has evolved in Colombia. Grain sorghum was first evaluated in 1957, and five years later, according to Kornerup (1968), 3,300 ha were planted to this crop and production had reached 7,600 t of grain, with average yields of 2.3 t/ha. Ten years later, in 1971, 92,000 ha were being cultivated and production grew to 240,000 t of grain. In 1973, more than 135,000 ha were being planted and in 1978 these surpassed the 200,000 ha barrier. To date (1960-1990), 1983 has been the record year, with 280,100 ha planted to sorghum in Colombia.

Production figures show that more than 100,000 t were being harvested in 1968; this figure increased to 200,000 t in 1971 and by 1974 production had reached more than 300,000 t. Over half a million tons were harvested in 1978 and in 1987 production was greater than 700,000 t. The largest harvest was obtained in 1990: 762,672 t.

The spectacular figures achieved in area planted and in production have not been

Table 3. Increase in area and production of the five most important cereals in Colombia. Year 1971-1976 versus 1980-1989.

	Area Planted (000 ha)				Production (000 t)			
Cereals	A	B	C	%	A	B	C	%
Sorghum	129	246	117	61	305	611	306	35
Rice	314	398	84	44	1286	1761	475	55
Barley	63	38	-25	-13	96	69	-27	-3
Maize	610	629	19	10	794	898	104	12
Wheat	45	41	- 4	-2	56	67	11	1
Total	1161	1352	191	100	2537	3406	869	100

Sources: OPSA, Ministry of Agriculture, FENAVI

Table 4. Evolution of sorghum production in Colombia for the period 1960-1990.

Years	Area planted (000 ha)	Production (000 t)	Yield (kg/ha)
1960	2.8	6.3	2250
1962	3.3	7.6	2303
1964	24.0	60.0	2500
1966	30.0	60.0	2000
1968	40.3	110.0	2730
1970	53.6	118.0	2202
1972	84.0	210.0	2500
1974	151.2	336.6	2226
1976	173.6	427.7	2464
1978	224.8	516.7	2299
1980	206.2	430.5	2090
1981	231.3	532.0	2300
1982	299.7	610.5	2037
1983	280.1	619.6	2212
1984	230.9	578.9	2507
1985	229.5	574.4	2503
1986	218.1	596.9	2737
1987	207.3	713.1	2638
1988	262.9	750.9	2856
1989	228.0	705.0	3092
1990	254.6	762.7	2996

Sources: OPSA, Ministry of Agriculture, FENALCE

achieved in terms of yields. During the 60's, maximum productivity was obtained in 1968, with 2,730 kg/ha. During the period 1970-1979, the outstanding year was 1971 with only 2,602 kg/ha; during the period 1980-1989 the highest average yields were obtained: 3,092 and 2,037 kg/ha in 1989 and in 1982, respectively. Productivity data also indicate that finalizing the decade of the 80's (1983-1989) there has been a tendency to improve productivity, even though a decline has been evident during 1990. Considering only data for the 80's, a total of 246,000 ha were planted to sorghum and 611,000 t of grain were harvested, for an average yield of 2,484 kg/ha.

Sorghum-Growing Regions

In Colombia, grain sorghum is planted in 23 administrative sections (states) (Table 5). These data indicate that the state where most area is planted is Tolima (59,238 ha), followed by Valle del Cauca (44,494), Cesar (35,258), Córdoba (29,400), Huila (17,338) and Meta (13,619). The states where the least amount of sorghum has been planted to date are Casanare (771), Arauca (610), Risaralda (547), Boyacá (375), and Caquetá (298).

Table 5. Sorghum area, production, and yields by states in Colombia. Average data for the period 1984-1990.

States	Area planted (ha)	Production (t)	Yield (kg/ha)
Antioquia	1,559	4,201	2,695
Atlántico	5,581	11,463	2,053
Arauca	610	995	1,631
Bolívar	9,352	2,067	2,146
Boyacá	375	924	2,464
Caldas	914	2,471	2,076
Caquetá	298	644	2,161
Casanare	771	1,581	2,051
Cauca	2,631	7,178	2,728
Cesar	35,258	75,159	2,132
Córdoba	29,400	96,939	3,297
Cundinamarca	5,849	13,097	2,239
Guajira	3,235	5,443	1,682
Huila	17,338	45,772	2,637
Magdalena	7,813	18,000	2,304
Meta	13,619	31,606	2,321
Norte de Santander	1,604	5,181	3,230
Quindío	926	2,506	2,706
Risaralda	547	1,997	3,651
Santander	4,404	8,923	2,026
Sucre	6,294	14,404	2,289
Tolima	59,238	164,606	2,779
Valle del Cauca	44,494	183,391	4,122
Totals	252,100	716,498	2,842

Grouping these sorghum-producing areas into major and minor regions, the following groups can be identified:

Regions	Area planted (ha)	Percentage
A. Major Regions		
1. Caribbean	101,337	40.2
2. Central (Alto Magdalena)	84,359	33.6
3. Geographical Valley of Cauca River	49,512	19.6
4. Llanos Orientales	15,000	5.9
B. Minor Regions		
5. Zulia (N. Santander)	1,604	0.6
6. Caquetá	298	0.1
Total	252,100	100.0

These previous data were based on those shown in Table 5. The states were divided as follows:

Caribe: Atlántico, Bolívar, Cesar, Córdoba, Guajira, Magdalena, Sucre, and Santander.

Central: Antioquia, Boyacá, Cundinamarca, Huila, and Tolima.

Geographical valley of the Cauca River: Caldas, Cauca, Quindío, Risaralda, and Valle del Cauca.

Llanos Orientales: Arauca, Casanare, and Meta.

Zulia: Zulia (N. Santander).

Caquetá: Caquetá.

These figures indicate that more than 70% of the area planted to sorghum in the country is located in the Caribbean and Alto Magdalena regions.

In terms of production, Table 5 indicated that most grain was harvested in the Valle del Cauca (183,391 ha), followed by Tolima (164,606), Córdoba (96,939), Cesar (75,159), Huila (45,722), Meta (31,606), and Bolívar (20,067). In these seven states, 617,490 t were harvested, which is equivalent to 86% of the total in Table 5. Distribution of the data by states follows:

Department	Tons	%
Valle del Cauca	183,391	25.6
Tolima	164,606	23.0
Córdoba	96,939	13.5
Cesar	75,159	10.5
Huila	45,722	6.4
Meta	31,606	4.4
Bolívar	20,067	2.8
Subtotal	617,490	86.2
Remaining	99,008	13.8
TOTAL	716,498	100.0

Production and productivity by sorghum-producing regions was classified as follows:

Regions	Tons	%	Yield (kg/ha)
A. Major Regions			
1. Caribbean	250,398	34.9	2,471
2. Central	228,550	31.9	2,709
3. Geographical valley of the Cauca River	197,543	27.6	3,990
4. Llanos Orientales	34,182	4.8	2,279
B. Minor Regions			
5. Zulia	5,181	0.7	3,230
6. Caquetá	644	0.1	2,161
TOTAL	716,498	100.0	2,807

These data show that the greatest average production during the period 1984-1990 was harvested in the Caribbean region of Colombia, representing 35% of total national production. However, these figures are not a consequence of greater productivity, but of more area planted. Of the three sorghum producing regions (Caribbean, Central, and geographical valley of the Cauca River) which on average have been planting 40,000 ha per year, the Caribbean has been, to date, the region with the highest yields (2,471 kg/ha). The Central region produced 2,709 kg/ha and the geographical valley of the Cauca River 3,990 kg/ha. The release of improved genotypes, adapted to the adverse conditions of the Caribbean tropic; the construction of infrastructure for a more efficient use of irrigation, drainage, drying and storage; the use of modern equipment for basic agronomic management practices; the timely and efficient application of inputs recommended by technical assistants; and a low production cost policy per ton of harvested grain are some of the factors to be considered if the Caribbean region is to reach an average productivity of at least 3 t/ha.

National Consumption

The imperious need to use a raw material with specific energetic and protein content characteristics to produce animal feed at a relatively low cost and with a high nutritive quality resulted in the accelerated development of grain sorghum cultivation.

The feed agroindustry consumes practically all sorghum produced in the country. When demand for this raw material has been greater than national production, the Government has had to import. Table 6 shows the use that this cereal has had in the animal industry, as well as the historical tendency of grain sorghum imports in theTable 6country, which were initiated in 1972. Since then, and up to 1990, the only years without the need to import sorghum were 1973, 1975, 1986, and 1989. The volume of imports has had large fluctuations: from 200 tons in 1974 to 205,700 in 1980. The largest volumes of imports were recorded in 1977, 1980, 1982, and 1985. Compared to national production these years, imports were equivalent to 31, 48, 22, and 24%, respectively.

National consumption has been growing at the pace that the agroindustry has been increasing its participation in the national economy. This increase is reflected in the last column of Table 6. Assigning an index of 100 to 1972, the index for 1977 would be 231 and

Table 6. Tendency of the Colombian animal industry to consume grain sorghum. Data for the period 1972-1990.

Years	National production (000 t)	Imports (000 t)	Total (000 t)	Index
1972	210.0	21.0	231.0	100
1974	336.6	0.2	336.8	146
1977	406.2	126.8·	553.0	231
1978	516.7	50.6	567.3	246
1979	501.3	4.7	506.0	219
1980	430.5	205.7	636.2	275
1981	532.0	55.0	587.0	254
1982	610.5	132.9	743.4	322
1983	619.6	97.8	717.4	311
1984	578.9	44.4	623.3	270
1985	574.4	135.6	710.0	307
1987	713.1	21.2	734.3	319
1988	750.9	43.3	794.2	344
1990	762.7	30.0	792.7	343

Sources: OPSA, Ministry of Agriculture, FENALCE

322 for 1982. Except for 1984, the index for the remaining years of the 80's would be 300, with 1988 and 1990 showing the highest indexes (344 and 343, respectively).

Rural Development and Social Equity

Sorghum cultivation is basically in the hands of the capitalist sector. This means that a high percentage of the agronomic practices are mechanically executed. However, this crop has also been involved in the development of rural areas which had been isolated in the past from technological advances. In regions such as La Mojana, Cereté, Espinal, Codazzi, Manatí, Juan de Acosta, Arenal, Magangué, Plato, Sabanas de Torres, Valle de San Juan, Tierralta, y Valencia, among other, sorghum cultivation has represented an important source of income for thousands of small farmers who relied for their income on cotton, rice, or maize production, or had nothing to plant. Sorghum represents an excellent agroeconomic alternative when grown in well-planned crop rotation systems. Due to the way this cereal is managed in agronomic terms, production also involves qualified labor. According to FENALCE, a hectare of sorghum requires 10-12 labor days. If an average of 250,000 ha are being planted annually in Colombia, approximately 25-30 thousand labor days are required per year to handle efficiently the agronomic practices needed by this crop.

Production of this species has expanded and broadened the interest and knowledge of sophisticated agricultural equipment, such as combines, seeding machines, and chisel plows which began to be used in regions where harvesting with machines is required because the lots are very large. The same phenomenon is true for the use of planes to apply chemical products and for the use of irrigation equipment. These innovations have opened the door to a greater development of the rural communities where it was difficult before to introduce technological changes which would improve their living status.

With the strengthening of FENALCE, the association of cereal growers in this country, sorghum producers have an agency that gives them support and orientation, and dictates and executes policies for the development and transfer of the most advanced technologies related to this crop. Thus, a sustained and balanced agricultural development and social welfare are projected, with the intention also of seeking for peaceful equity and social justice for the Colombian people.

Production Cost Structure

Real production costs, according to FENALCE's statistics, varies by regions. Table 7 shows these costs for five localities. Costs fluctuated between $227,882 (northern Cesar) and $406,722 (Córdoba). Based on expected yields, it is more expensive to produce a ton of grain sorghum in the south of Cesar ($131,614) than in Córdoba ($94,587). These figures reflect the differences in productive efficiency of these two agricultural subregions in the Caribbean.

Data in Table 7 also show a common denominator among the 17 factors that make up production costs: the great variation in costs. In analyzing the four most used inputs in sorghum production, it is evident that the cost per hectare of seed planted varied in the five subregions sampled: from $21,000 in Córdoba to $34,200 in the north of Cesar. In relation to total production costs per hectare, these figures were equivalent to 5.2 and 15.0 %, respectively. For the south of Cesar, Huila, and Tolima, percentages were 6.6, 7.7, and 7.8, in this order. Fertilizers also show a great variation: 7.3, 8.5 and 12.8% of production costs

Table 7. Production costs ($) per hectare of sorghum in various regions of the country. Data for 1991A.

Items	Córdoba	Cesar South	Cesar North	Huila	Tolima
Rent	40,000	35,000	35,000	50,000	70,000
Plowing	15,000	15,000	10,000	16,000	10,000
Raking	30,000	24,000	12,000	16,000	20,000
Planting	10,000	7,000	9,000	8,000	4,500
Application of inputs	20,999	23,800	17,500	18,600	23,300
Harvesting	45,500	28,800	15,000	21,600	21,000
Transportation	24,750	19,750	4,500	10,900	3,000
Vigilance, Birdcatching	6,000	2,000	7,428	—	—
Interests on credits	57,640	35,200	22,500	32,255	51,693
Admininistration and Unforeseen	32,933	29,912	10,610	22,662	26,552
Subtotal	282,822	220,462	143,538	196,017	235,045
Inputs					
Seed	21,000	21,750	34,200	25,020	29,000
Fertilizers	30,000	28,100	14,700	47,300	47,850
Herbicides	9,600	7,712	8,507	8,450	8,933
Insecticides	16,800	21,512	10,237	17,850	31,732
Packaging	28,000	19,800	5,700	13,440	—
Technical assistance	8,000	6,000	6,000	6,500	7,000
Other expenses	10,500	3,700	5,000	11,000	13,000
Subtotal	123,900	108,574	84,344	129,560	137,515
Total	406,722	329,036	227,882	325,577	372,560
Yield	4.3	2.5	2.2	3.0	3.5
Cost/ton	94,587	131,614	103,583	108,526	106,446

Source: FENALCE (Economics Department)

in Córdoba, south of Cesar, and Tolima, respectively. In the five subregions mentioned, the cost of herbicides and insecticides did not vary as much as seeds and fertilizers. The costs for insecticides showed a slightly greater variation than those of herbicides.

In the interaction between subregions for the use of the four inputs, Córdoba stands out for the relative and moderately low cost of applied inputs in terms of percentage, compared with the total cost of production per hectare. The opposite is true for Huila and Tolima. Cesar, except for seeds in the northern areas, had an intermediate position.

The following figures show, in percentages, the costs of inputs applied to the crop, in relation to the total cost of production in the five subregions being discussed. (This chapter did not include information on the Valle del Cauca because data were not available when writing this report.)

Department	Seed	Fertilizer	Herbicides	Insecticides
Córdoba	5.2	7.2	2.4	4.1
Cesar (south)	6.6	8.5	2.3	6.5
Cesar (north)	15.0	6.5	3.7	4.5
Huila	7.7	14.5	2.6	5.5
Tolima	7.8	12.8	2.4	8.5

Technological Constraints of the Crop

Diseases, particularly foliar diseases and head diseases, are a threat to sorghum producers since their incidence has been increasing as production of this cereal has expanded throughout the country. This constraint is much more serious in the humid Caribbean and in the Llanos Orientales than in the Alto Magdalena, Valle del Cauca, and dry Caribbean. The following are the most common among these diseases.

- Anthracnose *Colletotricum graminicola*
- Ring spot *Gloeocercospora sorghi*
- White spot *Helminthosporium sorghicola*
- Grey spot *Cercospora sorghi*
- Purple stain *Helminthosporium turcicum*
- Rust *Puccinia purpurea*

Most of these pathogens produce symptoms similar to those of abiotic nature, originating increases in the regular or concentric stains with bold colors. These effects become more severe due to the presence of the fungi. As a result of these pathological problems, farmers have had to apply fungicides for their control.

Saprophyte fungi attack the heads, especially *Fusarium* sp., *Curvularia* sp., *Penicillium* sp., and *Nigrospora* sp. which are common in zones with a high relative humidity, as is the case in the humid Caribbean and the Llanos Orientales. In the Central zone (Alto Magdalena), carbon rot (*Macrophomina phaseoli*) is this crop's most damaging disease. This fungi appears sporadically and is favored by specific climatic and edaphic conditions. It is most common in sandy soils under conditions of prolonged drought and high temperatures.

To date, powdery mildew, caused by the fungi *Peronosclerospora sorghi*, had not been recorded in Colombia. The main foci of this pathological disease have been recently found in the Caribbean region, four in the dry Caribbean and one in the humid Caribbean (Tierralta).

The most common entomological problems damaging the crop in Colombia are the ovary fly (*Contarinia sorghicola*), the head moth (*Celama sorghicola*), the beetle (*Euetheola bidentata*), the crazy ant (*Solenopsis* sp.), and the shoot eater (*Spodoptera* sp.).

Given the conditions of the Caribbean region, particularly the dry Caribbean, currently there is no tolerant or resistant germplasm available for the prolonged droughts prevalent in this sorghum-growing region.

In order to use more efficiently the soil resource in the Caribbean region, especially in areas where cotton is grown, farmers need improved genotypes that are early flowering and have high yields, and which can produce an abundant harvest in the first semester of the year. Thus the cotton grower will be able to keep his land productive during the whole year, growing sorghum during the first and cotton during the second semester.

In the Llanos Orientales, the crop's problems are not only those having to do with foliar and head diseases, but also those related to the excessive levels of aluminum in the savanna soils. The expansion of the sorghum frontier in this region of the country will depend on the acceptance by farmers of the two improved varieties recently released by ICA: Sorghica Real 40 and Sorghica Real 60, and of the possibility of producing commercial, high-yielding hybrids tolerant or resistant to savanna soil conditions.

The high costs of production in the four major sorghum-growing zones makes it essential to use improved genotypes with a high-yielding potential. Except for the Valle del Cauca and Córdoba, most hybrids recommended in the country have not met expectatives. Thus the need to continue research with commercial germplasm of foreign origin and to study the adaptation of genetic resources in order to obtain the improved genotypes adapted to the different sorghum regions in the country.

The pool of combines is not only insufficient, but also obsolete, causing delays in harvesting and the consequent losses due to collecting the grain when it is too dry. These inefficient and obsolete machines cause lodging of many of the plants and it is common to observe as much as 40% of the expected harvest left in the field. A similar phenomenon happens with the seed sowers, whose use increases production costs, since more than the recommended amount of seed is used per hectare, or the farmers have to practice broadcast planting.

With the exception of the correct use of seed, many farmers in this country do not follow the agronomic recommendations made by professional technical assistants, particularly in what relates to fertilizer application and control of weeds, pests, and diseases. Many farmers only put in practice part of the system recommended. All these factors affect yields. This is more evident in the Caribbean and the Llanos Orientales regions than in the Alto Magdalena and the geographical valley of the Cauca River. Thus the need for an appropriate technology transfer policy and for promoting the crop, especially at the regional level, such as is being done by FENALCE with ICA's collaboration. Also supporting this endeavor are some sorghum seed companies and some companies that distribute agricultural inputs.

Research

One of the basic objectives of agricultural research is that of eliminating or reducing the technological constraints affecting the sustained development of crops that are economically important in the country. This is even more valuable with crops such as sorghum that did not count with a "scientific ancestry" in our history of technology generation. Of foreign origin, sorghum only started to have agroeconomic importance at the end of the decade of the 50's and beginning of the 60's.

Once the adaptation of foreign hybrids had been defined, various multinational companies, such as Asgrow, Dekalb, Northrup King, and Pioneer started to evaluate their materials and to recommend them for planting in the different sorghum-growing regions of the country. At the same time that this adaptive research process was going on, national private enterprises —PROACOL S.A., Prosemillas, and Semillas del Tolima— as well as ICA started research projects in plant gene techniques to "create" the improved genotypes which together with the foreign hybrids, have placed sorghum in the position it now holds in the agricultural economy of Colombia. The first fruit of these efforts was the release of various improved varieties: ICA-Marupaanste, ICA-Pal, and ICA-Nataima released by ICA; VP-25 by Proacol S.A.; and Prosemillas-1 by Prosemillas; also the hybrids Tropical 4 and Tropical 9, released by Prosemillas; and Tolima 1 and Tolima 2, released by Semillas del Tolima Ltda.

Due to the spurt of this crop, in addition to ICA, there are currently 13 private enterprises generating or validating technology related to sorghum production. Eight of these enterprises are of national origin, the remaining are multinational. Table 8 shows the names of these enterprises whose research centers are located in the sorghum regions of the geographical valley of the Cauca River and the Central Zone (Alto Magdalena). It is in these same regions that they have their hybrid seed multiplication fields. Recently, two multinational enterprises have been trying to produce this type of seed in the dry areas of the Caribbean.

Among the companies shown in Table 8, some use their resources to apply technology leading to the production of hybrids adapted to the country's ecological conditions. Others conduct studies on adaptation of foreign hybrids, and a few others to the formation and evaluation of improved varieties and hybrids. The multinational or national enterprises in charge of multiplying and distributing hybrids of foreign origin are authorized by the Colombian government to import directly seed of hybrids or parental lines for national production of this seed; this activity is done in farmers' fields or in fields owned by the mentioned enterprises (Torregroza, 1991).

Table 8. Private sector enterprises dedicated to the generation of sorghum production technology in Colombia.

A. National enterprises	
1.	Agrogenética Colombiana
2.	Federación Nacional de Arroceros (Guild Enterprise)
3.	Proacol S.A.
4.	Procampo Villazca
5.	Biotecna Ltda.
6.	Semillas del Tolima
7.	Semillano
8.	Semivalle
B. Multinational Enterprises	
9.	AG-Seed de Colombia
10.	Cargill Cafetera de Manizales
11.	Ciba-Geigy Colombiana
12.	Semillas Pioneer de Colombia
13.	Semillas Tropicales

In order to recommend planting in the country of commercial seed of any variety or hybrid, be it of national or foreign origin, official approval by ICA is indispensable. Resolution No. 602, issued on 2 April 1984, establishes the standards to be met by the interested producer in order achieve the concept of agronomic efficiency of the genotypes subjected to field evaluation. If the germplasm resources are of foreign origin, ICA's Division of Plant Health is responsible for authorizing or denying the right to import seed to be evaluated in Colombia. Once these legal requisites have been complied with, the approved improved varieties or hybrids can be freely planted in the country. The final step in this agronomic process is seed multiplication and certification of the seed that the farmer is to select for his plantings. ICA's Seed Division, among other functions, has the responsibility of orienting the development of activities related with seed certification, analysis, and production, as well as coordinating the elaboration, revision, and up-dating of basic legislation related to this valuable crop (Torregroza, 1991).

From 1957 to 1990, improved genotypes of 15 national and multinational private enterprises were planted, in addition to those produced by ICA. Among the companies in Table 9, Proacol S.A., Procampo Villazca, Prosemillas, and Semillas del Tolima have registered improved varieties and hybrids of research conducted directly in Colombia (Torregroza, 1991). Of the 72 diverse improved genotypes (Table 10), 65 correspond to the private enterprise and 7 to ICA. All varieties of the private sector, as well as 12 of the 60 hybrids, are the result of breeding projects conducted in our country.

Table 9. Private enterprises producing improved sorghum genotypes whose seed has been planted in Colombia (1957-1990).

Enterprise	Number of genotypes
1. AG-Seed de Colombia	4
2. Asgrow	5
3. Cargill Cafetera de Manizales	5
4. Dekalb-Pfizer Genetics	5
5. Funk's - Ciba Geigy	3
6. Garrison Seed	1
7. Northrup King	10
8. Penta Genetics	3
9. Semillas Pioneer de Colombia	10
10. Proacol S.A.	3
11. Procampo Villazca	2
12. Prosemillas	7
13. Semillas del Tolima	5
14. Warner Seed	1
15. Young Seed	1
Total	65

Table 10. Total number of improved sorghum genotypes planted in Colombia between 1957 and 1990.

Genotypes	ICA	Private enterprise		Total
Varieties	6	5		11
Hybrids			61	
Origin				
Foreign		48		48
National	1	12		13
Total	7	65		72

ICA initiated in 1965 official sector technology generation and transfer activities related with sorghum production. A total of 840 accessions from the world collection and coming from the University of Purdue were then planted at the Nataima Research Center (Espinal, Tolima), located in the Central (Alto Magdalena) sorghum region. From the first observations of this experimental material, the 12 best accessions were selected; this germplasm resource gave origin to the improved varieties ICA-Marupaanste (Marupaanste), ICA-Pal (Sb-62) and ICA-Nataima (Mn-736). The nine remaining selections were: Bonita, E-75, E-124, E-173, Redlan, Sb-65, Serena, Wad-Bedshire, and Wheatland. The success at the Nataima Research Center encouraged sorghum research activities at other research centers: ICA-Palmira, ICA-Turipaná, ICA-Motilonia, ICA-Santa Lucía (now closed), and ICA-La Libertad. Instead of establishing a separate program, ICA created the Maize and Sorghum Program.

ICA's current administrative structure—established by Agreement No. 26 of 11 September 1989, coming from its Board of Directors and ratified by Decree No. 2326 of 13 October 1989 of the Ministry of Agriculture—defines that the operational units, created to conduct research both in crop and animal species, were to be multidisciplinary teams. In the case of sorghum, the group is integrated by scientists in the areas of entomology, breeding, plant physiology, plant pathology, and soils; this team is supported by a group of professionals in the areas of Agricultural Engineering and Agricultural Economics. This change in the philosophical focus and the new project planning and execution methodology are the basis for solving in an integrated team work the numerous agrotechnological constraints that this crop presents in the different sorghum-growing regions of the country.

For a more appropriate and convenient coordination, this group is located in the denominated Pilot Center at the Nataima Research Center. Other professionals that complement the activities of the multidisciplinary team are located in the Satellite Centers of the Motilonia, Turipaná, and La Libertad Research Centers. Following is the list of scientists in the sorghum team.

The different projects carried out in sorghum production have the following general objectives:

1. Produce different improved sorghum genotypes (varieties and hybrids) with a high physiological efficiency and other important

Research Center/Area of specialization	Degree of Specialization
Nataima	
Plant geneticist	Ph.D.
Entomologist	Ph.D.
Physiologist	Ph.D.
Plant pathologist	M.Sc.
Soil specialist	M.Sc.
Agricultural economist	M.Sc.
Agricultural engineer	M.Sc.
Production specialist (FENALCE)	B.Sc.
Team Leader	B.Sc.
Motilonia	
Plant geneticist	B.Sc.
Turipaná - (responsibilities shared with Maize Team)	
La Libertad	
Plant geneticist	M.Sc.
Production specialist (FENALCE)	B.Sc.

agronomic characteristics, appropriate for the diverse exploitation systems or management practices, and adapted to the ecological conditions prevalent in the sorghum-growing regions of the country.

a. With the cooperation of INTSORMIL and FENALCE, research is being conducted to obtain genotypes tolerant or resistant to the acid soils of the Llanos Orientales with a high or moderate content of aluminum (savanna soils).

b. In collaboration with INTSORMIL and FENALCE a group of drought tolerant or resistant genotypes are being evaluated (DLT drought nursery) in the dry Caribbean (Motilonia Research Center).

c. In collaboration with INTSORMIL and FENALCE, germplasm tolerant or resistant to diseases and insects is being observed, evaluated, and selected (ADIN nursery) in the Nataima Research Center.

2. Develop appropriate agronomic technology for the improved genotypes registered, in order that farmers can exploit—in the most profitable way—the genetic potential "stored" in the seed of the new materials available to them from the multidisciplinary team.

3. A series of projects are also conducted, for managing the main diseases and pests affecting sorghum production in the country.

4. Various physiological studies are carried out to define the different development phases of commercial and promising genotypes, as well as densities and population arrangements to determine the maximum yield potential of these materials. Research is also being conducted on the phytotoxic effect of atrazines and other herbicides on the development and production of the sorghum plant.

5. Within the projects on agronomic management, research is conducted on fertilization with major and minor elements, particularly on the effect of nitrogen on the agronomic performance of the sorghum plant.

6. In coordination with professionals from the research units of the Regional Extension, Training and Technological Diffusion Centers (CRECED), to carry out projects for validating and adjusting the agronomic recommendations suggested by the multidisciplinary team for each of the genotypes expected to be registered and commercially released in the country.

7. In collaboration with the respective offices of the Vice-management of Agricultural Technology Transfer, to plan and execute plans for divulging, by the most appropriate communication media, the scientific results and practices recommended as a result of research conducted in the Pilot Center, in the Satellite Centers, in the CRECED, and in farmers' fields.

The coming Tables (11-15) show a series of data on results of some of the projects conducted in cooperation with INTSORMIL and FENALCE, as well as the list of improved genotypes registered to date.

Seed Volume of the Genotypes Planted

As shown before in Tables 9 and 10, during the period 1957-1990, a total of 72 improved sorghum genotypes had been planted in the country. These genotypes belong to 15 private sector enterprises and 1 to the public sector (ICA), all of them conducting research projects on genetic breeding of this crop.

Based on data from ICA's Seed Division, Table 16 indicates the amount of seed of improved sorghum varieties and hybrids which has been planted each year in Colombia during the period 1973-1990. Of the 105,111 t of seed used over this period, 46% (48,502 t) correspond to improved varieties and 54% (56,609 t) to hybrids. Considering only seed of improved varieties planted to date in Colombia (Table 17), 82% is of the variety ICA-Nataima, followed by Prosemillas (9%), and Icaima (4%).

The greatest seed volumes of hybrids (Table 18) come from HW-1758 (6,759 t), E-57 (6,210), P-8255 (5,411), D-61 (4,894), P-8416A (4,771), NK-266 (3,814), and Savanna-5 (2,753). Of the hybrids included in Table 18, E-57, P-8225, P-8416A, and P-8202 are no longer planted in the country. Considering both improved varieties and hybrids (Table 19), seed of ICA-Nataima represents 38% of the total seed planted during the last 18 years, followed by the hybrids HW-1758 and D-61. Of the ten genotypes included in Table 19, three are improved varieties (ICA-Nataima, Prosemillas, and Icaima) and the remaining seven are hybrids.

Table 11. Agronomic performance of two characters of Sorghica Real 40 and four more genotypes planted in acid soils with aluminum saturation levels between 20 and 40%. Average data for seven sites in the Department of Meta.

Genotypes	Plant height (cm)	Yield (kg/ha) Semester A	Semester B	Average
Sorghica Real 40	162	3283	2793	3038
IS-3522	194	3121	2589	2855
IS-7151	196	2152	2479	2815
PPQ-2	167	2984	2315	2649
Icaima	151	712	2174	1443

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

Table 12. Plant height and yield of Sorghica Real 60 in comparison with six other genotypes planted in acid soils with aluminum saturation levels between 40 and 60%. Average data for twelve sites in the Department of Meta.

Genotypes	Plant height (cm)	Yield (kg/ha) Semester A	Semester B	Average
Sorghica Real 60	182	3224	2994	3109
IS-3071	190	2839	2421	2630
IS-3522	183	2538	2143	2340
IS-8577	187	3312	2795	3053
IS-6944	189	2609	2283	2446
50 X 61/1/910	178	2428	2123	2275
Ica Nataima	96	534	894	714

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

Table 13. Lines selected from the disease and insect nursery (ADIN) from INTSORMIL. C.I. Nataima, 1989B-1990A.

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

Source: Annual Report, National Cereals Section.

The Agreements

The Colombian Agricultural Research Institute (ICA), as a driving force of agricultural development and promoter of advances in the permanent evolution of scientific knowledge of the sector, has as one of its basic objectives to generate and transfer technologies that contribute to increasing productivity and production sustainability, with the corresponding socioeconomic growth and adequate redistribution of income among the Colombian population.

This policy requires not only the dynamics of all sections of the Institute, but must also be carried out in coordination with other private and public agencies, both at the national and international level, that have objectives common to those of ICA. Thus, projects can be diagnosed, planned, coordinated, executed, validated, and adjusted with econony of resources and avoiding duplication of efforts. These projects should tend to solve the technological constraints affecting the development of the sector. In joining efforts, results are achieved sooner and methods are better defined; in addition, greater advances are produced in scientific and technological knowledge. Resources are used more efficiently and the problems to be solved are better covered.

According to the Planning Vice-management, ICA is currently involved in 102 technical cooperation agreements, 79 of these at the national level and 23 at the international level. In reference to sorghum, the national project is carried out with the National Federation of Cereal Growers (FENALCE) and an international agreement exists with INTSORMIL.

The objective of the agreement with FENALCE, signed on 5 September 1984, is

Table 14. Agronomic performance of the eleven most contrasting genotypes from the disease and insect nursery (ADIN), in relation to the attack of Diatraea sp. C.I. Nataima, 1990A.

Genotypes	Days to flowering	Plant height (cm)	Length of panicle (cm)	No. of eggs/ 30 plants	No. of larvae/ 30 plants	No. of pupae/ 30 plants
Tx 2767	60	132	5	137	14	2
BT x 623	62	165	10	129	8	2
80B-2892	53	125	10	111	-	-
87L-3452	70	100	5	103	2	2
MB102-3	68	210	15	71	7	5
Sureño L.P.	59	110	10	6	-	-
87EON-115	59	110	10	6	-	-
8662802	56	130	5	4	-	-
Tx7078	50	100	15	3	-	-
MR103-3LP	47	105	10	3	-	-
87LG-7060	51	140	7	2	-	-

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

Table 15. Origin, year of registration and color of grain of the best sorghum genotypes cultivated by ICA to date.

Genotypes	Center of Origin	Year of registration	Grain Color
1. Improved Varieties			
ICA-Marupaanste	Nataima	1968	Pink
ICA-Pal	Palmira	1968	Brown
ICA-Nataima	Nataima	1972	Brown
Icaima	Nataima	1988	Red
Sorghica Real 40	La Libertad	1991	Brown
Sorghica Real 60	La Libertad	1991	Brown
2. Hybrids			
Sorghica NH-301	Nataima	1981	Brown

Table 16. Annual use of seed of grain sorghum improved varieties and hybrids in Colombia during the period 1973-1990.

	Varieties		Hybrids		
Year	Tons	%	Tons	%	Total
1973	2809	64	1610	36	4419
1974	1454	48	1550	52	3004
1975	2605	63	1584	37	4153
1976	3160	76	1005	24	4165
1977	3629	64	2072	36	5701
1978	3243	59	2282	41	5525
1979	2832	53	2340	47	5172
1980	3728	57	2832	43	6560
1981	3393	62	2049	38	5442
1982	3995	58	2878	42	6873
1983	3557	58	2541	42	6098
1984	2167	37	3747	63	5914
1985	2061	31	4549	69	6840
1986	2183	30	5031	70	7214
1987	2020	25	6112	75	8132
1988	1459	21	5391	79	6850
1989	2046	31	4512	69	6568
1990	2131	32	4562	68	6693
Total	48502	46	56609	54	105111

Source: Adapted from data of ICA's Seed Division.

that of carrying out cooperation programs according to the needs of both agencies in the areas of agricultural research, technology transfer, and basic seed production of cereal crops such as sorghum, wheat, maize, barley,

Table 17. Amount of sorghum seed produced of the most planted improved varieties in Colombia.

Varieties	Tons	%	Originated by	Year of registration
ICA-Nataima	40258	82	ICA	1972
Prosemilla 1	4268	2	Prosemillas	1977
Icaima	1811	4	ICA	1988
VP-25	1009	2	Proacol	1968
DR-7684	940	2	Semitolima	1984
Remaining	216	1		
Total	48502	100		

and oats. Research includes projects leading to solve technological constraints in the areas of breeding, plant pathology, entomology, plant physiology, soils, production, crop management, agricultural engineering, basic seed, new uses for cereals, institutional building, analysis of information obtained, and divulging of results. The latter is done by organizing field days and meetings and seminars, and by publishing articles for journals, brochures, manuals, and audiovisual aids. For the collaborative projects, FENALCE has assigned three agronomists to the research centers where ICA works with sorghum: one each in Nataima, La Libertad, and Turipaná. The professionals in the last two centers dedicate part of their time to research in maize also. FENALCE provides financial resources for overall expenses, commissions and publications. As a result of this agreement, several improved varieties (Icaima, Sorghica Real 40, Sorghica Real 60) and the hybrid Sorghica NH301 have been released. In addition, various technical and technology transfer articles and brochures have been published; and short courses, seminars, conferences, and field days have been organized.

Table 18. Amount of seed produced of the 12 most planted sorghum hybrids in Colombia during the period 1973-1990.

Hybrids	Tons	%	Originated by	Distributed by	Year of Registration
HW-1578	6759	12	Funk's	Cresemillas	1983
E-57*	6210	11	Dekalb	Proacol	1978
P-8225*	5411	10	Pioneer	Semivalle	1979
D-61	4894	9	Dekalb	Proacol	1981
P-8416A*	4771	8	Pioneer	Semivalle	1982
NK-266	3814	7	Northrup K.	Colsemillas	1979
SAVANNA-5	2753	5	Northrup K.	Colsemillas	1981
P-8202*	2117	4	Pioneer	Semivalle	1976
TROPICAL 4	1928	3	Prosemillas	S. Tropicales	1975
P-8187	1819	3	Pioneer	Semivalle	1987
TROPICAL-9	1585	3	Prosemillas	S. Tropicales	1975
TROPICAL-15	1400	2	Prosemillas	S. Tropicales	1984
Remaining	13148	23			
Total	56609	100			

*Planting of these hybrids has been discontinued in the country.

Table 19. Amount of seed produced of the 10 most planted improved sorghum genotypes in the country during the period 1973-1990.

Genotypes	Tons	%
ICA-Nataima	40258	38
HW-1758	6759	6
D-61	4894	5
Prosemillas-1	4268	4
NK-266	3814	4
Savanna-5	2753	3
Tropical-4	1928	2
P-8187	1819	2
Icaima	1811	2
Tropical-9	1585	1
Remaining	35222	33
Total	105111	100

The agreement with INTSORMIL was signed on 23 March 1988. Some of the contributions of this international institution have been:

- The visit to Colombia for short periods of time of scientists having ample experience in sorghum production.
- The stay in Colombia for long periods of time of scientists with ample experience and of support personnel.
- ICA scientists have received the opportunity to conduct postdoctoral research and make use of their sabbatical leave.
- Jobs for research assistants (graduate students) chosen among the Colombian personnel.
- Donation of germplasm and supply of equipment to be used by both parties.
- Recent literature to support collaborative research projects being conducted in Colombia.
- Supplies, equipment, and travel expenses for INTSORMIL's employees.
- Trips to the United States or to other countries for ICA personnel.
- Organization of periodical work meetings that benefit INTSORMIL's collaborators in Colombia and enhance the exchange of information among researchers.
- Support work meetings planned and organized by both parties.

As a result of the work achieved through this agreement, the sorghum germplasm bank has substantially increased its number of entries, particularly of genetic resources having tolerance or resistance to acid soils with aluminum toxicity, to drought, to head molds, to the ovary fly, and to anthracnose. These materials come from the nurseries that have arrived in the country with the cooperation of INTSORMIL and provide the sorghum multidisciplinary team the opportunity to evaluate these genotypes and select the most appropriate for the Colombian environment. The first two sorghum improved varieties tolerant to acid soils with aluminum toxicity had their origin in these nurseries: Sorghica Real 40 and Sorghica Real 60. FENALCE also participated in the research and transfer activities related with the release of these materials.

Another contribution made by INTSORMIL has been to provide the opportunity to two Colombian professionals to continue their postgraduate studies: one at the M.Sc. and the other at the Ph.D. level. Also, others have been able to participate in international meetings held in the United States. INTSORMIL has sponsored national and international meetings in Colombia and has assigned financial resources for equipment, overall expenses, salaries, and commissions for sorghum professionals.

The Crop's Perspectives

As was discussed before, sorghum grain is a basic raw material in the elaboration of feedstuffs. Thus, as the animal industry increases in the country, particularly aviculture, sorghum production follows the same pace. Therefore, the public and private sector and the gild associations must join efforts to enhance the development of this cereal, through a concerted policy leading to a more efficient and appropriate generation and transfer of the technology required by the crop in the future. It is indispensable that research offer alternatives for solving the technological limitations that are affecting this crop's production and productivity in each of the sorghum-growing regions of the country. The methodology projected by ICA for reducing or eliminating these constraints is adequate. The integration of the various disciplines of agronomic knowledge (the multidisciplinary team) related to sorghum production will provide an overview of the species' problems in each growing zone and will make more feasible the planning and execution of projects for solving the respective constraints. Thus the reason why the multidisciplinary team must conduct a series of integrated projects that make sorghum production a sustainable system that can attain high yields and give greater economic return, without harming the natural resources.

Of the four major sorghum-growing regions in Colombia, the Caribbean and the Llanos Orientales have the greatest potential for the future. The goals of research to be conducted in the northern region must focus on the formation of improved early genotypes (varieties and hybrids), having medium or short plant stature; being resistant or tolerant to drought, diseases (primarily those attacking the head), pests, and birds; presenting semi-open or open heads with healthy grains; and yielding at least 4.5 t/ha in the humid Caribbean and 3.5 t/ha in the dry Caribbean. This perspective will allow sorghum to be planted with a minimum of risks during the first semesters in the cotton-growing region of the Atlantic Coast and will enable sorghum to compete advantageously with cotton during the second semesters.

In the Llanos Orientales, sorghum genotypes must be adapted to the acid savanna soils with a high aluminum content. Sorghica Real 40 and Sorghica Real 60 are the first two improved varieties to change the potential for sorghum in this region. However, the real "sorghum revolution" will begin when hybrids adapted to such soils are planted in the region. These must have a stature no higher than 170 cm, must be resistant or tolerant to diseases (primarily head molds), pests, and birds; the heads should be open or semi-open and have dark grains. Average yield of these hybrids should be at least 4.0 t/ha. Without any doubt, sorghum will be one of the species to be included in the group for pastoral systems projected for the Colombian foothills.

Sorghum's perspectives in the other two major zones (Alto Magdalena—central zone— and the geographical valley of the Cauca River) are based on the obtention of improved high-yielding genotypes that require a minimum of agricultural inputs in order to reduce production costs. Improved hybrids or varieties for the geographical valley of the Cauca River must have commercial average yields of at least 7 t/ha and of 5 t/ha for the Alto Magdalena. This must be one of the specific objectives of the plant genetics projects conducted by ICA's sorghum multidisciplinary team and also of plant geneticists in the private sector. Once these improved materials have been bred with the desired characteristics described, it is mandatory that a more appropriate production system or systems be generated in order to exploit the maximum genetic potential of these germplasm resources. All these scientific breakthroughs must be complemented with regional technology transfer plans, using the most advanced communication media in order to reach the farmer in an efficient way. If the goals proposed in this chapter are reached in the medium and long term, Colombia would not only be self-sufficient of this raw material for the animal industry, but would also have enough surplus for exports and would be able to face, with comparative advantage, the government's new economic policy of free marketing.

Conclusions

Literature on the geographical origin of sorghum indicates that this plant species had its origin in the northeastern quadrant of Africa and was introduced in the New World during the period of African slave trade through the Canary Islands, probably during the XVI Century or at the beginning of the XVII Century.

It has been indicated that sorghum arrived in Colombia through the port of Cartagena, which was considered in the past to be the main slave trade port in Hispanic America.

Seed of Giant milo, one of the varieties introduced from Africa, is still grown in the Atlantic Coast.

Sorghum grain is a basic raw material in the feedstuff industry; this makes it a fundamental product in the agricultural sector in order to support the growing animal industry, particularly aviculture.

Of the five most important cereals in the country, sorghum occupies the third place in terms of area planted, and the second place in terms of production.

The first grain sorghum plantings were done in 1957. By 1960, a total of 6,300 t of grain were being harvested from 2,800 ha planted; average yields were 2.3 t/ha. During the decade of the 80's, an average of 246,000 ha were planted; these produced 611,000 t of grain and average yields went up to 2.5 t/ha. Average figures for 1990 were 255,000 ha planted, 763,000 t of grain, and yields of 3.0 t/ha.

The main sorghum-growing states in Colombia have been: Tolima, Valle del Cauca, Cesar, Córdoba, Huila, and Meta.

The main sorghum-producing states have been: Valle del Cauca, Tolima, Córdoba, Cesar, Huila, and Meta.

Of the four main sorghum-growing regions (Caribbean, Alto Magdalena, geographical valley of the Cauca River, and Llanos Orientales) and of the two minor regions (El Zulia and Caquetá) in which the sorghum territory of the country is divided, the Caribbean and the Alto Magdalena are the regions where most sorghum has been planted and where more tons of grain have been harvested.

In Colombia, production costs vary from one region to the other. Data recorded during 1991 for five regions indicate that the range went from $227,882 (northern Cesar) to $406,722 (Córdoba), while the cost per ton fluctuated between $94,587 (Córdoba) to $131,614 (southern Cesar).

Technological constraints affecting sorghum production include foliar and head diseases, insects, lack of improved genotypes adapted to regions with low precipitation, high production costs, use of obsolete and inefficient agricultural machinery (particularly combines), and inadequate agronomic crop management.

In addition to ICA, Colombia has eight national and five multinational enterprises conducting research to produce improved genotypes adapted to the agroecological conditions prevalent in the country.

ICA's research activities in sorghum are conducted in the Research Centers of Nataima (Espinal, Tolima), Motilonia (Codazzi, Cesar), La Libertad (Villavicencio, Meta), and Turipaná (Cereté, Córdoba).

Based on the current structuring of ICA, the technology generation projects in the area of sorghum production are done by an integrated and coordinated team, under the concept of multidisciplinary research. This team is integrated by entomologists, breeders, plant pathologists, plant physiologists, soils and production specialists, economists, and agricultural engineers. In the case of sorghum, the group is composed of 12 professionals, 3 of them having a Ph.D. degree, 6 an M.Sc. and the rest a B.Sc. in Agronomy.

The basic objective of the research projects is to produce different types of improved genotypes adapted to the diverse agroclimatic and edaphic condition prevalent in the regions where this cereal is grown; in addition, to generate the most appropriate production systems, in order that sorghum cultivation become an economically profitable enterprise within the concept of sustainable and competitive agriculture, without damaging the natural resources.

During the period 1957-1990, 11 improved sorghum varieties and 61 hybrids have been planted in Colombia. Of these 72 genotypes, ICA has produced 6 varieties and 1 hybrid; and the private enterprise, 5 varieties and 60 hybrids. The varieties, as well as 12 of the hybrids, were the result of genetic plant breeding conducted in the country by the private sector. The 48 hybrids of foreign origin were produced by the following companies: AG-Seed (4), Asgrow (5), Cargill (5), Dekalb (5), Funk's (3), Pioneer (10), Northrup King (10), Penta Genetics (3), Garrison Seed (1), Warner Seed (1), and Young Seed (1).

Improved genotypes obtained by ICA to date are: ICA-Marupaanste (1968), ICA-Pal (1968), ICA-Nataima (1972), Icaima (1988), Sorghica Real 40 (1990), Sorghica Real 60 (1990), and Sorghica NH301 (1981). The first six are improved varieties and the last is a hybrid.

According to data recorded by ICA's Seed Division, 105,111 t of sorghum seed were planted in Colombia during the period 1973-1990. Of this amount, 46% were varieties (48,502) and 54% hybrids (56,609). The most planted improved varieties were: ICA-Nataima (40,258), Prosemillas 1 (4,268), and Icaima (1,811); and among the hybrids currently recommended, the highest figures correspond to HW-1758 (6,759), D-61 (4,894), NK-266 (3,814), and Savanna 5 (2,753).

Of the total amount of sorghum seed (105,111 t) planted in the different regions, ICA-Nataima was found to be the most used (38%), followed by HW-1758 (6%), E-57 (6%), P-8225 (5%), D-61 (5%), P-8416 A (4%), Prosemillas-1 (4%), NK-266 (4%), and Savanna 5 (4%). E-57, P-8225, and P-8416A are no longer being planted.

As of July 1991, seed of the following genotypes were available for planting in Colombia.

Improved varieties		
ICA-Nataima	Icaima	Prosemillas-1
VP-25	Triunfo	DR-7684
Hybrids		
Sorghica NH-301	DK-38	D-61
Savanna-5	NK-2888	NK-266
KS-786	KS-903	S-9750
P-8187	P-8239	P-8171
P-8232	P-8315	HW-1758
G-522DR	G-135	YS-60
YS-285	AG-30	Ag-31
Tropical-15	Alfa-2	Guapo-ST
El Rendidor	Rendidor-87	Cargill 1125DR
Cargill 1127	Cargill CL-603	Macau-90
Sinupar 2R	Expro-6	Expro-7

The outstanding aspects of the ICA-FENALCE and ICA-INTSORMIL agreements are: (1) Assignment of three professionals paid by FENALCE, dedicated to ICA's sorghum production. (2) The release of Icaima and Sorghica NH301 as a result of collaborative projects with FENALCE. Of the ICA-INTSORMIL agreements, the following aspects are outstanding: (1) Broadening of the sorghum germplasm base with materials tolerant to acid soils, drought, diseases, and pests. (2) Release of the first two improved sorghum varieties tolerant to acid soils with high aluminum toxicity: Sorghica Real 40 and Sorghica Real 60. (FENALCE also participated in this project.) (3) Training of two ICA professionals, at the Ph.D. and M.Sc. levels. (4) Together with FENALCE and the El Alcaraván Farm, organization and sponsoring of the international sorghum production meeting entitled "Sorghum for the Future".

The potential for sorghum production in Colombia are enormous. Its greater possibilities of expansion are in the Caribbean and Llanos Orientales. To meet this challenge, ICA'S multidisciplinary sorghum team and the private enterprise must "construct" ideal genotypes for these sorghum-growing regions. For the first, improved varieties or hybrids must have short plant stature, be early flowering, have resistance or tolerance to drought and foliar diseases, have open or semi-open heads with dark grains, and yield on average at least 4.5 t/ha in the humid Caribbean and 3.5 t/ha in the dry Caribbean.

The sorghum revolution will take place in the Llanos Orientales when hybrids start to be planted that have tolerance or resistance to acid savanna soils with a high aluminum content. These improved genotypes must have short plant stature, be resistant or tolerant to head diseases, have open or semiopen heads with dark grain, and yield on average no less than 4 t/ha. This species is foreseen to be another of the crops to be included in the pastoral system projected for the Colombian foothills.

For the Alto Magdalena region and the geographical valley of the Cauca River, genotypes must have a high average productivity with a minimum use of applied agricultural inputs in order to reduce production costs. Average yield of these germplasm resources should be no less than 7 t/ha in the Cauca Valley and 5 t/ha in the Alto Magdalena.

If these medium and long term goals are met, Colombia would not only produce all the sorghum required today by the animal industry and by its future expansions, but would also have enough surplus for exporting, which would give the country a comparative advantage in facing the challenge of the free-market economic policy currently in force.

Summary

Sorghum, originating in the northeastern quadrant of Africa, arrived at the American continent probably through the Canary Islands, during the period of African black slave trade to the New World. It is feasible that this historic event took place during the XVI Century or beginnings of the XVII Century. In Colombia it was probably introduced through the port of Cartagena in the XVI century. Having slight agroeconomic importance up to the decade of the 50's, sorghum became important with the growth of the feedstuff industry in Colombia, particularly that of fowl and egg production. Among the native varieties arriving from Africa, Giant milo is still cultivated in some regions of the Atlantic Coast, and another milo type in the state of Santander.

Among the five economically most important cereals in the country, sorghum occupies the third place in terms of area planted and the second place in terms of production. Of the 1,352,100 ha planted on average during the decade of the 80's, 245,700 ha were dedicated to sorghum and produced 611,200 t of the 3,406,400 t of grain produced by these five cereals. The first plantings of sorghum hybrids took place in 1957 and by 1960, a total of 6,300 t of grain were being harvested from 2,800 ha, with average yields of 2.3 t/ha. In 1970 these figures were 118,000 t, 53,600 ha, and 2.2 t/ha, respectively, and in 1980, these figures were 430,500 t, 206,200 t, and 2.1 t/ha, in the same order. In 1990, a total of 254,600 ha were planted and 762,700 t were harvested; yields averaged 3.0 t/ha. To date, both in terms of area planted and volume harvested, Tolima, Valle del Cauca, Córdoba, Cesar, Huila, and Meta have been the leading states. Among the four mayor zones (Caribbean, Alto Magdalena or Central Zone, geographical valley of the Cauca River, and Llanos Orientales) into which the sorghum-growing territory has been divided, the Caribbean and Alto Magdalena are the regions where most sorghum has been planted and more volume harvested. Production costs have varied from one state to the other, and from one region to the other. Without taking into account information for the Cauca Valley, data for the five regions in 1991 indicated a range between $227,882/ha (northern Cesar) and $406,722/ha (Córdoba). Costs per ton fluctuated between $94,587 (Córdoba) and $131,614 (southern Cesar); expected yields are 4.3 and 2.5 t/ha, respectively.

Technological constraints to sorghum production in the country include foliar and head diseases, insect attacks (such as shoot eaters and ovary flies), lack of improved genotypes tolerant or resistant to drought, high production costs, use of inefficient and obsolete agricultural machinery (especially combines), and inadequate agronomic management of the crop.

In addition to ICA, the private sector (represented by 8 national and 5 multinational enterprises) conducts research for the obtention of improved genotypes adapted to the agroecological conditions prevalent in the country. The sorghum research projects set in motion in 1965, are currently conducted by ICA in four of its research centers: Nataima (located in Espinal, Tolima), Motilonia (Codazzi, Cesar), La Libertad (Villavicencio, Meta) and Turipaná

(Ceretê, Córdoba). In concurrence with ICA's present structure, research in sorghum production is conducted through an integrated and coordinated team work; this multidisciplinary team is formed by entomologists, plant breeders, plant pathologists, physiologists, soils and production specialists, economists, and agricultural engineers. Twelve professionals form up the team, 3 of which have a Ph.D. degree, 6 an M.Sc., and the remaining a B.Sc.

The fundamental objective of the research projects is to obtain the different types of improved genotypes required for the varying agroclimatic and edaphic conditions prevalent in the regions where sorghum is grown in an adequate way, as well as to generate more appropriate production systems, such that make this crop an economically profitable enterprise and a sustainable and competitive agricultural system without damaging the natural resources.

From 1957 to 1990, a total of 72 genotypes have been planted in the Colombian territory; 11 of these have been improved varieties and 61 hybrids. ICA has released 6 improved varieties and 1 hybrid; the private enterprise, 5 varieties and 60 hybrids. Both the improved varieties as well as 12 of the hybrids were the result of plant genetics projects that this sector has been conducting in the country. In turn, the multinational enterprises are responsible for 48 hybrids. ICA's improved varieties are: ICA-Marupaanste (1968), ICA-Pal (1968), ICA-Nataima (1972), Icaima (1988), Sorghica Real 60 (1990), Sorghica Real 40 (1990), and the hybrid Sorghica NH301 (1981).

Data recorded by ICA's Seed Division indicate that 105,111 t of sorghum seed were planted during the period 1973-1990; of these, 46% came from improved varieties (48,502 t) and 54% from hybrids (56,609 t). Among the varieties, the most planted were ICA-Nataima (40,258 t of seed), Prosemillas 1 (4,258), and Icaima (1,811); and among the hybrids currently recommended: HW-1758 (6,759), D-61 (4,894), NK-266 (3,814), and Savanna-5 (2,753). In terms of percentage of total seed planted (105,11 t), ICA-Nataima represented 38% of the total; this variety was followed by E-57 (6%), HW-1758 (6%), P-8225 (5%), D-61 (5%), P8416A (4%), Prosemillas 1 (4%), NK-266 (4%), NK-266 (4), and Savanna-5 (4%). E-57, P-8225 and P-8416A are no longer being planted. Based on results of agronomic efficiency concepts and the corresponding records made at ICA's Seed Division, on July 1991 there was seed available of 6 improved varieties and 33 hybrids.

The technological development in which ICA is involved for sorghum production is carried out through ICA-FENALCE and ICA-INTSORMIL agreements. The most outstanding achievement of the first agreement was the obtention of Icaima and Sorghica NH301, and of Sorghica Real 40 and Sorghica Real 60 for the second agreement, as well as broadening the germplasm bank with sorghum materials tolerant or resistant to acid soils, drought, diseases, and pests. FENALCE participated in the project for the formation of the first improved sorghum varieties tolerant to aluminum-toxic acid soils.

Given the growth of the animal industry, sorghum has very good perspectives in the country, being the Caribbean and Llanos Orientales regions those with more possibilities of expansion in the medium and long term. For the first zone, both ICA's multidisciplinary team and the private enterprise must "construct" improved genotypes (varieties and hybrids) having short plant stature; being early flowering; having resistance or tolerance to drought, pests, and foliar and head diseases; presenting open or semiopen heads with dark grains; and yielding at least 4.5 t/ha in the humid Caribbean and 3.5 t/ha in the dry Caribbean. The real "sorghum revolution" will take place in the Llanos Orientales when hybrids are planted that are tolerant or resistant to acid savanna soils with high aluminum contents. This germplasm resource must have medium to short stature plants; be resistant or tolerant to pests, and foliar and head diseases; heads must be open or semiopen with dark grains; and yields should average at least 4 t/ha. Without any doubt, this species will be one of the crops that, together with rice, maize, and soybeans (among others), that will integrate the pastoral system projected for the Colombian foothills.

The research focus for the Alto Magdalena region and the geographical valley of the Cauca River must lead to the obtention of improved genotypes with high average productivity and that require a minimum of applied agricultural inputs in order to reduce production costs. In the geographical valley of the Cauca River, these new materials must yield at least 7 t/ha and 5 t/ha in the Alto Magdalena region.

Achievement of these goals in the medium and long term will imply that the country can produce enough sorghum grain to supply the current demand of the feedstuff industry and its future requirements; it also implies producing surplus sorghum for export and having a comparative advantage in the face of the challenge imposed by the free-market economic policy in force.

Bibliography

Del Castillo, M. Nicolás. 1982. Esclavos negros en Cartagena y sus aportes. Léxicos. Bogotá, Publicaciones del Instituto Caro y Cuervo. LXII: 247p.

Mellaje, Rolando. 1973. Breve historia de la esclavitud en América Latina. México. Secretaría de Educación Pública. Dirección General de Educación Audiovisual y Divulgación. Septentas 115: 191p.

Kornerup, Jeans Otto. 1968. El cultivo del sorgo de grano. Colombia. Agricultura Tropical 24:836-848.

Patiño, Víctor M. 1969. Plantas y animales domésticos en América Equinoccial. Volume IV: Plantas introducidas. Cali, First Edition, Imprenta Departamental:86-89.

Paul, L. Comptom. 1990. Agronomía del sorgo. Hyderebat, India. International Crop Improvement for the Semi-Arid Tropics (ICRISAT). El Salvador, C. A. Centro de Tecnología Agrícola (CENTA): 31p.

Quinby, J. R. 1974. Sorghum improvement and the genetics of growth. Texas College Station. Texas A&M University Press.

Torregroza, C. Manuel. 1989. La producción comercial de semilla híbrida F en sorgo granífero. Colombia, Semillas 14:9-12.

Torregroza, C. Manuel. 1991. El uso de semilla de variedades mejoradas y de híbridos en el cultivo del sorgo en Colombia, Instituto Colombiano Agropecuario. Cali, CIAT. International Sorghum Production Seminar: Sorghum for the Future, 49p.

Towards Sustainable Agriculture in Honduras with Inter-CRSP Collaboration

Roberto Villeda-Toledo[1]

Thank you Mr. Chairman for your introduction. During this workshop, you have heard presentations on INTSORMIL activities in Honduras by Dr. Dan Meckenstock, Dr. Francisco Goméz, and Dr. Miguel López. Now I would like to give a brief explanation of how the Government of Honduras (GOH) is trying to develop a sustainable agriculture in Southern Honduras with Inter-CRSP support.

But first, let me give you some background information. In Honduras, we are presently carrying out a structural adjustment in our economy in cooperation with the International Monetary Fund (IMF) and the World Bank (we just signed an agreement with the IMF last month). Most of you understand what it means in terms of social and political pressures for a developing country to make fundamental changes in its economy, but, on the positive side, agricultural development has the relevance and attention of the GOH. Why is this happening?

This is happening because agriculture is Honduras' main economic activity—with agriculture generating more than 80 percent of the country's export earnings and 60 percent of our population is involved in agriculture. Consequently, our Economic Structural Adjustment Plan is oriented towards reactivating agricultural development through an Agricultural Sector Program that was adopted earlier this year.

Our Agricultural Sector Program represents a national effort to overcome the principal constraints to agricultural development. Some of these constraints are:

- Statist and paternalistic policies,
- Inadequate infrastructure development,
- Distorted relative prices of goods and factors of production,
- A deteriorating natural resource base,
- And an inadequate human capital development characterized by low literacy rates and malnutrition in large segments of the labor force.

The Agricultural Sector Program that I just mentioned encompasses 12 agricultural polices related mainly to the following areas:

- Agricultural price policy.
- Creation of opportunities for the private sector to get involved in all phases of agriculture.
- A complete restructuring of the agricultural credit program.
- Development of an agricultural marketing system.
- Natural resource and environmental policies.
- Land tenure reorganization.
- Reorientation of science and technology.
- Institutional development.

New science and technology policies focus on promotion of agricultural exports and development of agricultural resources and production systems in such a way that we can maintain environmental quality and enhance production. It is under this policy that the GOH believes a closer and stronger relation with the CRSP is feasible.

Honduras has been involved with the CRSPs since 1981, first with INTSORMIL and more recently with the Pond Dynamics/Aquaculture CRSP (1983) and Bean/Cowpea CRSP (1983). In the next few weeks, we will sign a memorandum of agreement with the Soils Management CRSP and we are looking forward to negotiating similar agreements with the Peanut CRSP, Human Nutrition CRSP, and Stock Assessment CRSP.

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The Honduran Government agrees with the CRSP Council that Southern Honduras possesses excellent opportunities for implementing an integrated systems approach to agricultural development. This zone encompasses hillside subsistence farming, two important watersheds for the entire region, export crops on the coastal plain, and aquaculture in the Gulf of Fonseca. Dr. Meckenstock referred on Monday to this unique setting and the need to develop a sustainable agriculture. He also mentioned the general degradation of the natural resource base that not only promises to reduce productivity but threatens to stifle production as well, if prudent measures are not taken soon.

This is a succinct review of the opportunity that the GOH and CRSPs have under the new agricultural policy to develop an integrated approach to sustainable agriculture in Honduras. The task at hand is not easy. We will have to achieve inter-institutional coordination, not only among the five Honduran institutions that will be involved, but also in the development of new mechanisms of coordination among the eight CRSPs. Obtaining the necessary funds to carry out this program is also a challenge. Currently, we are in the process of identifying sources of local currency that will be needed for host country counterpart costs.

"We must be bold", as John Mitchell stated in his presentation on Monday. Only through bold efforts will we be able to reach the goal of a sustainable agriculture. The sooner we begin the better. Thank you.

INRAN/INTSORMIL Collaboration

Moussa Adamou[1]

Introduction

Niger is a landlocked country covering about 1.27 million km^2, 75% of which is desert, 15% semi-arid and only about 10% arable land. The country is under a continental climate of the Sahelian type with 3 seasons:

- Rainy season from May to October
- Cold and dry season from November to January
- Hot and dry season from February to April.

The rainfall, decreasing progressively from the south to the north of the country, shows a regression from 900 mm to 0 mm. Soils are mostly sandy with some fertile heavy irrigated depressions along the Niger river and in a few valleys.

The climate of Niger has become more and more hostile for agriculture, with the progression of the desert. The climatic dryness of these past years has seriously damaged the natural vegetation, causing the loss of many plant species.

Economy and Agriculture

Food production in Niger is marginal because of the deleterious effects of high temperatures, low soil fertility and low rainfall. Before the 1968 drought, Niger produced about 1.25 million metric tons of food which was then considerable and the country was self-sufficient. Since then drought periods have become more frequent and severe. So alimentary self-sufficiency has now become the major priority.

About 85% of Niger's population live in rural areas. The population growth rate is about 2.8%. The annual per capita income was $300 in 1983 but has since decreased. The gross agricultural product (including forestry and fisheries) represents about 33% of the gross national product, and is increasing at an average rate of 3.2% per year, due to the increase in cultivated area which in turn has led to natural resource deterioration.

Goal of Agricultural Research

Since the major constraints are low rainfall, low soil fertility, high temperatures and to some extent low yielding cultivars, agricultural research has been directed toward increasing yield of cereal crops through the investigation of the interactions between water, nutrients and temperatures and by improving the yield potential of different varieties.

Concerning crop species, cereals occupy 90% of the cultivated area. Pearl millet and sorghum which are dryland crops, represent 75% and 20% respectively of the cereal acreage. The remaining 5% of cereal acreage is devoted to irrigated rice and corn. Among legume crops, cowpea is the most important followed by groundnut and other beans.

Millet and sorghum are critical as primary food sources. The most important concern of the Niger government and the National Research Institute (INRAN) is to bring the production of these major cereals and legumes to higher and more stable levels of production by improving cultural practices and breeding superior varieties of these species.

The major constraints of these crops are the following:

Drought, high soil temperature, low fertility and/or toxicity of soils, insects, diseases, weeds and parasitic plants, sandy winds, etc.

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In addition to these constraints there are also socio-economic constraints.

INRAN/INTSORMIL Collaborative Program

INTSORMIL is considered as one of the most important USAID CRSPs operating in Niger for the improvement of our two major cereals.

The collaborative program between INRAN and INTSORMIL contains several interdisciplinary activities. As shown by the collaborative plan, INTSORMIL principal investigators develop research plans and budgets with the INRAN scientists. Each plan is submitted to the Director General of INRAN for his approval.

INRAN/INTSORMIL Collaborative Research Projects

The current collaborative research projects which are underway include the following:

- grain sorghum emergence studies
- on-farm variety trials
- Breeding program (Introgression of elite sorghum germplasm - hybrid production)
- Economic program (on-farm modeling of the potential impact of new technologies).
- Food quality program (for different regions of the country)
- Millet progam - characterization of African pearl millet landraces.
- Pathology program - Selection for high and low reactions to long smut.
- Physiololgy program - Sorghum and millet nutrient use efficiency - screening for drought resistance.

Training of INRAN Researchers

Research in Niger is also constrained by the lack of trained personnel. There is a need for a stronger program of training personnel.

General Comments

Dialogue between INRAN and INTSORMIL scientists to establish solid relationships must continue. The conditions contributing to effective collaboration are frankness and common respect. The integration of scientists from both sides is necessary for the task to be easy.

Priorities in the Sudan in the 1990s

El-Hilu Omer[1]

Introduction

Sudan is the largest country on the African continent with an area of 12.5 million Sq. Km. Environmental conditions in the country range from desert, where annual precipitation is 0-100 mm, to equatorial climate, where rainfall exceeds 1200 mm.

Sorghum, the popular cereal diet of the population, is grown throughout the country under irrigation, but mainly as rainfed crop in the vast central Vertisols of the country. Cropping pattern and allocation of land varies from one sector to the other. In the irrigated large schemes like the Gezira and Rahad, the farmer cultivates 1.05-4.2 ha in a rotation of cotton-wheat/groundnut-fallow. The traditional sector constitutes nearly 30% of the total area under sorghum, mostly small areas in low rainfall regions. It is the sector with the poorest average yield. The mechanized sector occupies the largest area (62%) under sorghum. Mechanized farming is practiced in several areas within the central clay plain of the country; Gedaref (Eastern State), Damazin and Kosti (Central State), Dalanj (Kordofan State) and Renk (Upper Nile State). Gedaref and Damazin are the largest locations. Land ownership within the mechanized sector ranges between 420-630 ha, but some farmers cultivate more. Sorghum in the rainfed sector is almost exclusively grown as a monocrop and the recommendation of rotating sesame with sorghum is adopted by very few farmers. Sunflower, a relatively newly introduced crop, is gaining popularity among producers particularly the big company growers. Farmers varieties still dominate the rainfed production, but there is increasing preference to grow improved varieties in the high rainfall areas where Dabar-1, U.B.7 and Gadam El-Hamam predominate. Other rainfed farmers in drier areas still prefer the tall varieties of Korakola, Agab Siedo, Feterita Gedaref and Safra because of early maturity, drought tolerance and large size grains. Sorghum growers in the traditional sector go for local varieties popular in their respective locations; Nagad in the drier west and a range of late maturing cultivars in higher rainfall Nuba Mountains.

The irrigated sector has, in last few seasons, witnessed appreciable improvement reflected in keenness of farmers to plant Hageen Dura-1. In season 1990 the production of seed was far short of demand and most H.D.1 growers realize the benefit of applying the recommended package.

Pearl millet is grown by traditional farmers in West Sudan where the crop is considered the main staple food. The millet growing areas in the west are characterized by low rainfall of less than 500 mm, poor management practices, poor soil fertility and poor grain yield. The crop occupies about 1.6 ha. In spite of the economic importance of the crop, it has received little attention compared to sorghum. In good seasons, an appreciable area of millet is grown in the mechanized schemes within the sorghum areas of the central clay plain (60,000 ha in 1988). The only irrigated millet is grown in Tokar in the Eastern State.

In cooperation with ICRISAT in the late 1970s, an improvement program was initiated with the objective of developing high yielding, drought-tolerant, early maturing varieties with acceptable grain quality and resistance to prevailing pests and diseases. One cultivar, Serere Composite-2 introduced from Uganda, through ICRISAT, outyielded local cultivars, but it is not finding the acceptability it deserves. Farmers prefer Golden Yellow Bold Grains, besides complaints regarding susceptibility to *Raghuva albipunctella* locally known as "Nafasha" and lack of uniformity.

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Over ninety percent of grain produced in the Sudan is harvested exclusively under dryland conditions in the semi-arid regions. During the 1980s, Sudan has experienced some seasons of abundance when produce far exceeded home consumption. On the other hand, drought in many years resulted in great deficit. 1989 was a drought season, but 1990 was the worst in recent history when mechanized productive area diminished to about 1.6 million ha (Table 1). The country is now facing great grain shortage. Low production greatly inflated consumer prices to almost four times those before the season. The government policy is to achieve self-sufficiency in grain production. It is already planned to expand sorghum production under irrigation. The Gezira scheme alone is expected to cultivate nearly 300,000 ha of sorghum this season. Similar expansion is expected in other irrigated schemes. This policy is to off-set shortages created by recurrent droughts.

Table 1. Sorghum yield in million metric tons and sorghum area in million ha.

	Sorghum yield in million metric tons		
Year	Irrigated	Mechanized	Total including traditional
1980	0.31	0.94	1.69
1981	0.30	1.24	2.15
1982	0.36	1.27	2.22
1983	0.36	1.08	1.81
1984	0.44	0.39	1.10
1985	0.66	2.33	3.28
1986	0.46	2.40	3.28
1987	0.35	0.85	1.36
1988	0.49	3.36	4.64
1989	0.44	0.78	1.60
1990	0.51	0.55	1.52*

Source: Agr. situation and outlook, Dept. of Agric. Ec., Agr. Report

	Sorghum Area in Million ha		
Year	Irrigated	Mechanized	Total
1980	0.16	1.22	2.19
1981	0.31	2.34	4.17
1982	0.34	2.44	4.30
1983	0.28	2.20	3.45
1984	0.32	1.91	3.36
1985	0.47	3.59	5.53
1986	0.35	3.44	4.96
1987	0.30	2.23	3.39
1988	0.37	4.20	5.88
1989	0.38	2.64	3.22
1990	0.46	1.68	2.44+

Research Achievements

The national agricultural research system, in collaboration with INTSORMIL, is concerned with determining the research program, implementing it and communicating findings to users. Before outlining research priorities it is appropriate to highlight the achievements.

Crop improvement

- A number of open-pollinated cultivars developed by the collaborative program are at various levels of testing for the rainland.
- M 90393, P967083, ICSV 112 and Cr 35/18 have already passed the on-farm stage of testing and are due for release. The feed-back from farmers is very encouraging.
- The hybrid program has also made good progress and a number of newly developed hybrids are at the national variety trial. They are impressive and gave superior results.
- Recently SRN-39 and IS-9830 have officially been released as *Striga* resistant cultivars.
- The seed of SRN-39 has already been increased commercially by the Sudanese-Canadian Project and all of last years produce was purchased by the agricultural bank for distribution to farmers in affected areas.
- SRN-39 is uniform, drought resistant with popular grain quality and its yield under *Striga* conditions excels other popular varieties.
- In collaboration with Global-2000 great expansion in H.D.1 demonstration plots was conducted. Convincing evidence of improved package superiority has been shown in most Gezira and Managil groups (Table 2).
- New chemical products for control of major pests and diseases have been recommended or in the final stage of submission to the Technical Committee.
- A number of introduced and local cultivars have been evaluated for resistance to pests and diseases.

Table 2. Yields of Hageen Dura-I in farmers' fields demonstrated plots compared to those of traditional cultivars in 13 groups in the Gezira scheme.

Group	Grain yields (t/ha)		
	Area (ha)	Group average	Demonstration plots
South	60.9	1.11	4.50
Centre	63.0	1.44	3.54
Wadi Shair	63.0	0.98	2.61
Massallamia	63.0	1.28	3.00
W. Habouba	62.6	1.20	2.70
N. West	63.0	0.86	1.93
Makashfi	126.0	1.03	2.25
Huda	126.0	1.01	2.74
Mansi	126.0	0.75	2.70
Tahamid	69.0	1.01	3.21
Matoug	142.4	0.79	2.61
Gamousi	126.0	1.03	3.90
Matouri	126.0	0.66	2.12
Mean	93.63	1.01	2.91

Source: Farah, S.M. (1991). Proceedings of the Second Annual Research Coordination Meeting (IDSM) UNDP and NARS in Egypt-Somalia-Sudan-Syria-Yemen. Damascus, May, 1991.

- Improvement of Ugandi grain quality is in progress in collaboration with ICRISAT.

Food Technology

- Characterization of Sudanese sorghum, millet varieties and elite breeder material, e.g., physical, chemical and processing attributes.
- Development of a process for dehulling sorghum and millet for production of improved flour. The technology is now applied commercially.
- Prescribed the best proportions of sorghum/millet to wheat flour for making composite flour bread.
- Developed new innovations of immediate use to cereal food industry.
- The nutritional value of some popular sorghum and millet varieties has been evaluated in cooperation with collaborating scientists.

Research Priorities

Sorghum breeding

The objectives of the breeding program in the 1990s shall still address major constraints outlined in 1989 at the Scottsdale Conference.

- Continue efforts to introduce open-pollinated varieties and hybrids suitable for high rainfall areas and irrigation.
- Develop more *Striga* resistant cultivars.
- Initiate and develop a pest and disease resistance program.

Millet breeding

- Breed adapted varieties that combine high yield and grain acceptability with early maturity and drought tolerance.
- Breed varieties that are more resistant to *Raghuva*.
- Screen and identify millet varieties that are resistant to *Striga*.

Sorghum Agronomy

Agronomic research in the mechanized sector is still fragmentary and not yet finalized. Now that ARC has established a farm in Gedaref with scientists on site, it is expected that more concerted effort will be put by ARC and the Sudanese-Canadian Project to continue addressing priorities related to:

- The best tillage method for maximizing water conservation.
- Find the optimum plant population for low and high rainfall areas.
- Verify the benefits of row planting over widely adopted broadcast seeding.
- Prescribe the nutritional requirements of the crop for high and low rainfall areas.
- Determine the best crop sequence for the mechanized sector.

It has been agreed that a good proportion of ARC farm at Simsim shall be utilized by the Sudanese-Canadian Project as demo plots. The ARC agronomist is expected to be involved in these activities.

Millet Agronomy

One of the major causes of yield instability in Kordofan is low rainfall. The agronomist will focus on problems related to drought.

- Land preparation method suited for the light sandy soils.
- Competition studies and efficient utilization of existing natural resources.
- Screening for drought tolerance.
- Crop nutrition and soil improvement studies.
- Organic and inorganic fertilization.
- Mixed cropping.

Entomology

The most serious pests are the stem borers (viz. *Chilo partillus, Sesamia critica*), a problem associated with late sorghum sowing, midge in southern Blue Nile and aphids. The emphasis of the program will be directed to integrated control. This involves:

- Screening cultivars for pest resistance.
- Chemical screening.
- Explore the possibility of biological control.

Pathology

Most known sorghum diseases exist in the Sudan, but relative importance varies from one location to the other. However, smuts, charcoal rot, *Pythium* rot, anthracnose and bacterial streak stand as major constraints. The program in the 1990s shall concentrate on the following:

- Screening drought resistant cultivars for charcoal rot in collaboration with the breeder.
- Finalize work on seed dressing against covered smut and *Pythium* seedling rot.
- Screening for long smut resistance.
- Identify sources of resistance against anthracnose and races of causal organism.
- Screen germplasm for bacterial streak resistance and identify possible biotypes of the causal organism.
- Survey diseases on millet and assess their relative importance to initiate a suitable research program.

Economics

Economic evaluation is an integral part of technology transfer. Any recommendation will not get the approval of the concerned ARC Technical Committee unless economic evaluation clearly shows a benefit.

- The economist shall work closely with the agronomist and other scientists in evaluating economic benefit of new technologies.
- Examine current production practices in selected areas to identify levels of technology, yields, problems ... etc.
- Examine and assess new technologies that are potentially good alternatives, considering, profitability, risk and system compatibility.

Striga

Striga in importance in Sudan comes next to drought because of its potential danger and increasing incidence. The '1990s should address the following:

- Development of new resistant cultivars with acceptable grain yield and quality.
- Optimum plant population for SRN-39.
- Development of an integrated control approach to the problem.

Donor Funded Sorghum/Millet Research Regional Organizations

UNDP Regional Project (Egypt-Somalia-Sudan-Syria and Yemen).

The objectives of the project are:

- Improvement of sorghum and millet cultivars and husbandry techniques.
- Stabilize grain yields and increase their use as human food.
- Upgrading the capacity of the national agricultural systems.
- Support cooperation in research networks.
- Develop farming techniques which conserve moisture nutrients and soils.
- Aim at transfer of technology to farmers.

Besides assisting in achieving these objectives, UNDP has subcontracted with ICRISAT to undertake training of national researchers and technicians, act as repository of germplasm and technology, supplies improved material, provides short term consultancies whenever needed, participates in workshops and acts as a link between participating countries and international networks.

The project provides equipment, supplies, and vehicles within approved budgets, conducts annual coordination meetings and travelling workshops in member countries to encourage interaction between scientists and exchange of information. The steering committee of the project evaluates research results, approves research proposals and provides guidance to the whole activities of the project.

Eastern African Regional Sorghum and Millet Network (EARSAM).

Member countries of this network are: Burundi, Ethiopia, Kenya, Rwanda, Somalia, Sudan, Tanzania and Uganda.

Objectives of EARSAM are basically similar to UNDP project, but here the network organizes and promotes regional testing of elite breeding material in selected ecological zones, assists in training and manpower development, provides supplies and facilities needed to upgrade research capabilities within approved budgets for approved proposals.

Our national program receives partial funding in two areas; breeding for drought resistance and *Striga* research. Sudan, among other member countries, receives the EARSAM elite yield trial (EESYT).

In-country Organizations

Simsim Dryland Farming Project

Though administratively independent of ARC, the Sudanese-Canadian Simsim Dryland Project conducts research related to sorghum, sesame, sunflower, cotton, maize, millet and food legumes. The project deals with production technology aspects:

- Identify and develop improved mechanized cropping techniques and promote the adoption by local farmers through demo farms of improved, profitable sustainable cropping system.
- Promote permanent settlement of farmers in the region.
- Train farm workers at various levels.
- Conduct machinery testing and development.

In the past the project had little coordination with ARC. Recently, a team of three senior researchers from ARC has been chosen as consultants to coordinate and supervise project research in 1991. A technical committee for the rainland has newly been nominated. Its main objectives are to look into dryland research activities, coordinate and suggest new research problems. Although the project is not a fund donor to ARC, its cause and objectives are of direct benefit to the promotion of ARC mandate.

Global-2000

The main objective of Global-2000 is to increase the production of cereals through promotion and adoption of improved packages. Though Global-2000 is not a research organization, it works closely with ARC and some ARC workers are cooperating with it. Seed increase of improved elite open-pollinated varieties was carried out by Global-2000 as prerelease multiplication and demonstration trials. The expansion in the production of H.D.1 in the irrigated sector is to a great extent promoted through efforts of Global-2000.

Training Requirements

Table 3 shows the existing number of scientists involved in sorghum-millet research in stations where there is main emphasis on cereal research. Apart from the breeders, all other scientists conduct research on other crops. Table 4 lists the number of post-graduate trainees in the different disciplines and the expected needs in the 1990s. We have already four vacancies for master degrees in ICRISAT under UNDP project.

In-service Training

With the limited manpower, the ARC scientific staff are obliged to deal with many problems related to their narrow field of specialization. In-service training helps them

Table 3. Distribution of ARC Sorghum/Millet Scientists.

		Research Station				
	GRS	Rahad	A/Naama	El Obeid	Gedaref	Total
Breeding	1	0	1	1	0	3
Agronomy	1	1	1	1	1	5
Soil Science	1	0	1	0	0	2
Entomology	1	1	1	0	0	3
Pathology	1	0	1	0	0	2
Striga	1	0	0	0	0	1
Economics	2	0	0	1	0	3
Ag. Eng.	1	1	1	0	1	4
Total	9	3	6	3	2	23

Table 4. ARC Sorghum/Millet Training Needs in 1990s.

	Existing Post-graduate trainees	Expected needs in 1990s
Breeding	0	3
Agronomy/Crop Physiology	1	1
Soil Science	0	2
Entomology	1	2
Pathology	0	2
Striga	0	1
Economics	1	1
Ag. Eng.	0	2
Total	3	14

keep with the recent advances in their disciplines, acquire new techniques and strengthen their relation with scientists in international organizations. We hope that INTSORMIL gives the in-service training due consideration in the 1990s.

This is the first time for Sudan to be represented by three members of ARC in an INTSORMIL Conference. On behalf of my colleagues I take this opportunity to thank the administration and the organizers of this conference for extending the invitation to us. Thanks are also extended to the coordinator Dr. Gebisa Ejeta and collaborators and all those who helped in keeping our program viable and progressing.

Poster Session

Abstracts

Technical Presentations - Abstracts

Agrometeorology

Agrometeorological Approaches for Estimating Water Stress: Implications for Millet Breeding. L.M.R. Pereira, A. Weiss, F.R. Bidinger, V. Mahalaskshmi and K.G. Hubbard, University of Nebraska, Lincoln, NE.

One method to improve millet productivity is for plant breeders to know the frequency of occurrences of stress during different stages of crop development. Simple statistical analyses (e.g. means and standard deviations) of climatic variables are inadequate for these purposes.

Two methods of analyzing stress will be discussed: duration of dry spells and a heatwater stress index. A dry spell was defined as one day with less than 5mm of precipitation. The heat/water stress index is the ratio of the accumulation of temperatures greater than 30 degrees Celsius divided by the total precipitation for the period. If there was no precipitation during a period then the ratio was set equal to the numerator. The growing season was divided into three periods, emergence to panicle initiation (GS1), panicle initiation to anthesis (GS2), and anthesis to maturity (GS3). Probability distribution of occurrence of dry spell greater than 6, 9, and 14 days showed specific patterns across SW-NE and SE-NW transects. Analyses of heat/water stress index for similar transects is currently being pursued.

Agronomy/Physiology

Residual Effect of Crop Rotation on Soil Mineral Nitrogen and Grain Sorghum Yield. M. Bagayoko, S.C. Mason and M.D. Clegg, I.E.R., Bamako MALI.

A cropping system experiment with an 8-year history of continuous soybean and sorghum, and soybean-sorghum rotations with fertilizer treatments of control, nitrogen (45 kg ha^{-1} on soybean plots and 90 kg ha^{-1} on sorghum plots), and manure (16 Mg dry matter ha^{-1}) was terminated in 1987. In 1988 the residual effects of these treatments on sorghum grain yield and soil mineral N were determined. Treatments with soybeans as the previous crop produced 2.6 Mg ha^{-1} more sorghum grain than continuous sorghum, while rotation treatments with soybeans present two years previously produced 1.4 Mg ha^{-1} more grain. Soil NO_3^--N levels were influenced more than NH_4^+-N and total mineral N levels. Soybeans as the previous crop resulted in 41, 36 and 9 kg ha^{-1} more NO_3^--N in the 150 cm soil profile than did continuous sorghum in May, June and October, respectively. Rotation treatments with soybean present two years previously resulted in 24 and 18 kg ha^{-1} more NO_3^--N in May and June. This indicates that the beneficial effects of rotating sorghum with soybeans are still present two years after the last soybean crop.

The Pattern of Grain Fill Within the Panicle of Grain Sorghum. R.W. Heiniger, R.L. Vanderlip and K.D. Kofoid, Kansas State University, Manhattan, KS.

The yield of grain sorghum [*Sorghum bicolor* (L.) Moench] is made up of several components including panicles produced, kernels per panicle, and weight per kernel. Kernel weight has an important influence upon sorghum yield since it provides the last opportunity for the plant to compensate for environment. Although some factors affecting this grain filling period have been studied in relation to the whole panicle, little is known about the pattern of grain fill within the panicle and the factors which influence it. Knowledge of this pattern could aid crop physiologists in determining the mechanisms which limit kernel size, and would enable a more accurate simulation of sorghum yield by plant growth models. The objectives of this study were to determine the grain fill pattern within the sorghum panicle, and to compare the intra panicle grain fill patterns of two hybrids, DeKalb DK-46 (open panicle) and Pioneer 8500 (closed panicle).

A field study was done in Manhattan, Kansas in 1989 in which DeKalb DK-46 and Pioneer 8500 were planted in a randomized complete block design. Heads were tagged at first bloom over a period of six days. Two samples a week consisting of 10 heads each were collected over a period of seven weeks. Heads from these samples were split into four sections according to the number of whorls on the rachis. Seed numbers and section seed weights were recorded. Seed weights were calculated by dividing section weights by seed numbers in the section.

Kernel weights within the panicles of both hybrids increased from the base to the apex. The differences in seed weights were due to the rate at which the kernels in the panicle sections filled with those at the apex filling at a significantly faster rate than those at the bottom. Only the lower two sections of the DeKalb DK-46 showed differences in the length of the effective fill period (EFP). Pioneer 8500 had greater seed numbers in the middle sections while DeKalb DK-46 had greater seed number in the base and apical sections.

DeKalb DK-46 had slightly greater average seed weights. This was due to greater seed weights in the base section when compared to the base section of Pioneer 8500. Pioneer 8500 had a faster average rate of fill, however, the EFP was slightly longer for DeKalb DK-46 due to the longer EFP of its base section. DeKalb DK-46 had significantly greater seed numbers in all sections.

Neither the length of the effective fill period nor numbers of seeds have an influence on seed weight relationships within the panicle.

Screening Sorghum for Manganese Toxicity. W.G. Mgema, R.B. Clark and J.F. Pedersen, University of Nebraska, Lincoln NE.

Manganese toxicity can be a major constraint for growth of sorghum [*Sorghum bicolor* (L.) Moench] on acid soils. This study was conducted to develop screening methods for Mn toxicity tolerance in sorghum. The objectives were to (1) determine levels of Mn needed to induce Mn toxicity and to screen sorghum genotypes for Mn toxicity tolerance, (2) evaluate traits to assess genotypic variation to high Mn, and (3) evaluate sorghum genotypes for tolerance to Mn toxicity. Four 10-day-old seedlings of genotypes with diverse genetic backgrounds were grown in 1.9-L nutrient solution for 10 days at 18 (check), 3,000, 6,000, 9,000, and 12,000 μM Mn as $MnCl_2$ under growth chamber conditions. Visual Mn Toxicity symptoms, net root elongation (length of longest seminal root before and after treatment), net shoot and root dry matter yields (corrected for initial growth at time plants were transferred to treatments), and total root length were traits measured to assess plant responses to high Mn. Shoot and root dry matter yield reductions appeared to be one of the best traits to evaluate Mn toxicity compared to the other traits. Moderate reductions in dry matter yields did not occur until Mn levels were above 3,000 μM Mn, and 9,000 μM Mn caused severe dry matter reductions. Genotypic differences in tolerance to high Mn were noted in the genotypes tested: NB9040, ICA-Nataima, and B-Wheatland showed relatively good tolerance to high Mn, and SC283 (known for its high degree of tolerance to high Al) was relatively susceptible to high Mn.

Tillage and Fertilizer Practices for Dryland Sorghum Production in Botswana. N. Persaud, S. Beynon, A. McPherson and N. Mokete, Sebele Research Station, Gaborone, Botswana.

In August of 1988 Botswana's Department of Agricultural Research, with INTSORMIL's assistance, initiated a comprehensive research program in order to provide clear recommendations on tillage and fertilizer management practices for dryland crops. As part of this program, two multilocational trials, E1 and E2, were conducted during the 1989-90 cropping season. For E1, six tractor-implemented primary tillage systems were evaluated with and without fertilizer at nine sites. The six tillage systems were T1- conventional, T2-double ploughing, T3-deep strip tillage, T4-plough + cultivate, T5-conventional with wide rows and T6-the traditional broadcast/plough system. Compound 2:3:2 fertilizer was banded at 0 and

150 kg/ha, except for T6 where it was applied broadcast before ploughing. For E2 factorial combinations of N rates of 0, 10, 20, 40 and 80 kg/ha as lime ammonium nitrate, and P rates of 0, 20, 40 and 60 kg/ha as single superphosphate were evaluated at three of the nine sites. Rainfall at all sites during the 89-90 season was below the long-term average recorded at the nearest synoptic station. Nevertheless overall site mean yields two to five times the national average of 300 kg/ha were obtained. Tillage and fertilizer did not interact at any of the sites. Compared to T1, positive yield benefit was obtained for T2 and T4, the treatments with an early inversion tillage, at those sites where the overall site mean yield was less than 1100 kg/ha off those sites with overall site mean yields greater than 1100 kg/ha, T1 tended to perform as well as, or better than, T2 and T4. Except at one site, T3 performed poorly compared to T1. T5 performed similarly to T3 at most sites. A relatively weak response was obtained from the banded 2:3:2 fertilizer. However for T6, where the fertilizer was applied broadcast, there was close to 50% increase in the overall mean yield across the sites. Probably, when banded next to the seed, fertilizers are not utilized optimally. This is also probably why T6 performed generally better, or as good as, T2 and T4. Results for E2 showed statistically significant yield increases from applied P where the soil P was less than 5 mg/kg. Response to N was significant at one site where the rainfall was well-distributed throughout the season. There was no significant interaction between N and P rates.

Leaf Water Relations, Net CO_2 Assimilation, Stomatal Conductance, and Osmotic Concentration As Affected By Water Deficit in Sorghum. G.S. Premachandra, J.D. Axtell and R.J. Joly, Purdue University, West Lafayette, IN.

Six cultivars of sorghum (*Sorghum bicolor* L.) previously identified as either pre-flowering drought susceptible (CS3541, B-35, bm-15) or tolerant (K886, TX7078, N-15) based on seed yield, were grown in pots and subjected to water deficit by withholding water beginning 40 days after planting. Leaf water potential (ψ, osmotic potential (ψ_π), relative water content (RWC), net CO_2 assimilation rate, leaf epicuticular wax content and total plant weight were measured, and turgor potential (ψ_p), relative growth rate (RGR) and root/shoot ratio were estimated at the beginning of the experiment and 21 days after the onset of treatment. Leaf water potential of stressed plants varied widely (-0.83 to -2.68 MPa) among cultivars, but no differences were observed among irrigated controls. No significant differences in osmotic potential at full turgor were observed between irrigated and stressed plants for any of the cultivars, suggesting that osmotic adjustment was of minor importance in the pre-flowering stress tolerance of these cultivars. Stressed plants of CS3541, K886 and TX7078 exhibited smaller reductions in transpiration and net CO_2 assimilation rate and RGR, relative to controls, than did B-35, bm-15 or N-15. After 21 days without water, leaf epicuticular wax content was lower in stressed plants than in irrigated controls in CS3541, K886 and TX7078, but no differences were observed for the other cultivars.

Response of Pearl Millet to Nitrogen Rate and Timing of Application. Abdoul W. Toure and J.W. Maranville, University of Nebraska Lincoln NE.

Optimal nitrogen (N) rate and timing of application might be useful tools to improve N use efficiency in cereals. Field experiments were conducted in 1989 and 1990 to determine the response of pearl millet (*pennisetum americanum*) to different N rates and timing of application. Rates were 0, 28, 56, and 112 kg/ha N applied at 0, 25, and 50 days after emergence. Genotypes ICTP-8203 and 68A X MLS were planted in four row plots 75 cm apart. Parameters measured to evaluate response were dry matter, grain yield, total N uptake and N use efficiency (NE). Nitrogen rate tended to influence grain yield, total biomass, total N uptake and NE but its effect was significant only on total N uptake and NE measured as grain produced per unit N absorbed (NE2). Time of application significantly affected grain yield (P=0.01), total biomass (P=0.01), total N uptake (P=0.01), NE as total biomass produced per unit of N absorbed (NE1) (P=0.10) and NE2 (P=0.07) only when 112 kg/ha N was applied. Splitting effect was significant on grain yield (P=0.05) and highly significant on total biomass (P=0.01) when 56 kg/ha N was applied. Genotype differences were observed between ICTP-8203 and 68A X MLS for grain yield, (P=0.01) total N uptake (P=0.01), NE1 (P=0.10) and NE2 (0.07). A significant year * variety interaction was detected for NHI (P=0.05) NE2 (P=0.05) leaf total N (P=0.05) and 100 seed weight (P=0.05). A significant variety * N interaction detected for 100 seed weight (P=0.02), grain yield (P=0.05) and NE1 (P=0.05) was dependent on either the N rate or the time of N application. In conclusion, pearl millet tended to respond to N rate and timing of application, but the environmental conditions of this study (high residual soil nitrate) might have limited information on its yielding potential in low soil N conditions.

Agricultural Economics

The Grain Market System in Mozambique: The Case of Sorghum. Firmino Gabriel Mucavele, University of Florida, Gainsville, FL.

In Mozambique maize (corn), groundnuts (peanuts), rice, cowpea and sorghum are the major crops. A large number of farmers have been shifting production gradually from sorghum to maize despite its susceptibility to drought.

This paper analyzes some of the important factors contributing for the decline of sorghum production in Mozambique giving more emphasis to the grain market system. The major objective is to review the evolution of grain market structure and policies in Mozambique to locate the problems of the market system.

It is concluded that the fixed price system should be limited to a few agriculture products where government can be able to effectively support and control. The analysis of real prices should be done to predict the behavior of producers and avoid decreases in the real prices. It would be desirable that real producer prices of sorghum at least remain constant in the short term, with perspective to stabilize them in the long run. For those products which the price would remain controlled, it would be better if the prices were adjusted regularly based on exchange rate changes, and international prices. There should be an integrated system of reforms, agriculture policies, and market institutions and technological improvements for the smallholder farmers.

Bio-Technology

Sorghum Suspension Cultures and Callus Formation from Suspension Culture Protoplasts. Tishu Cai and L.G. Butler.

Suspension cultures of seven sorghum cultivars were initiated from embryogenic calli derived from cultured mature or immature embryos and young inflorescences. The liquid medium was composed of MS mineral salts, B5 vitamins and supplements (per liter) of 2 mg 2,4-D, 30g sucrose, 7.7 mg glycine, 200 mg L-asparagine, 0.25 mg calcium pantothenate, without or with 0.5 mg D-biotin and 5 mg ascorbic acid. The fast growing finely dispersed suspensions required 3 to 16 months to establish. The suspensions consist of small cells filled with cytoplasm and large vacuolated cells. From these suspension cultures, protoplasts were isolated and transformed by post-doctoral researchers Drs. Jianying Peng and Fujiang Wen in Dr. Thomas K. Hodge's laboratory in the Department of Botany and Plant Pathology, Purdue University. The protocols for protoplast isolation and transformation were similar to those used for rice protoplasts. Protoplasts were readily isolated from three day old subcultures of two sorghum cultivars. Protoplast-derived calli have been obtained from both cultivars. Attempts to regenerate the suspension cultures and the protocalli are underway.

Isolation and Characterization of Water-soluble Striga Seed Germination Stimulants. Bupé Siame and Larry G. Butler, Purdue University, West Lafayette IN.

The seeds of *Striga asiatica* (witchweed) germinate only when they have been exposed to chemical stimulants released from a potential host root. The purpose of this investigation was to isolate and characterize water-soluble *Striga asiatica* germination stimulants exuded by Sorghum roots.

Sorghum seeds were surface sterilized, germinated on wet filter paper in the dark and grown on wet cotton or glass wool. Water-soluble exudates were collected daily until the seedlings were ten days old. The stimulant activity from the aqueous exudate was extracted into ethyl acetate, the ethyl acetate was removed and the residue was taken up in methanol. The crude stimulant was loaded on to a Sephadex LH20 column and eluted with methanol. Fractions with stimulant activity were pooled and the methanol volume reduced. The sample was further purified by HPLC on a C-18 preparative column and the HPLC peaks collected as separate fractions. UV/VIS spectra of the peaks were obtained by using an on-line Photodiode Array Detector. The peaks with stimulant activity were subjected to chemical tests and the mass spectrum was obtained.

Stimulation and Inhibition of *Striga* Seed Germination. Yohan Weerasuriya and Larry G. Butler, Purdue University, West Lafayette IN.

We are investigating several natural and synthetic materials and environmental factors which influence the germination of preconditioned *Striga asiatica* seeds.

Sorghum cultivars susceptible to *Striga* infestation have been shown to produce a water-soluble germination stimulant. Some resistant cultivars do not produce this stimulant. Other plant species such as cowpea and soybean also produce a stimulant or stimulants that germinate *Striga asiatica* seeds. Several other legumes and cereals are being tested for the production of water-soluble germination stimulant.

Nonionic and cationic detergents have proved to be good inhibitors of *Striga* seed germination. Chicken antibodies have also been shown to inhibit *Striga* seed germination. Rabbit antibodies against surface antigens on *Striga* seeds are now being tested as inhibitors of *Striga* seed germination.

Breeding

Soil Bioassay for Evaluating Al-Tolerance of Sorghum and Millets. J.L. Ahlrichs, G. Ejeta, W.G. Smart and T.G. Toulemonde, Purdue University, West Lafayette, IN.

A rapid bioassay is used to evaluate the physiological tolerance of genotypes of sorghum and pearl millet to the aluminum in acid soils. The bioassay is based on root elongation in appropriately toxic soil vs. non-toxic soils during the first two or three days after germination. Six studies using the bioassay demonstrate:

1. a distinctly different frequency distribution of root lengths in a tolerant sorghum, SC283, than in sensitive, TAM428.

2. the ability to clearly separate tolerant from sensitive sorghum genotypes from a collection classified by L.M. Gourley from field and greenhouse/growth chamber studies.

3. the ability to separate tolerant from sensitive sorghum genotypes from a collection classified in Brazil by V.C. Baligar et al. from field and greenhouse studies.

4. the necessary sensitivity to illustrate the dominance of Al tolerance and the presence of hybrid vigor in the F1 of a cross between tolerant, SC283, and sensitive, TAM428 genotype; and to determine the segregation ratio in the F3 seed of this cross.

5. the greater Al tolerance of R.R. Duncan's regenerated TX 430 (R-TX430) over the parent (TX430).

6. the much greater tolerance of millet than of sorghum for Al with no individual genotypes among the millets studied showing a particularly greater or lesser tolerance.

Tester Choice in Evaluating New Parental Lines in Grain Sorghum [*Sorghum bicolor* (L.) Moench]. Chibwe Chungu, M.A. Abdullai, J.H. Harris and D.J. Andrews, University of Nebraska, Lincoln NE.

Breeding hybrids involves developing both male and female (A-lines) inbred parents. For economy in breeding evaluation of emerging B-lines (A-lines maintainers) for combining ability (CA) through crossing on appropriate male sterile testers should be done at an early stage. The type of testers to use is however important. In our research three types of testers were compared; (1) an inbred A1 restorer (sterilized on A2 cytoplasm - tester 1), (2) a random mating ms_3 population (tester 2), and (3) a male sterile cms F1 hybrid (tester 3) in three locations. An experiment was conducted with 54 testcrosses derived from crossing 18 possible B-lines to each tester. Principal objectives were: (1) to determine if testers differed in ranking males for CA, (20 to see if testers differed in how well they best separated the B-lines for CA. The mean yield of testcrosses of tester 1 over location (5960 kg/ha) was significantly higher than the mean yields of tester 2 (4860 kg/ha) and tester 3 (5260 kg/ha) which were not different. Generally, no correlation was found in ranks of males either between or within location so that CA values are only applicable to tester and location. The variances between testcrosses within testers were similar, thus any tester would be equally effective. However, the magnitude of the variance for tester 1 was higher than that of tester 2 and tester 3.

<u>Estimation of Synthetic Variety Yields in Pearl Millet *Pennisetum glaucam* (L.) R. Br. Through Parental Line Evaluation, *per se* and in Tester Combinations</u>. R.M. Chirwa, D.J. Andrews and J.F. Rajewski, University of Nebraska, Lincoln NE.

Pearl millet is a naturally cross-pollinated crop. In countries where hybrid production is not yet feasible, improved heterotic varieties remain the best option due to ease of multiplication and stable performance. Superior synthetic varieties are only produced where parents which combine well are used, however, many complete diallel tests become too resource-consuming where several morphologically different synthetics are possible. In this study, three varieties were made from three designated sets of parent lines. In each case, predictions of variety performance were compared using parent line <u>per se</u> values, testcross values from a partial diallel, and topcross values to a common unrelated variety tester, and combinations of these. Predictions were compared to actual variety performances.

<u>Assimilate Partitioning in Reduced Progressive Senescent Sorghums at Different Growth Stages</u>. J.A. Dahlberg, D.M. Vietor and F.R. Miller, Texas A&M University, College Station, TX.

Two reduced progressive senescent and two senescent sorghums were field grown at the TAES research farm near College Station, TX in 1989 and 1990. The first fully expanded leaf (panicle differentiation) and the penultimate leaf (anthesis and grain fill) were exposed to 3.7 MBg of 14C02 for four minutes while sealed in an illuminated leaf chamber at constant temperature (30 C). Whole plants were harvested four days after labeling and ground. One hundred mg samples were combusted using a Packard Oxidizer and counted using liquid scintillation techniques. At panicle differentiation approximately 65-75% of the 14C recovered was found in new and expanding leaf tissue while 25-35% went to root and stem tissue. At anthesis, a significantly larger percentage of 14C assimilate was recovered in the main stems of BTx378 than all other cultivars. More 14C-assimilate was partitioned to panicles of RTx430 compared to all other cultivars. B35 contained greater recovered label in the labeled leaf than all other cultivars. At grain fill, the percentage of label in the grain of RTx430, RTx7000 and BTx378 were significantly greater than B35. Conversely, the percent recovery of 14C-assimilate in the labeled leaf of B35 was greater than other cultivars. At present, research is being conducted to determine the amounts of labeled sucrose, fructose, glucose and starch in the four cultivars under study using a modified colorimetric assay.

<u>Overall Acid Soil Tolerance: Several Pieces of The Mechanism Puzzle in Sorghum</u>. R.R. Duncan and R.E. Wilkinson, University of Georgia, Griffin GA.

Acid soil stress is a major constraint on crop production in many subtropical and tropical regions of the world. Sorghum is quite sensitive to the complex problems associated with acid soils: Al and Mn toxicities; Ca and Mg deficiencies. Little is known about the physiological - biochemical parameters involved in acid soil stress tolerance. Since stress phenomena are multifaceted and sorghum plants react and attempt to 'adapt' to stress, basic investigations must concentrate on each piece of the complex puzzle and ascertain its interactive relationship to the overall tolerance mechanism. Thus far, Georgia research has shown that 1) Al^{3+} toxicity is handled by exclusionary mechanisms at the soil-root interface, 2) gibberellic acid (GA) precursor biosynthesis and its subsequent influence on shoot growth is influenced by excess $[H^+]$ and $[Mn^{2+}]$ interactions, 3) excess H^+ and Mn^{2+} interact with indoleacetic acid (IAA) influence on root growth, and 4) excess H^+ interacts with electrogenic ion pumps (via H^+ - ATPases) and ion pores or channels (voltage-gated openings through which ions diffuse into the cytosol) to mediate influx - efflux of critical ions such as Ca^{2+}, Mg^{2+}, and others. Genotypic differences have been found for all these phenomena and additional studies should provide more insight into the complex tolerance puzzle.

<u>Breeding Photoperiod Sensitive Hybrids.</u> Francisco Gomez and Dan Meckenstock, TAM/EAP, Tegucigalpa, HONDURAS.

Photoperiod sensitivity is routinely bred out of tropical sorghum in order to adapt it to Temperate Zones. In the tropics, where growing seasons are longer, photoperiod sensitivity can be used as a tool to increase crop production. Sorghum breeding efforts in Honduras are aimed at blending the yield potential yield developed in temperate sorghums with photoperiod sensitivity genes of tropical sorghums to increase production. These cultivars are custom engineered for Central America and contrast strikingly with conventional lines and hybrids. They ar taller, later maturing, and can sustain a high rate of growth for a longer period of time. Although yield potential is still being improved, preliminary maicillo hybrids yielded 5.8 t/ha in demonstration plots. This is 6 times the national yield average.

<u>Characterization of Sorghum Genotypes for Glycinebetaine.</u> Edwin M. Grote, G. Ejeta, Wen-Ju Yang and D. Rhodes, Purdue University, West Lafayette, IN.

Glycinebetaine is thought to play a role as a cytoplasmic osmotic solute and/or osmoprotectant in some higher plant species. The objective of this study was to evaluate genotypic variation in sorghum, monitor glycinebetain accumulation during crop development, and to determine if deficient mutants have the ability to synthesize glycinebetaine when provided with appropriate precursor. Post-flowering analysis of the flag leaves of over 230 genotypes of sorghum (*Sorghum bicolor* (L.) Moench) grown at West Lafayette, Indiana indicated a range of glycinebetaine levels from 0.1 to 33 μmol/gfw. Sampling for glycinebetaine every ten days (from 6 weeks after planting to physiological maturity) among seven selected genotypes grown under a stress free environment indicated that levels of glycinebetaine are low when the plant is in the vegetative phase and increase as the plants reach maturity. Glycinebetaine deficient mutants supplied with $^2H_3$-betaine aldehyde oxidized this precursor to $^2H_3$-glycinebetaine indicating that deficiency is not at betaine aldehyde dehydrogenase, but more likely at the choline monooxygenase step in the biosynthetic pathway. F_1 hybrids between beta and null glycinebetaine genotypes showed intermediate levels suggesting that the deficiency may be inherited as a recessive gene. Genetic studies are currently underway to establish the mode of inheritance for glycinebetaine accumulation more clearly.

<u>A Study of Some Physiological Components of Drought Resistance in Some Inbred Sorghum [*Sorghum bicolor* (L.) Moench] Lines and Progenies Subjected to Prolonged Water.</u> B.W. Khizzah, R.J. Newton, F.R. Miller, D.T. Rosenow and J.T. Cothern Texas A&M University, College Station, TX.

Water potential, osmotic potential, relative water content, percent moisture loss and heat tolerance components of drought resistance were determined over a range of water stress in some inbred sorghum lines and their progenies. The study was conducted as a first step in the investigation of the genetic control of these characters. Cultivars RTx430, BTx3197, RTx7000, B35, F_1 and reciprocals were grown in the greenhouse under conditions typical of warm humid and sunny days and were adequately watered until anthesis when watering was withheld and the media allowed to dry slowly. Significant differences were observed among cultivars for all characters at different stress levels. F_1 were either lower or higher than the parents, reciprocals and F_1 means in most cases were significantly different suggesting cytoplasmic influence. Correlations were observed between above ground dry matter, osmotic potential and percent moisture loss; between heat stress and relative water content and between water potential and relative water content. Further studies in the F_2 segregating populations and backcrosses should provide a better understanding of the genetic control of these characters.

The Use of Protogyny to Make Grain Hybrids in Pearl Millet. Barnabus Kiula, D. Andrews and J.F. Rajewski, University of Nebraska, Lincoln, NE.

In pearl millet, hybrids are restricted to those combinations that can be made between existing nuclear-cytoplasmic male sterile (cms) seed parents and good restorers. The use of natural protogyny (the period between stigma emergence and anther dehiscence on a head) to make hybrids is less restrictive and would permit superior combinations to be used and, also, avoid problems associated with cms. Some selfing in the designated protogyny "seed parent" might, however, occur but its effect will depend on competition in the hybrid crop between inbred and hybrid plants. To investigate this, experiments on three pro-hybrids were conducted using mixed proportions of hybrid and inbred ("seed parent") seed. In two cases, the presence of up to 20% inbred seed did not result in a significant reduction in hybrid yield. The use of protogyny to make hybrids in pearl millet appears to have potential even if some "seed parent" selfing occurs, provided a dominant hybrid phenotype is chosen.

Use of Mutagens to Induce Variability in Finger Millet. F.R. Muza, S.C. Gupta, D.J. Lee and D.J. Andrews, University of Nebraska, Lincoln NE.

In finger millet there is a lack of variability for useful traits which have been discovered in other cereals, such as genetic male sterility, major height genes, certain grain traits such as waxy, and forage traits such as the brown mid-rib (bmr).

To attempt to create such variability, seeds of 10 finger millet varieties were treated with 5 doses of x-rays (10, 20, 30, 40 and 50 Kr), and another set of the same varieties was treated with 5 doses of ethylmethanesulfonate (EMS) (0.2, 0.4, 0.6, 1.0 and 1.5%). We will be screening segregating generations for the traits described.

Comparative Performance of Single, Three-Way and Double-Cross Sorghum Hybrids in A1 and A2 Cytoplasms. G.A. Ombakho and F.R. Miller, Texas A&M University, College Station, TX.

Two different sets of field trials were conducted during the summer season of 1990 at the Texas A&M University, College Station research farm. The purpose of the trials was for preliminary comparison of performance among different types of sorghum (*Sorghum bicolor* (L.) Moench) hybrids. Two different sources of cytoplasmic-genic male-sterility (A1 and A2) were used in the production of the hybrids. Data were recorded for grain yield, 1000-seed weight, and test weight. Similar trends were observed in the two sets of experiments. The hybrids significantly outperformed the parental lines for all the traits. Single crosses and three-way crosses gave equivalent means for grain yield but differed significantly for the other traits. Single crosses yielded significantly more than double-cross hybrids. The difference in mean yield between three-way and double-cross hybrids was not significant.

Interaction Effects of Sorghum Genotype, Water Level and Nutrient Level. A.B. Onken, G.C. Peterson, M.D. Doumbia, A.A. Sow and D.T. Rosenow, Texas A&M University, Lubbock, TX.

Major constraints to sorghum production in Sahelian Africa are low soil fertility and lack of available water. These two factors frequently interact, resulting in food shortages.

Sorghum breeding lines have been studied in field, greenhouse and lysimeter trials in the U.S. and West Africa in an effort to identify and define differences in responses to 1) low levels of water and fertility, 2) minimum inputs and 3) interaction effects of water and fertility.

Results have consistently shown that yields at low and high fertility, as well as yield responses to inputs, are all independent of one another. Thus, the popularly held concept that selection of sorghums under adequate nutrient conditions will result in sorghums that perform well under nutrient stress is not correct. Sorghum performance at low nutrient levels, yield potential under good conditions and responsiveness to inputs appear to each be under separate genetic control.

Soil fertility level has small effects on ET, but results in proportional changes in E and T. Percentage increases in WUE_{ET} are linearly and positively related to percentage increases in yield due to soil fertility, even at small percentages of increased yield. Increasing soil fertility level results in increased T and decreased E under field conditions. The resulting increased yield is proportionally different per unit of T than under lesser fertility conditions, resulting in increased WUE_T. The above results indicate that two additional popularly held concepts are not correct; 1) it is necessary to have large (>50%) increases in yield to derive a benefit from fertilizer in improving WUE_{ET} and 2) that WUE_{ET} increases under field conditions due to fertilizer, where ET is little changed, are due to reductions in E and not increases in WUE_T.

Sorghum genotype, water level and fertility level interact to affect nutrient use and water use efficiencies. This interaction must be quantified in order to have sufficient knowledge to develop appropriate agronomic solutions to insure stability and sustainability of sorghum production in Sahelian Africa.

Genetic Variation Among African Pearl Millet Populations. B. Ouendeba, G. Ejeta, W. Hanna and A. Kumar, Purdue University, West Lafayette, IN.

Pearl millet [*Pennisetum glaucum* (L.) R.Br.] is widely grown in the semi-arid regions of Africa. Farmers rely on diverse landraces that have good yield stability but limited yield potential. The objective of this study is to characterize and describe pearl millet landrace populations for their efficient utilization in breeding programs. Ten populations widely grown in several African countries and two experimental pearl millet hybrids were evaluated at two locations in Niger during the 1989 rainy season. Downy mildew incidence, days to flowering, spike length, peduncle length, spike girth, flag leaf width, stem diameter, spike number per plant, nonproductive tillers per plant, plant height, spike yield per plot, grain yield per plot, and 1000-seed weight were measured on the different entries. The populations were all significantly different for all characters evaluated. The Niger landraces showed much less variation than the other African millets for all characters investigated. Ward's cluster and principal component analyses were used to investigate the nature and degree of divergence in these populations. The cluster analyses revealed similarities between Niger and Senegal as well as between Niger and Nigeria pearl millet landraces. Four principal components were found to explain more than 90% of the total variation. Flowering time, plant height, stem diameter, spike length, and yield seemed to be the major sources of diversity among the populations. These results could be useful in choosing potentially heterotic pearl millet populations for intercrossing in the development of improved varieties, synthetics, and hybrids for use in Africa.

Heterotic Patterns Among African Pearl Millet Landraces. B. Ouendeba, G. Ejeta, W. Hanna and A. Kumar, Purdue University, West Lafayette, IN.

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is a major staple food of the semi-arid regions of Africa. Local landraces that have evolved in the region have stable but low grain yield. The objective of this study was to evaluate the combining ability and heterosis among African pearl millet populations and to explore the utility of interpopulation improvement for higher grain yield. Five populations and their 10 interpopulation crosses were evaluated in a randomized complete block design with six replications at two locations in Niger during the 1989 and 1990 rainy seasons. Natural incidence of downy mildew, flowering time, spike length, spike girth, number of productive tillers per plant, plant height, spike yield, grain yield, and 1000-seed weight were measured on different populations. An analysis of variance was performed on all traits across locations and years. Griffing's Method 4, Model 1 was used to estimate the general and specific combining ability effects. Significant differences among entries for most of the traits were observed. High parent heterosis for grain yield ranged from 25% (Iniari x Ugandi) to 81% (Mansori x Ex-Bornu). Six of the crosses showed significant heterosis and gave 36 to 81% more grain yield than their best parents. All crosses except one were significantly more tolerant to downy mildew than their best parents. Mean squares for general combining ability were significant for most traits indicating the importance of additive gene effects for these traits. The large heterotic effects and the magnitude of the additive effects indicate that pearl millet breeders in the semi-arid regions of Africa can make significant progress by using selections after recombination of these diverse populations.

<u>Genetic and Morphological Characterization of Epicuticular Wax Mutants</u>. Paul J. Peters, J.D. Axtell, P.J. Rich, M.A. Jenks, Y. Kebede and S.E. Wyatt, Purdue University, West Lafayette IN.

Epicuticular wax (EW) has been associated with drought resistance in sorghum. This may result from reduced cuticular transpiration and/or increased dispersion of heat through the reflection of light. Our studies utilized sets of near isogenic lines of normal, bloomless (no visible EW), and sparse bloom (reduced visible EW) mutants developed through chemical mutagenesis. Determination of chemical, morphological, and genetic variation as well as performance under drought stress has been made. Differences between EW mutants are being associated with quantitative and qualitative differences in EW chemical composition, and EW structure, as revealed by scanning electron microscopy (SEM). Allelism tests distinguish at least three loci involved in EW production among 23 mutants characterized. Segregation ratios support the hypothesis of simple inheritance for 19 of 29 EW mutants evaluated. In addition, yield trials conducted under irrigated and drought stressed conditions demonstrate correlations between EW production and drought resistance. Disease resistance to fungal pathogens also has been associated with EW differences.

<u>New Opportunities with Male-Sterile F_1's and Three-Way Hybrids in Pearl Millet</u>. K.N. Rai, C.T. Hash and A.S. Rao, ICRISAT, Andhra Pradesh, INDIA.

High grain yield and phenotypic uniformity are the two most important attributes of single-cross grain hybrids in pearl millet [*Pennisetum glaucum* (L.) R. Br.]. However, seed production of these hybrids is constrained by low seed yield of the male-sterile inbred lines and rapid breakdown of their resistance to downy mildew [*Sclerospora graminicola* (Sacc.) Schroet]. These two adverse factors increase the cost of hybrid seed production and call for ambitious disease resistance breeding efforts to provide for the rapid replacement of hybrid parents. Both of these problems may be overcome, to a larger extent, by resorting to male-sterile F_1's for breeding three-way hybrids. Results of nine male-sterile F_1's and their parental lines evaluated in 11 environments showed that male-sterile F_1's outyielded their higher-yielding parental lines by 30-108%, and their flowering tended to be more in the direction of the earlier-flowering parental lines with heterosis in the range of partial dominance to overdominance. This heterosis for earliness should facilitate seed production of three-way hybrids with early-flowering restorers. Preliminary results also showed that (a) downy mildew resistance of male-sterile F_1's was comparable to their more resistant parental lines, (b) three-way hybrids based on male-sterile F_1's tended to have grain yield and maturity comparable to single-cross hybrids based on their early-maturing parental lines, and (c) phenotypic variability in three-way hybrids was, as expected, slightly more than in single-cross hybrids but much less than in open-pollinated varieties. These results suggest that male-sterile F_1's may provide new opportunities for (1) reducing the cost of hybrid seed production, and (2) producing three-way hybrids having appropriate maturity and high grain yield coupled with greater yield stability and an acceptable level of phenotypic variability.

Environmental Effect on Protein Content in Isogenic Sorghum with Different Plant Color. R. Rodriguez-Herrera, H. Williams-Alanis and I. Garza-Cano, INIFAP CIFAP-TAM, Tamaulipas MEXICO.

During 1989 and 1990, in the Rio Bravo Experimental Station at Rio Bravo, Tamaulipas, Mexico, a study was carried out to compare grain and forage total protein on isogenic sorghum for plant color. The genotypes evaluated were 34: six B lines (3 with red color plant (R) and its 3 isogenic version in tan color (T), four R lines (2 (R) and 2 Tan) and 24 hybrids (6 RxR, 6 RxT, 6 TxR and 6 TxT). All of them were grown with irrigation in the springs of 1989 and 1990.

The protein analysis was made by the Harris method (1970) at grain physiological maturity. The plant (without root) was divided in grain and rest of the plant and were analyzed by the same method.

In the evaluation of 1989, the grain protein content among the hybrids was higher in those where the female parent had tan color; the protein content followed the order Tan x Tan > Tan x Red > Red x Tan > Tan x Tan, with 7.0, 6.7, 6.3 and 6.2 percent respectively. While among the B lines, the tan plant had higher protein content than those of red plant. Among the R lines the grain of the red plant genotypes presented more protein.

In the evaluation of 1990, the order was RxR>RxC>TxT>TxR, while in both B and R lines the tan plant sorghums presented less protein content. In two years was observed that genotypes with more grain protein content presented less forage protein content

Sugar Partitioning and Resistance to Charcoal Rot in Sorghum. A. Tenkouano, F.R. Miller, R.A. Frederiksen, D.T. Rosenow and J.T. Cothren, Texas A&M University, College Station, TX.

The relationship of nonstructural carbohydrate partitioning and resistance to *Macrophomina phaseolina (Tassi)* Goid in *Sorghum bicolor* (L.) Moench was investigated. The carbohydrate content of stems, leaves, and panicles of two resistant (B35, SC599-11E) and two susceptible cultivars (BTx378, BTx623) and their F_1 progenies were determined at boot stage, anthesis, 15 days after anthesis, physiological maturity and 15 days after physiological maturity. These materials were also inoculated with *M. phaseolina* at anthesis, 15 days after anthesis, and physiological maturity, under water stress and nonstress conditions.

Significant differences were found between cultivars for disease response *in vivo*. Significant differences also were obtained for NSC content and partitioning between plant parts over time. Stem soluble NSC depletion rates were lower for resistant cultivars than for susceptible cultivars. Resistant lines also maintained relatively constant NSC levels due to a partial compensatory increase in reserve NSC content. In contrast, both soluble and reserve NSC were depleted in susceptible cultivars.

Highest infection levels were obtained with inoculation at anthesis, i.e. when inoculation was followed by a period of rapid stem sugar depletion. No evidence was found to support the concept of grain fill as the driving force in stem sugar depletion.

Grain Filling Rates in Some Genotypes of Sorghum [*Sorghum bicolor* (L.) Moench]. A. Toure, F.R. Miller, L.W. Rooney and C. McDonough, Texas A&M University, College Station, TX.

Malisor 84-7 developed in the Malian Sorghum Improvement Program is so far the only improved variety known to have significant resistance to head bug (*Eurystylus marginatus*). Three experiments were conducted to determine grain filling rates, moisture content, change in kernel structure during development of different cultivars, and to explore characteristics of Malisor 84-7 as associated with head bug resistance.

Cultivars showed differences in grain filling rates. Dry matter accumulation was faster for Malisor 84-7 kernels than for CSM-63, BTx623, and Black sorghum. Black sorghum had the lowest dry matter percentage. The dry weight of gain/day (g) of Malisor 84-7 increased rapidly from day 0 to 6, and then leveled off, while the other cultivars continued to increase until day 12 to 15. Moisture content also showed differences among cultivars. Malisor 84-7 consistently has the lowest water content in the caryopsis. Black sorghum had the highest water content during development and drydown.

Using scanning electron microscopy we saw that protein bodies began to develop in CSM-63 and Malisor 84-7 three days after anthesis, and by six days for the other varieties. Starch filling in Malisor 84-7 and BTx623 was rapid.

The resistance character(s) of Malisor 84-7 seem to be the hardness and the ratio of water/carbohydrate concentration in the developing caryopsis and only indirectly to rapidity of dry matter accumulation, glume length, and glume opening.

Selecting Sorghum Genotypes for *Striga* Resistance Using An Agar Gel Assay. R. Vogler, G. Ejeta and L.G. Butler, Purdue University, West Lafayette, IN.

Resistance to *Striga spp.* (witchweed) in some varieties of sorghum (*Sorghum bicolor* (L.) Moench) can be attributed to low stimulation of *Striga* seeds to germinate. A laboratory assay was developed as an aid to separate genotypes in segregating populations. The assay utilizes conditioned *Striga* seeds embedded in water agar and screens for the capacity of water-soluble root exudate of a host plant to stimulate the germination of *Striga* seeds. Three sorghum cultivars, SRN39 (resistant), Framida (resistant), P954063 (susceptible), and 29 F_7 progenies resulting from intercrosses among them and selected for agronomic traits and grain quality under *Striga*-free conditions, were screened with this assay for their capacity to stimulate the germination of *S. asiatica* seeds. Measurements of distance from the 72 hour-old host root to the furthermost germinated *Striga* seed were recorded and differences between the lines allowed for the separation into classes of low and high stimulators. All genotypes were also tested for field resistance under *S. asiatica* and observations were recorded for sorghum vigor loss at 52 and 73 days after planting, days to half-bloom, grain yield; and for *Striga* days to first bloom, weekly counts beginning from 8 weeks after planting through harvest, and dry weight of *Striga* at sorghum harvest. An analysis of variance was conducted on all field and laboratory data. Highly significant differences were found among genotypes for all variables analyzed. Stimulant production, as determined through measurement of germination distance, was significantly correlated with all parameters of *Striga* infestation and effect of the parasite on the host indicating promising use of the agar assay as a screening technique for gentic resistance to witchweed.

Entomology

Decision Tools for Grasshopper Control in The Sahel - Project Overview. Leonard Coop, B. Croft and M. Kogan, Oregon State University, Corvallis OR.

Crop loss assessment and crop/pest damage research are necessary for developing integrated pest management programs. Improved economic thresholds for grasshoppers in the Sahel are being developed from survey, experimental, and modeling approaches. Survey and experimental data from 1990 and 1991 crop seasons were collected around

Mourdiah, Mali in collaboration with the Mali crop protection service (NPV), Mali IER, British NRI Pilot IPM project, Ciba-Geigy, USAID/Africa Bureau, and USAID/Mali. Grasshoppers, other millet pests and millet were sampled every 10 days in 3-4 fields in 8-14 villages during the preharvest period. Insecticide treatments were the regular practices used by farmers and NPV; which ranged from 0-4 applications in 1990. Fields in selected villages had 0.5 ha areas left untreated as control plots. At harvest, yields and losses from drought and pests were assessed using the 'adjusted length method' of crop loss assessment. Relationships between grasshopper densities, percentage defoliation, and yield loss were significant for data collected over a wide range of crop and treatment conditions in 1990. Experimental caging studies of grasshopper feeding behavior and injury rates were used to compare five chronic savannah species. Sleeve cage experiments in 1990 gave highest spike damage rates by *Kraussaria angulifera* and *Cataloipus cymbiferus*. *Hieroglyphus daganensis* damaged millet at a higher rate during the early milk stage than early flowering and dough stages. Damage of individual kernels was greatest (>50% dry weight removed) for flowering to mid-milk stage feeding. Survey and experimental data will be used to revise a model simulating grasshopper injury to Sahelian millet (GHLSIM), first developed for *Oedaleus senegalensis* from 1987-1989. Field and modeling results are being used to show effects of grasshopper densities on crop loss over a wide range of crop and environmental conditions. These relationships will be used to develop economic injury levels and economic thresholds, and to allow decreased reliance on chemical control. Initial comparisons and economic evaluation of alternative and more sustainable methods of pest control are planned for 1991-92.

Millet Crop Loss Assessment and Pest Damage Recognition. Leonard Coop, G. Dively, A. Dreves and B. Croft, Oregon State University, Corvallis, OR.

A method of assessing crop losses in millet, known as the 'adjusted length method', was developed with USAID support between 1983 and 1990. Although the method provides a high degree of precision for effort expended with direct spike pests, losses from indirect factors such as drought, weeds, and stem borers can also be estimated. The method involves summing spike damage lengths that are first adjusted relative to spike size on a per hill basis and using proportionality equations to estimate losses. In surveys conducted in Senegal (1983), Gambia (1984), Chad (1987) and Mali (1990), losses from aborted plants and spikes and reductions in plant hill population were equal to or greater than the combined losses due to direct pests, which averaged 25, 11, 36 and 32% of yields. *Heliocheilus* head borers and downy mildew were the greatest loss factors in the 1983 and 1984 surveys. Grasshopper damage ranked second and first in importance in the 1987 and 1990 surveys, compared to less than 5% during the earlier two surveys.

In 1990, losses in 42 fields from 14 villages in Mali were assessed. Yields averaged for villages ranged from 29 to 1271 kg/ha. Total pest losses ranged from 18 to 87% (mean = 32%). Grasshoppers were the greatest cause of loss, ranging from 4 to 71% of the total pest losses, followed by losses of up to 24% by blister beetles. Losses by *Pachnoda* beetles, *Heliocheilus* head borers, birds, and diseases were common but less severe.

The adjusted length method offers several advantages over other loss assessment techniques. It provides results based on averages weighed for spikes of variable size and allows for explicit calculations of yield and pest losses. It also eliminates bias due to pest/spike size interactions, without the need for conversion factors or threshing of grain. Comparison with a similar method developed by GDZ for use in Niger is planned for 1991.

Damage symptoms to millet spikes from major loss factors, including birds, grasshoppers, *Pachnoda* blister beetles, head borers, stem borers, and diseases are displayed with diagnostic features as an aid for detection and assessment of damage.

SORKAM: A Grain Sorghum Crop Growth Model. Douglas Jost, G. Teetes, T. Gerik and W. Rosenthal, Texas A&M University, College Station, TX.

The simulation model SORKAM describes the morphological development of a well-fertilized single grain sorghum plant in response to the environment. SORKAM is intended as a guide for further research to evaluate growth and development of grain sorghum, as well as an aid in making managerial decisions. Applications of SORKAM include evaluating sowing date alternatives, evaluating row spacings or plant populations, scheduling irrigation, evaluating yield variations for years of above and below normal rainfall, and assessing the impact of stresses on grain yield.

The addition of a sorghum midge (*Contarinia sorghicola*) interaction component to the model may prove beneficial in monitoring midge population outbreaks, timing insecticide applications for maximum effectiveness, and evaluating new management strategies. Validation of the sorghum midge component of the model is being conducted by gathering data in Nueces and Hill counties. However, research is still needed before substantial results may be indicated.

Sorghum Resistance to Sugarcane Aphid in Southern Africa. C.S. Manthe, G.L. Teetes, G.C. Peterson and K. Leuschner, Texas A&M University, College Station, TX.

Sorghum cultivars from Botswana and Zimbabwe, converted lines from Texas A&M University, and breeding lines from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), were screened for resistance to the sugarcane aphid, *Melanaphis sacchari* (Zehntner) in the greenhouse. Resistance mechanisms and inheritance of resistance were also assessed in the greenhouse and field, for a selected group of resistance lines. Resistance was confirmed in 30 lines from Texas A&M University, five breeding lines from ICRISAT, and seven cultivars from Zimbabwe. Six lines (TAM428, IS12609C, IS5188C, IS12664C, IS1144C, and SA1429) had high levels of antibiosis and antibiosis and antixenosis as seedlings and mature plants. Low levels of antibiosis and tolerance to aphid feeding were found in lines IS12637C, IS6264C and IS12610C. Progenies of crosses between resistant (TAM428, IS12661C) and susceptible (ATx3038, SC120) parental lines segregated in a 3:1 ratio (resistant: susceptible) indicating that resistance was inherited as a dominant, monogenic character.

A Combined Approach to Evaluate Natural Mortality in Sorghum Midge. Ricardo Magallanes-Cedeño, G.L. Teetes and J.H. Matis, Texas A&M University, College Station, TX.

A field data collection of sorghum midge, *Contarinia sorghicola* Coq. (Diptera: Cecidomyiidae) is analyzed through a conventional life table procedure and compartmental models theory. Random samplings of florets of a susceptible sorghum plot planted May 18, 1990 were made since anthesis every two or three days in College Station, Texas. Each floret was dissected under a microscope, and the number, life stage, and position of sorghum midges were recorded. A discussion is presented showing how results provided by conventional life table procedures are conveniently reinforced by those obtained with compartmental models analysis, since this technique provides prompt information on turnover rates among development stages of the insect. Knowledge of these type of factors can be a valuable tool for modelling purposes.

Food Quality and Nutrition

Weaning Food from Composite of Extruded or Press Dried Pearl Millet and Cowpea. H.D. Almeida-Dominguez, M.H. Gomez, S.O. Serna-Saldivar and L.W. Rooney, Texas A&M University, College Station TX.

Weaning foods were produced from a composite of 70% pearl millet (*Pennisetum americanum*) and 30% cowpea (*Vigna unguiculata*). Decorticated millet flour was puffed using a Wenger TX-52 twin-screw extruder or heated with 3 parts of water and pressed against a hot griddle to produce dry flakes. Dehulled cowpea was boiled, ground and press dried. Press drying increased the water absorption (WAI) and solubility (WSI) indices and enzyme susceptible starch (ESS) of decorticated millet flour 2.6, 1.6 and 2.8 times, respectively. While extrusion puffing increased them 2.3, 2.6 and 2.7 times, respectively. Press dried millet showed higher WAI than extruded millet and two commercial rice and high-protein baby foods. WAI of cowpea increased 2.5 times during processing while the WSI decreased by 75%. Composite flours developed more cold viscosity than commercial samples. Addition of 15% sugar reduced the viscosity by one third. Composites and commercial samples had ESS values of above 80 and 98%, respectively. Composites had 17% protein and 72 and 110%, respectively, of the RDA/WHO lysine and threonine requirements for a 2 year old child. Composites are suitable for cold baby food pastes or for further enzyme treatment (malt addition) to produce drinkable baby food.

Parboiling Technologies Applied to Pearl Millet (*Pennisetum americanum*). C.J. Clegg, L.W. Rooney, R.D. Waniska, Texas A&M University, College Station, TX.

Pearl millet (*Pennisetum americanum*) was parboiled by boil-soak-boil, soak-boil, and soak-boil-soak methods. Then parboiled millet was dried at room temperature (23°C) for 3 days or sun dried (30°C) for 8 hr. A soft and intermediate endosperm types of pearl millet was used. Milling properties, texture and chemical analysis were measured on parboiled and nonparboiled pearl millet. For texture, an Ottawa Texture Measurement System loaded onto a 4500 series Instron Universal Testing Machine extruded the cooked parboiled and nonparboiled pearl millet and maximum force of extrusion was recorded.

Parboiling improved the milling properties of pearl millet. No significant difference was observed between BSB and SB parboiling methods. Soft endosperm millet showed significant decortication yield improvement (control, 71%; parboiled, 82%). Drying at room temperature had better decortication yield than drying by sun. BSB parboiled pearl millet kernels had translucent, vitreous endosperm texture. SB and SBS had opaque centers in the endosperm. Protein, lipid and ash content of parboiled pearl millet was slightly lower than the control. Decortication removed more lipid from the parboiled pearl millet than the control. Starch content of control and parboiled pearl millet were similar; ESS of parboiled pearl millet was significantly higher. Cooked nonparboiled pearl millet was more sticky than cooked parboiled millet. Color of cooked pearl millet was not significantly different. Parboiled millet were firmer than raw millet after 14, 18, 22 and 26 min of cooking (i.e., 516 N for parboiled blue pearl millet and 437 N for nonparboiled blue pearl millet at 22 min).

Evaluation of Malting Characteristics in Sorghum Genotypes. de Franca, J.G.E., L.W. Rooney, R.D. Waniska, and F.R. Miller, Texas A&M University, College Station, TX.

Malting characteristics of sorghum are important in the opaque beer industry. Sorghum cultivars and crosses (61) from the breeding program were evaluated for decortication yield and malting qualities, especially diastatic activity. Grain (150 g) was steeped, germinated and dried to prepare malted sorghum. Growing conditions affected decortication and malting properties of sorghum. Highest decortication yields were observed with ATx623*IS9530, ATx623*BTx435, ATx632* BTx 432 and RTx2817. The highest diastatic activity (>24 SDU) was observed in malts prepared from IS9530, ATx378*BTx432, ATx378*IS9530, SA3067 and ATx378*BTx 430. Eight (8) other cultivars produced malts with >20 SDU. Hybrids utilizing BTx378 and IS9530 yielded malts with higher diastatic activity and lower dry matter losses than other parents. Malt quality appears to be the result of additive genetic traits. Genotypes with red pericarp usually had higher diastatic activity. Some sorghum genotypes studied could be used to produce sorghum opaque beer.

Changes of Sorghum Starch during Parboiling. M.H. Gomez, R. Young, R.D. Waniska, and L.W. Rooney, Texas A&M University, College Station, TX.

Sorghum varying in endosperm texture (P721-soft and Dorado-intermediate) and starch composition (R3338-waxy) were parboiled. During the process (boiling, soaking for 12 hr, and boiling) the starch underwent hydration, moisture equilibration and partial gelatinization. Changes in starch during and after processing were analyzed by high performance, size exclusion chromatography and x-ray diffraction techniques.

Solubility of starch at 85°C increased and starch crystallinity slightly decreased during the first boiling. Starch solubility increased during soaking for the regular starch sorghums, while a solubility reduction was observed for the waxy cultivar. A significant increase in starch crystallinity also occurred during soaking, suggesting some realignment of the starch molecules analogous to annealing. The second boiling decreased starch solubility in Dorado and R3338 sorghums, while no solubility changes were observed in P721. Some starch crystallinity remained after the second boiling, indicating that only partial starch gelatinization occurred. The solubility increases probably resulted from the partial gelatinization of starch, while solubility decreases resulted from retrogradation and recrystallization of starch molecules.

In general, parboiling caused some gelatinization and reorientation of starch molecules which decreased starch solubility and crystallinity. Softer endosperm texture contained less dispersible and soluble starch than intermediate endosperm texture. Starch solubility and crystallinity of the waxy cultivar was slightly decreased by the process.

Tannins and Phenols in Black Sorghum. Gous, F., R.D. Waniska, L.W. Rooney and F.R. Miller, Texas A&M University, College Station, TX.

Shawaya, an uniquely black pigmented sorghum found in western Sudan, was investigated for flavonoid pigments in the caryopsis. Shawaya contains substantial amounts of anthocyanidin pigments (27 Abs/ml/g), flavan-4-ols (19 Abs/ml/g) and phenolic acids (0.9 mg/g; mostly ferulic and p-coumaric acids) but only some phenolic compounds (6.7 mg/g) and no tannins. Concentration of anthocyanidin pigments and flavan-4-ols were between 2-10 times greater than ATx623*SC103-12, a red pericarp hybrid containing tannins. During the "conversion" process, Shawaya retained its black pigmentation but tannin content was lost. Light microscopic analysis revealed a thick pericarp with pigments located mainly in the epicarp and the cross and tube cells, i.e. no pigmented testa layer. The original Shawaya cultivar also contained a thick pigmented testa.

Shawaya was efficiently decorticated (78%) in 4 min to reveal a heteroyellow endosperm. The bran contained most (94%) of the pigments and phenolic compounds. Acidic methanol (1% HCl) most efficiently extracted the pigments from the bran. Paper chromatography separated 3 anthocyanidin compounds: luteolinidin (0.30 mg/g), apigeninidin (0.30 mg/g), and an unidentified anthocyanidin (0.22 mg/g). The anthocyanidins differed in their light stabilities; however, the crude extract was considerably more light stable than any of the individual anthocyanidins. All anthocyanidins were stable at 70°C for 24 h; but the crude extract was less stable than the individual anthocyanidins. The anthocyanidins and the crude extract retained 40-50% of their chromaticity at Ph 7 compared to Ph 2. Hence, these pigments would be more effective than most anthocyanidins in foods systems.

Content of phenols in Shawaya changed during caryopsis development with maximum levels observed at 35 days after anthesis [DAA] for phenolic compounds (0.27 mg/caryopsis), 35 DAA for phenolic acids (0.036 mg/caryopsis), and 28-42 DAA for flavan-4-ols (0.76 Abs/ml/caryopsis). Other researchers, however, observed maximum levels of phenolic compounds and tannins at 5-22 DAA, i.e. at immature stages of kernel development. Thus, Shawaya has different biochemical pathways for phenol metabolism than most sorghums.

Absorption and Distribution of ^{14}C-Condensed Tannins and Related Sorghum Polyphenols in Chicks. Jimenez-Ramsey, L.M., J.C. Rogler, T.L. Housley, L.G. Butler and R.G. Elkin, Purdue University, West Lafayette IN.

It is unknown whether condensed tannins and related polyphenols from high tannin sorghum (HTS) grain are absorbed from the digestive tract of animals. To study this phenomenon, immature seeds from an HTS cultivar (BR-64) were labeled with ^{14}C by either: (1) incubation for 4 hours in 100 mM HEPES buffer (pH 7.2) containing $NaH^{14}CO_3$ or (2) exposing whole panicles to $^{14}CO_2$ in a closed system for 7 hours. The seeds were then air-dried, extracted with acidic methanol, and fractionated and purified according to Reddy and Butler (J. Agric. Food Chem. 37:383 [1989]). Four fractions were obtained: aqueous acetate, ethanol (batchwise), ethanol (column), and acetone. The acetone fraction contained ^{14}C-tannin. The acetate and ethanol fractions contained non-tannin, ^{14}C-labeled phenolic compounds. The ^{14}C-labeled fractions were lyophilized, placed into starch capsules and administered directly into the crops of 3-week-old broiler chicks. Blood samples were obtained by cardiac puncture at 8 hours post dosing. Immediately following procurement of the blood sample, birds were euthanized and tissues were collected. All tissues (except plasma) were lyophilized, ground, and oxidized, and the trapped $^{14}CO_2$ was counted by liquid scintillation spectrometry. Plasma was oxidized without pre-treatment. The results suggest that condensed tannins are not absorbed from the digestive tract. In contrast, smaller molecular weight polyphenols contained in the other fractions are absorbed and distributed in various body tissues. These may be at least partially responsible for the observed toxic effects associated with feeding HTS.

Microstructure of Parboiled Sorghum using Scanning Electron Microscopy. C.M. McDonough, R. Young, and L.W. Rooney, Texas A&M University, College Station, TX.

Soft (P721) and hard (Dorado) varieties of sorghum were parboiled using a boil-soak-boil procedure; grain was brought to boil in 15 min., immediately removed from heat and soaked overnight (12 hrs), brought to boil again in 15 min, and finally air dried. This process induced basic structural changes that allowed soft endosperm sorghum varieties to be "hardened" and thus be milled in a manner similar to hard endosperm varieties.

Samples of undecorticated grain were viewed with scanning electron microscopy. Areas that were opaque in raw kernel floury endosperm were transparent and vitreous after parboiling; this was especially dramatic in P721. After α-amylase digestion, it was apparent that the protein matrix became somewhat amorphous. The matrix seemed to have "melted" into the air spaces normally found in the floury endosperm of raw grain, producing a solid, vitreous appearance. However, protein bodies were still round and visible within the protein matrix, and appeared to sustain little structural damage during the parboiling process. Starch in the parboiled grain was partially gelatinized (approx 60% birefringence; determined using light microscopy). Starch granules in treated samples observed with the SEM appeared to contain concentric rings of material, and were judged to be partially gelatinized. The pericarp was compressed and/or distorted in places, but generally was unaffected structurally by parboiling. ß-Glucans in the pericarp, however, bound less die after processing as indicated using fluorescence microscopy.

Microstructure of Parboiled Pearl Millet. C.M. McDonough, C.J. Clegg and L.W. Rooney, Texas A&M University, College Station, TX.

Three parboiling methods (BSB, SBS, SB) and two drying methods (air, sun) were tested to optimize decortication yield in yellow (soft) and blue (hard) pearl millet varieties. The parboiled kernels were harder than the raw controls and appeared to be totally or partially translucent, depending upon the cooking method. Parboiled kernels had higher decortication yields. SEM and light microscopy revealed swollen, partially gelatinized starch granules in the endosperm, which could be linked to better decortication yields in the parboiled product. Yellow millet responded better to parboiling than blue millet. There was evidence of a starch annealing effect occurring in the parboiled kernels. The low-energy intensive treatment (SB) produced acceptable kernels that were corneous and partially translucent, indicating its usefulness at the village level.

Possible Health Benefits of Sorghum and Millet Bran. T.K. Rooney, L.W. Rooney, and J.R. Lupton, Texas A&M University, College Station, TX.

The effects of sorghum and millet bran on blood and liver cholesterol levels and colonic physiology were examined using 110 male Sprague-Dawley rats. A white sorghum (low tannin), a brown sorghum (high tannin) and a pearl millet were decorticated at the 8% level and the bran fractions were analyzed for total dietary fiber (TDF). A basal fiber-free (FF) diet, containing cholesterol and cholic acid to induce hypercholesterolemia, was uniformly diluted with the following fiber supplements to achieve 6% TDF: cellulose (C), pectin (P), wheat bran (WB), oat bran (OB), American Blend (AB), white sorghum bran (WSB), brown sorghum bran (BSB) and millet bran (MB). After 21 days on the diets, the animals were sacrificed and the following measurements were taken: serum and liver cholesterol (SC and LC), cecal surface area (CSA), colonic pH, and dry fecal weight. SC values of BSB (228 ± 17 mg/dl) and WSB (232 ± 16 mg/dl) were not significantly different from C (199 ± 17 mg/dl) or WB (261 ± 17 mg/dl) but were significantly different from ($p<0.05$) from MS (1.88 ± 10 mg/dl), P (151 ± 10 mg/dl) and OB (144 ± 9 mg/dl). Liver cholesterol values resulted in a similar pattern, the BSB, WSB, MB and WB having significantly ($p<.05$) higher values than the P and OB. In the colon, BSB, WSB, and MB acted like WB by neither decreasing pH or increasing cecal surface area but increasing dry fecal weight significantly when compared to OB and P ($p<0.5$).

Effects of Parboiling and Decortication on the Nutritional Value of Pearl Millet and Sorghum. S.O. Serna-Saldivar, C.J. Clegg, L.W. Rooney, Texas A&M University, College Station, TX.

Raw and parboiled sorghum and pearl millet grains were decorticated to remove 17.5% of their weight. Decortication resulted in the loss of protein, insoluble dietary fiber, fat, ash, lysine and other amino acids. Parboiled grain were decorticated more effectively as estimated by losses of protein, fat and ash. Decorticated-parboiled kernels contained a slightly lower lysine content than raw kernels. Weaning rats fed whole regular or P721 sorghums grew slightly better than counterparts fed respective decorticated or parboiled-decorticated diets. Millet and P721 sorghum contained more lysine and consequently had better rat growth and PER than regular sorghum. Rats fed pearl millet and P721 sorghum consumed, absorbed and retained more nitrogen (N) than counterparts fed regular sorghum. Decortication of raw and parboiled kernels significantly increased both the protein and dry matter digestibilities likely due to the significant losses of fiber-rich pericarp tissue. Only slight differences in chemical composition and nutritional value existed between parboiled and raw grains decorticated to the same extent. The higher lysine content of P721 sorghum and millet resulted in better protein quality as estimated by amino acid scores, PER and N retention.

The Tortilla-Making Characteristics of Three Improved Sorghum Cultivars Compared to Maicillos Criollos in Honduras. S.O. Serna-Saldivar, M.H. Gomez, F.A. Gomez, D.H. Meckenstock and L.W. Rooney, Texas A&M University/EAP, College Station TX.

Grain of three improved sorghums and their Maicillo Criollo counterparts grown on each of 3 farms in Honduras were lime-cooked and processed into table tortillas. The native sorghums were smaller, less dense, and softer than the improved sorghums. The most important difference was in the color of the glumes. The improved cultivars contained straw-colored glumes and tan plant color, while the native possessed purple glumes and purple plant color. The cultivars differed significantly in their lime-cooking requirements and characteristics of tortillas. Soft textured grains required less cooking than harder counterparts. The optimum nixtamal moisture content was 53-55% for processing into masa and tortillas. The three improved cultivars and Sureño (used as a positive control) produced acceptable tortillas. The native Maicillo Criollo sorghums produced darker color tortillas. Tortillas from sorghums with purple glumes darkened during lime-cooking. All sorghums and their respective tortillas had similar proximate composition.

The improved Maicillo developed in Honduras have a definite advantage over the old Maicillo Criollos because of significant improvement in tortilla color which is an important aspect of tortilla quality. The improved types will resist grain weathering and discoloring better than the native sorghums.

Grain Quality Characteristics of Tan and Non-Tan Isogenic Sorghum Genotypes. H. Torres-Montalvo, G. Vázquez-Carrillo, L. Mendoza-Onofre and H. Williams-Alanis, INIFAP CIFAP-TAM, Tamaulipas, MEXICO.

Most of sorghum genotypes grown in Mexico and U.S. are red types (R), although there is an increasing interest in developing tan types (T). There are some reports showing advantages in grain quality and agronomic traits of the tan plant genotypes but little is known when isogenic genotypes are compared. INIFAP's elite germoplasm, one B line (LRB 104), one R line (LRB 25) in both versions (T and R types) as well as the four hybrids (T x T, T x R, R x T and R x R) involving those parental lines were evaluated under irrigated and drought field conditions at Zacatepec, Morales (Mexico), in the winter of 1988-89. In the drought treatment, water was withheld for 42 days from panicle initiation to anthesis.

Grain weight, tannins and fiber contents were statistically lower in the tan genotypes than in their isogenic red types. Dry matter in vitro digestibility of the grain showed a tendency to be higher in the tan types also. Under irrigation, grains had lower weight, protein, lysine and fat content; but higher levels of phenols, tannins and fiber than those grains of the plants grown under drought stress. No maternal effects on these grain characteristics were found between the T x R hybrid against the R x T.

Plant Pathology

Dilatory Resistance to *Colletotrichum Graminicola* and Latent Period of Anthracnose on Sorghum Genotypes. Carlos R. Casela and R.A. Frederiksen, Texas A&M University, College Station, TX.

Dilatory resistance to *Colletotrichum graminicola* and the latent period of anthracnose were evaluated on ten sorghum genotypes. Dilatory resistance was evaluated in the field on plots isolated by a resistant genotype. Plants were inoculated with a spore suspension of the pathogen at 62 days after emergence and plots were evaluated for disease severity at weekly intervals. The latent period was evaluated in the greenhouse on leaves of 30 day-old plants inoculated with a spore suspension of the same isolate used in the field. Significant differences were observed for partial resistance and latent period among the cultivars under evaluation. The latent period of anthracnose was closely correlated with the level of dilatory resistance in the field. The results indicated, however, that other components such as infection frequency and sporulation rate should be examined.

RAPD Markers for *Gibberella fujikuroi* (*Fusarium* section *Liseola*). N.M. DuTeau and J.F. Leslie, Kansas State University, Manhattan, KS.

We have developed genetic markers for differentiating isolates belonging to the six mating populations within *Fusarium* section *Liseola* using arbitrarily selected 10 base primers. Some of these primers appear to yield a specific pattern for all of the members of a particular mating population.

RAPD (Random Amplified Polymorphic DNA) Markers As A System for Differentiating Between Isolates of *Colletotrichum graminicola* on Sorghum. P.A.I. Guthrie, R.A. Frederiksen and G.N. Odvody, Texas A&M University, College Station, TX.

The extensive genetic variability found within *Colletotrichum graminicola* often hinders the efficient deployment of anthracnose-resistant sorghum cultivars. This research seeks to develop a tool for rapidly identifying which races of the pathogen are present within a given area, enabling growers to optimize their use of the available sorghum germplasm. Race identification by inoculation of a standard set of differentials is a time-consuming and laborious technique, as is the use of RFLPs, especially in the early probe development stage. However, RAPD (random amplified polymorphic DNA), a PCR technique based on random priming, holds promise as a novel type of polymorphism marker. Whereas traditional PCR relies upon having sequence information to generate the flanking primers, RAPD requires no such information. The technique uses one or more short random-sequence primer(s) whose complementary sequence (s) will probably occur by chance at several places in the genome, resulting in amplification of several fragments of DNA, providing that certain spatial conditions are satisfied. These fragments are generated in such abundance by PCR that they can be seen by ordinary ethidium bromide staining of an agarose gel, and polymorphisms between isolates are readily apparent. A database of RAPD patterns matched against race information obtained from differentials is currently being developed, with the ultimate aim of being able to obtain race information directly from an isolate's RAPD signature.

Aggressiveness of Isolates of *Gibberella fujikuroi*, (*Fusarium* Section Liseola) on Grain Sorghum. D.J. Jardine and J.F. Leslie, Kansas State University, Manhattan, KS.

Fusarium strains (teleomorph = *Gibberella fujikuroi*) having an unusual appearance in that they produced a yellow-brown diffusible pigment on certain media have been isolated from sorghum plants in Kansas. Although these strains would be classified as *F. moniliforme* based on spore morphology, these yellow strains did not successfully cross with standard *F. moniliforme* testers, indicating that they are a genetically discrete biological species. These yellow isolates can be subdivided into vegetative compatibility groups indicating that there are multiple genetically distinct strains in the population rather than just the clones of a single strain. To date, 55 percent of *F. moniliforme* isolates collected from Kansas sorghum are in this yellow group and they can cause both a seedling blight and stalk rot in sorghum. The objectives of this study were to determine if there is variability in the aggressiveness of isolates from different vegetative compatibility groups, and to determine if there is evidence of strain specificity to different sorghum cultivars.

Eleven isolates representing the most common vegetative compatibility groups of Kansas yellow strains (*G. fujikuroi*, mating group F) and two *F. moniliforme* isolates (*G. fujikuroi* mating group A) were toothpick inoculated into the peduncle of grain sorghum 'cv. Wheatland' plants approximately two weeks after anthesis. Eighteen days later, the peduncles were split and the resultant lesions measured. In a second experiment, two of the yellow isolates demonstrating the most (strains 1155 and 1163) and least (strains 728 and 1183) aggressiveness were selected to use in evaluating cultivar specificity. The cultivars used were SC-599 and B-1778 (resistant to *F. moniliforme*) and Wheatland and BKS-45 (susceptible to *F. moniliforme*). After each experiment, tissue samples were collected from each lesion and tested for vegetative compatibility with the strain used to inoculate that plant.

Variation for aggressiveness to sorghum was observed in yellow isolates of *G. fujikuroi* but not to a high degree. Cultivar resistance appears to be general across the species rather than strain specific. Resistance to the yellow strains followed the known resistance to *F. moniliforme*. Reisolation of strains from the inoculated plants indicated that there can be significant contamination even under controlled greenhouse conditions. Contamination among the isolates used in the second study was 45, 15, 66 and 22 percent for isolates 728, 1155, 1163 and 1183, respectively. Five percent of the non-inoculated control plants also were contaminated.

Environmental Conditions Affecting the Efficacy of *Gaertneriomyces* spp. As A Biocontrol Agent of Sorghum Downy Mildew. I.S. Kunene, G.N. Odvody and R.A. Frederiksen, Texas A&M University, College Station, TX.

The chytrid *Gaertneriomyces* was evaluated for its efficacy as a biocontrol agent by adding it to *Peronosclerospora sorghi* oospore infested soil in microplots using three methods, incorporation, banding or addition of the culture filtrate. Reduction in disease incidence differed significantly (P=0.05) for the various application methods, with incorporation giving the highest disease reduction, 60%. The effect of time interval between chytrid incorporation and planting of the test crop during a four week interval was not significant (P=0.05). When various levels (doses) of chytrid inoculum were incorporated and evaluated for disease reduction, a linear response was obtained fitting the model y=80-38x. Irrigation in addition to the chytrid inoculum significantly (P=0.05) improved downy mildew control by as much as 40%.

Mechanism of Parasitism and Identity of the Chytrid Used for Biocontrol of Systemic Sorghum Downy Mildew. I.S. Kunene, G.N. Odvody and R.A. Frederiksen, Texas A&M University, College Station, TX.

Zoospores of the chytrid in a liquid culture were used to flood oospores of *Peronosclerospora sorghi* on agar plates. After two days the oospore-chytrid material was fixed and processed for SEM viewing. Lysis of oospore wall, by the chytrid was evident. Another chytrid zoospore culture was processed for the TEM to identify the chytrid to genus. The nucleus was observed lying in the posterior of the zoospore and it had a basal concavity. The kinetosome and non-functional centriole were located distally to the concavity. Aggregates of lipid globules were evident in the anterior of the zoospore. This is a *Gaertneriomyces* zoospore.

Geographic Distribution of Mating Populations from *Gibberella fujikuroi* (*Fusarium* section *Liseola*. J.F. Leslie, S. Shaw and V. Elliott, Kansas State University, Manhattan, KS.

Over 1000 isolates of *Gibberella fujikuroi* have been recovered from within the United States and elsewhere. These isolates are widely distributed, with members of the "A", "F" and "D" populations being the most widespread. "A" isolates are most common in corn; "F" isolates are most common from sorghum; and "D" isolates are found at significant rates from both. All of the mating populations have been recovered in the United States, and virtually all commercial fields, feeds and feedstuffs examined were infested with fungal strains belonging to this group. Populations from outside the United States have been less extensively characterized, but many of the some patterns also are appearing. Based on the widespread distribution of this fungus, problems associated with the toxins it produces need to be more closely examined.

Investigation of The Mating Groups of *Fusarium* Section *Liseola* on Sorghum in Texas. S.B.A.. Mansuetus, G.N. Odvody, R.A. Frederiksen, J.F. Leslie and D.T. Rosenow, Texas A&M University, College Station, TX.

Fusarium species were isolated from heads of sorghum cultivars differing in grain mold (GM) resistance and grown at four Texas locations in 1990. The number of colony forming units (CFU) of *Fusarium* species was positively correlated with GM (r=0.74), and differed significantly (P=0.05) for the various locations. Species in *Fusarium* section *Liseola* accounted for 35% of the isolates, but no species in this section were recovered from black sorghums. Forty-five isolates from this section were crossed to standard tester strains (A-F) to determine the mating population to which each isolate belonged. Isolates from all six mating populations were recovered; however, not all mating populations were represented at all sites.

Characterization of Host Specialized Isolates of *Sporisorium Reilianum*, Using Molecular Markers. G. Naidoo, C.W. Magill and R.A. Frederiksen, Texas A&M University, College Station, TX.

Both maize and sorghum are hosts of *Sporisorium reilianum*, the causal organism of head smut. Light and scanning electron microscopy reveal that teliospores from sori on maize and sorghum are morphologically indistinguishable. In addition, starch gel-electrophoresis of sporidial extracts did not provide any distinctive isozyme marker. RFLP's and RAPD's are being sought which will be useful as genetic markers and as an aid in distinguishing between the maize and sorghum pathotypes. Nine discrete chromosome-sized fragments were separated using Pulse field gel electrophoresis (PFGE). The width and densities of the bands suggest that there may be as many as 15 such fragments. Using *Saccharomyces cerevisiae* as a standard, preliminary estimates indicate that the genome size ranges between 18 and 27 Mbs. Flow cytofluorometric measurements of nuclear DNA reveal a genome size of 30 Mbs.

Incidence and Expression of Sorghum Yellow Banding Virus in South Texas. G.N. Odvody, R.W. Toler, M.P.K. Theu and J.C. Remmers, Texas A&M University, Corpus Christi, TX.

By 1989 Sorghum Yellow Banding Virus (SYBV) was observed in 1 county nonadjacent to and 7 counties contiguous with the initial site of observation near Floresville, Texas in 1984. SYBV occurred naturally only on sorghum x sudan grass hybrids except for one occurrence on grain sorghum tillers. No SYBV was observed on primary growth and initial or highest incidence was generally observed at field perimeters on basal rather than stem tillers. The virus can be detected in several infected plant tissues including roots. In an irrigated field, incidence of SYBV increased with each of two ratooned crops (<1% and 10-30%). The slow recovery single ratoon crop of several dryland fields had a higher incidence of SYBV (10-25%) than the comparable irrigated ratoon crop. In greenhouse tests, SYBV occurred in the first (1991), third (1990), and subsequent ratoon crops of sorghum x sudan only when grown in soil from a SYBV-affected field. Wider row widths increased field incidence of SYBV in 1990. Aphids did not transmit the virus and vectors are yet unknown, but results indicate a soilborne mechanism for SYBV. Mechanically-inoculated sudan grass and sorghum x sudan grass cultivars differed in resistance to the virus.

Developing RFLP Markers for Sorghum Head Smut Resistance Genes. B.J. Oh, G.W. Xu, R.A. Frederiksen and C.W. Magill, Texas A&M University, College Station, TX.

Construction of a restriction fragment length polymorphism (RFLP) map for sorghum is being undertaken. One of the goals is to improve the ability to select and combine genes for disease resistance via their linkage to easily detectable RFLP markers. This study has concentrated on the evaluation of restriction enzymes, and the identification of suitable probes, including heterologus probes from maize and homologous probes from sorghum. Sorghum genomic DNA prepared from 4 resistant lines and 4 susceptible lines was digested with, restriction endonucleases, electrophoresed, Southern blotted, and hybridized with labelled maize and sorghum probes. Of 16 potential crosses using these lines as parents in crosses, the maximum polymorphism detected, 70% was between SC325 (resistant) and RTx7078 (susceptible). The minimum polymorphism detected, 42% was between CS3541 (resistant) and BTx399 (susceptible). The percentages of different probe-enzyme combinations that detected RFLPs were *Eco*RV 17.1%, *Eco*RV 28.4%, and *Hind III* 17%. As a consequence of these results, the F_2 population derived from the cross of SC325 and RTx7078 was selected as a mapping population. Currently, individual plants in the F_2 population are being screened for the presence of disease resistance genes by inoculation with the sorghum head smut fungus (*Sporisorium reilianum*).

Pseudomonas andropogonis: A Diverse Bacterial Incitant of Leaf Stripe in Sorghum. B.A. Ramundo and L.E. Claflin, Kansas State University, Manhattan KS.

The bacterium, *Pseudomonas andropogonis*, is the causal agent of bacterial leaf stripe in sorghum and infects a wide range of other plant hosts including numerous species of the Gramineae, and Leguminosae families. In addition, *P. andropogonis* has been isolated from diseased *Bougainvilla* sp., *Coffea arabica*, and *Limonium* sp.

We have evaluated 12 different strains of *P. andropogonis* isolated from a variety of hosts and geographic locations to determine the heterogeneity within this bacterial species. Results of phenotypic tests, dot-immunobinding assay, SDS-polyacrylamide gel electrophoresis of membrane proteins, plasmid analysis, restriction endonuclease analysis, and host range studies revealed some variation between strains; however, a pattern of dissimilarity was not clearly determined.

Systemic Colonization of Grain Sorghum Plants by *Xanthomonas Campestris* pv. *Holcicola*. J. R. Reddy, L.E. Claflin and B.A. Ramundo, Kansas State University, Manhattan, KS.

Two-week-old sorghum plants (Cv. 80B3039) were inoculated by injuring the roots with a knife and then pouring 10 ml of a streptomycin resistant suspension (1.3 x 10 colony forming units/ml) of *Xanthomonas campestris* pv. *holcicola* onto the soil surface. Tissue from inoculated and healthy plants was removed at monthly intervals and examined for *X. c. holcicola* by plating on MBY and MXP media amended with 100 ug/ml of streptomycin and by direct immunofluorescent staining (IFS). Cells of *X. c. holcicola* were observed by IFS and recovered from root, stem, and leaf tissue from inoculated plants although bacterial leaf streak symptoms were not observed. Bacteria were not recovered from non-inoculated plants. *X. c. holcicola* is systemic in sorghum plants and is probably translocated in the xylem tissue. Recovery of cells of *X. c. holcicola* was highest from stem and lowest from root tissue.

Application of Cloned DNA Fragments to Differentiate and Detect *Peronosclerospora* Species. Cheng-Lin Yao, C.W. Magill, R.A. Frederiksen and M.R. Bonde. Texas A&M University, College Station, TX.

Downy mildew was detected by DNA hybridization in endosperm, pericarp, and pedicel tissues, but not in embryos of maize seeds infected with a species of *Peronosclerospora* from China that had proved difficult to classify by standard techniques. Plasmid $_{p}$CLY83, which had been selected from a *P. maydis* DNA library served as the probe. No evidence for hybridization was detected between the probe and DNA's extracted from ten common seedborne fungi of maize: *Colletotrichum graminicola, Acremonium strictum, Curvularia lunata, Fusarium moniliforme, Bipolaris maydis, Macrophomina phaseolina, Rhizoctonia* sp., *Rhizopus* sp., *Penicillium* sp., *Alternaria* sp. Hybridization also was not detected with DNA's isolated from plant tissues infected with *Sclerospora graminicola* or *Sclerophthora macrospora*. The hybridizing DNA of the pathogen from China was readily distinguished from *Peronosclerospora sorhi*, and *P. maydis* by differences in *Eco*RI, *Bam*HI and *Hind* III restriction patterns. RFLP patterns on blots of DNA from the plants shows symptoms of downy mildew in this case were the same as those for *P. philippinensis* and *P. sacchari*.

Portal of Entry of *Xanthomonas Campestris* pv. *Holcicola* into Grain Sorghum Plants. P. Zvoutete, L.E. Claflin and B.A. Ramundo, Kansas State University, Manhattan KS.

The mode of entry into grain sorghum (*Sorghum bicolor*) by *Xanthomonas campestris* pv. *holcicola* was determined by scanning electron microscopy (SEM). Wounded and healthy leaf tissue of 3-wk-old plants were mist-inoculated with a suspension of *X. c. holcicola* (strain KS 66) and examined by SEM 1, 2, 3, 5, 7 and 9 days after inoculation. Three days after inoculation, bacteria were observed predominately in and around stomates and wounds with evidence of bacterial lysis in "unprotected" sites. Small water-soaked lesions were evident 5 days after inoculation and vein-limited lesions became necrotic after 7 days. All plants wounded prior to inoculation developed symptoms whereas 20-30% of the healthy plants exhibited symptoms. *X. c. holcicola* enters sorghum plants via stomates and wounds; with preference for wound ingress.

Seedborne Role and Longevity of *Xanthomonas Campestris* pv. *Holcicola* in Grain Sorghum. P. Zvoutete, L.E. Claflin and B.A. Ramundo, Kansas State University, Manhattan, KS.

Xanthomonas campestris pv. *holcicola*, causal agent of bacterial streak of sorghum (*Sorghum bicolor*), was found on and inside the seed coat of grain sorghum. *X. c. holcicola* was isolated from surface sterilized and unsterilized seeds harvested from inoculated sorghum plants, as well as from leaf, lemma, and palea tissues. Recovery of cells of *X. c. holcicola* in the seed decreased gradually from 8.4×10^5 colony forming units (CFU) at harvest to 4.4×10^3 CFU after 24 mo in storage. Population of *X. c. holcicola* decreased from 8.8 and 4.1×10^6 CFU at harvest to 5.0 and 3.3×10^3 CFU for leaf and glume/lemma/palea tissue, respectively, after 24 mo storage in an unheated building.

Seed Technology

Polyphenol Levels in Sorghum as an Indicator of Resistance to Field Deterioration. J.H. Luhanga and C.H. Andrews, Mississippi State University, Mississippi State, MS.

Post-maturation and pre-harvest environmental conditions adversely affect seed quality in Mississippi. Rapid and efficient evaluation procedures are needed to determine resistance potential in sorghum. The objective of this study was to establish the relationship between polyphenol (condensed tannin) and resistance of aluminum-tolerant sorghum genotypes to field deterioration.

Field deterioration studies were conducted for two years (1988 and 1989) in order to determine the resistance potential of genotypes. Thirty breeding lines were exposed to ambient conditions for 30 days after physiological maturity. Condensed tannin assays were conducted on selected genotypes harvested at physiological maturity.

There was a substantial (31%) decline in germination of all genotypes due to adverse environmental conditions. There was also a differential response to field deterioration among genotypes. Some breeding lines were resistant. Tannin levels (in catechin equivalents) were significantly different among genotypes. Resistant genotypes had a high tannin content. The amount of tannin among genotypes harvested at physiological maturity was significantly correlated with field deterioration germination after 15 days exposure to ambient conditions; there was a similar relationship after 30 days.

Polyphenol levels (condensed tannin) can, therefore, be a good and quick indicator for determining resistance potential to field deterioration in sorghum.

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