Sorghum and Millets

Commodity and Research Environments

International Crops Research Institute for the Semi-Arid Tropics

Abstract

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Sorghum and millets are strategic commodities for worldwide food security, particularly in the harsh environments of the semi-arid tropics. This volume outlines the production and research environment of these crops in each major region, and seeks to provide a guide to the research required to achieve sustained improvements in production.

Résumé

Environnements de recherche et de matière première pour le sorgho et les mils. **Le sorgho et les mils constituent des matières premières stratégiques pour la sécurité alimentaire sur le plan international, notamment dans les milieux moins favorables des zones tropicales semi-arides. Cet ouvrage donne un aperçu de l'environnement de la recherche et de la production de ces cultures dans chaque région principale, afin de servir de guide aux travaux de recherche nécessaires pour réaliser des améliorations durables de la production.**

Resumen

Ambientes de producción e investigación del sorgo y el mijo. El sorgo y el mijo están reconocidos internacionalemente como productos estratégicos con respecto a la seguridad alimenticia, específicamente en ambientes menos favorables como son los trópicos semiáridos. Este tomo resume los ambientes de producción e investigación relacionada a estos productos en cada una de las regiones principals y sirve de guía para fijar las pautas de investigación requerida a fin de lograr mejoras sostenibles en su producción.

Sorghum and Millets
Commodity and Research Environments

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1993

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Preface

Sorghum and millets are extremely important cereal crops worldwide, for human food, animal feed, and to a lesser extent for industrial use. Sorghum in particular is widely grown, with significant production in Asia, western, eastern, and southern Africa, and in the Americas. A diversity of species of millet is extensively produced, mainly in Asia and Africa.

Much of the production of these crops is in the semi-arid tropics (SAT), where they are mainly produced by small-holders in the more marginal environments. Thus, sorghum and millets are crucial to the food security of many of the poorest people in the SAT.

Yet the last decade has seen an international decline in the area of production of these crops. For sorghum, production has remained stable or marginally declined in most regions, due to the improved productivity associated with the use of improved varieties and better production technology. A similar situation exists for millets in Asia, In western Africa, the area of pearl millet has increased, but at a rate less than that of the population and mainly in more marginal agricultural areas.

The overall shift of demand away from sorghum and millets as food grains probably reflects a basic shift of consumption patterns to other cereals. Paradoxically, this shift is paralleled by an increasing demand for sorghum as a feed grain, for industrial uses, and for forage. These represent specific new challenges in improvement of these crops.

Sorghum and the millets are mandate crops of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Active programs of improvement of these crops by ICRISAT are in progress in Asia (centered in India), western Africa (centered in Niger, Nigeria, and Mali), southern Africa (centered in Zimbabwe), eastern Africa (centered in Kenya), and Latin America (centered in Mexico). ICRISAT's research is done in close interaction with the national agricultural research systems of the regions, in a research portfolio designed to address the strategic needs and priority constraints to improved productivity and yield stability in the major production systems in those regions.

The fact that sorghum and millets are, in comparison to other cereals, particularly well adapted to the more marginal stress-prone environments of the SAT emphasizes their importance to food security in these areas.

The achievement of significant and sustained increases in production in the marginal environments of the SAT represents a major scientific and managerial challenge. The agricultural environments of the SAT are characterized by a highly variable climate, a fragile ecosystem, and significant abiotic and biotic constraints to productivity that vary across time and location. Among other things, this demands effective research in crop improvement and natural resource management for the development of the necessary improved genetic materials and management systems, and in socioeconomic constraints to adoption.

The papers in this book were developed for the In-house Review of the ICRISAT Cereals Program in December 1992. The objective was to provide a background of the production and research environments of sorghum and millet in each major region, against which the adequacy and relevance of the current research portfolio could be judged, and on which a future research portfolio to achieve sustained increases in production could be constructed.

We believe that these papers represent a strategic resource in knowledge regarding international sorghum and millets production and improvement at this time. Therefore they are presented in this way, to enable more general access. We trust they will prove useful.

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Pearl Millet in Western Africa

K. Anand Kumar[1]

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Pearl Millet in Western Africa

K. Anand Kumar

Abstract

The area sown to pearl millet (Pennisetum glaucum) *in western Africa is estimated at 12 million ha with an annual production of 9.6 million t. Between 1969-86, the cultivated area increased annually by 0.6%, production by 1.4% per year, and yield per ha at 0.5%, all below the rate of population growth of 2.6%. Production trends indicate that: (1) extending cultivation to marginal areas has been the most common response to increasing population pressure without increases in productivity, (2) average yields have remained static, (3) use of inputs is minimal, and (4) fluctuations in prices do not encourage input investments. Production has to be doubled through increased productivity.*

Millet grain has little commercial status and marketable surpluses as a direct share of agricultural sales are low. Millet indirectly contributes to the receipts from livestock sales. Industrial utilization of the grain remains largely unexplored. Millet straw plays an important part as a livestock feed.

The bulk of the crop is grown in the Southern Sahelian Zone (annual rainfall 300-600 mm) and the Sudanian Zone (600-1000 mm). On-farm constraints include: moisture and nutrient stress, stand establishment, insect pests, diseases, Striga, *low yield potential of local cultivars, and poor management practices. The factors involved and technologies needed to alleviate these constraints are mentioned. There is a need for coordinated research by the crop improvement and resource management programs. In addition, several unfavorable policies hinder investment in and adoption of improved technologies.*

Estimates of manpower available for millet improvement research in the region are about 25-30 scientists. Operational limitations include manpower, seed, funding, liaison between research and extension, lack of information, time spent on millet research, transport, and equipment. ICRISATs comparative advantages are: review of priorities and progress of research, multidisciplinary approach, strategic research on stress factors, work across agroecological zones, and adequate funding and facilities.

Between 1986 to-date, our program has been involved with the National Agricultural Research Systems (NARSs) in the supply of seed of improved varieties, training and consultancies, exchange of genetic material, joint research, joint trials, and regional workshops. Several varieties in nine countries are undergoing testing—on-station, on-farm, recommended for cultivation, or being grown by farmers. The West and Central African Millet Research Network (WCAMRN) was established in 1990 with the primary objective to strengthen NARSs. Three projects are currently in operation.

The External Program Review (EPR) agreed that emphasis for western Africa should be on applied research. They suggested consideration of stress resistance factors and aspects of varietal selection. In the In-House Review (IHR) held in March 1992, 15 research projects were retained. These address themes of our Medium Term Plan (MTP).

Seven research themes in the MTP for millet that relate to work in western Africa are presented. Research goals outlined in the MTP are comprehensive and encourage both within- and across-program interaction. They will direct us towards developing and contributing to improved technologies.

Production and Consumption

The area sown to pearl millet *(Pennisetum glaucum)* in western Africa is estimated at 12 million ha with an annual production of 9.6 million t. Major producers are Nigeria, Niger, Mali, Burkina Faso, and Senegal: between them they account for 84% of the production. Average yields range from 500 kg ha^{-1} in Burkina Faso to over 1 t in Gambia (Table 1). One of the reasons for this range in productivity is that in Mauritania, Niger, and Senegal production is confined to the Sahelian Zone, and in Burkina Faso and Mali millet is grown in all three of the bioclimatic zones. The reasons attributed to this low production include: biotic and abiotic constraints, little viable research on development and adoption of improved technology, unfavorable agricultural policies, and lack of trained manpower.

In western Africa between 1969 and 1986, the area sown to pearl millet has increased at 0.6% per year, production at 1.4%, and yield per ha at 0.5%, all below the rate of population growth of 2.6%. In Niger, the area sown increased at 3% per year, production at 2.7%, and yield per ha decreased by 0.3%, again all below the rate of population growth of 3.3% (Fig. 1).

Table 1. Area, production, and yield of pearl millet in western Africa.

Country	Area ('000 ha)	Production ('000 t)	Average yield (kg ha-')
Nigeria	3900	3800	970
Niger	3300	1750	530
Mali	1590	1290	810
Burkina Faso	1280	650	510
Senegal	910	580	630
Chad	530	310	580
Ghana	160	100	630
Togo	120	960	770
Cote d'Ivore	80	50	560
Gambia	60	70	1080
Cameroon	50	30	520
Mauritania	30	10	440
Benin	10	10	60
Total	**12020**	**9610**	**-**

Source: ISC 1993.

Table 2. Population statistics for Niger, 1988.

Total population	7.2 million
Urban population	1.1 million
Rural population	6.1 million
Under 10 years	2.8 million
Annual population growth (%)	
Niger	3.3
CILSS countries	2.6
Africa	2.9
World average	1.8
Population doubling time (years)	21
Primary sector: Agriculture, animal husbandry	

Source: MSDP 1988.

Long-term statistics on cereal production in Niger obtained from the Ministry of Planning are used to illustrate production trends. These trends are more or less similar in all countries.

The population of Niger is 7.2 million, of which 85% is rural, mostly engaged in agriculture and animal husbandry. The population growth rate is 3.3% with a doubling time of 21 years (Table 2). Pearl millet constitutes about 70% of the cereal production and 53% of total agricultural production. As shown in Figure 2, a significant increase in national production of millet is noticed up to 1969. From 1969 onwards, and following the Sahelian droughts of the early 1970s, the increase in production is less pronounced. The area sown to pearl millet has increased significantly by 250% between 1953 and 1989. A significant increase in area has resulted from cultivation extended into marginal lands because of increasing population pressure (Fig. 3).

Average yields have declined in recent times (Fig. 4). Use of improved production techniques—fertilizer and improved varieties—is very limited. Fertilizer use in western Africa is limited and ranges from 0.8 kg ha^{-1} to 5.7 kg ha^{-1} in the major millet-producing countries. Fertilizer consumption in 1982 ranged from 3700 t in Niger to 195 000 t in Nigeria (Table 3). Even this small quantity is not all applied to

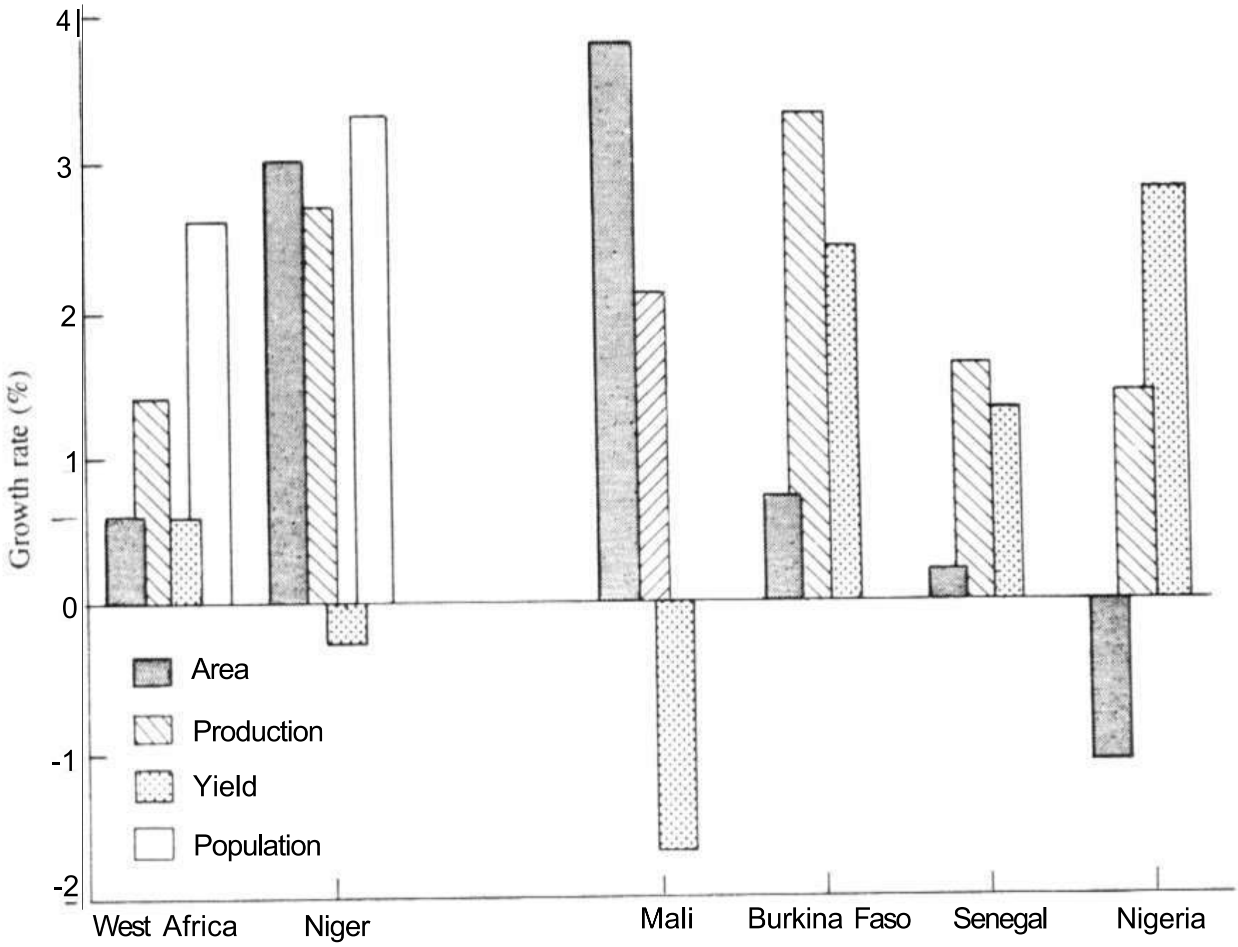

Figure 1. Growth rate of production, area, and productivity of pearl millet in western Africa, 1969-71 average vs 1980-86 average. **Source: FAO 1967,1971,1980,1986.**

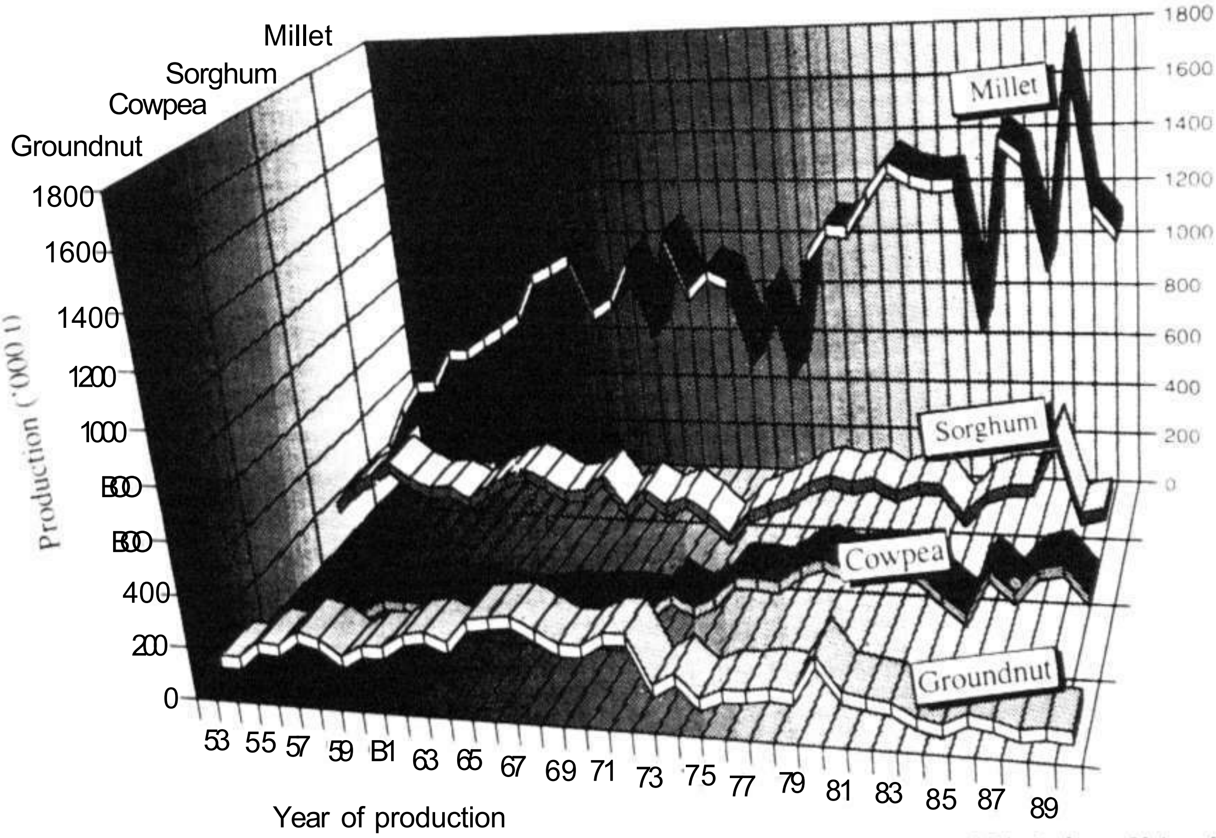

Figure 2. Production of the principal crops in Niger, 1953-91. **Source: Ministere d'Agriculture et d'Elevage 1992.**

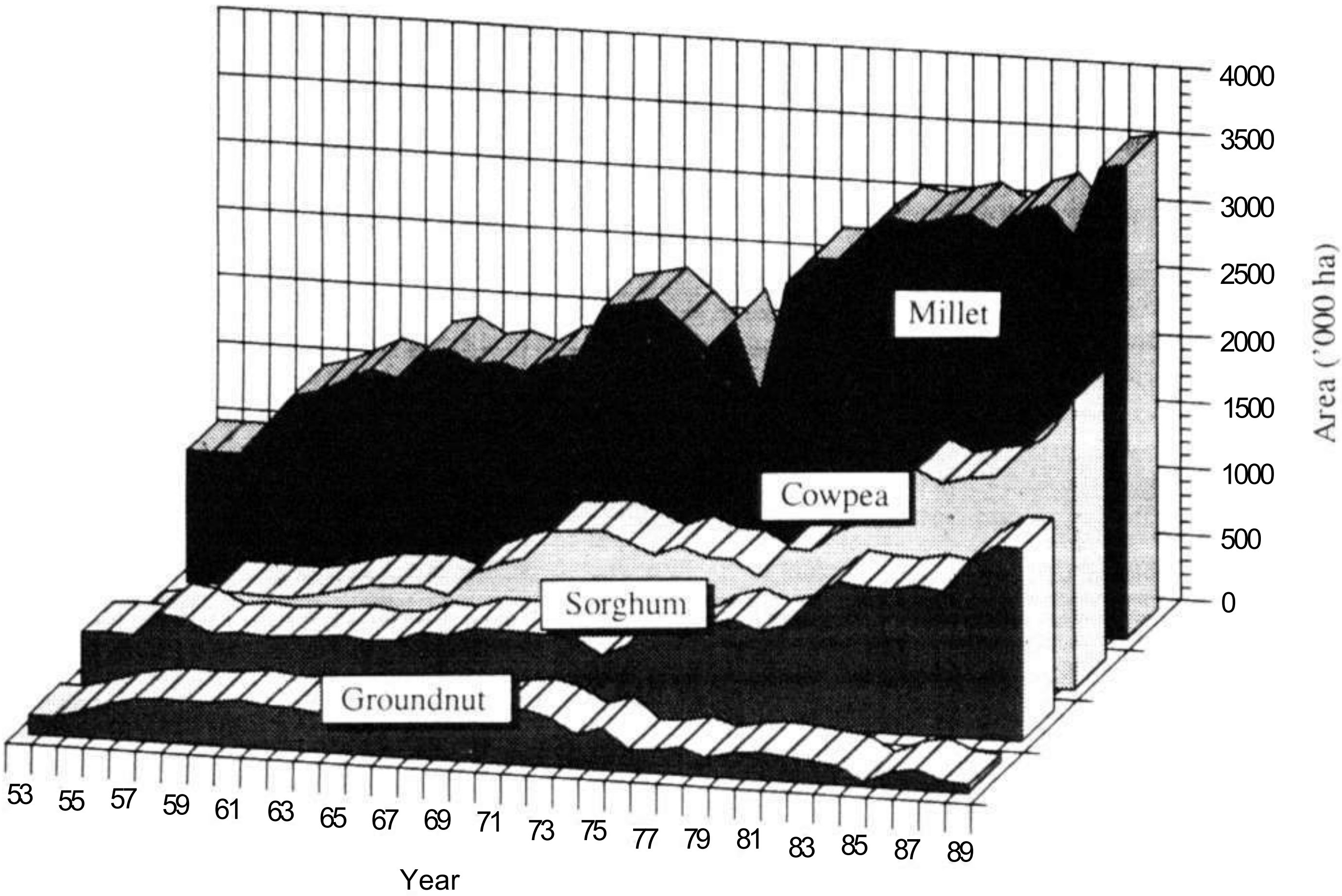

Figure 3. Areas of the main crops in Niger, 1953-89. **Source: Ministere d'Agriculture et d'Elevage 1992.**

Table 3. Average level of and growth in fertilizer consumption in western Africa.

Country	1979-81 average (kg ha^{-1})	Growth (%)[1]	Consumption ('000 t)[2]
Benin	1.3	-8.9	2.2
Burkina Faso[3]	2.9	25.5	8.4
Cameroon	5.3	6.6	38.6
Chad	0.5	-3.3	3.6
Gambia	15.2	27.9	2.0
Ghana	7.4	23.5	22.7
C6te d'Ivoire	13.3	6.5	45.3
Mali[3]	5.7	7.0	11.2
Mauritania	7.2	28.2	0.5
Niger[3]	0.8	23.1	3.7
Nigeria[3]	5.4	33.5	195.4
Senegal[3]	4.6	8.7	20.7
Togo	2.5	23.6	2.5

1. Annual compound growth rale 1969/70-1971/72 average to 1980/81-1982/83 average.
2. 1980/81-1982/83 average.
3. Major millet-producing countries.

Source: Mudahar 1986.

millet, but is used on other crops such as groundnut (*Arachis hypogaea),* cotton, and rice *(Oryza sativa).* This low use is attributed to low demand at the farm and national level, and fluctuations in supply.

The relationship between population, cereal harvest, and per capita output shown in Figure 5 indicates that production has not followed the exponential growth of the population—and has resulted in stationary per capita output. The mean for the last 30 years is 280 kg per capita. In the 1960s, production has largely covered the needs of the population; later, an annual trend for a shortfall beginning in 1984 is seen. These shortfalls were met by food aid and imports. Currently, the cereal production situation is worse than during the Sahelian drought of the 1970s (Fig. 6). The price of millet fluctuates, depending on annual production (Fig. 7). Millet is a valuable market commodity only in poor rainfall years—which is exactly the period

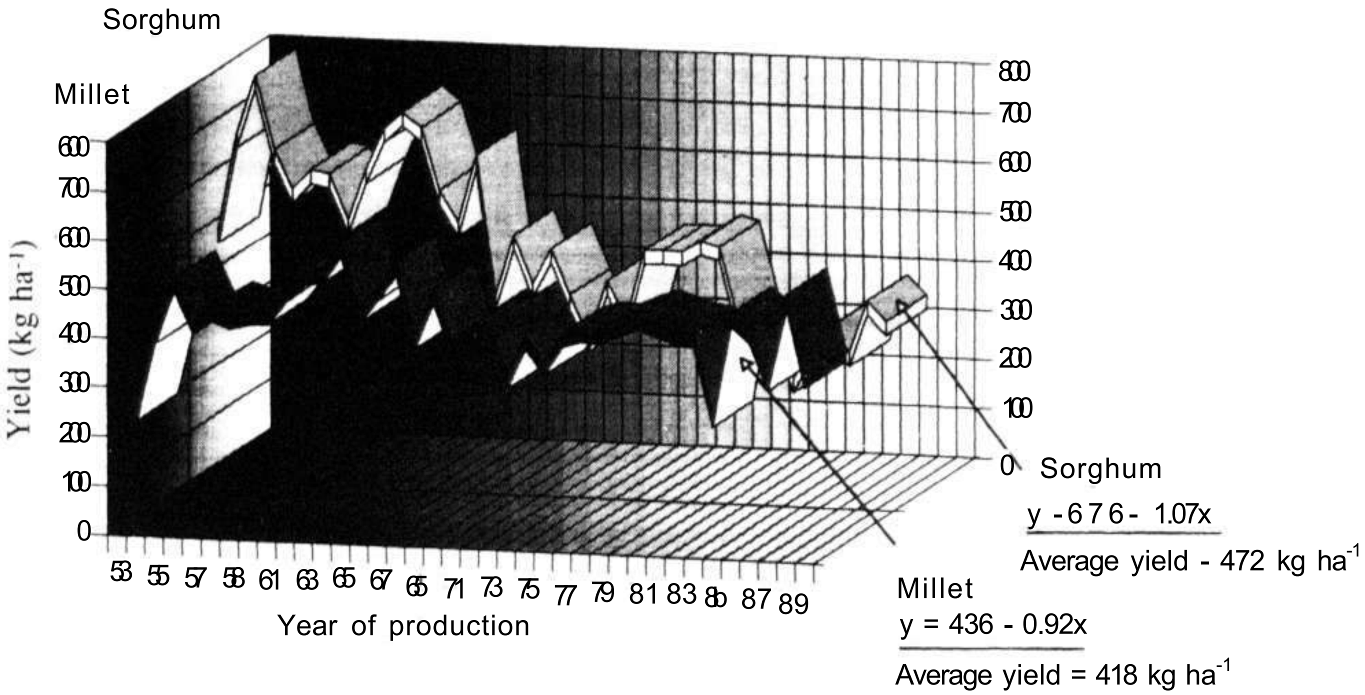

Figure 4. Sorghum and millet yields in Niger, 1953-91. **Source: Ministere d' Agriculture et d'Elevage 1992.**

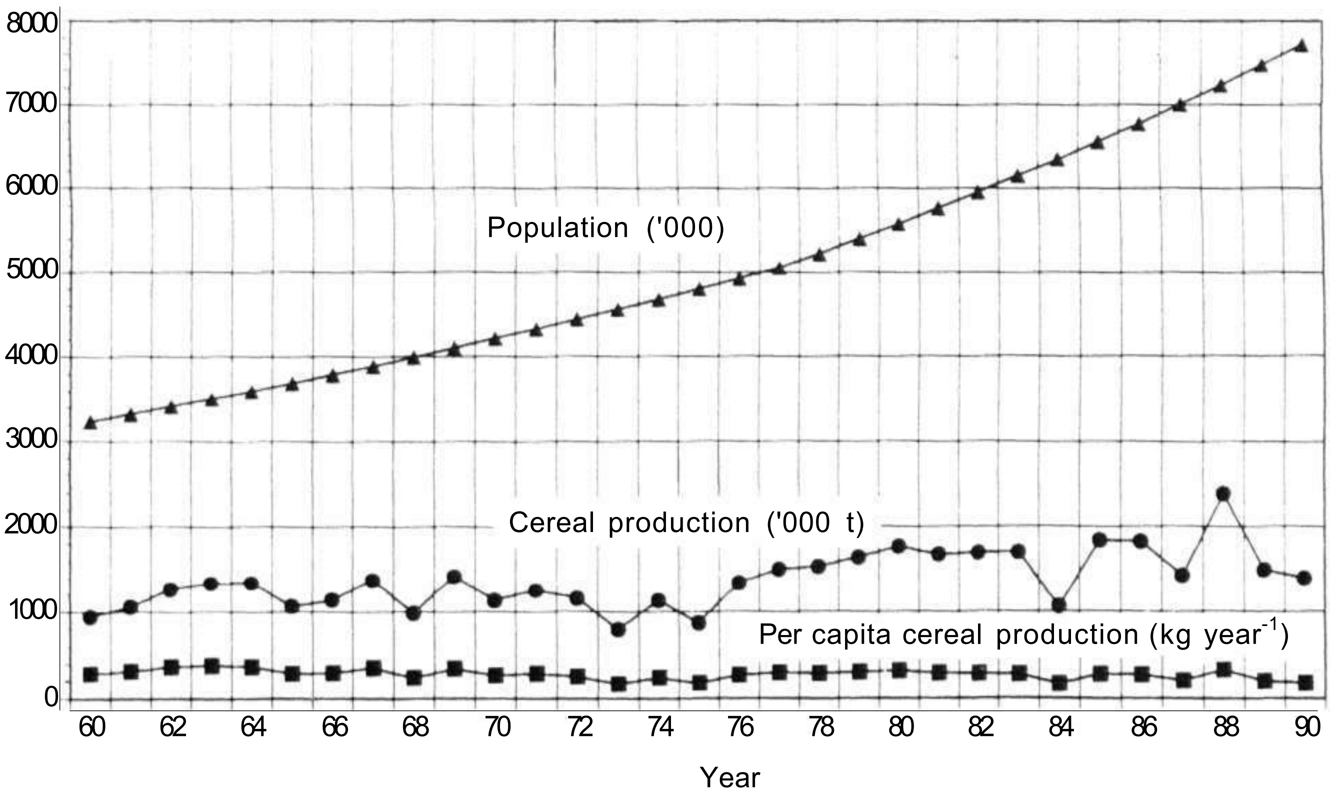

Figure 5. Relationship between population, cereal production, and per capita cereal production in Niger, 1960-91. **Source: Ministere d' Agriculture et d'Elevage 1992.**

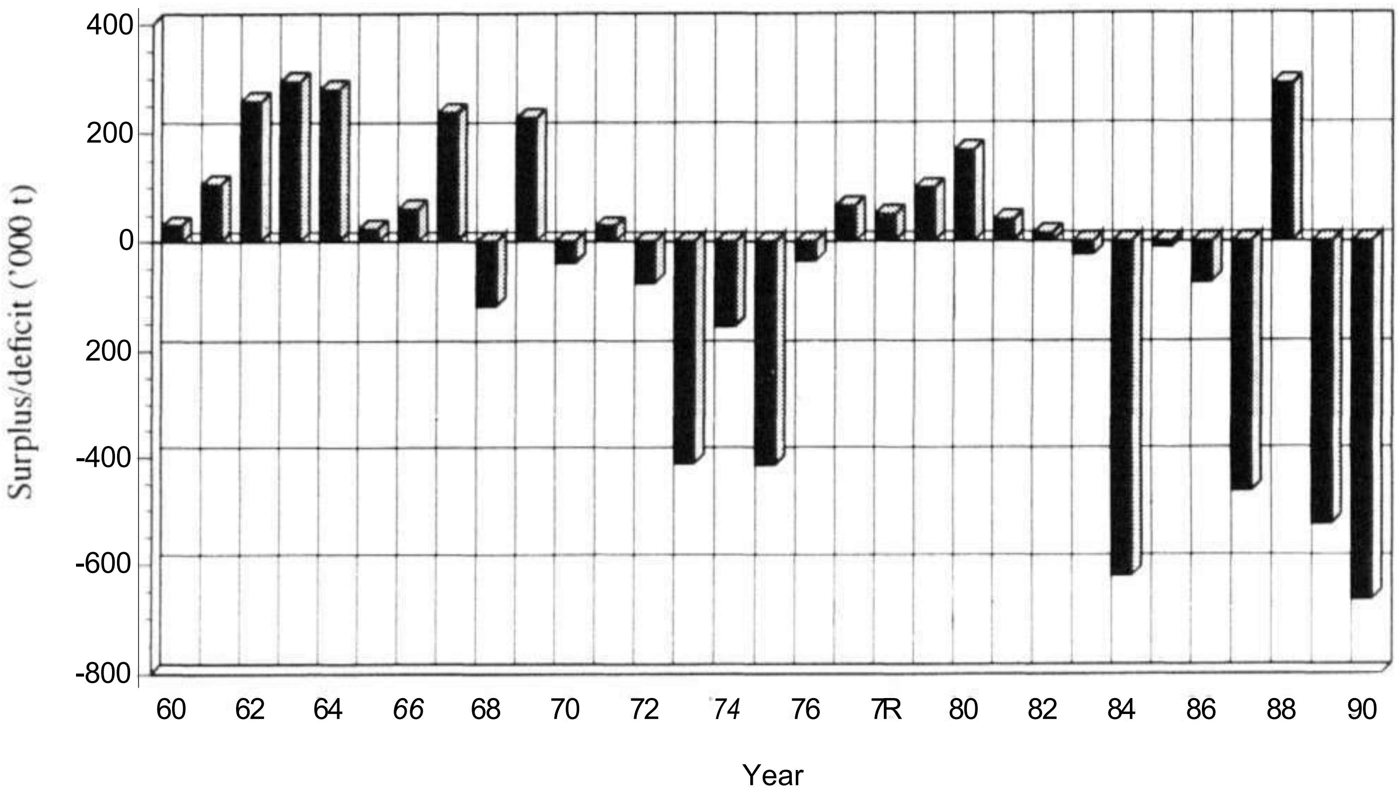

Figure 6. Surplus or deficit in cereal requirements in Niger, 1960-90. **Source: Ministere d'Agriculture et d'Elevage 1992.**

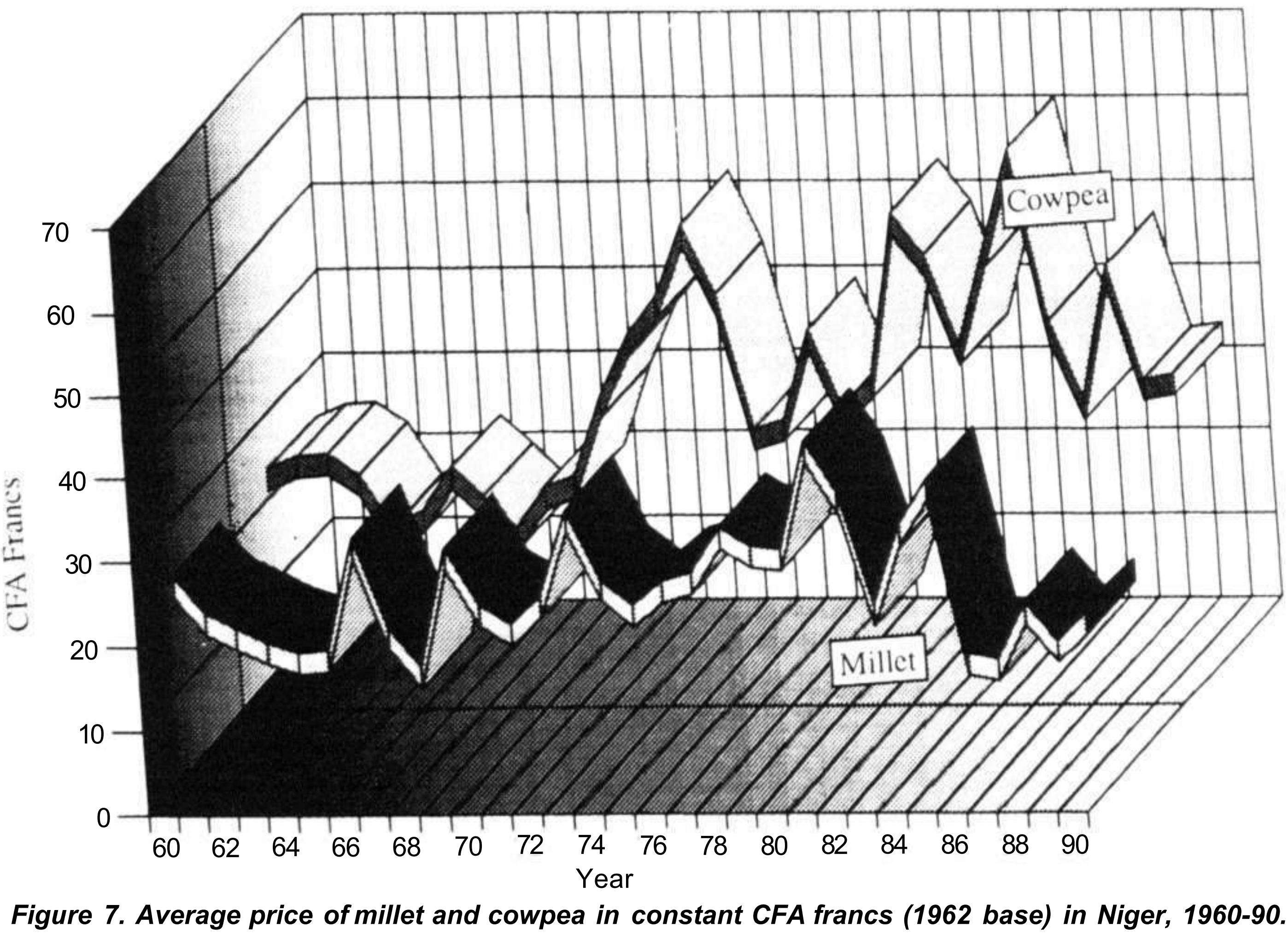

Figure 7. Average price of millet and cowpea in constant CFA francs (1962 base) in Niger, 1960-90. (247 CFA francs = US$ 1.00 in 1962.). **Source: Ministere d'Agriculture et d'Elevage 1992.**

when a farmer cannot afford to sell his stocks in case the following year is also bad. In Niger, between 1985 and 1989 the prices have gone down remarkably in the absence of assured price policies. When farmers do not get a remunerative price for their product, investment in production inputs is minimal.

The production trends of pearl millet in western Africa show that extending cultivation into marginal areas has been the most common response to increasing population pressure; average yields have remained static; the use of inputs is minimal; and fluctuations in prices do not encourage input investments.

By the year 2010, the population of Niger could double to 14 million, and the demand would be for 3.3 million tons of cereals. The situation is similar in other countries. This means that production has to be doubled through (1) extending cultivation, (2) increasing cropping intensity, or (3) increasing productivity. Opportunities for extending arable land and cropping intensity are limited and the only alternative is increasing productivity.

Utilization Trends

Millet grain is the basic diet for farm households and poor residents and has little commercial status. It is mainly used in the preparation of traditional foods. Marketable surpluses of millet as a direct share of agricultural sales are only between 5-10%. Industrial utilization of the grain remains largely unexplored. There have been some studies on keeping quality of the flour, and composite flours for making bread, biscuits, and weaning foods. Significant commercialization of these products is not expected with the current production trends.

In western Africa, most of the household receipts occur from the sale of livestock. Millet grain and bran are used as poultry feed and crop residues for livestock. Millet therefore indirectly contributes to receipts from livestock sales much more than that which is observed from direct sales.

Millet stover has an important role in feeding livestock during the dry season. Emphasis is given to the leaves as feed following harvest, while a large proportion of the stem is used as mulch or for construction. The estimated straw production in western Africa is 35 million t annually. Only the leaves (comprising 40% of the straw) would be sufficient to feed 16 million tropical livestock units during the dry season. Livestock corralling in the field returns nutrients to the crop land.

Given this situation of crop utilization, our research on millet would benefit the poor and result in the development of a less endowed region, thus addressing our concerns of equity in distribution of research benefits.

Environment

Areas

In western Africa there are three bioclimatic zones: the Sahelian, Sudanian, and Northern Guinean Zones. The area grown to pearl millet in the Northern Guinean Zone is not significant. These bioclimatic zones are distinguished by annual rainfall, length of the growing season, soil types, cultural practices, and maturity of traditional varieties (Table 4).

The bulk of the pearl millet crop is grown in the Sahelian Zone with an annual rainfall of 300-600 mm and a growing season of 60-100 days, and the Sudanian Zone with an annual rainfall of 600-900 mm and a growing season of 100-150 days. The major soil types are coarse textured Arenosols, Luvisols, and Regosols, which are sandy and are low in organic matter, nitrogen, and phosphorous.

Two types of pearl millet-—early and late—are grown in these two bioclimatic zones. Early millets that mature in 75-100 days are grown in the Sahelian Zone and the late, photoperiod-sensitive types that mature in 100-150 days are grown in the Sudanian Zone. In the Sahelian Zone, pearl millet is intercropped with low densities of cowpea *(Vigna unguiculata),* and in the Sudanian Zone it is intercropped with sorghum *{Sorghum bicolor)* and maize *(Zea mays),* or with cowpea and groundnut.

Table 4. Characteristics of two bioclimatic zones in western Africa.

Bioclimatic zone	Rainfall (mm)	Soil types (Alfisols)	Growing season (d)	Cropping system
Southern Sahelian	300-600	Sandy (Arenosols, Luvisols, Regosols)	60-100	Sole crop of early millet and intercropping with cowpea and sorghum
Sudanian	600-900	Loamy sand Sandy loam (Luvisols, Arenosols)	100-150	Intercrops of early and late millets, sorghum/maize, and cowpea/groundnut

On-farm constraints to production

On-farm constraints to production fall into two groups: (1) abiotic and biotic constraints that can be alleviated through breeding, and (2) production constraints that can be addressed through improved agronomic techniques. In addition, unfavorable agricultural policies discourage increases in production. Several of the on-farm constraints are interrelated and can be addressed through coordinated crop improvement and resource management research.

Priority on-farm constraints for the Sahelian Zone include: stand establishment, moisture and nutrient stress, insect pests, *Striga,* low yield potential of local cultivars, and traditional management practices. For the Sudanian Zone, stand establishment, nutrient stress, insects, diseases, *Striga,* low yield potential of local cultivars, and traditional management practices are important (Table 5).

Table 5. Prioritization of on-farm constraints to millet production in western Africa.

	Zone	
Constraint	Sahelian	Sudanian
Stand establishment	1	1
Moisture stress	1	2
Nutrient stress	1	
Insects	1	
Diseases	2	
Striga	I	
Local cultivars	1	
Traditional management	1	
Grain quality	3	3

1. Sahelian Zone (300-600 mm); Sudanian Zone (600-900 mm annual rainfall).

Source: ISC 1991. 1993; ICRISAT 1987.

As shown in Table 6, constraints of stand establishment, moisture stress, and nutrient stress, particularly of phosphorus and nitrogen, can largely be overcome by using improved varieties and better management practices that involve use of tillage, fertilizer, crop residues and animal manure, timely planting, weeding and interculture operations, intercropping, and rotations.

The stem borer and head caterpillar significantly reduce grain production. Integrated pest management techniques that would include use of resistant varieties, improved management, pheromones, and parasites would effectively reduce the damage. By using screening techniques developed at ICRISAT Center for downy mildew, impressive progress has been made in the development of disease-resistant varieties. Breeding of resistant varieties is the only viable strategy for the control of downy mildew. For *Striga,* a feasible strategy would be a practical system of control with components that would include a resistant cultivar, application of nitrogen fertilizer and farmyard manure, destruction of the parasite to prevent seeding, and use of noncereal crops in association or in rotation.

Table 6. Strategies to overcome major on-farm constraints to millet production in western Africa.

Constraint	Factor(s)	Strategy
Stand establishment	Moisture, temperature, sand storms	Superior varieties, tillage, ridging, residues
Moisture stress	Drought during crop establishment and grain filling	Timely planting, correct (drought) planting densities, soil management, early and drought-tolerant varieties,
Nutrient stress (soil fertility)	Low inherent fertility	Timely planting, fertilization, rotations, intercropping, efficient nutrient-use genotypes
Insects	Stem borers Head caterpillars	Genetic resistances, cultural practices, IPM
Diseases	Downy mildew Smut	Genetic resistances
Striga	*Striga*	Cultural practices, genetic resistances, IPM
Local cultivars	Low production potential	Adapted and high yielding varieties with stability of production
Traditional management	No tillage Local varieties Low densities Low intensity Intercropping Minimal inputs	Improved management techniques, improved varieties
Consumer acceptance	Grain quality	Improved varieties with ease of dehulling acceptable for local products

Pearl millet was domesticated in western Africa and its extensive variability is a result of human selection. In response to biotic and abiotic constraints, local cultivars tend to be vegetative and perform best at low population densities. They do not show wide adaptation. Biomass production is high and the harvest index is between 10-20% compared to over 25% for improved varieties. They are less responsive to improved fertility in terms of grain production. As droughts are frequent, most improved varieties are early versions of these local cultivars. The area sown to improved varieties is between 2% and 10%. For the long term, adapted high-yielding varieties and hybrids with stability of production are necessary for major breakthroughs in production.

Under the situation of subsistence farming, grain yields are also limited by poor management. Some general improvement of the environment in terms of better management techniques is essential for success from genetic improvement.

Development of varieties acceptable for local food preparation with improved dehulling, and ability to store flour is important if millet is going to be used on a wider scale in urban areas.

To alleviate these on-farm constraints, there is a clear need for coordinated research by the crop improvement and resource management programs.

Policy constraints

The policy constraints most frequently expressed by the National Agricultural Research Systems (NARSs) include mechanisms for technology transfer (infrastructure' for seed production, input availability, and extension services), remunerative prices for the grain, stability and accessibility to markets, credit availability to purchase inputs, and lack of long-term investment in research.

NARS: Strengths and Weaknesses

Though the staff numbers appear adequate for millet research in western African NARSs, they include not only breeders, entomologists, pathologists, and agronomists, but also cereal quality scientists, engineers, sociologists, and economists (Table 7). Considering the time each scientist directly devotes to millet research, the available manpower is about 25-30 scientists. An adequate number of substations are available.

The operational constraints most frequently expressed by NARS scientists include lack of manpower—both trained scientists and technicians; lack of improved varieties; lack of facilities for seed multiplication; lack of operational funds; poor contact between research and extension for dissemination of improved technology; lack of information; lower proportion of time allocated to millet research; and availability of transport and equipment.

Variety development is a protracted process and the current situation in the NARSs hinders long-term commitment of skilled scientists to breeding research and limits their output. It must be noted that there are relatively strong millet programs in Niger, Nigeria, Burkina Faso, Mali, and Senegal—countries where ICRISAT began cooperative programs in the mid-1970s. The advantage of NARSs is that they are conversant with the local environment, can directly interact with extension services and farmers, and are better placed to undertake location-specific research. The NARSs are changing

Table 7. Staff and infrastructure for millet improvement in NARSs.

	Staff		Infrastructure		
Country	Scientists	Technicians	Stations	Support	Laboratories
Benin	2	5	1	2	NA
Burkina Faso	13	18	5	NA	6
Cameroon	5	NA[1]	4	11	6
Chad	4	15	2	5	1
Cote d'Ivoire	4	8	1	16	2
Gambia	4	10	2	4	1
Ghana	5	1	1	NA	NA
Guinea Bissau	19	20	2	3	2
Mali	10	NA	6	NA	7
Mauritania	4	3	1	8	5
Niger	17	24	2	9	12
Nigeria	6+11	NA	1	NA	NA
Senegal	4	9	1	10	3

1. NA = Not available.

Source: ISC 1991.

gradually and in the right direction: these changes include awareness to setup research priorities; appreciation of the value of multidisciplinary research; increased number of trained scientists and technicians; increased sharing of research results; the need for regional research; and increased interaction with ICRISAT.

ICRISAT's Comparative Advantage

ICRISAT has a comparative advantage in (1) the systematic use of adapted germplasm in the development of improved varieties, (2) already having adequate facilities in place for stress screening techniques for identification and utilization of resistances, (3) interaction with the resource management program—particularly evaluation of performance of improved varieties under improved technology, and (4) our capability to carry out research with mentor institutes. We have the ability to plan and work towards long-term goals and undertake strategic research. We have adequate staff, funding, and laboratory and field facilities for research and training. We have excellent rapport with the NARSs. One disadvantage is the limited number of experimental sites available and the need to finance NARSs for management of experiments.

Other Research and Development Players

In western Africa there are several agencies that are involved in research and development, generally on a short-term basis. These are special projects of FAO, regional organizations such as the Comite permanent inter-Etats de lutte contre la secheresse dans le Sahel, Mali (CILSS) [Institut du Sahel, Mali (INSAH)], bilaterally funded projects, and nongovernmental organizations (NGOs) that work directly with farmers. Thanks to these bilateral agencies, several scientists and technicians were trained and a proportion of operational expenditures have been met.

NARS-ICRISAT Collaboration

Between 1986 to-date, the pearl millet improvement program in western Africa has been involved in a range of cooperative activities with the NARSs. These include supply of seed of improved varieties, training and consultancies, exchange of genetic material, joint research, joint trials, and conduct of regional workshops. The level of collaboration is proportional to the strength of the national programs. We have close collaboration with programs in Burkina Faso; Mali, Niger, Nigeria, and Senegal. ICRISAT's cooperative activities seek to address the operational constraints most frequently expressed by the NARS—training and seed.

We have trained over 30 technicians from 6 countries and conducted 7 regional workshops and 3 training workshops. We regularly provide large quantities of seed of improved varieties. For example, in 1992 we supplied 280 kg of seed to seven national programs.

Varieties co-developed by ICRISAT and NARS are beginning to reach farmers' fields. Seven varieties each in Burkina Faso, Ghana, and Niger; 4 varieties each in Mali and Mauritania; 1 variety each in Chad and Togo; 3 varieties in Nigeria; and 12 in Senegal are in tests—on-station, on-farm, recommended for cultivation, or already being cultivated by farmers.

West and Central African Millet Research Network (WCAMRN)

WCAMRN (also known by the French acronym of ROCAFREMI), with 14 member countries, was formally established in 1990. The objectives of the network are: to develop and strengthen cooperation between NARSs, regional institutes, and international institutes; to encourage multidisciplinary research; to assist in information dissemination; and to facilitate better use of human and material resources to extend improved technologies to farmers-

Last year a Memorandum of Understanding between ICRISAT and the donor agency, the

Swiss Development Cooperation, was signed to formally begin activities of the network. Funding is assured until April 1994. Currently three projects are in operation: provision of quality seed to farmers, and development of methods for integrated control of millet head pests and downy mildew. A fourth project on development of millet-based production systems will be initiated next year. A coordinator was recently recruited. This network will facilitate productive linkages between ICRISAT and the national programs.

Policy Environment

External Program Review (EPR)

The EPR agreed that in western Africa emphasis should be on applied rather than strategic research. The panels were impressed with the quality of work and commitment of the staff. They suggested that we breed for stress resistance factors for the Sahelian Zone and yield potential for the Sudanian Zone; select late varieties for the Sahelian Zone to avoid problems of insect pests, and select early varieties for periodical and residual planting in the Sudanian Zone; and emphasize research on *Striga* and drought tolerance. The suggested emphasis is reflected in the projects approved in our last In-house Review held in March.

In-house Review (IHR)

During the IHR of the Pearl Millet Improvement Program 22 projects were reviewed and 15 projects were retained, including revised proposals and new projects. Currently, most of these projects address themes of our MTP. Included in these projects is one that relates to our cooperative activities and one collaborative project with the Institut

Table 8. Pearl millet: MTP themes, output, related projects, and themes.

Rank	Theme	Output	Directly related projects	Related themes[1]
59	Terminal drought stress	Knowledge on interactions of nutrient stress, moisture stress, and management Improved screening technique Elite cultivars with good GFAUTDS[2] Information on photoperiod sensitivity	3	2+4
64	Downy mildew	Variability in pathogen Cultivars with durable resistance Information on pathogen epidemiology	1	2+1
68	*Striga*	Biology of the parasite Screening techniques Sources resistance Knowledge of cultural practices IPM strategies	1	2+1
69	Low grain yield	Information on specific traits and selection criteria Adapted populations with high yield potential Adapted varieties and hybrids Impact of improved varieties	7	6+2
83	Head caterpillars	Knowledge of pest and screening Knowledge on cultural practices Cultivars with resistance Sources of resistance and inheritance	1	2+1
84	High temperature	Screening methods Interaction of high temperature, moisture stress, and management Sources of heat tolerance Varieties with high levels of seedling heat tolerance IPM strategies	1	2+2
87	Stem borer	Knowledge of pest biology Knowledge on practices Pheromone for cultural control Sources of resistance and improved varieties IPM strategies	1	2+1

1. Pearl millet and resource management themes on soil fertility, water deficit, technology adoption/evaluation of impact, and characterization of production environments.
2. Grain rilling ability under terminal drought stress.

francais de recherche scientifique pour le developpment en cooperation (ORSTOM).

Medium Term Plan (MTP)

Seven research themes relate to our work in western Africa, representing principal constraints to millet production. Themes 59 and 84 with three research projects address abiotic constraints; themes 64, 68, 83, and 87 and four projects deal with downy mildew, *Striga,* head caterpillar, and stem borer; and 69 and 103 are on yield potential and stability with seven projects (Table 8). Some of these themes are shared with IC and SADC. The goal is to achieve superior productivity and stability through development and adoption of improved varieties and hybrids. After this IHR, we will 'fine tune' the objectives of some of our research projects to reflect the global objectives and output as outlined in the MTP.

Conclusion

Production of pearl millet has the potential to be greatly increased but interventions are required concurrently in a number of different areas including breeding, crop protection, and crop agronomy in addition to strengthening research capabilities of NARSs and favorable agricultural policies. Research goals outlined in our MTP are comprehensive and encourage both within- and across-program integration. They will direct us towards translating research into tangible impacts—improved varieties and technologies—that would contribute to increases in millet production and productivity.

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Sorghum in Western Africa

S.K. Debrah[1]

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Sorghum in Western Africa

S.K. Debrah

Abstract

Sorghum (Sorghum bicolor) *is one of the main staple crops in the food system of western Africa and represents about 37% of the total foodgrain production. It is produced as a subsistence crop from small, family-based farms ranging in size from 2 to 6 ha using family labor as the principal input. Long-term sorghum yields in western Africa as a whole average 766 kg ha*$^{-1}$*, but in the predominantly arid and semi-arid areas, they average 620 kg ha*$^{'1}$*. Aggregate sorghum production declined at an annual compound rate of -0.2% per annum from 532 00 t in 1971 to 50700 t in 1991. The decline was mainly due to declining harvested areas, as yields grew moderately during the same period.*

Although sorghum research in western Africa dates back to the mid-1960s, sorghum is still dominated by local varieties. The notable varieties are SH 60 in Senegal, Tiemarifing in Mali, Nagawhite in Ghana, and Farafara in Nigeria. The most common sorghum diseases in both the local and introduced varieties are grey leaf spot and leaf anthracnose in the Northern Guinean and Sudanian Zones, while sooty stripe and long smut are prevalent in the Sudanian Zone. The introduced varieties suffer mostly from grain mold in the wetter areas of western Africa, and Striga hermonthica *is a serious weed parasite that attacks both local and introduced varieties in both the Northern Guinean and Sudanian Zones. Stem borers, notably* B. fusca, *and head bugs, particularly* E. immaculatus, *are the two major groups of insect pests that attack sorghum in the region.*

Sorghum is mainly used for human consumption in western Africa and is consumed in the form of stiff or thin porridges, as steam-cooked products, or as beverages. Its utilization for industrial purposes is not widespread in the region, and it continues to be regarded as a subsistence crop. In recent times, evidence is beginning to emerge, both on a per capita basis and on the basis of the shares of sorghum in total foodgrain consumption, that western Africa consumers are shifting their consumption patterns. Annual per capita consumption of pearl millet and sorghum, for example, fell by more than 22 kg from the mid-1960s to the mid-1980s, while rice and wheat consumption rose by more than 16 kg during the same period. The factors responsible for the shifting pattern include changes in relative prices, rising incomes, and urbanization. Despite the shifting trend, sorghum will remain important in the food system, and technological adjustments, infrastructure, and policy changes would be needed to raise the competitiveness of sorghum in the food system of western Africa.

Introduction

Western Africa is a region of enormous environmental and cultural diversity. It consists of 16 countries and covers a total land area of 1.58 million km^2. With the exception of a few countries, the region is classified by the World Bank as among the poorest third of the world's developing countries with per capita incomes of US$ 320 or less. The human population, which grows at an annual rate of 2.9%, was estimated to be 185 million in 1986 and is projected to reach 284 million by the year 2000. Sorghum *(Sorghum bicolor),* pearl millet *(Pennisetum glaucum),* maize *(Zea mays),* rice *(Oryza sativa),* and fonio *(Digitaria exilis)* the West African Semi-Arid Tropics (WASAT) and absorb 50 to 80% percent of total farm-level resources (Matlon 1987). Millet and sorghum account for 80% of total cereal production and constitute the main staple diet in the subregion.

The Physical Environment

Major agroecological zones

Roughly 54% of the total land area in western Africa may be considered as arid, defined as those areas where the length of the growing season (LGS) is less than 90 days. Twenty percent of the land area is semi-arid (90-180 pgd), 16% subhumid (180-270 LGS), and 10% humid (270 LGS). The semi-arid region, commonly referred to as the WASAT, receives mean annual rainfall ranging between roughly 250 and 1300 mm. Within the WASAT one can delimit broad agroclimatic zones such as the Sahelian, the Sahelo-Sudanian, the Sudanian, and the Sudano-Guinean, each with distinct agricultural systems and potential. Table 1 summarizes the major features of the agroclimatic zones in the WASAT. In general, climatic constraints, which include short unimodal rainy seasons, high intraseason variability, and high rainfall intensity, are more severe in the Sahelian Zone, and ease as one goes southwards towards the Sudano-Guinean Zone. Climatic and edaphic factors favor the production of a wider range of cash and food crops in the Sudanian and particularly the Sudano-Guinean Zones than in the Sahelian and Sahelo-Sudanian Zones.

Within the broad agroclimatic zones, farmers have adapted to microvariations with highly flexible management practices. For example, in the Sahel and the Sahelo-Sudanian Zones, where the soils tend to be droughty, rapidly exhausted, and subject to high risk of erosion, farmers grow millet and fonio for subsistence. In the Sudanian and Sudano-Guinean Zones where the soils are deeper, farmers tend to grow the less drought-tolerant crops, including sorghum, maize, and rice. Livestock rearing and off-farm employment provide additional sources of income for farmers in these zones.

Table 1. Major characteristics of the principal agroclimatic zones of the WASAT.

	Agroclimatic zones			
	Sahelian	Sahelo-Sudanian	Sudanian	Sudano-Guinean
Annual rainfall (mm)	<350	350-650	600-800	800-1100
Total area (% of WASAT)	24	30	21	24
Cultivable soils (% of WASAT)	29	30	37	42
Total of population (% of WASAT)	16	19	59	6
Farming system and major crops	Migratory livestock rearing plus millet and fonio for subsistence	Millet, cowpea (intercropped with millet), fonio, groundnuts and sorghum as secondary crop	Transition between millet and sorghum based systems. Maize, groundnuts, cotton also cultivated.	High crop diversification. Cotton, maize, rice, cowpea, groundnuts, vegetable, livestock rearing and off-farm activities

Source: Adapted from Matlon (1990).

Climatic and soil constraints of the WASAT

Other than low rainfall, several climatic characteristics limit the region's cultural potential. The WASAT has a significantly shorter crop-growing season than other semi-arid tropics (SATs) with similar rainfall. Although high temperature and solar radiation during the rainy season are conducive to rapid plant growth, they also cause high evaporation. Evaporative demands in the WASAT are highest during the sowing and grain-filling periods, thereby increasing the risk of early and late season water stress. Rainfall intensity can be high, usually causing topsoil erosion of up to 60% of rainfall loss through runoff. Even in years of normal total rainfall, the distribution tends to be erratic, with drought periods of 2 weeks or longer common, particularly in the Sahel. Variation in annual totals is also high. The annual coefficient of variation of rainfall is 20 to 30% in the Sudan and 30 to 50% in the Sahel. Soil texture varies from loamy sands in the northern Sahel to sandy loams in the southern Sudan areas. Except for limited Vertisol pockets, clay content is uniformly low, less than 20%, and the soils are structurally inert and have poor water holding capacity.

Due to the low clay and organic matter content (generally lower than 1%), cation exchange capacities tend to be less than 5 milliequivalents per 100 grams of soil. As a result, soils are highly fragile. In addition to low natural fertility, the major physical properties of WASAT soils that limit crop production potential include: (1) very low structural porosity and consequently high bulk density, which reduces root penetration and water circulation, (2) a tendency for compacting and hardening during the dry season, which results in early erosion runoff and which severely restricts preseason and post-season cultivation, (3) generally poor infiltration, except on eolian sandy soils, due to rapid surface crusting of soils even after cultivation, (4) low values of available water compared to typical Asian SAT soils, and (5) increasing susceptibility to erosion with continuous cultivation.

Long-term Averages in the Harvested Areas, Yields, and Production of Major Foodgrains in Western Africa

In order to appreciate the importance of sorghum and millet as foodgrains in western Africa, their production statistics are reviewed alongside rice and maize, which are also important foodgrains in the region. The 16 countries of the western African region are grouped by whether they fall predominantly in the drier areas (arid or semi-arid) or predominantly in the wetter areas (humid or subhumid) of western Africa. Comparisons of aggregate production, harvested area, yields, and growth rates of the major foodgrains are then made for the region as a whole with differences between the drier and wetter areas highlighted.

Table 2 summarizes the long-term averages in the harvested areas, yields, and production of rice, maize, millet, and sorghum in western Africa between 1969 and 1986 (for rice and maize), and between 1969 and 1991 for millet and sorghum. Sorghum and millet predominate over rice and maize in the region as a whole, both in terms of harvested area and production. Rice and maize are also important in the region as a whole but their production is mainly concentrated in the humid/subhumid zones of western Africa. The major rice-producing countries (all located in the wetter areas) are Nigeria, Sierra Leone, and Cdte d'Ivoire; production averaged 1 073 000 t per annum in Nigeria, 515 000 t in Sierra Leone, and 466 00 t in Cote d'Ivoire over the past two decades.

Although harvested areas of millet and sorghum are generally larger in the arid/semi-arid zones of western Africa, they yield higher in the humid/subhumid zones. The long-term average yields of millet and sorghum in western Africa as a whole are 654 and 766 kg ha^{-1}, respectively. In the WASAT (predominantly arid/semi-arid zones of western Africa), average long-term yields of millet are 579 kg ha^{-1}, and for sorghum 620 kg ha^{1}. In the humid/subhumid zones millet averages 728 kg ha^{-1} and sorghum

Table 2. Long-term averages of harvested area ('000 ha), yield (kg ha^{-1}), and production ('000 t) of major food grains in western Africa.

		Food crop[1]											
		Rice			Maize			Millet			Sorghum		
Region/Country	Ecological zone	Harvested area	Yield	Produetion	Harvested area	Yield	Production	Harvested area	Yield	Production	Harvested area	Yield	Production
West Africa		157	1348	206	218	941	205	859	654	530	766	766	548
Burkina Faso	A/SA[3]	33	1223	36	123	830	104	962	508	499	1136	683	783
Chad	A/SA	55	912	36	25	1238	23	775	597	402	456	670	294
Gambia	A/SA	23	1444	33	11	1200	13	45	900	40	11	1025	11
Mali	A/SA	169	947	160	95	944	92	1281	707	902	778	858	664
Mauritania[2]	A/SA	3	2769	6	7	551	4	110	324	34	113	617	72
Niger	A/SA	21	2057	43	11	683	8	3087	404	1248	1064	338	336
Senegal[2]	A/SA	72	1586	112	72	1009	76	985	613	603	133	902	120
Subtotal	A/SA	51	1562	61	49	922	45	1035	579	532	806	620	440
Benin	H/SH	7.8	1241	9.7	411	756	324	43	509	43	100	692	115
Cote d'Ivoire[2]	H/SH	408	1142	466	555	660	363	71	570	41	44	590	28
Ghana[2]	H/SH	76	983	74	380	1063	402	208	504	105	222	715	155
Guinea	H/SH	469	851	395	50	1074	54	40	1500	60	11	810	11
Guinea Bissau	H/SH	65	983	64	11	819	10	20	600	12	17	702	11
Liberia[2]	H/SH	206	1249	258	-[4]	-	-	-	-	-	-	-	-
Nigeria[4]	H/SH	545	1864	1073	1364	1244	1440	4486	796	3493	5271	803	4082
Sierra Leone	H/SH	373	1383	515	13	955	12	15	1133	16	12	1518	15
Togo	H/SH	19	932	17	149	1089	157	127	803	94	149	743	108
Subtotal	H/SH	241	1181	319	367	958	345	688	728	528	764	827	594

1. Rice and maize averaged over 1971-86; sorghum and millet over 1971-91 periods.
2. Indicates relatively high-income countries defined as those with a 1985 per capita GNP of US $350 or more in constant 1983 - 1985 US$ (World Bank, 1987).
3. A/SA = countries predominantly in arid/semi-arid zone; H/SH = countries predominantly in humid/sub-humid zone.
4. A dash (-) means that for these countries, no distinction is made between sorghum and millet.

Source: FAO 1980. 1981. 1985, 1986.

827 kg ha^{-1}. As a result of higher yields of sorghum and millet in the humid/subhumid zones, the combined long-term aggregate production of sorghum and millet is 15% higher than the long-term aggregate production in the arid/semi-arid zones even though the combined harvested areas in the wetter areas are only 79% of those of the drier areas.

Figure 1 shows long-term average yields of sorghum and millet for seven countries located in the WASAT. Sorghum yields in the WASAT range from as high as 1025 kg ha^{-1} in Gambia to as low as 338 kg ha^{*1} in Niger over the last 20 years. It is only in Niger and Mauritania that sorghum yields fell below the WASAT average of 620 kg ha^{-1} over the last 20 years. Millet yields range from as high as 900 kg ha^{-1} in Gambia to as low as 324 kg ha^{-1} in Mauritania. Millet yields fell below the WASAT average of 579 kg ha^{-1} in Burkina Faso, Niger, and Mauritania over the last 20 years.

Figure 2 shows the long-term shares in aggregate production of the major foodgrains in western Africa between 1971 and 1991. Sorghum and millet together represented roughly 72% of total foodgrain production while maize and rice production represented 28%. In the drier areas millet is the most important food crop, representing almost 50% of total production, and together with sorghum they represent 90% of total foodgrain production. In the wetter areas, the relative shares of rice and maize in total production are higher than in the drier areas. The principal crop in the wetter areas is sorghum,

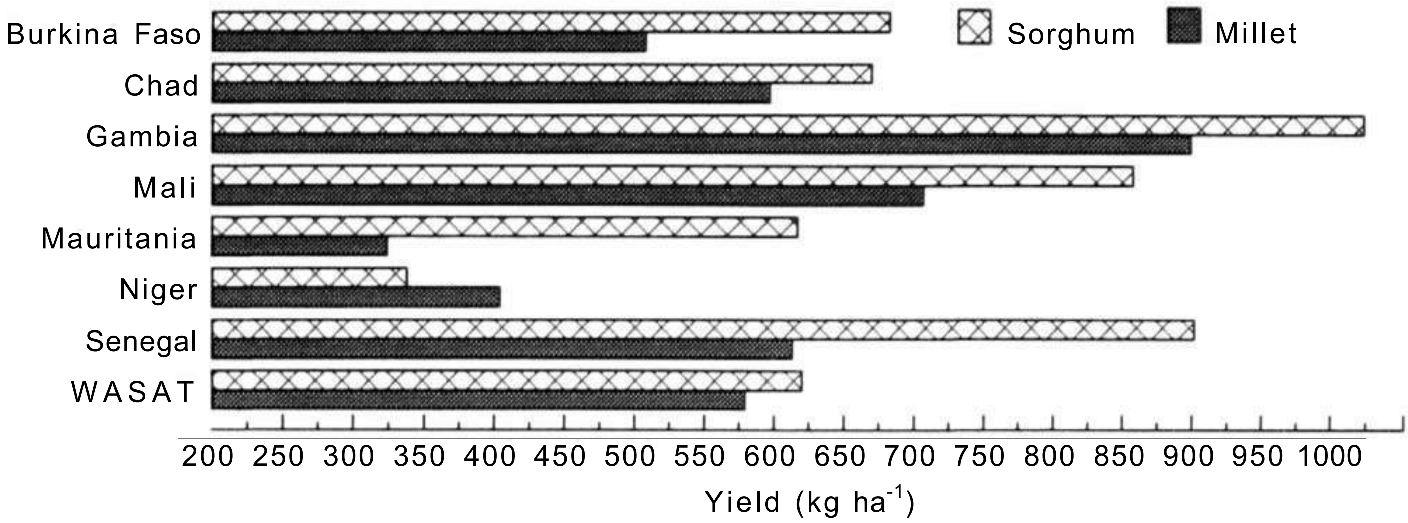

Figure 1. Long-term sorghum and millet yields in selected countries of the WASAT, 1971-1991 average.

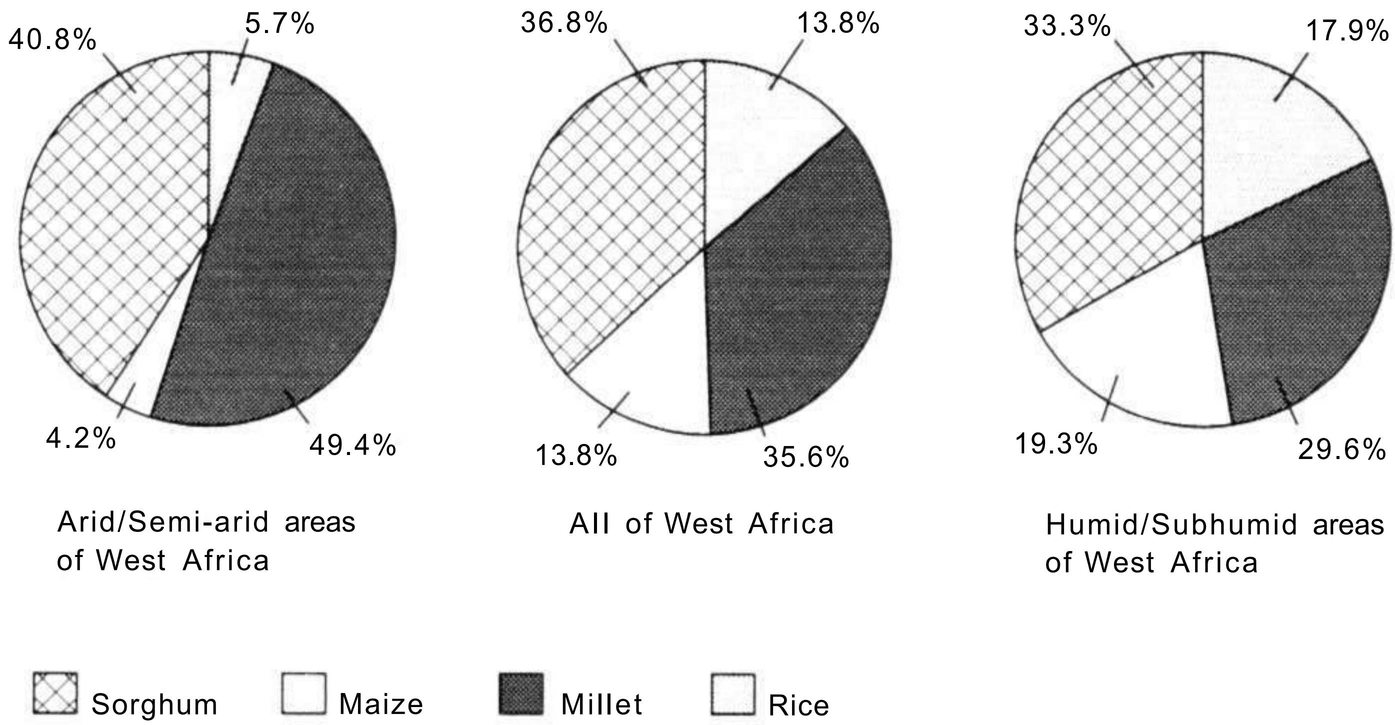

Figure 2. Long-term shares in aggregate production of the major foodgrains in western Africa, 1971-1991 average.

occupying 33%, followed by millet, representing 30%, Rice and maize together occupy 37% of the total foodgrain production.

Trends in the aggregate production of the major foodgrains

Aggregate sorghum production in western Africa as a whole (Table 3) virtually stagnated over the past 20 years. It decreased at an annual compound rate of -0.2% from the 1969-71 average of 532 000 t to 507 000 t in 1991. While the wetter areas of western Africa experienced moderate growths in aggregate production, the countries in the drier areas experienced slight declines in production. The countries of Guinea, Guinea Bissau, and Sierra Leone all experienced growth rates of 6% or more per annum in sorghum production. Aggregate millet production

Table 3. Aggregate production trends and growth rates of major cereals in western Africa.

		Aggregate production ('000 t)											
		Rice			Maize			Millet			Sorghum		
Region/Country	Eco-logical zone	(1969-71) average	(1980-86) average	Growth rate (%)	(1969 71) average	(1980-86) average	Growth rate (%)	(1969-71) average	1991	Growth rate (%)	(1969-71) average	1991	Growth rate (%)
West Africa		141	223	4.7	168	217	2.6	463	570	1.0	532	507	-0.2
Burkina Faso	A/SA[2]	39	35	-1.0	64	116	6.1	364	618	2.7	666	952	1.8
Chad	A/SA	42	29	-3.6	12	26	8.0	615	502	-1.0	,3	294	-
Gambia	A/SA	39	34	-1.4	4	16	14.8	40	50	1.1	-	11	-
Mali	A/SA	161	147	-0.9	67	98	3.8	784	790	0.0	-	664	-
Mauritania[1]	A/SA	1	11	27.0	4	4	0.0	81	70	-0.7	-	72	-
Niger	A/SA	34	50	3.9	2	8	14.8	974	1434	1.9	262	393	2.0
Senegal[1]	A/SA	118	112	-0.5	42	88	7.6	539	571	0.3	-	120	-
Subtotal	A/SA	62	60	-0.3	28	51	6.2	485	497	0.1	464	358	-1.3
Benin	H/SH	4	10	9.5	201	361	6.0	6	23	6.9	52	104	3.5
Cote d'Ivoire[1]	H/SH	335	477	3.6	257	407	4.7	31	47	2.1	14	26	3.1
Ghana[1]	H/SH	55	74	3.0	417	408	-0.2	120	122	0.0	147	188	12
Guinea	H/SH	364	402	0.9	68	51	-2.8	-	60	-	8	34	7.5
Guinea Bissau	H/SH	30	74	9.4	2	12	19.6	6	18	5.6	3	10	6.2
Liberia[1]	H/SH	184	272	3.9	na[4]	na	na	na	na	na	na	na	na
Nigeria[1]	H/SH	352	1308	14.0	1215	1490	2.0	2792	4702	2.6	3632	605	12
Sierra Leone	H/SH	474	517	0.8	10	13	2.6	6	23	6.9	6	21	6.4
Togo	H/SH	18	18	0.0	160	160	0.2	121	75	-2.3	90	125	1.6
Subtotal	H/SH	202	350	5.6	291	363	2.2	440	634	1.8	552	639	0.8

1. Indicates relatively high-income countries defined as those with a 1985 per capita GNP of US $350 or more in constant 1983-1985 US$ (World Bank. 1987).
2. A/SA - countries predominantly in arid/semi-arid zone; H/SH - countries predominantly in humid/sub-humid zone.
3. A dash (-) means that for these countries, no distinction is made between sorghum and millet.
4. na means data not available.

Source: FAO 1980,1981,1985,1986.

in western Africa, on the other hand, grew from 463 000 t in 1969-71 to 639 000 t in 1991 for an annual compound growth rate of 1.8%. Aggregate millet production in the countries located in the drier areas stagnated over the 20-year period while those in the wetter areas grew at an annual compound rate of 1.8%. Most of the growth was experienced in Benin, Sierra Leone, and Guinea Bissau. Except for Chad, Mauritania, and Togo where millet production declined, the countries in western Africa as a whole experienced a moderate growth in millet production between 1971 and 1991.

The growth rates in rice production in western Africa are high in the countries located in the wetter areas, where growth rates of between 3.5 and 14% per annum were recorded between 1971 and 1991. The biggest rice-producing countries are Cote D'Ivoire, Guinea, Liberia, Nigeria, and Sierra Leone, where at least 272 000 t was produced on average per annum. Maize production grew at a compound growth rate of 2.6% per annum in western Africa as a whole, but most of the growth was recorded in the drier areas where growth averaged 6.2% per annum. The big maize-producing countries are

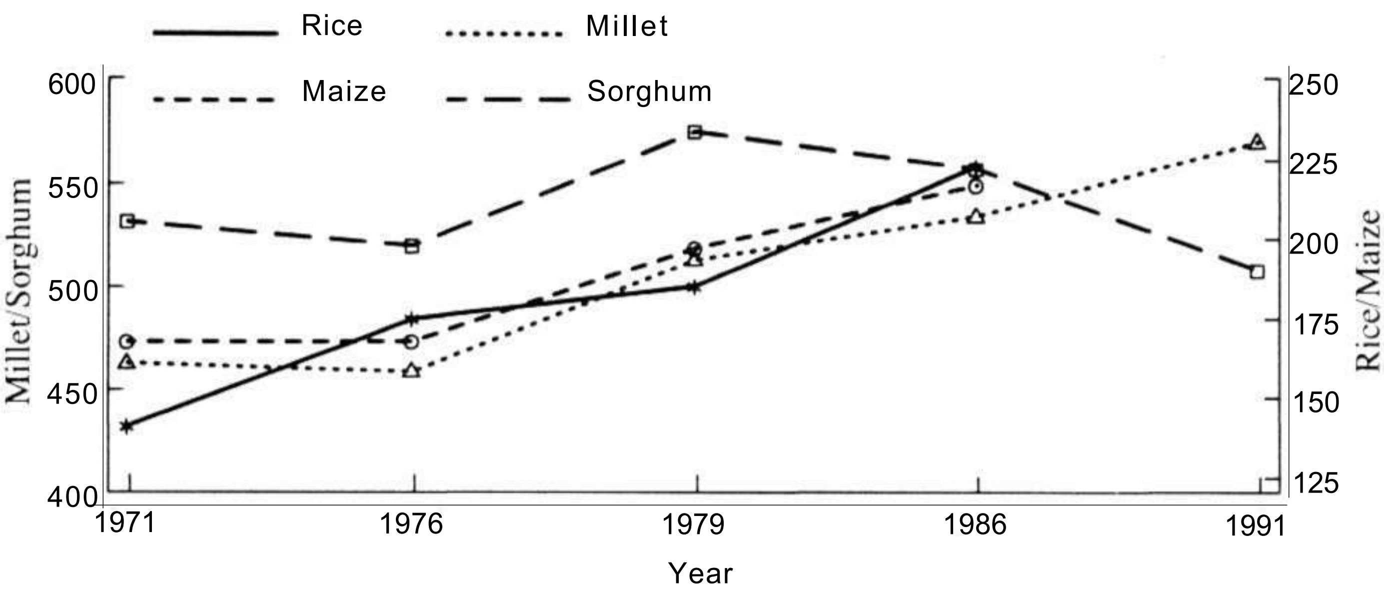

Figure 3. Production trends ('000 t) of rice and maize (1971-86) and of sorghum and millet (1971-91) in western Africa.

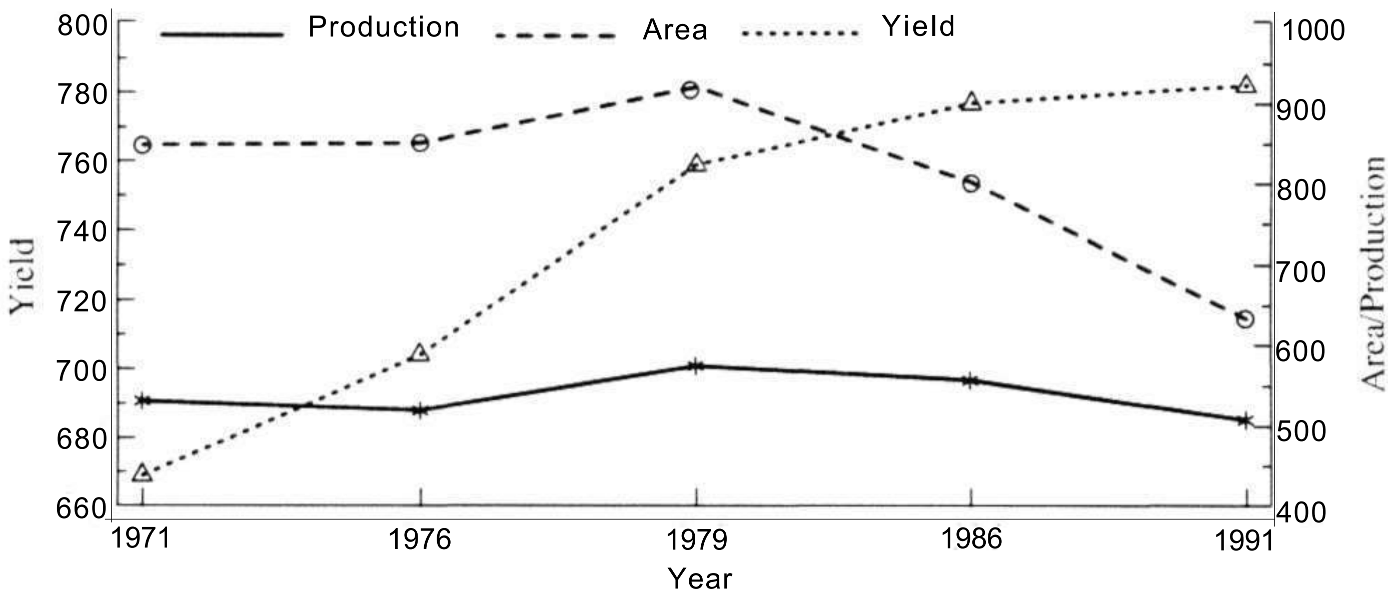

Figure 4. Trends in harvested areas ('000 ha), yield (kg ha^{-1}), and production ('000 t) of sorghum in western Africa, 1971-1991.

Burkina Faso, Benin, Cote d'Ivoire, Ghana, and Nigeria, where at least 116 000 t was produced on average per annum between 1971 and 1991. Figure 3 compares the growth rates of the major food grains in the region. Except for sorghum, foodgrain production has been increasing steadily between 1971 and 1991. Sorghum production declined between 1971 and 1976, increased between 1976 and 1979, and has been falling ever since.

Trends in sorghum harvested areas, yields, and production

Figure 4 illustrates the general trend in harvested area, yield, and production of sorghum in western Africa over the period between 1971 and 1991. The growth in sorghum production from the 1971 average of 532 000 t to the 1979 average of 575 000 t was due both to increasing growth rates in harvested areas as well as growth in yields. Higher yields, rather than increasing harvested areas, appeared to explain much of the growth in aggregate production. Between 1979 and 1986 harvested areas of sorghum dropped substantially (from 921 000 ha to 802 000 ha) while yields increased moderately from 759 to 777 kg ha^{-1}. A combination of these resulted in a reduction in aggregate production from 575 000 t in 1979 to 557 000 t in 1986. Similarly, between 1986 and 1991 increases in sorghum yield were not high enough to compensate for the rapid decline in harvested areas, leading to a shortfall in aggregate production. A comparison of trends in the harvested areas and yields of the major foodgrains in the region are made in Tables 4 and 5, respectively.

Sorghum Utilization in Western Africa

In western Africa, sorghum is a basic staple food for human consumption. Its use as animal feed is not yet well developed. Other uses of sorghum and millet include the use of their stalks as building materials and as energy sources in many areas. When used as food, sorghum is consumed in many forms: the simplest is as boiled or roasted whole grain. The other sorghum food forms require primary processing (dehulling and milling) of the grain before being cooked into porridge or brewed into beverages. Dehulling and milling are usually done in the traditional way by women by pounding the whole grains in large wooden or stone mortars

Table 4. Trends in harvested area and growth rates of major cereals in western Africa.

		Harvested area ('000 t)											
		Rice			Maize			Millet			Sorghum		
Region/Country	Ecological zone	(1969-71) average	(1980-86) average	Growth rate (%)	(1969-71) average	(1980-86) average	Growth rate (%)	(1969 71) average	1991	Growth rate (%)	(1969 71) average	1991	Growth rate (%)
West Africa		122	167	3.1	196	221	1.2	848	770	-0.5	849	634	-1.4
Burkina Faso	A/SA[2]	40	30	-2.8	102	133	2.7	857	1188	1.6	1131	1302	0.7
Chad	A/SA	44	31	-3.4	6	32	18.2	925	1233	1.4	-[3]	456	-
Gambia	A/SA	28	22	-2.3	7	12	5.5	42	53	1.1	-	11	-
Mali	A/SA	158	168	0.6	78	99	2.4	953	1107	0.8	-	778	-
Mauritania[1]	A/SA	1	4	14.8	7	7	0.0	263	173	-2.0	-	113	-
Niger	A/SA	16	22	3.2	3	12	14.8	2313	3683	2.3	589	1512	4.8
Senegal[1]	A/SA	91	65	-3.3	52	79	4.2	996	897	-0.5	-	133	-
Subtotal	A/SA	54	49	-0.9	36	53	3.9	907	993	0.4	860	614	-1.7
Benin	H/SH	3	8	10.3	359	434	1.9	16	35	4.0	91	141	2.2
Cote d'Ivoire[1]	H/SH	286	426	4.0	333	595	5.5	63	78	1.0	28	46	2.5
Ghana[1]	H/SH	55	75	3.1	387	387	0.0	218	192	-0.6	209	254	0.9
Guinea	H/SH	411	489	1.7	59	49	-0.2	-	40	-	11	24	3.9
Guinea Bissau	H/SH	30	77	9.8	3	44	1.6	1 1	20	3.0	5	13	4.9
Liberia[1]	H/SH	154	215	3.4	na[4]	na	na	na	na	na	na	na	na
Nigeria[1]	H/SH	272	650	5.7	1398	1295	-0.1	5022	4083	-0.1	5572	4518	-1.0
Sierra Leone	H/SH	331	374	1.2	10	13	2.6	6	26	7.6	5	30	8.3
Togo	H/SH	25	19	-2.7	144	160	1.0	190	130	-1.9	-	181	-
Subtotal	H/SH	174	259	4.0	337	368	0.8	789	575	-1.6	845	651	-1.3

1. Indicates relatively high-income countries defined as those with a 1985 per capita GNP of US$ 350 or more in constant 1983-1985 US$ (World Bank 1987).
2. A/SA - countries predominantly in arid/semi-arid zone; H/SH - countries predominantly in humid/sub-humid zone.
3. A dash (-) means that for these countries, no distinction is made between sorghum and millet.
4. na - data not available.

Source: FAO 1980, 1981, 1985, 1986.

Table 5. Yield trends of major cereals in western Africa and growth rates.

		Yields (kg ha^{-1})											
		Rice			Maize			Millet			Sorghum		
Region/Country	Eco-logical zone	(1969-71) average	(1980-86) average	Growth rate (%)	(1969-71) average	(1980-86) average	Growth rate (%)	(1969-71) average	1991	Growth rate (%)	(1969-71) average	1991	Growth rate (%)
West Africa		1176	1389	1.6	868	959	1.0	600	759	1.2	669	781	0.8
Burkina Faso	A/SA[2]	980	1401	3.6	630	867	3.2	425	522	1.3	589	729	1.0
Chad	A/SA	963	834	-1.4	1943	1040	-6.0	665	879	1.4	-[3]	640	-
Gambia	A/SA	1414	1523	0.7	566	1362	9.2	960	936	-0.1	-	1025	-
Mali	A/SA	1017	880	-1.4	866	961	1.0	823	719	-0.7	-	858	-
Mauritania[1]	A/SA	1008	3047	11.6	580	568	-0.2	308	371	0.9	-	617	-
Niger	A/SA	2090	2231	0.6	600	686	1.3	421	385	-0.4	445	267	-2.5
Senegal[1]	A/SA	1293	1708	2.8	684	1101	4.9	542	635	0.8	-	902	-
Subtotal	A/SA	1252	1660	2.9	838	941	12	592	635	0.3	517	720	1.7
Benin	H/SH	1372	1150	-1.7	559	794	3.6	375	660	2.9	565	736	1.3
Cote d'Ivoire[1]	H/SH	1168	1119	-0.4	773	688	-1.1	488	599	1.0	507	565	0.5
Ghana[1]	H/SH	1000	997	-0.0	1078	1057	-0.2	549	626	0.7	705	769	0.4
Guinea	H/SH	886	833	-0.6	1153	1041	-1.0	-	1500	-	727	1411	3.4
Guinea Bissau	H/SH	994	921	-0.8	628	840	3.0	531	925	2.8	573	859	2.0
Liberia[1]	H/SH	1194	1264	0.6	na[4]	na	na	na	na	na	na	na	na
Nigeria[1]	H/SH	1293	2012	4.5	869	1405	4.9	556	1150	1.5	652	1021	2.3
Sierra Leone	H/SH	1431	1386	-0.3	984	949	-0.4	1115	855	-1.1	1261	644	-3.3
Togo	H/SH	709	924	2.7	1109	1032	-0.7	638	586	-0.4	680	682	0.0
Subtotal	H/SH	1116	1178	0.5	894	976	0.8	607	867	1.8	713	836	0.8

1. Indicates relatively high-income countries defined as those with a 1985 per capita GNP of US$ 350 or more in constant 1983-1985 US$ (World Bank 1987).
2. A/SA = countries predominantly in arid/semi-arid zone; H/SH - countries predominantly in humid/sub-humid zone.
3. A dash (-) means that for these countries, no distinction is made between sorghum and millet.
4. na - data not available.

Source: FAO 1980, 1981. 1985. 1986.

to extract the flour (sorghum meal) for food preparation.

The most common meals prepared from processed sorghum are (1) porridges, which may be thin or stiff, e.g., *ogi* from Nigeria or *to* from Mali and Burkina Faso, (2) steamed cooked products such as *couscous,* or (3) beverages such as *dolo* from Burkina Faso and Mali or *pito* from Ghana and Togo. In western Africa, Nigeria has emerged as a pioneer in the industrial utilization of sorghum. For example, the Institute of Agricultural Research (IAR) in Nigeria has developed the technology for sorghum/wheat composite bread and confectionery using the local sorghum variety SK 5912. Ever since the Nigerian government banned cereal imports (notably barley and wheat) in 1988, the breweries in Nigeria have been using sorghum as raw material for clear beer-making.

Sorghum utilization trends in western Africa

There is a major imbalance between the composition of cereals consumption and that of production in the WASAT. In particular, there is a shifting pattern from sorghum consumption to rice and wheat consumption. Annual per capita rice and wheat consumption in western Africa as a whole rose by more than 16 kg from the early 1960s to the early 1980s, whereas millet and sorghum consumption fell by more than 22 kg. Maize consumption rose by less than 1 kg per person per year over the same period (Delgado and Reardon 1991).

The share of cereals consumption accounted for by sorghum and millet in selected countries in western Africa from the late 1960s to the second half of the 1980s is shown in Table 6. A general trend emerging from the table is that the shares of sorghum and millet in total cereal consumption have been decreasing while those of rice and wheat have been increasing. In Mali, for example, the share of sorghum and millet in total cereal consumption dropped from 74% in the late 1960s to 67% in the mid-1980s, while rice and wheat shares increased by 5 and 2 percentage points, respectively, over the same period. Delgado and Reardon (1991) investigated the determinants of the changing patterns of cereal use in western Africa and concluded that the pattern is demand-driven. They claim structural factors rather than such short-run factors as harvest shortfalls or price dips are more responsible for the changing patterns. Evidence from Mali, Senegal, and Burkina Faso (Table 7)

Table 7. Demand elasticities[1] for grain from aggregate data in three Sahelian countries, 1966-86.

	Mali	Senegal	Burkina Faso
% change in sorghum/millet/maize[2] demand with respect to a 1% change in:			
Own price	-0.07	-0.11	-0.50
Wheat price	0.05	-0.03	0.02[3]
Rice price	0.24	0.13[3]	0.05
Income	-0.28[3]	-0.24	1.13[3]
Rice demand			
Own price	-1.50[3]	-0.66	-0.96
Wheat price	-0.08[3]	0.01	-0.39
Sorghum/millet/ maize price	0.75	0.13[3]	0.48[3]
Income	0.91	-0.17	1.71
Wheat demand			
Own price	-0.20	0.36	-0.51
Wheat price	-0.26[3]	0.02[3]	-0.60
Sorghum/millet/ maize price	0.47	-0.06	0.32
Income	2.44	0.51	0.73[3]

1. 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. 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.
2. Burkina Faso estimates are for millet/sorghum only.
3. Not statistically significant at 10%.

Table 6. Changing cereals use patterns (crop share of all cereals used as food) in western Africa, 1966-70 and 1982-86.[1]

Country	Millet/Sorghum 196670 (%)	Millet/Sorghum 1982-86 (%)	Maize 1966-70 (%)	Maize 1982-86 (%)	Rice 1966-70 (%)	Rice 1982-86 (%)	Wheat 1966-70 (%)	Wheat 1982-86 (%)
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

1. The authors calculated the shares of cereals use using FAO's disappearance concept. Rows will not sum to 100% because consumption of minor cereals, either domestically produced or imported is not included in the table.
Source: Delgado and Reardon 1991.

show inelastic coarse grain demand response to own price. For example, a long-term rise of 1% in sorghum price in Mali, with other factors equal, is associated with a 0.07% decrease in quantity demanded for coarse grain. During the 1985 and 1986 bumper harvests of coarse grains in the Sahel, with the subsequent fall in grain prices, increases in coarse grain consumption were not experienced; rather, commercial imports of wheat and rice continued.

Cross-price elasticities that measure substitution or complementary effects of changes in the prices of other crops on the quantity demanded of coarse grains show virtually no impact of wheat and rice prices on coarse grain consumption. Microlevel evidence from household surveys from Ouagadougou, Burkina Faso, and seven regional capitals in Mali showed the predominance of nonprice or structural factors as determinants of the changing patterns of cereal consumption. Urbanization, employment patterns, and increasing values of women's time were cited as strong nonprice factors. For example, the lower processing/preparation costs of rice appear to be an incentive for its consumption in households where women participate in the labor force.

In the rural areas, rice and wheat are not usually consumed to any large extent except in areas where they are widely grown. Maize is therefore the major competitor of sorghum and millet. On the demand side, maize appears to attract WASAT rural consumers because it is cheaper than millet and sorghum.

Sorghum's Role in the Farming System

Resource use patterns

Most of the food grain production in the WASAT is from small, family-based farms ranging from small nuclear families to large extended or compound families including between 6 and 17 members. The cultivated area per family averages between 2 and 6 ha, but households in which animal traction is used as a power source cultivate larger areas, as is the case of Mali where animal traction households cultivate on average 10 ha as compared with 3 ha per manual household (Sanogo et al. 1992). The household's total crop land area is usually divided into a number of fields or plots, of which about a third is located around the compound. In extended families, some of the fields are collectively owned by the entire family, and major decisions, such as the allocation of labor and utilization of the output, are vested in the household head. Individual family members however have user rights to fields that they may cultivate during the growing season.

In the traditional production system, capital inputs consist mainly of hand tools, seed, and small quantities of organic fertilizer, usually household and farmyard manure. The traditional bush-fallow method of maintaining soil fertility is being abandoned, owing to increasing population pressure. Nearly all farm households keep poultry and small ruminants and in some cases cattle, but only about 10% of the WASAT farmers employ animal traction as a power source. In Mali, animal traction is well developed in the cotton-growing areas and draught power use is estimated to range from 3 to 6 oxen-days ha^{1}. Roughly 32% of the total available draught power is allocated to cotton and only about 17% to cereal crops (Sanogo et al. 1992).

Labor input per unit area, primarily from family resources, ranges from 24 to 37 man-days ha^{-1}, varying as a function of crop, population density, and length of cropping season. Periods of peak labor input generally correspond with planting and weeding, when timeliness can critically affect potential yields. In the sorghum-based cropping systems in Mali, about 79% of the total family labor is spent on weeding, harvesting, and threshing activities with 21% spent on land preparation and planting (Sanogo et al. 1992).

Cropping system

Farmers in the WASAT generally pursue a wide range of cropping activities within each household production unit. Crop diversification occurs both through use of crops in intercrop mixtures on the same plots, as well as through sole cropping across dispersed plot areas. About 80% of the cropped area in the WASAT is intercropped (Fussel and Serafini 1985). In many areas sorghum and millet are intercropped with other cereals (maize, sorghum, or millet), legumes [e.g., cowpea *(Vigna unguiculata)],* and other crops [e.g., groundnuts *(Arachis hypogaea)].*

The general objectives of crop diversification in the WASAT are (1) to make more efficient use of production factors by spreading their use across enterprises with different temporal profiles, (2) to increase aggregate productivity by matching physiological requirements of specific crops to distinct microenvironments, (3) to meet domestic household consumption requirements in the context of multiple crop failures in both factor and product markets, (4) to reduce aggregate production and income risks to the extent that the crops are not closely correlated, and (5) in the case of intercropping, to exploit morphological complementarities and compensatory behavior of crop components to improve and stabilize plot-level productivity.

Millet, cowpea (intercropped with millet), fonio, and groundnuts are the major upland crops typically grown between the isohyetes of 250 to 650 mm of annual rainfall in the Sahelo-Sahelian Zone. Sorghum and maize are more important in the Sudanian Zone, but maize cultivation is limited to heavily fertilized soils adjacent to the compound and represent less than 25% of the total cultivated area. In the Sudano-Guinean Zone, important shares of the cultivated area are sown to market-oriented crops such as cotton, maize, rice, cowpea, groundnuts, and vegetables. Sorghum is replaced by maize as the dominant food staple in the southern portion of the zone. Millet in this zone is limited primarily to poorer land types in the drier northern half and is grown as a component of the cereal/cereal relay cropping system.

In general, as one moves from the more arid to the more humid zones the number of crops and enterprises increases, and the area shares of the individual crop enterprises decrease. In a survey Matlon and Fafchamps (1988) found crop diversification to be lower in the Sahel and highest in the Northern Guinean Zone. In the Sahel, where the risks of crop loss are highest, the harsh environmental conditions unfortunately do not permit many crops to be grown economically.

Table 8 illustrates typical differences in crop yields for the various crops grown as sole or as intercrops in the cropping system, using Mali as an example. Sorghum grown as a sole crop yielded 896 kg ha^{-1} across village and tillage systems as compared with 713 kg ha^{-1} in a sorghum/cowpea intercropping system. Similarly, millet sole crop yielded 572 kg ha^{-1} as compared with 556 kg ha^{-1} in a millet/cowpea intercrop.

Labor productivity and returns to labor

Millet, maize, sorghum, rice, cotton, and other crops compete for family resources, of which labor is the single most important input in the farming system. Labor use and labor productivity (crop output per man-day of work) varies widely across agroclimatic zones. In the Sahel, it is estimated that approximately 317 hours of labor input is required per hectare as compared with 692 and 727 hours per hectare in the northern Guinean and Sudan savanna, respectively (Matlon and Fafchamps 1988). Within the same agroclimatic zone, however, the level of labor input as well as its productivity varies across crops, farm size, and tillage system. In Mali, labor productivity in maize production was estimated at 46.5 kg per man-day of work, while it was 25 kg per man-day in sole crop sorghum, and 12.8 kg in sorghum/cowpea intercrop (Sanogo et al. 1992). In Zimbabwe, Rohrbach (1991) estimated labor productivities of 46 kg in sorghum production, 42 kg in maize production, and 66 kg per man day in finger millet *(Eleusine coracana)* production. Labor in the production of market-oriented crops returns more per unit than in the production of subsistence crops. Examples from Mali show that grounduts return CFA 3275, cotton CFA 2526, maize CFA 1901, sorghum CFA 1343 and millet CFA 778 per man-day (300 CFA francs - US$ 1.00).

Table 8. Crop yield (t ha^{-1}) in four WASIP-Mali study villages, Mali, 1990 cropping season.

	OHV[1] Zone				CMDT[2] Zone						
	Dibaro		Nankila		Garasso		Siramana		All Villagees		
Crop	AT[3]	HT	AT	HT	AT	HT	AT	HT	AT	HT	All
Cotton	-	-	-	-	1.341 (0.426)[4]	1.169 (0.508)	1.895 (0.508)	-	1.618 (0.553)	1.169 (0.508)	1.658 (0.660)
Fonio	0.670 (0.141)	0.492 (0.174)	-	-	-	-	-	-	0.670 (0.141)	0.492 (0.174)	0.605 (0.173)
Maize	-	-	1.231 (0.405)	0.839 (0.239)	2.197 (1.383)	2.048 (1.644)	2.351 (1.068)	1.214 (0.715)	2.126 (0.952)	1.367 (0.866)	2.008 (1.168)
Millet	0.628 (0.264)	-	-	-	0.860 (0.329)	0.708 (0.198)	0.300 (0.168)	0.294 (0.231)	0.596 (0.237)	0.501 (0.214)	0.572 (0.340)
Groundnut	0.508 (0.252)	-	1.041 (0.150)	-	0.602 (0.303)	0.620 (0.141)	0.783 (0.257)	-	0.733 (0.240)	0.620 (0.141)	0.762 (0.290)
Rice	-	-	1.070 (0.353)	-	-	-	-	-	1.070 (0.353)	-	1.070 (0.353)
Sorghum	1.175 (0.405)	0.880 (0.192)	0.732 (0.304)	0.667 (0.492)	1.095 (0.397)	1.130 (0.450)	0.674 (0.337)	0.400 (0.50)	0.919 (0.316)	0.769 (0.296)	0.896 (0.425)
Voandzu	0.437 (0.140)	0.315 (0.34)	-	-	-	-	-	-	0.437 (0.140)	0.315 (0.34)	0.440 (0.237)
Cowpea/millet	0.263 (0.53)	-	-	-	-	-	0.71 (0.51)	-	0.167 (0.58)	-	0.155 (0.115)
Cowpea/sorghum	0.287 (0.110)	0.274 (0.94)	-	0.252 (0.120)	-	-	0.73 (0.67)	-	0.180 (0.23)	0.263 (0.79)	0.206 (0.130)
Millet/cowpea	0.710 (0.110)	-	-	-	-	-	0.435 (0.159)	-	0.572 (0.135)	-	0.556 (0.202)
Sorghum/cowpea	0.836 (0.300)	0.695 (0.242)	0.652 (0.435)	0.450 (0.170)	-	-	0.787 (0.438)	-	0.758 (0.391)	0.572 (0.206)	0.713 (0.367)

1. OHV = Operation Hante Vallee
2. CMDT = Compagnie Malienne pour le Developpement des Textiles
3. AT = animal traction households, HT = hand tillage or manual households
4. Numbers in parentheses are standard deviations

Source: Sanogo et al. 1992.

Sorghum varieties in the WASAT

Local varieties. The most dominant race of cultivated sorghum in western Africa is the guinea, whose characteristics include a loose panicle, open glumes, and flattened grain (Harlan and de Wet 1972). The most common local varieties in the WASAT are listed in Table 9, and include SH 60 from Senegal, Tiemarifing from Mali, Nagawhite from Ghana, and Farafara from Nigeria. WASAT farmers typically assign vernacular names to local sorghum landraces based on morphological characteristics, resistance, or adaptation to stress or food quality characteristics. An example from

Table 9. Important sorghum landraces in selected WASAT countries.

Country	Important landraces
Burkina Faso	S29, Gnofing, Ouedezoure
Cote d'Ivoire	Monogboho
Chad	51-69
Ghana	Nagawhite, Kadaga
Mali	SH2D2, Tiemarifing, CSM 388
Niger	Bagoba, Mourmoure, Jan-jare
Nigeria	Kaura, Farafara
Senegal	SH 60, RT 50, Hadien-Kori

Source: Chantereau and Nicou (1991) and survey results of the western African Sorghum Research Network research impact questionnaires.

Mali (Tables 10 and 11) shows the relative importance of some sorghum varieties in the farming system and illustrates farmers' perceptions of the desirable characteristics and problems with the varieties that they grow.

Introduced sorghum varieties in western Africa. Sorghum varietal research involving international research organizations in western Africa dates back to the 1960s when the Institut de recherches agronomiques tropicales et des cultures vivrieres (IRAT) began work in francophone western African countries in 1964. At about the same time, selection from local landraces was taking place in the national program of Nigeria. The ICRISAT western African program established a collaborative program with Burkina Faso in 1975 where large numbers of

Table 10. Importance, major traits, and problems of sorghum varieties as perceived by farmers in the CMDT[1] Zone, Mali, 1990 cropping season.

	Characteristics						
Variety	Number of fields planted	Share of variety in total	Average experience with variety	Major traits cited	% of households citing	Major problems cited	% of households citing
SH2D2	5	5%	2 years	Earliness	100	No major problem	100
Bimbriba	5	5%	7 years	High grain product Good flour quality Heavy grain	25 50 25	*Striga* susceptible Drought susceptible	25 25
CSM 388	1	1%	1 year	Good taste	100	No major problem	100
Igrou	1	1%	5 years	High grain product	100	No major problem	100
Kiassou	3	3%	3 years	Earliness High grain product	50 50	No major problem	100
Kind	3	3%	3 years	Earliness	100	*Striga* susceptible Bad *to* conservation	50 50
Labachi	1	*1%*	2 years	*Striga* tolerant	100	No major problem	100
Magnoble	18	18%	18 years	Earliness	94	*Striga* susceptible	75
Niakable	1	1%	5 years	Earliness	100	*Striga* susceptible	100
Pedro	1	1%	8 years	High grain product	100	No major problem	100
Seguuetana (red)	8	10%	14 years	*Striga* tolerant Weed tolerant Earliness	57 14 14	Bad *to* taste Bad *to* conservation No major problem	43 14 28
Sambou	5	5%	2 years	Earliness	100	No major problem	100
Teniteni	1	1%	3 years	Earliness	100	*Striga* susceptible	100
Timary	1	*1%*	5 years	Good taste	100	No major problem	100
Seguetana (white)	24	29%	10 years	*Striga* tolerant Earliness	76 10	No major problem Disease susceptible	76
Zozan gualaka	6	8%	16 years	Earliness High grain product Good taste	33 50 17	Drought susceptible Bird attack No major problem	67 17 16

1. CMDT = Compagnie Malienne pour le Developpement des Textiles.

Source: Sanogo et al. 1992.

Table 11. Importance, major traits, and problems of sorghum varieties as perceived by farmers in the OHV Zone, Mali, 1990 cropping season.

	Characteristics						
Variety	Number of fields planted	Share of variety in total	Average experience with variety	Major traits cited	% of house-holds citing	Major problems cited	% of house-holds citing
Bimbiba	7	13%	18 years	High grain production Good taste Drought tolerant	50 16 17	*Striga* susceptible	100
CSM 388	1	2%	4 years	High grain production	100	No major problem	100
Dereni	15	27%	4 years	High grain production Good taste	77 23	Drought susceptible No major problem	46 23
Dlongon	1	2%	10 years	High grain production	100	Bird attack	100
Donron	1	2%	6 years	High grain production	100	*Striga* susceptible	100
Gnofing	1	2%	6 years	Earliness	100	Bird attack	100
Kende	13	6%	16 years	Earliness Good taste	67 33	*Striga* susceptible Bird attack	33 33
Samakoka	7	13%	10 years	Earliness *Styriga* tolerant	83 17	Bird attack Weed susceptible	33 33
Tiemarifing	17	31%	7 years	Earliness High grain production Heavy grains	27 53 7	*Striga* susceptible Bird attack	53 53
Seguetana (white)	1	2%	4 years	*Striga* tolerant	100	Drought susceptible	100

1. OHV - Operation Haute Vallee.

Source; Sanogo et al. 1992.

collections and introductions were screened. The combined efforts led to the creation of varieties and hybrids listed in Table 12. They include IRAT and ICRISAT lines that are reputed to be high yielding and resistant to *Striga.*

Major sorghum diseases and insect pests[2]

In western Africa sorghum is attacked by several fungi, bacteria, viruses, and the parasitic weed *Striga hermonthica.* In local and introduced genotypes alike, gray leaf spot and leaf anthracnose are prevalent in the Northern Guinean and Sudanian Zone; sooty stripe and long

2. The discussion on sorghum diseases is based on Thomas 1992.

Table 12. Important sorghum varieties and hybrids in selected countries in western Africa in the 1960s and 1970s.

Country	Important varieties
Burkina Faso	IRATS6, S7, S8;E35-1; ICSV 1002 BF; 16-5; Framida
Cote d'Ivoire	Framida
Mali	IRAT 74, 75,76; Malisor 84-1, 84-5, 84-7; ICSV 1063 BF
Niger	IRAT S10
Nigeria	SK 5912(SSC3), L187(SSV6), L1499(SSV7)
Senegal	E 35-1; IRAT S11,S13, S15
Guinea Bissau	ICSV 126 IN, ICSV 1674 BF
	Hybrids
Cote d'Ivoire, Senegal and Burkina Faso	IRAT S12, IRAT 179, IRAT 181

smut occur more frequently in the Sudanian Zone. Grain mold is found mostly in introduced genotypes that mature during periods of high rainfall. Oval leaf spot, zonate leaf spot, leaf blight, head smut, and covered smut occur at low levels in both the Northern Guinean and Sudanian Zones. In Mali, covered smut is becoming more prevalent and head smut continues to be a problem in farmers' fields.

Striga occurs abundantly in all zones and attacks all genotypes. In Mali, a survey of seven villages (Hoffmann 1991) showed that 78% of all the sorghum fields in the seven villages taken together was infested by *Striga,* The two major groups of insect pests that attack sorghum in western Africa are the stem borers, notably *B. fusca,* and head bugs, particularly *E. immaculatus.* Sorghum midge is also important locally.

Sorghum Research Institutions and Achievements in Western Africa

With the exception of Nigeria and Senegal, both of which have benefitted from a long history of bilateral technical assistance, national sorghum and millet improvement programs in western Africa are relatively young and, for most countries, weak. Since the early 1960s sorghum research in western Africa has been a collaborative effort between the national research systems and international research organizations. In western Africa, Burkina Faso and Mali are considered to have relatively strong sorghum and millet research programs.

IRAT

Research in sorghum breeding, agronomy, crop protection, and grain technology was conducted by IRAT in Senegal, Burkina Faso, Niger, and Benin in 1965. Initially sorghum breeding involved mass selection and pure line isolation from western and Central Africa. Later on, exotic varieties were used as sources of dwarfism genes and the creation of hybrids. The major IRAT varieties are listed in Table 12.

ICRISAT West African Program in Burkina Faso

In 1975, ICRISAT began a collaborative program with Burkina Faso where a multidisciplinary team worked on sorghum and millet improvement. Breeding, plant protection, and agronomic studies on cropping systems as well as socioeconomic studies of the production environment were undertaken. The total research effort led to the development of high yielding sorghum cultivars that are tolerant to the region's major pests and diseases. They have unfortunately not made the required impacts because of several factors. Under normal rainfall conditions and with low input levels under farmers' management, the yield advantages of the modern cultivars are small. Seed multiplication and extension services are also chronically weak in the NARSs: promising materials face major constraints in getting off the research station on a scale sufficient to determine their true impact. Inadequate attention was paid to post-harvest characteristics and consumer preferences, making the high-yielding cultivars unattractive to farmers in the WASAT. The technology packages developed from the Burkina

Table 13. Technology packages and sorghum grain yields including components of improved management in the Sudanian Zone of Western Africa.

Improved management component	Grain yield (kg ha^{-1})[1]
None	500-700
Variety	400-800
Plowing	600-950
Fertilizer	700-1200
Plowing, fertilizer	900-1500
Plowing, fertilizer, tied ridges	1000-2000
Variety, plowing, fertilizer, tied ridges	1500-3000
Plowing, fertilizer, irrigation	2000-3500
Variety, plowing, fertilizer, irrigation	3000-4500

1. These approximate yield ranges are estimated from a variety of research station trials and on-farm tests conducted in Burkina Faso during 1980-86 and should be treated only as illustrating rough orders of magnitude.

Source: Matlon 1990.

Faso program and their associated sorghum yield ranges are summarized in Table 13.

ICRISAT/Mali Bilateral Program

The ICRISAT/Mali bilateral project was initiated in 1977 through a 1-year grant from the Ford Foundation to begin research on sorghum and millet. Funding was thereafter provided by USAID until the end of the project in 1991. The bilateral program made remarkable achievements in sorghum and millet breeding as well as cropping systems research. The program made good progress in transferring valuable traits from the local 'guineense' sorghums to the more productive 'exotic' sorghums. As a result, improved sorghum varieties such as Malisor-7 and Malisor-5 with semicompact heads, shorter stems, good pest resistance, and satisfactory food qualities were developed. Malisor-7 has been found to be resistant to head bugs. In millet breeding, varieties such as IBV-8001 and NKK with high yields and resistance to pests and diseases have been extended to farmers in the Segou, Kayes, and Koulikoro regions.

Agronomy and cropping systems research has demonstrated that sorghum/cowpea and millet/cowpea intercropping systems show a 30% yield increase over the corresponding monocrop system. Maize/millet associations have also been found to have about a 40% yield advantage and have been adopted by farmers in the CMDT region. The program also introduced new cowpea varieties into sorghum/millet intercrop systems that have had considerable impact at the farmer level.

The West African Sorghum Improvement Programs (WASIP)

ICRISAT established sorghum improvement programs in Kano, Nigeria, and at Bamako in Mali in 1988 to cover the needs of the major agroecological zones in the subregion. The Mali regional program has the mandate to focus on the higher rainfall zones while the Nigerian regional program focuses on the lower rainfall zones. Both programs are staffed with multidisciplinary teams and collaborate with the National Agricultural Research Systems (NARSs). For example, the breeders work with food scientists in the national programs to help select for desirable postharvest traits. Emphasis is being placed on production stability, particularly in screening for resistance or tolerance to a wider range of stress. *Striga* research dealing with its biology and control methods forms a very important aspect of the WASIP-Mali research program. The entomology program routinely screens for resistance to panicle insect pests. The agronomy programs in both Mali and Nigeria's WASIP undertake long-term studies on soil fertility, cropping systems, and on-farm trials in collaboration with the economics subprogram. The WASIP-Mali pathology program has developed an artificial inoculation technique for sooty stripe that is simple and cost-effective and may be used in the national programs for screening sooty stripe. The entomology program has provided basic data on head bug biology and assessed the reaction of a set of sorghum varieties to their attack in terms of quantity and quality loss.

The West and Central African Sorghum Research Network (WCASRN)

WCASRN, which became operative in 1985, involves 17 collaborating NARSs from the subregion, and the coordinator is a member of the WASIP-Mali staff. The sorghum research network supports research conducted in the WASIP programs. Regional sorghum variety adaptation trials, *Striga* trials, and sorghum disease resistance nurseries permit the exchange of materials among sorghum researchers in the region. The network also organizes short-term training, regional workshops, and monitoring tours for its members. NARSs identified as lead centers conduct research on leaf anthracnose, long smut, grain quality, head bugs, and wheat-sorghum composite flour.

Conclusion

Sorghum is one of the basic food staples in western Africa and represents roughly 37% of total food grain production. Aggregate sorghum production has, however, been declining in the last 20 years due mainly to declining harvested areas. As a result of rapid population increases, per capita production has decreased far below per capita food requirements. Unless coarse grain production keeps pace with growing demand, we can expect to see increases in prices that could adversely affect the absolute poor who depend directly on coarse grains for subsistence. The international, regional, and national agricultural research institutions in the subregion that work on sorghum have made considerable progress in developing varieties and techniques for increased production. They have however not made the required impacts because of several factors, including national food grain and pricing policies that favor the production and consumption of maize, rice, and wheat. There is growing evidence, both on a per capita basis and on the basis of shares of sorghum and millet in total food grain consumption, that western African consumers are shifting from sorghum and millet to rice, maize, and wheat consumption. The factors responsible for this shifting pattern include changes in relative prices, rising incomes, and urbanization. Despite this shifting trend, sorghum will remain important in the western African food system, and policies as well infrastructural and technological adjustments would be necessary to make sorghum competitive once again. To this end, research efforts should be directed towards technologies that reduce unit production costs as well as those that alleviate yield and stability constraints. From the demand side, research efforts need be directed towards expanding sorghum demand by improving product attributes and diversified end-markets.

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Sorghum and Millet in Southern Africa

K.L. Leuschner, D.D. Rohrbach, and M. Osmanzai[1]

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Sorghum and Millet in Southern Africa

K.L. Leuschner, D.D. Rohrbach, and M. Osmanzai

Abstract

Roughly one-third of the arable land in the Southern African Development Community (SADC) region is semi-arid and suitable for the production of sorghum (Sorghum bicolor) *and millet* (Pennisetum glaucum *and* Eleusine coracana). *These crops currently account for 25% of cereal grain sowings and 20% of coarse grain production in the region. Rainfall and associated production levels are highly variable. These crops are generally cultivated distant from commercial markets and are primarily used for household food security. Small quantities are used for a commercial opaque beer brewing industry. The vast majority of sorghum and millet is sown by small farmers. Few of these farmers use improved production inputs and most still sow landrace cultivars. While farmers have begun adopting improved cultivars, the use of chemical fertilizers and insecticide is rare. The main constraints to increased production are limited and erratic rainfall and low soil fertility. While pests and diseases are common, in general farmers do not perceive these to be sources of major yield loss. Small producers appear most concerned with regional outbreaks of armoured cricket and* Striga, *and with losses due to storage pests. The strength of the national agricultural research systems (NARS) in the region has significantly improved as a result of postgraduate training provided through the SADCIICRISAT specially funded Sorghum and Millet Improvement Program (SMIP) based in Zimbabwe. However, the priority of most national research programs remains targeted toward the development of cash crops and crop-livestock systems in higher rainfall areas. Severe constraints in national research funding reinforce this choice. In all likelihood, longer-term support for sorghum and millet research will remain limited. In consequence, national programs will maintain an applied research focus. ICRISAT can provide support in the form of strategic research, but there will also be a need to collaborate with the national systems to improve the efficiency of adaptive and applied research on new technology for the region. High priority is placed on near-term research impact, both to offset the high costs of food shortfalls associated with drought and to demonstrate the value of national investments in sorghum and millet research.*

Physical Environment

The countries covered by the Southern African Development Community (SADC) form a large and diverse contiguous area south of the equator. The area stretches from near the equator (0°) to about 30°S latitude, and lies between the Atlantic Ocean (11°E latitude) and the Indian Ocean (41°E longitude). Approximately 95% of the region is north of the Tropic of Capricorn. Only one-third of Botswana, a small portion of Mozambique, and the small countries of Lesotho and Swaziland lie outside the tropics. The total land area is 4.9 million km^2.

Most of the land lies at an elevation between 600 to 1600 m. Approximately one-third of the arable area of the region is semi-arid with an average annual rainfall of 400-600 mm. Lowlands are restricted mainly to the coastal areas of Angola, Tanzania, and Mozambique, and to relatively limited inland areas such as the Lower Shire Valley in Malawi and the Zambezi Valley.

These differences in location and physiography are reflected in the wide range of climates, soils, and crop management requirements found within the region. The general agroclimatic areas suitable for sorghum and millet rainfed production are shown in Figures 1 and 2.

The total arable land consists ot about 23 million ha, with a cropping intensity of about 52% (FAO 1978). FAO also estimates that the arable area could be expanded by 5 million ha, and that a 15% increase in cropping intensity is also feasible.

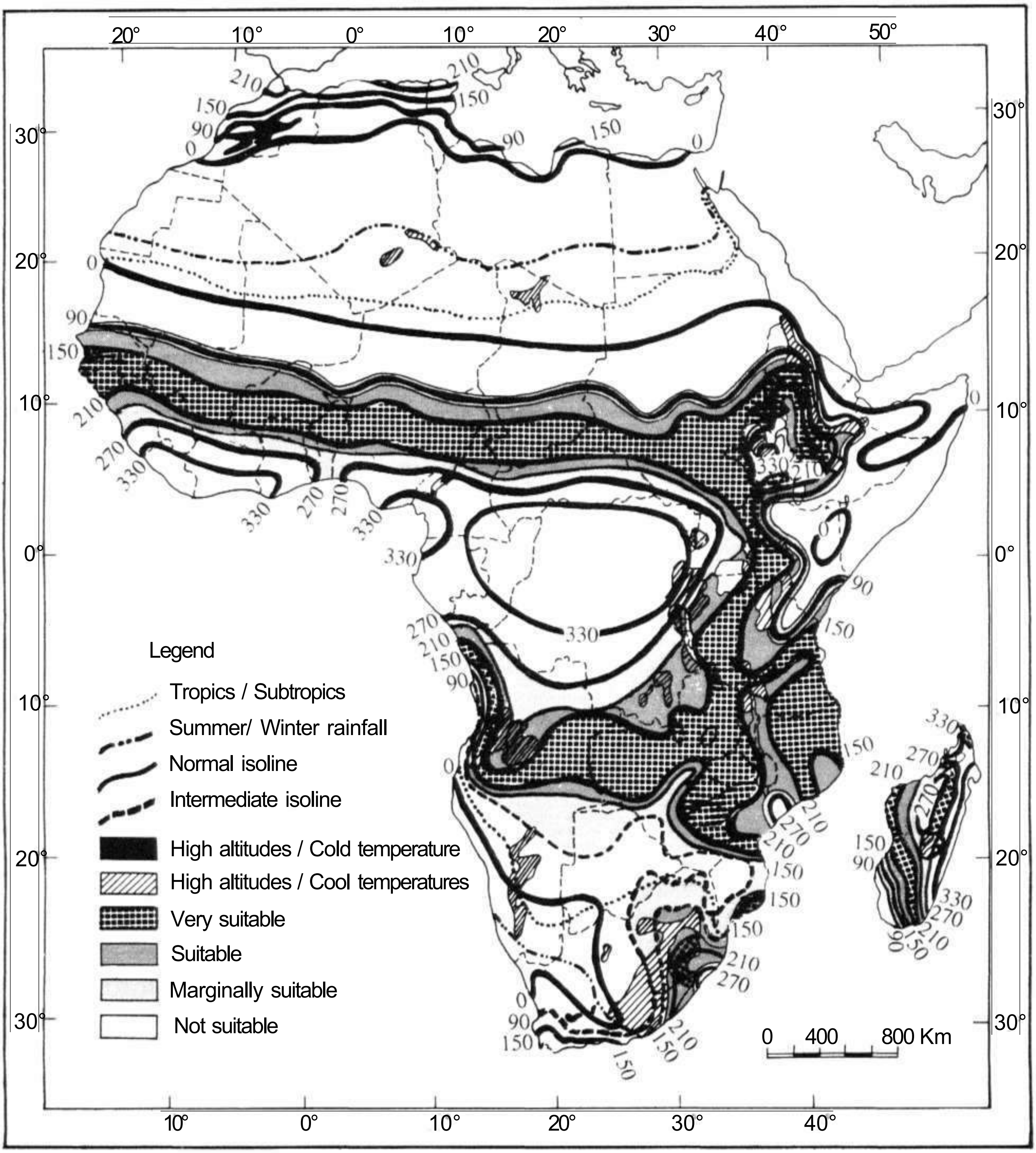

Figure 1. Generalized agroclimatic area suitability assessment for rainfed sorghum production in Africa. (Figures indicate length of growing period in days.) **Source: FAO 1978.**

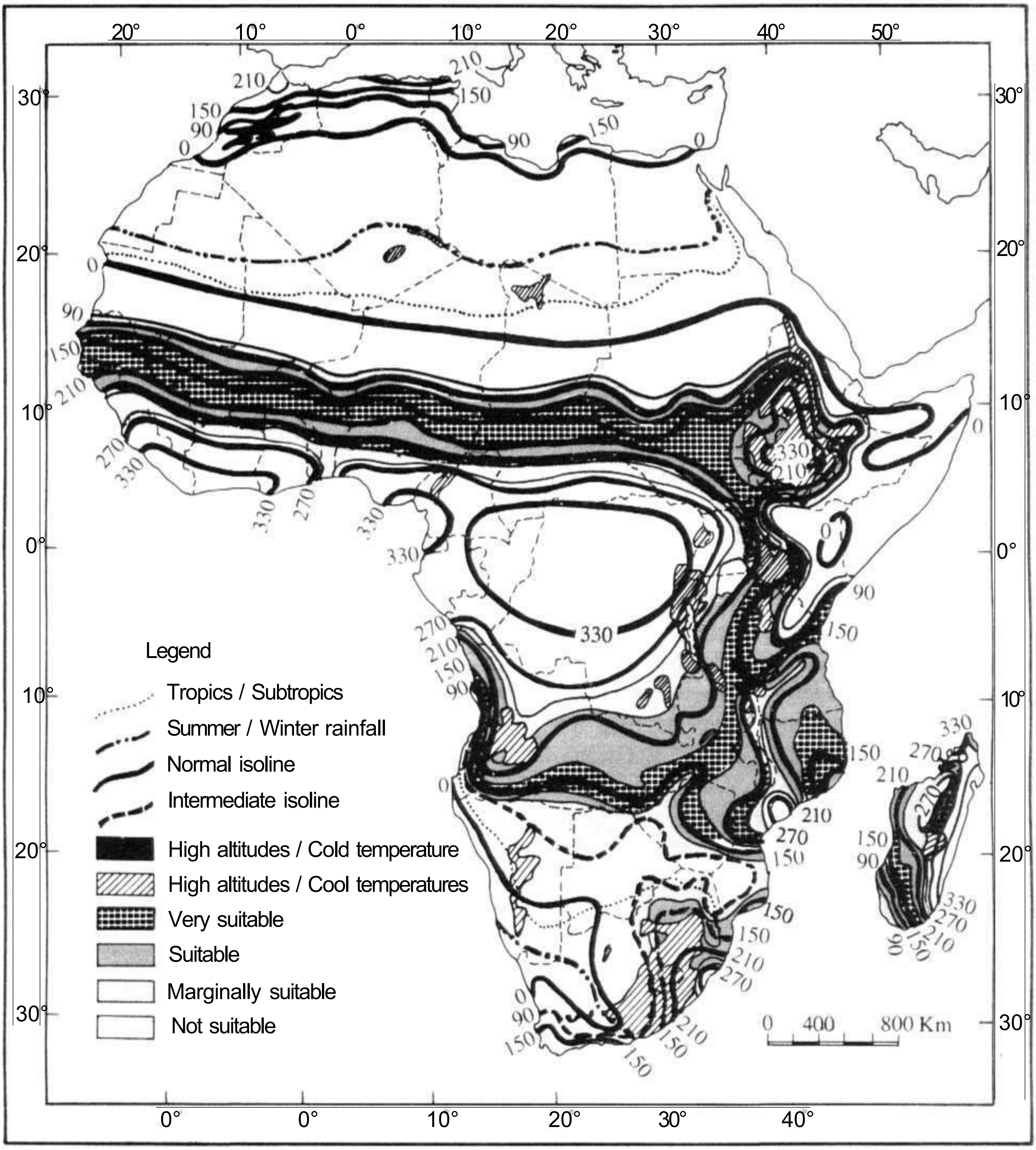

Figure 2. Generalized agroclimatic area suitability assessment for rainfed millet production in Africa. (Figures indicate length of growing period in days.) **Source: FAO 1978.**

The region's semi-arid areas are highly prone to drought. The availability of soil water is often poor because of a late start to the rainy season, an early finish, a mid-season drought, or, more commonly, a combination of these events. For example, in 1991-92 rainfall in Zimbabwe, one of the countries worst hit by the drought, was less than 50% of normal. The rains started late and ended early, and yield losses were compounded by an extended mid-season drought.

Most of the soils in the region are inherently of low fertility. There is increasing evidence to show that continuous cultivation of these soils, without sustainable land management practices to ensure soil fertility maintenance, is leading to land degradation and decreasing productivity. Coupled to this is the problem of soil erosion, which results in a combined reduction of the arable area, fertility, and the availability of water for crop growth. More efficient use of the limited soil and water resources is essential for the development of stable and sustainable sorghum *(Sorghum bicolor)* and millet (*Pennisetum glaucum* and *Eleusine coracana)* based cropping systems in southern Africa.

Agroeconomic Environment

Sorghum and millet account for only 23% of the total cereal grain production in the SADC region (Table 1), but the relative importance of these crops varies widely within each national food system. Sorghum and millet account for over 85% of total grain production in Botswana, but only 2% of cereal production in Swaziland. Sorghum and millet are the dominant grain crops in only two countries (Botswana and Namibia). All other countries in the region primarily produce maize *(Zea mays).*

It is necessary to disaggregate national statistics to highlight areas and populations critically dependent on sorghum and millet for their survival. The predominance of maize in most of the economies in the SADC region obscures the fact that sorghum and pearl millet remain essential food sources for some of the poorest and most food-insecure rural populations in the region. These encompass one-third of the arable land in the SADC region—that which is classified as semi-arid.

In Zimbabwe, for example, while maize accounts for roughly 80% of all cereal production and a similar proportion of cereal calories, three-quarters of all small holdings lie in regions receiving less than 650 mm of annual (unimodal) rainfall. These areas are frequently subjected to severe mid-season dry spells and drought. Most farmers in these regions consistently fail to produce enough food to meet their basic family requirements.

Zimbabwe commonly produces enough grain to allow export into the SADC region. But the build-up of large grain stocks and the country's reputation as a grain exporter are largely a product of the contributions of a small number of large-scale commercial farmers and a minority of better endowed small-holders farming in higher rainfall zones. Roughly 20% of the nation's small-holders account for 90% of the sector's

Table 1. Sorghum and millet production in the SADC region, 1988-90.

	Sorghum			Millet			
Country	Area ('000 ha)	Yield (kg ha^{-1})	Production ('000 t)	Area ('000 ha)	Yield (kg ha^{-1})	Production ('000 t)	Total cereal production (%)
Angola	(Combined with millet data)			107	582	62	15.4
Botswana	191	329	63	10	239	2	86.0
Lesotho	64	544	36	0	0	0	26.7
Malawi	30	632	19	19	585	11	10.3
Mozambique	368	440	173	20	250	5	31.3
Namibia	15	529	8	92	654	56	50.0
Swaziland	2	1750	4	0	0	0	2.1
Tanzania	457	933	430	251	1048	260	25.7
Zambia	49	609	30	50	587	29	3.3
Zimbabwe	94	659	62	160	611	98	9.7

Source: FAO 1991a.

marketed output. The 60% of small-holders operating in the extensive semi-arid areas are most commonly net buyers of grain. Yet they are among the poorest farmers in the country.

Sorghum and millet account for approximately one-quarter of cereals sown in the SADC region (Fig. 3). In 1988-90, Tanzania, Mozambique, and Botswana accounted for over three-quarters of the average of 1.3 million ha sown to sorghum annually in the region (Fig. 4), and Tanzania, Zimbabwe, and Namibia accounted for over three-quarters of the average of 655 000 ha sown to millet annually in the region (Fig. 5). These are the principal countries in the region in which expansion of the area sown to improved cultivars can be targeted.

Average grain yields for sorghum and millet are generally low, around 500 kg ha^{-1}, except in Swaziland and Tanzania (Fig. 6). In most countries maize yields are substantially higher than those for sorghum and millet. This is largly because the maize-based farming systems are centered in the more favorable higher-rainfall zones

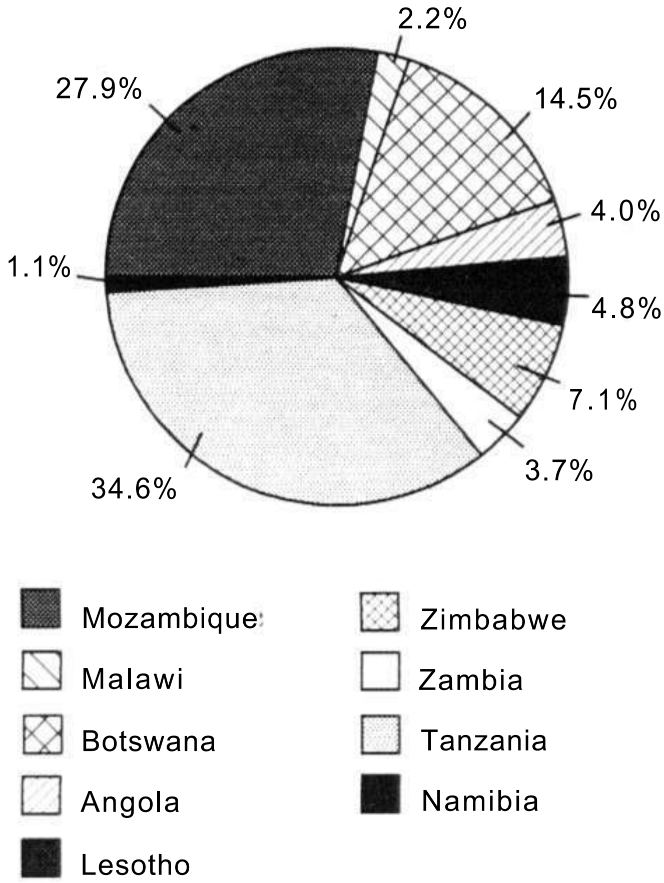

Figure 4. Distribution of sorghum production area in the SADC region. 1988-90. **Source: FAO 1991a.**

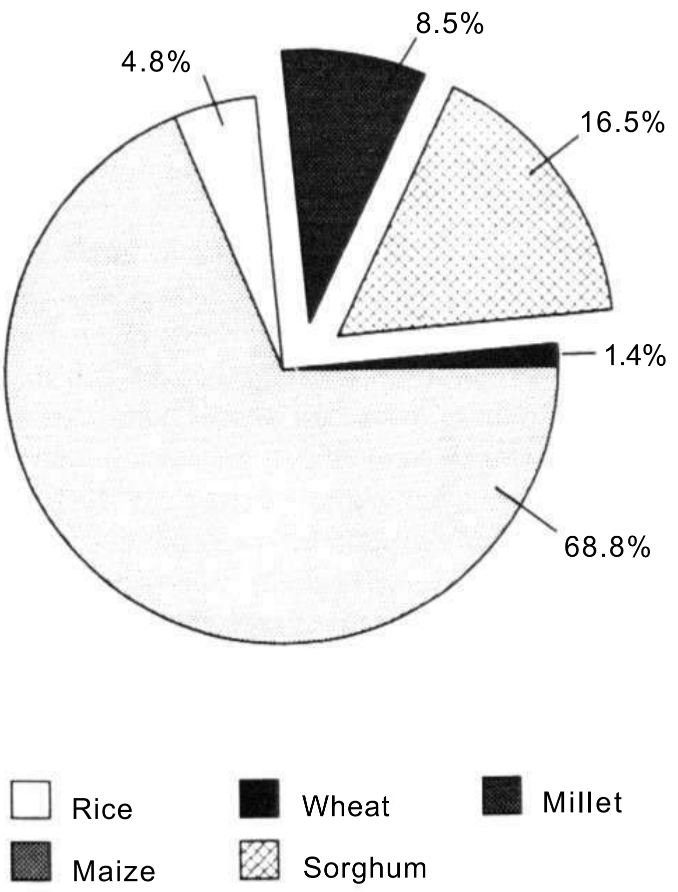

Figure 3. Proportion of lands sown to alternative grains in the SADC region, 1988-90. **Source: FAO 1991a.**

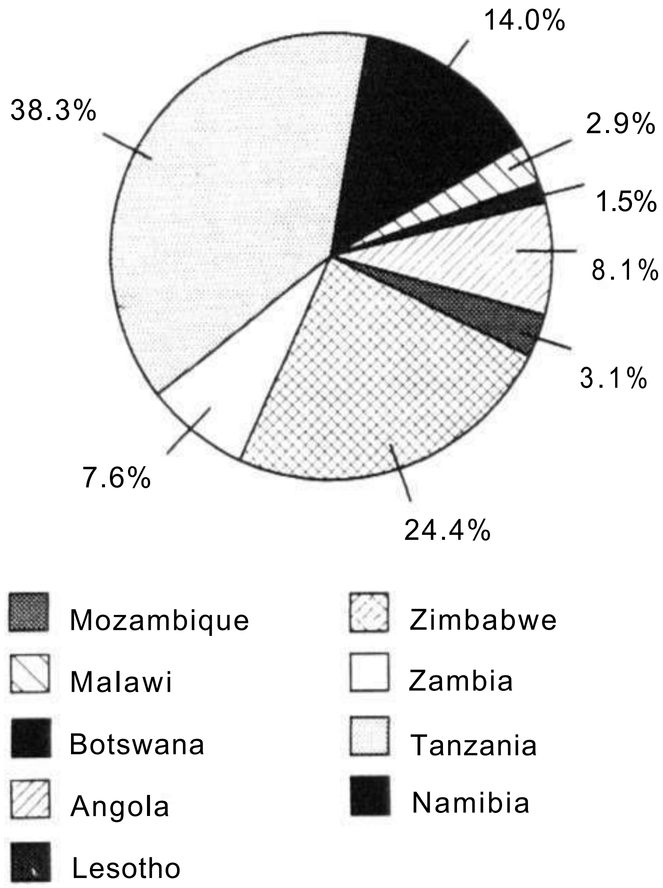

Figure 5. Distribution of millet production area in the SADC region, 1988-90. **Source: FAO 1991a.**

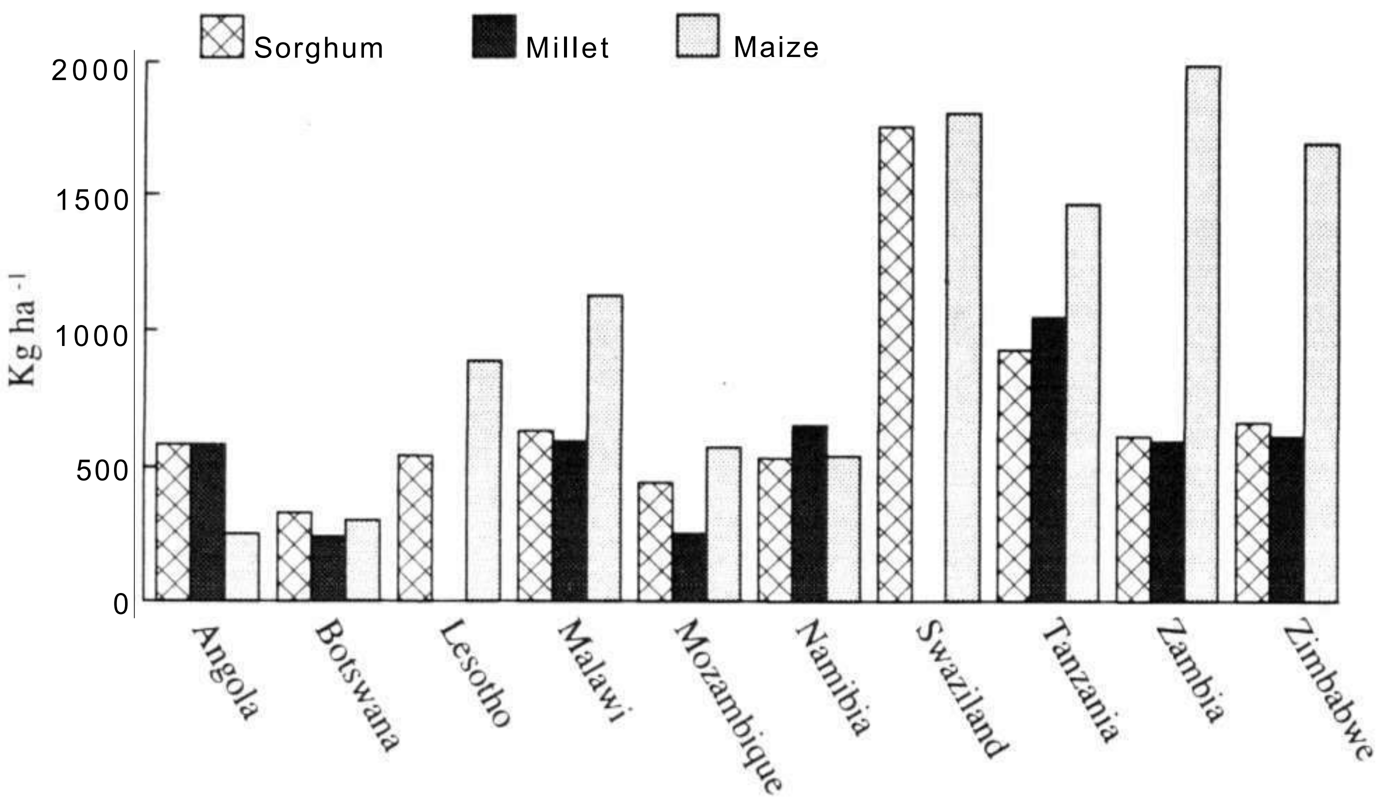

Figure 6. Average coarse grain yields in the SADC region, 1988-90. **Source: FAO 1991a.**

while the sorghum- and millet-based systems are in the less favorable lower rainfall zones that are more subject to drought. In addition, maize has historically benefited from more research and extension in comparison to sorghum and millet.

This has important implications for the competitive position of sorghum and millet in the industrial economy. Sorghum and millet produced in drought-prone regions will generally not compete on the industrial market with maize produced in higher rainfall areas. This is particularly true when the major urban and industrial centers of a country are based in the high rainfall zones. Sorghum and millet produce lower average and more erratic yields, and incur higher grain assembly and transport costs compared with maize. Such constraints imply that even if sorghum and millet achieve significant gains in average productivity, competition with maize as an industrial input will still prove difficult.

Low average sorghum and millet yields have also led to situations where imports of maize into sorghum and millet production zones offer a lower-priced food source than the locally produced small grains. Botswana consumes substantially more imported maize than domestically produced sorghum. In northern Namibia, imported maize is consistently cheaper on the retail market. In general, poorer households facing food deficits will seek out and consume cheaper maize imports. Farmers with a small surplus of sorghum and millet will primarily sell this into a traditional opaque beer market at premium prices.

In effect, the principal niche for sorghum and millet in much of the SADC region is as food-security crops. In most of the areas of production, households consistently fail to produce enough grain to meet their annual consumption requirements. It follows that increases in yields will first be allocated to meeting family food supplies. The largest market opportunities in the short and medium term lie in the redistribution of grain from surplus to deficit rural households, and from surplus to deficit rural regions. As the production base grows and becomes more consistent, industrial utilization, particularly in the stockfeed industry, may increase.

While there is currently a small niche for sorghum on the commercial market in the opaque beer brewing industry, this accounts for less than 1% of total utilization in SADC. Also, the brewing industry has shown a proclivity to source its sorghum input from larger-scale commercial farmers rather than from the 'average' small-holder. The larger farmers can consistently supply sorghum grain of a more uniform quality. Expansion of industrial utilization is dependent upon such competitive supply parameters, while the level of development of food technologies is less of a constraint.

Average growth rates of sorghum and millet area, yield, and production are highly variable across the region. This is partly a result of fluctuations in rainfall, but also a product of the poor quality of national production data, particularly for outlying production regions with lower population densities. Available data indicate that 4 of the 10 SADC countries experienced significant growth in sorghum area planted during the last decade (Fig. 7), but that 2 of the largest producers (Tanzania and Zimbabwe) experienced a sharp decline in area. A similar record applies to the eight SADC countries growing millet (Fig. 8). However, one result of the 1991-92 drought has been a significant increase in area planted to both sorghum and millet during the current 1992-93 planting season.

The average growth rates being recorded for sorghum and millet yields are also highly variable (Table 2). There does not appear to be any

Table 2. Average annual growth in sorghum and millet yields in the SADC region, 1979-81 to 1988-90.

Country	Sorghum	Millet
Angola	No data	-0.6
Botswana	6.4	5.9
Lesotho	-7.2	Not applicable
Malawi	-0.6	-0.2
Mozambique	-3.9	0.0
Namibia	2.5	4.2
Swaziland	9.9	Not applicable
Tanzania	2.2	3.0
Zambia	1.1	-6.3
Zimbabwe	3.1	3.7

Source: FAO 1988, 1991b,

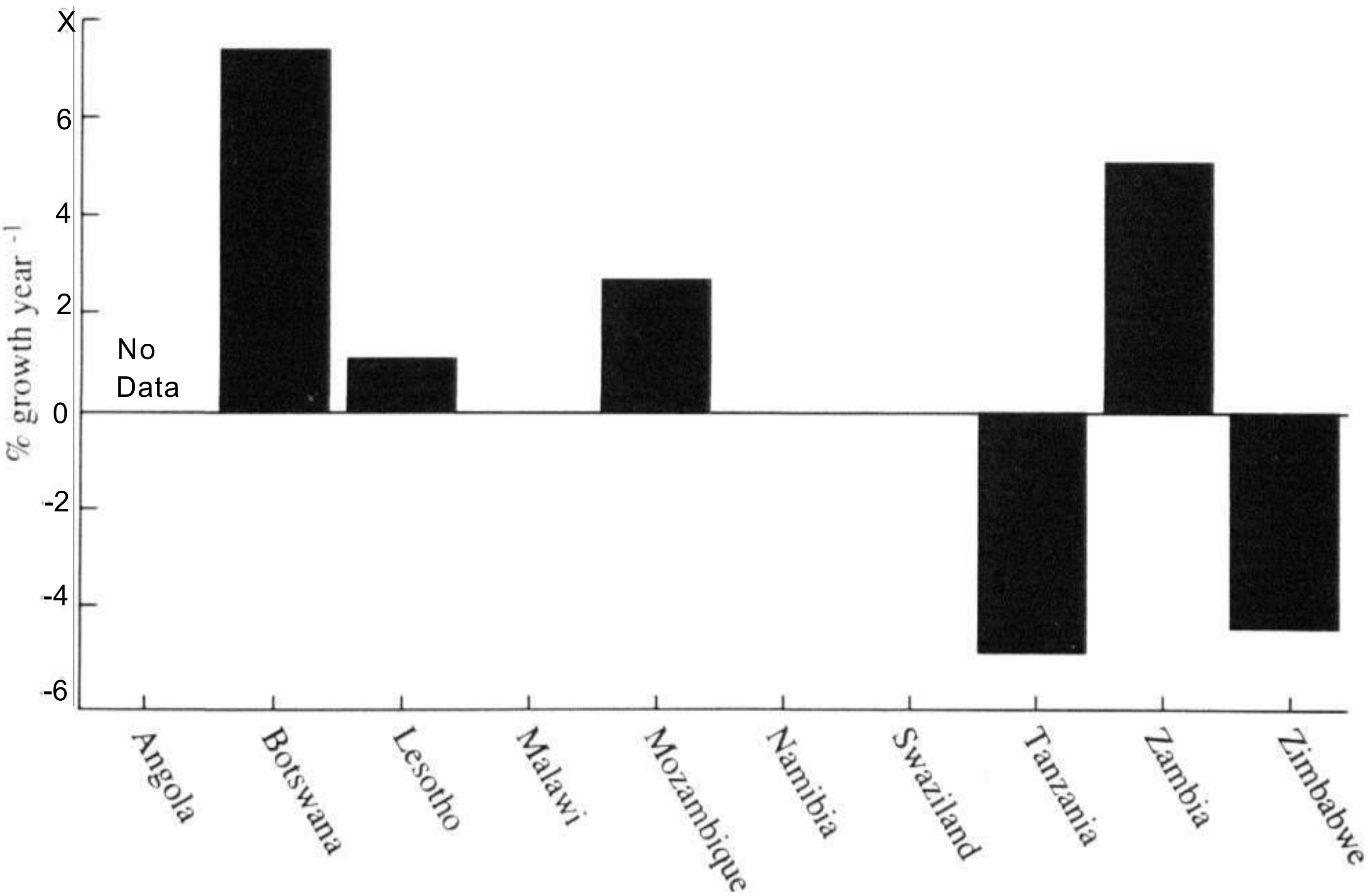

Figure 7. Average annual growth in sorghum area in the SADC region, 1979-81 to 1988-90. **Source: FAO 1991a.**

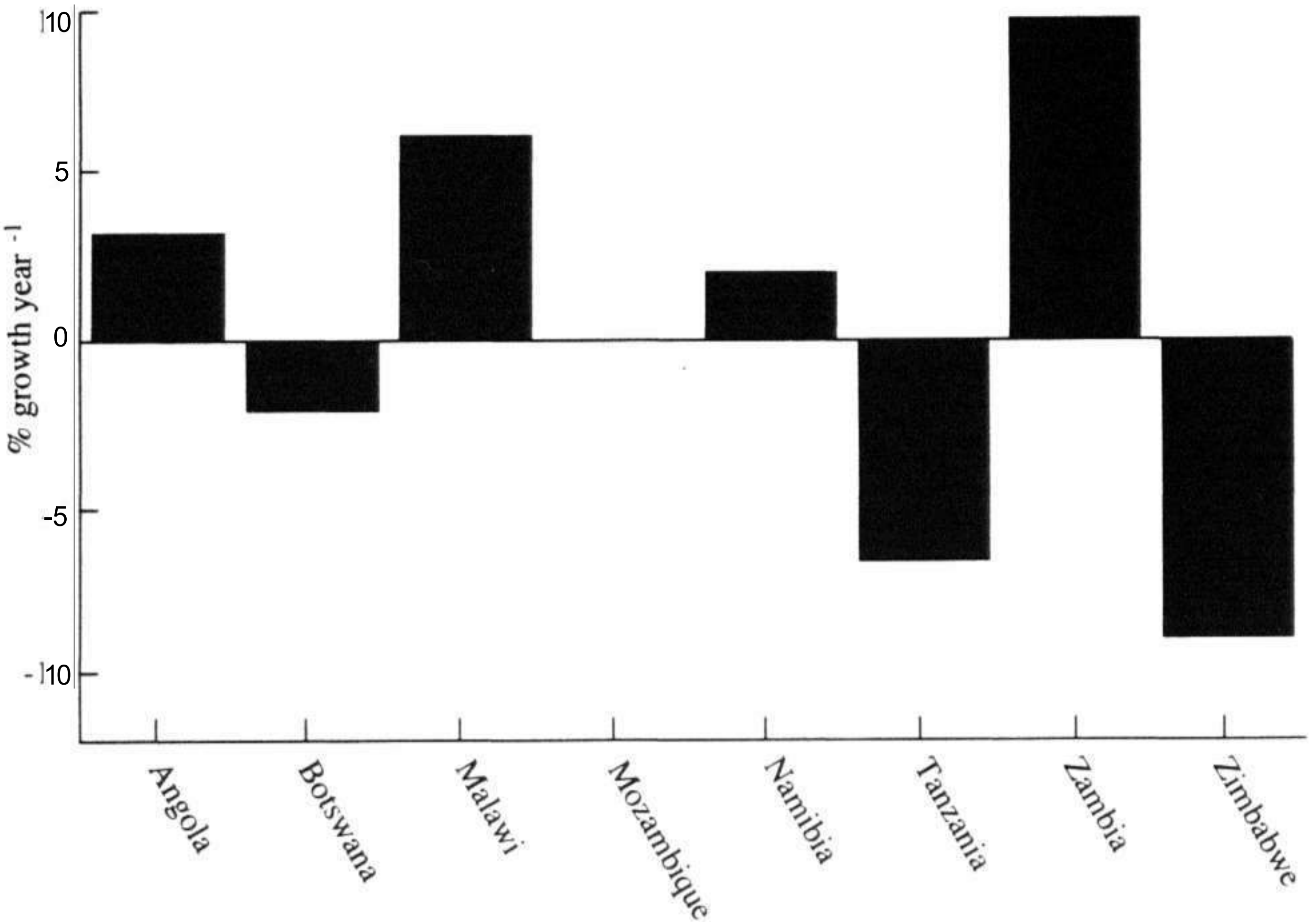

Figure 8. Average annual growth in millet area in the SADC region, 1979-81 to 1988-90. **Source: FAO 1991a.**

correspondence between these rates of change in average yields and the distribution and adoption of improved technology. Again, this variability reflects both drought-induced fluctuations in productivity and inaccurate national statistics.

Levels of adoption of improved technology are extremely limited. Small farmers have shown an interest in adopting new open-pollinated varieties, particularly in Zimbabwe, Namibia, and Tanzania. However, the vast majority of the sorghum and millet area is sown without fertilizer, and it is rare for insecticide to be used on the field crop. Investment by smallholders in production inputs has been discouraged by the perception that the returns to the allocation of scarce capital (cash) are much higher from commitments to school fees and the search for off-farm employment. Improved cultivars must clearly prove their value under low-input conditions. These cultivars must increase the average level of yields when rains are poor and. provide the potential for significant yield gains if rains are favorable.

Biological Environment

Landrace cultivars

The majority of farmers in the semi-arid tropics of SADC continue to depend on local sorghum and millet landrace cultivars. Such cultivars are low yielding but well adapted to the environment in which they were selected. They have good food and brewing qualities.

Because of their good adaptability, food quality, and insect and disease resistance traits, such germplasm represents a strategic resource for use in crop improvement programs. Extensive collection has already been undertaken by ICRISAT and NARSs in the region.

Improved open-pollinated cultivars

Open-pollinated cultivars offer the best prospects for near-term crop improvement gains for sorghum and millet in SADC. Such cultivars have the advantage of being relatively high yielding, input responsive, and tolerant to drought. At the same time they are easy to propagate. They require little seed industry infrastructure and input, and can fit into a diversity of cropping systems in both high- and low-input situations. Seed can be produced on a small scale through nongovernmental organizations and farmers' cooperatives. To achieve successful adoption, these cultivars must have acceptable food and brewing qualities and should not be more susceptible to insects and diseases than local landraces.

Hybrids

Hybrids currently are of limited use in the SADC region. A major constraint to the adoption of hybrids is the lack of efficient seed production agencies. At present only Zimbabwe and Zambia are able to produce hybrid seed, but international seed companies are showing increased interest in sorghum seed production in Lesotho, Tanzania, and Mozambique.

Table 3. Important insect pests of sorghum and pearl millet in the SADC region.

Common name	Scientific name	Yield loss[1] (%)	Countries of incidence
Sorghum			
Shoot fly	*Atherigona soccata*	10-40%	Botswana, Tanzania, Zimbabwe
Stem borer	*Chilo partellus*	10-45%	Botswana, Zimbabwe, Malawi
	Busseola fusca	10-30%	Lesotho
	Sesamia sp	Not known	SADC
Aphids	*Rhopalosiphum maidis*	Yield loss not clear	SADC
	Melanaphis sacchari	10-50%	Zambia, Botswana, Malawi
Head bugs	*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
Boll worm	*Helicoverpa armigera*	10-20%	Botswana, Zambia
Armoured cricket	*Acanthoplus speiseri*	10-30%	Zambia, ZimbabweNamibia, Botswana
Storage pests	*Sitotraga cerealella*	>12%	All SADC countries
Pearl Millet			
Shoot fly	*Atherigona approximata*	>30%	Zambia
Bollworm	*Helicoverpa armigera*	10-20%	Botswana

1. Very preliminary estimates on limited data.

Cropping Systems

In the SADC region the diversity of crops within a given cropping system increases with the level of rainfall. Sorghum and millet are occasionally intercropped with each other and with maize. In some regions, sorghum and millet are intercropped or rotated with legumes—principally cowpea *(Vigna uniguiculata),* groundnut *(Arachis hypogaea),* bambaranut (V7-*gna subterranea),* or pigeonpea *(Cajanus cajan).* These grains are commonly intercropped with low density plantings of pumpkin or squash *(Cucurbita* spp). Planting periods often extend for several months as farmers diversify their cropping system to cope with the risks of low rainfall and drought.

Disease and Insect Constraints

In the SADC region, sorghum and millet are attacked by a number of insect pests (Table 3) and diseases (Table 4). In general, however, the losses are low and few farmers employ special practices for crop protection. Those insects with the potential to cause catastrophic losses attract the greatest attention. These include armoured cricket, which can be devastating in large populations, and storage insects.

Table 4. Common diseases on sorghum and pearl millet in the SADC region.

Common name	Scientific name	Yield loss[1] (%)	Countries of incidence
Sorghum			
Downy mildew	*Peronosclerospora sorghi*	30-40%	SADC
Leaf blight	*Exserohilum turcicum*	10-20%	SADC
Anthracnose	*Colletotrichum graminicola*	10-20% (grain)	SADC, particularly Zambia, Zimbabwe, Tanzania
Ergot	*Sphacelia sorghi*	10-50%	SADC
Covered-kernel smut	*Sporisorium sorghi*	5%	SADC
Loose smut	*Sphacelotheca cruenta*	5%	SADC
Head smut	*Sporisorium reilianum*	2%	SADC
Long smut	*Tolyposporium ehrenbergii*	2%	SADC, particularly Tanzania
Sooty stripe	*Ramulispora sorghi*	5%	Zambia, Zimbabwe, Tanzania
Pearl Millet			
Downy mildew	*Sclerospora graminicola*	30%	Tanzania, Zimbabwe, Mozambique, Zambia
Ergot	*Claviceps fusiformis*	10-15%	Tanzania, Zimbabwe,
Smut	*Tolyposporium penicilliariae*	5-10%	Tanzania, Zimbabwe, Zambia, Malawi
False mildew	*Beniowskia sphaeroidea*	2%	Zimbabwe

1. Very preliminary estimates on limited data.

This situation may change as result of adoption of new high-yielding cultivars and the increased commercialization of production. Large-scale production of sorghum at Pandamatenga, Botswana, which receives up to four applications of insecticide, has demonstrated how vulnerable some sorghum hybrids can be to insects and diseases. *Striga* incidence seems to be increasing. For small-scale farmers with poor storage facilities, an increase in productivity may create additional problems in grain storage for extended periods.

It is clear that improvements in productivity of sorghum and millet within existing farming systems, and from intensified systems of production, are likely to result in increased losses due to pest attack. Improved crop protection technology will be required, including host plant resistance, cultural control, and the use of chemicals/ biocides in integrated pest management.

Research Environment

Strengths and weaknesses of National Agricultural Research Systems (NARS)

During the past decade, the regional Sorghum and Millet Improvement Program (SMIP) has supported an extensive training program for NARS scientists. This has included postgraduate training for more than 90 scientists, and in-service workshops on special topics. Concerns remain, however, regarding high rates of staff turnover and the lack of operational funding in national institutions. The inflation-adjusted budgets of many national research programs are declining. The combination of funding constraints and the tightening of research priorities has discouraged commitments to research on sorghum and millet. These trends have been reinforced by public perceptions of sorghum and millet as traditional, subsistence crops. This is compounded by the limited awareness among policy makers regarding the potential contributions of sorghum and millet to reducing food insecurity caused by drought.

Comparative Advantage of ICRISAT's Regional Program

ICRISAT's activities in southern Africa were initiated in 1983 at the request of the SADC Heads of State. Following the SADC mandate, high priority was placed on degree education and the provision of in-service training for young sorghum and millet scientists in the region. Efforts to help strengthen national research programs prompted an emphasis on applied and collaborative research targeted towards the rapid adaptation and dissemination of improved technologies in farmers' fields. ICRISAT has accepted principal responsibility for coordinating a regional network of sorghum and millet scientists capable of making effective use of the world technology base. In addition, this network aims to facilitate the cooperative exploitation of expertise residing within each of the NARS in the southern African region.

Many of the NARS scientists who undertook postgraduate training outside the region during the past 5 to 10 years are now returning (Table 5). Consequently, the NARSs are expected to take increasing responsibility for managing the regional research network. To assist this development, SMIP has initiated development of collaborative workplans with each NARS. These workplans identify the research responsibilities and technical contributions for the NARS and SMIP. Under this model, SADC/ ICRISAT may continue to provide, in collaboration with the appropriate NARS, backstop research support in more strategic areas such as the development of parental lines for national breeding programs, the analysis of long-term issues of resource sustainability, and the improvement of research methodology. Stronger national programs may begin to develop technologies of regional value. Smaller programs will likely continue to operate with an applied focus.

However, it is necessary to recognize that NARS capabilities in improvement of sorghum and millet production will remain limited as long as research funding remains constrained and national priorities emphasize commercial

Table 5. NARS staff strengths in sorghum and pearl millet improvement in SADC in 1984 and 1993.

	Angola		Bot-swana		Lesotho		Malawi		Mozam-bique		Namibia		Swazi-land		Tan-zania		Zambia		Zim-babwe		Total	
Discipline[1]	'84	'93	'84	'93	'84	'93	'84	'93	'84	'93.	'84	'93	'84	'93	'84	'93	'84	'93	'84	'93	'84	'93
Agronomy	1	1	1			2			2	1		2	1		2	5	1	3	2	1	10	18
Plant Breeding		2	1	2	1	1	2	2		1		1			2	3	1	6	2	3	9	22
Pathology		1	1					1					1			1		1	1	1	3	6
Entomology			1	1				1							1	1		2	1	1	3	7
Economics				1		1						!								1	0	5
Food Science						1										1		2		1	0	6
Seed Technology				2				1													0	3
Biometrics														1							0	1
Agric. Extension																					0	0
Forages																					0	0
Agroclimatology																					0	0
Others																1			1	1	1	2
Total	1	4	4	6	1	5	2	5	2	2		4	2	9	5	12	2	14	7	9	26	70

1. Includes part-time and full-time staff.

crops in zones of higher agricultural potential. The education and training support provided by SMIP has built most national programs to the limits of their capabilities. Therefore, the number of scientists is likely to decline, rather than increase, over the next 5 to 10 years. These factors may lead ICRISAT to maintain a significant component of applied research in the region for the foreseeable future. In so far as the regional ICRISAT program remains dependent on donor funds, the SMIP research agenda will be influenced by demands for research impact in the relatively short term. Collaborative workplans may need to incorporate an element of on-farm technology testing and planning for monitoring technology dissemination into farmers' fields.

Policy Environment

The ICRISAT Medium Term Plan (MTP)

During the MTP planning process in 1992-1993, it was recognized that greater interaction between the regional programs and ICRISAT Center would enhance the flow of technologies to national programs and ultimately to small farmers. The regional program can better exploit the spillover effects of research conducted elsewhere in the ICRISAT system. However, it was also recognized that regional programs may have priority problems that do not coincide with the more strategically oriented agenda of the MTP. Research priorities may be more heavily influenced by the strengths and weaknesses of each regions's NARSs. There is a need for ICRISAT to retain a capacity, within the limits of its resources, to respond flexibly to such needs.

The External Program Review (EPR), 1990

The major recommendation of the EPR with respect to southern Africa was that SMIP should reduce its scale of operations in order to focus more on collaborative research and backstopping for national programs. Concerns were raised about the sustainability of a large program heavily dependent on special donor funding. This recommendation is currently being implemented with the elimination of support for postgraduate training and a sharp reduction in the scale of research on food technology.

Cereals Program In-House Review (IHR), 1992

The In-house Review of the Cereals Program is expected to result in greater integration and closer research collaboration across ICRISAT's regional programs. This should also promote a clearer recognition of the comparative advantage for various aspects of research in each of the regional centers.

Conclusion

In 1984, ICRISAT established a research base in southern Africa at the invitation of the SADC Heads of State. This program has been primarily supported with complementary donor funding, with the objective of developing national research capabilities in sorghum and millet. Correspondingly, ICRISAT's efforts have concentrated on training national scientists and germplasm development.

- SADC/ICRISAT is now seeking to consolidate this institutional and technological base. National programs can be expected to undertake greater responsibility for the region's applied and adaptive research. SADC/ICRISAT may begin to pursue a more strategic research agenda.
- Yet both donors and national governments are particularly anxious to see the payoffs to past investments in agricultural research. These will help justify the continuation of these investments and instill confidence in national scientists. More importantly, productivity gains derived from the adoption of improved technologies will begin offsetting the high costs of food deficits associated with limited rainfall and drought.
- The limited adoption of improved technologies to date reflects, in part, the limited availability of those improved technologies. However it also reflects a breakdown in the production-support systems necessary to make technology available and profitable. This problem is relatively more severe in semi-arid regions, especially those that are more isolated.
- Concerns about research impact must accordingly be linked with efforts to resolve institutional constraints to the adoption of technology. These include problems of seed supply, agrochemical input supply, limited and often inappropriate extension support, and the difficulties of assuring a consistent market for erratic levels of grain surplus. Research scientists must work cooperatively with input suppliers, extension services, and policy makers to assure research investments achieve a payoff. ICRISAT can contribute to the strengthening of such linkages.
- Sorghum and millet will continue to play an important role in the food systems of southern Africa for the foreseeable future. These grains will primarily contribute as food security crops. Emphasis must continue to be placed on the development of technologies that increase minimum yields in periods of drought. Early productivity gains must be pursued through the introduction of technologies with relatively lower cash costs. Additional demands on scarce farm labor must be limited. As these crops become more commercialized, these constraints will become less binding.
- This implies that in the near term, ICRISAT will need to maintain a significant applied component in its research agenda in the SADC region. Efforts to strengthen national research programs will continue. Over time, greater emphasis will be allocated to strategic research.

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Sorghum and Millet in Eastern Africa

S.Z. Mukuru[1]

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Sorghum and Millet in Eastern Africa

S.Z. Mukuru

Abstract

The eastern African region covers an area estimated at 6.181 million km^2 with a population of approximately 173.7 million people. The region contains diverse agroecological zones based on length of growing season, rainfall, altitude, and temperature. However, for ease of operation the region is divided into three broad agroecological zones: dry and hot lowlands characterized by low and erratic rainfall, subhumid zones characterized by high rainfall, and cool highlands characterized by low temperatures. Sorghum (Sorghum bicolor,) *and millets* (Pennisetum glaucum, Eleusine *spp, and other genera) are important components in the traditional farming systems and in the diets of millions of people in these major agroecological zones. A wide range of traditional foods and beverages are prepared from sorghum and millets including leavened bread, thick and thin porridges, and alcoholic and nonalcoholic beverages.*

Sorghum is cultivated on approximately 6.36 million ha from sea level to over 2000 m above sea level. Millets are cultivated on approximately 2.43 million ha: pearl millet predominates in the dry and hot lowlands, and finger millet is cultivated in the subhumid zones. Grain yields for both sorghum and millets in the region are very low.

The predominant sorghum types cultivated by farmers in the region are farmers' landraces. Almost all the major types of cultivated sorghum ranging from caudatum to durra are well represented in the region. Several improved high-yielding cultivars have been released by NARS for cultivation by farmers in individual countries but these have not been widely adopted. The low rate of adoption of improved cultivars is attributed to ineffective extension services and lack of on-farm research, seeds of improved cultivars, credit facilities, and inputs to farmers.

All the NARS in the region have active research programs on sorghum and millets. NARS program staffing is variable in quality and quantity ranging from poor to adequate. The region has a total of 76 scientists covering a range of disciplines.

NARS sorghum and millet scientists in the region initiated the Eastern Africa Regional Sorghum and Millet (EARSAM) network in 1986 with the main objective of strengthening ties among NARS, promoting free exchange of scientific information and germplasm, and testing elite cultivars in the region. The network is managed by a Steering Committee composed of active NARS sorghum and millet scientists.

Since its inception, the EARSAM network, with ICR1SAT assistance, has promoted free flow of germplasm and information among NARS; initiated and implemented regional testing of elite germplasm in different agroecological zones; provided a forum for NARS scientists to freely exchange research information through regional workshops, research monitoring tours, etc; initiated, implemented, and coordinated collaborative research projects; improved the scientific skills of both NARS scientists and technicians through EARSAM-organized short courses; and improved scientific leadership by involving NARS scientists in the planning and decision making process of all EARSAM network research and related activities.

An in-house review was held in October 1992 and all the sorghum and millet research projects were reviewed, discussed, and modified. The ICRISAT 1994-98 Medium Term Plan includes 12 themes on sorghum, pearl millet, and finger millet research in eastern Africa.

The eastern African region is comprised of eight countries: Burundi, Ethiopia, Kenya, Rwanda, Somalia, Sudan, Tanzania, and Uganda. The region covers an area estimated at 6.18 million km^2 with a population estimate of 173.7 million people in 1992. Sudan is the biggest country in the region with 2.5 million km^2, while Rwanda and Burundi are the smallest with 0.26 and 0.28 million km^2, respectively. Ethiopia has the highest population of 54.3 million people followed by Tanzania, Sudan, and Kenya with 27.4, 26.5, and 26.2 million people, respectively. Burundi and Rwanda have the lowest populations of 5.8 and 7.7 million people, respectively, but have the highest population density in the region.

Food production in the region has not kept pace with population growth and in some countries food production has actually declined due to frequent severe droughts, or civil wars, or both.

Physical Environment

The eastern African region contains diverse agroecological zones based on length of growing seasons, rainfall, temperature, and altitude. For practical purposes, the region is divided into three main broad agroecological zones. These are the dry and hot lowlands characterized by short rainy seasons with low and erratic rainfall (2 to 3 months), the wet and humid zones characterized by long rainy seasons with adequate rainfall (3 to 5 months), and the cool highland zones characterized by low temperatures during the growing season. More than 70% of the sorghum *(Sorghum bicolor),* and millets *(Pennisetum glaucum, Eleusine* spp, and other genera) in the region are cultivated in the dry and hot lowlands.

Production and Consumption

Sorghum and millets are important components in the traditional farming systems and in diets of millions of people in the region. Of the total area cultivated to cereals in each country in the region, sorghum and millets are either the first or second most important cereals. In drought-stressed zones of the region, sorghum and pearl millet are the predominant cereals.

The eastern African region is unique in that it contains areas of sorghum production in all ecological niches in which the crop is normally cultivated, ranging from near sea level to 2000 meters above sea level. Globally, eastern Africa is the single most important region for high-altitude, cold-tolerant sorghum in terms of both genetic diversity and tonnage produced. High-altitude, cold-tolerant sorghums are traditionally cultivated in the highland areas of Ethiopia, Uganda, Rwanda, and Burundi. There is also great potential for cold-tolerant sorghum production in the dry cool highlands of Kenya and Tanzania.

The area under sorghum cultivation in eastern Africa was estimated at 6.36 million ha in 1989 with total production of 4.82 million t. Sudan is by far the largest sorghum producer in the region with 2.49 million t produced on 3.7 million ha. Ethiopia is the next highest sorghum producer with 0.98 million t produced on 0.9 million ha. Sorghum yields in the region are very low ranging from 1.47 t ha^{-1} in Burundi to 0.46 t ha^{-1} in Somalia.

Finger millet is predominantly grown in intermediate altitude areas with moderate rainfall but infertile soils. Uganda is the largest finger millet producer in the region with 0.22 million ha, followed by Ethiopia with 0.20 million ha, and Tanzania and Sudan with 0.15 million ha each. Kenya, Burundi, and Rwanda produce relatively smaller amounts of finger millet while Somalia produces none at all. Yields of finger millet are low, ranging from 500 kg ha^{-1} in Sudan to over 1000 kg ha^{-1} in Uganda.

Pearl millet is predominantly grown in low altitude areas with low and erratic rainfall. Sudan is by far the largest producer of pearl millet with 1.4 million ha producing 0.58 million t. Tanzania is next with 0.15 million ha producing 0.15 million t. Uganda and Kenya produce smaller amounts of pearl millet while the other countries, Somalia, Rwanda, and Burundi, do not produce pearl millet.

Types of Varieties

The region is recognized as the origin and center of diversity for sorghum and finger millet, and contains tremendous sorghum genetic variability, especially in Ethiopia and Sudan. Landraces of sorghum and millets have been collected from the more accessible areas in the region. These include the cultivated and wild and weedy types. Almost all the major types of cultivated sorghum ranging from caudatum to durra are well represented in the region. A wide range of variability in morphoagronomic characters exists among landraces in the region, such as maturity, plant height, plant pigmentation, midrib color, panicle length and width, panicle compactness and shape, glume color, grain color, size, and weight.

Several improved high-yielding cultivars have been released for farmers* cultivation by each National Agricultural Research System (NARS) in the region with varying levels of adoption. In general, though, the adoption rate of the improved cultivars in each of the eight countries in the region is very low. In some countries (Tanzania, Sudan, and Burundi) the adoption rate is improving.

The low adoption of improved cultivars is attributed to lack of on-farm research, seeds of improved cultivars, credit facilities, and inputs to farmers, as well as poor extension services.

Utilization

A wide range of traditional foods and beverages are prepared from sorghum and millets. The major traditional foods are as follows:

Leavened bread	-	*Injera* in Ethiopia, *kisra* in Sudan;
Thick porridge	-	*Ugali* in Tanzania, Kenya, and Uganda; *sof* or *mofo* in Somalia;
Thin porridge	-	*Uji* in Kenya, Uganda, and Tanzania;
Nonalcoholic beverages	-	*Hulum, abrey,* and *huswa* in Sudan; *obushera* in Uganda;
Alcoholic beverages	-	*Pombe* in Tanzania; *busaa* in Kenya; *omuramba* in Uganda.

Constraints to Production

A range of sorghum and millet production constraints has been identified and prioritized by NARSs. The major constraints of regional importance are as follows:

- Lack of improved and adapted high-yielding cultivars. Low-yielding traditional landraces are predominantly grown; there is thus potential to improve the yield and stability of the existing varieties and landraces. Seed set, crop maturity, and plant height are important traits to be considered.

- Drought and soil management. Many of the soils in the region are of low fertility. Increased production on such soils is only possible when improved varieties are grown with improvement in soil management. Drought, poor stand establishment, temperature, and nutrient stresses all significantly reduce production. Intercropping and sole cropping are both practised, and further work is required on the relationships of interplanted crops.

- Diseases. Priority diseases for regional research include anthracnose, leaf blight, covered smut, grain mold, and ergot for sorghum. For finger millet the priority disease is blast disease and for pearl millet it is ergot. Many of these diseases are widespread in the region and they sometimes cause severe damage to crops. Downy mildew, rust, and smut are also common in the region; they do not appear to do much damage to the local landraces, but the situation could change with the introduction of improved cultivars.

- **Insect pests.** The predominant insects pests of sorghum are stem borers, shoot fly, midge, head bugs, and storage insects. Several of the insects found on sorghum also attack millets, but do not appear to significantly damage the crop.

- **Birds.** Quelea and other species cause significant damage to sorghum and millets. The actual extent of damage has not been critically evaluated.

- ***Striga.*** Several species of this parasitic weed attack sorghum and finger millet crops resulting in significant production losses.

- **Lack of on-farm trials and demonstrations.** To transfer research results to farmers, it is important to conduct verification trials on farmers' fields, coupled with economic analysis to provide feedback from farmers to researchers.

- **Lack of marketing systems and incentives.** Most countries have no official market or pricing policies for either sorghum or millets. Consequently, these crops do not enter into official trading systems and this is a disincentive to growers. Proper and cost-effective distribution of grain with adequate price control is essential to absorb excess production.

- **Lack of postharvest handling and utilization.** Eastern African countries are increasingly expressing concern about postharvest handling, storage pests, and utilization aspects of sorghum and millets. It is important that for rapid acceptance, improved cultivars should be of acceptable quality for food products, brewing, and livestock and poultry feed.

- **Seed production.** One of the bottlenecks to rapid adoption of improved varieties and hybrids by farmers in the region is the lack of seed. Improved high-yielding and adapted cultivars have been released by NARSs but seeds of these are not available to farmers. Seed production, marketing, and distribution should be given high priority in the region.

All the NARSs in the region have active research programs on sorghum. Only Uganda, Kenya, Tanzania, Sudan, and Ethiopia have active research programs on either finger millet, or pearl millet, or both. The strength of NARS research programs in the region varies from country to country.

Research by NARS

Improvement work on sorghum was initiated in 1920 in Sudan, 1948 in Tanzania, 1953 in Ethiopia, and 1958 in East Africa (Kenya, Uganda, and Tanzania) at Serere, Uganda. Research work on sorghum was initiated in the 1970s for Somalia, Rwanda, Burundi, and in Kenya and Tanzania, after the break-up of the East African Community in 1977. The research work up through the early 1950s concentrated mainly on collection and assessment of local material as well as a few introductions. Later, full-scale breeding programs were initiated at Serere, Uganda, Wad Medani, Sudan, and Nazreth in Ethiopia.

Pearl millet and finger millet research was initiated much later at the Serere Research Station in the 1960s and pearl millet research at Wad Medani in 1978, which later shifted to El Obeid, Sudan.

Research manpower available to NARSs in the region is adequate for most countries except Rwanda and Burundi. The region has a total of 76 scientists, 16 at PhD level, 40 at MSc level, and 20 at BSc level. Sudan has the largest number of trained scientist with 9 PhDs and 2 MScs; Tanzania has 3 scientists at PhD and 4 at MSc levels; Ethiopia has 1 at PhD and 12 at MSc levels; Somalia has 8 at MSc level; Rwanda has 1 at MSc level; and Burundi has only 1 scientist at BSc level.

Eastern Africa Regional Sorghum and Millet (EARSAM) Network

The EARSAM network was established at the EARSAM Sorghum and Millet Regional Workshop in 1986 in Bujumbura, Burundi, by NARS sorghum and millet scientists in the region. The overall objective of the network has been to strengthen the ties among NARSs in the region; promote free exchange of scientific information and germplasm; develop collaborative research projects with lead NARSs on priority constraints to production of regional importance; and develop a coordinated regional testing network for elite cultivars in the region. The EARSAM network is managed by a Steering Committee comprised of one scientist from each country of the region. The Steering Committee prepares short- and long-term network action plans based on prioritized problems of regional significance and provides overall guidance for networking activities.

Since its inception, the EARSAM network has made positive and significant impact on sorghum and millets research in the region. Some of the major impacts that the EARSAM network has made on NARSs are as follows:

1. Promoted free flow of elite germplasm, including sources of various resistance, among NARS and from ICRISAT to NARSs.
2. Initiated and implemented regional testing of elite germplasm in different agroecological zones in the region to identify elite, high yielding germplasm with broad adaptation and adaptability in each agroecological zone.
3. Improved the scientific skills of both NARS scientists and technicians through EARSAM network-organized short courses and in-service training at ICRISAT Center and consultancies by ICRISAT scientists travelling in the region.
4. Provided a forum for NARS scientists to freely exchange research information and germplasm, and promoted scientific interaction among the scientists through regional workshops, research monitoring tours, scientific working groups, etc.
5. Initiated, implemented, and coordinated collaborative research projects among NARSs, and between NARSs and ICRISAT.
6. Improved the scientific leadership by involving NARS scientists in the planning and decision making process of all EARSAM network research and other related activities through the EARSAM Steering Committees.

NARS-ICRISAT Collaboration

Through the EARSAM network a number of collaborative research projects have been developed between the leading NARSs in the region and ICRISAT. Through collaborative research projects, ICRISAT scientists have transferred specific technologies developed at ICRISAT Center to NARS lead scientists. The following collaborative research projects have been initiated and implemented.

- *Striga* resistance screening with the Institute of Agricultural Research (IAR), Ethiopia, and the Agricultural Research Corporation (ARC), Sudan.
- Investigations on long smut *(Tolyposporium ehrenbergii)* with the Kenya Agricultural Research Institute (KARI), Kenya.
- Development of a screening technique for covered smut *(Sporisorium sorghi)* with KARI, Kenya.
- Drought resistance studies with ARC, Sudan.
- Investigations on ergot *(Sphacelia sorghi)* with IAR, Ethiopia, and l'Institut des sciences agronomiques du Rwanda (ISAR), Rwanda.
- Investigations on anthracnose *(Collotrichum graminicola)* with IAR, Ethiopia.
- Investigations on sorghum stem borer (*Chilo partellus)* with the Research Division, Ministry of Agriculture, Somalia, and IAR, Ethiopia.
- Evaluation of nutritional and food qualities of sorghum in eastern Africa with IAR (Ethiopia), University of Nairobi (Kenya), and ARC Food Research Centre (Sudan).
- Finger millet head blast *(Pyricularia qrisea)* resistance screening, with KARI, Kenya, and Makerere University College, Uganda.

Policy Environment

ICRISAT's 1994-98 Medium Term Plan includes 12 themes related to research work in eastern Africa on sorghum, finger millet, and pearl millet. The sorghum research themes are: *Striga* 18, stem borer 34, grain mold 35, low temperature 44, anthracnose 48, midge 49, drought 65, and leaf blight 66. Finger millet research themes are blast disease 67 and improvement of grain yield 73, while those for pearl millet are drought 59 and downy mildew 64.

During the EARCAL In-house Review, which was held in October 1992, all the sorghum and millet research projects were reviewed, discussed, and modified. Three projects, one each on sorghum, finger millet, and pearl millet, were recommended. A project on cooperative regional trials and nurseries was discontinued, because this is an EARSAM network activity rather than a research project.

Sorghum in Latin America

C.L. Paul[1]

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Sorghum in Latin America

C.L. Paul

Abstract

Latin American countries have become more urban and industrialized; but with the majority of the rural population still having limited access to land, credit, inputs, markets, etc, they have remained poor. Overall, 62% of rural families live below the poverty line and 34% live in destitution.

Approximately 9 million t of sorghum (Sorghum bicolor) *are produced in Latin America with Mexico producing 50% of this, Argentina 25%, and Central America 6%. Except for some inland valleys and eroded mountain slopes of Central America, the crop is produced on intermediate to large farms utilizing hybrids imported from the USA and cultivars developed in the region. In Guatemala, El Salvador, Honduras, Nicaragua, and Haiti, a large part of the production is on small subsistence holdings often of less than I ha in size where farmers use photoperiod-sensitive landraces intercropped with maize (Zea* mays) *and beans* (Phaseolus vulgaris*) using traditional practices. These small farmers grow sorghum as insurance against failure of the staple food crop of maize; when such a failure occurs (often due to drought) sorghum replaces it in the human diet. Overall in the region, sorghum genotypes having ICRISAT germplasm are grown on about 120 000 ha and produce some 250 000 t of grain that generate US$ 40 million of gross income annually. In South America the acid soil savannas of Brazil. Colombia, Bolivia, and Venezuela constitute an abundant potential area for sorghum of some 300 million ha, but genotypes adapted to acid soil conditions need to be developed.*

*Abiotic and biotic stresses include cold (Mexican highlands), drought (expecially in Central and northern Mexico, hillsides of Central America, northeastern Brazil, and the Chaco region of Paraguay, Argentina, and Bolivia), acid soils (*cerrados *of Brazil, and* llanos *of Venezuela, Colombia, and Bolivia), downy mildew, anthracnose, leaf spots, grain molds, stem borer, and midge.*

The main constraints to sorghum production in the region are lack of early-maturing, tropically adapted cultivars with high yield potential and tolerance to the major stresses; poor cultural practices, especially in the control of planting density and weeds; inadequate seed production technology; high input costs; low level of technological inputs; poor credit and marketing facilities; and a lack of technology in the uses of the grain. The food-type sorghums suffer from severe bird damage in many areas, and food technology has not been adequately developed.

Although the majority of the countries in the region have well-developed agricultural research institutions, the sorghum component is weak in many of them because of low salaries and poor operational budgets. Training at the MSc and PhD levels is needed for Central American countries, and at the Visiting Scientist and Research Fellow levels for Mexico and South America.

ICRISATs Latin American Sorghum Improvement Program (LASIP) has a comparative advantage in the development of tropically-adapted germplasm for the major biotic and abiotic stresses and in the development of food-type cultivars. LASIP's work with the National Agricultural Research Systems (NARS) in the development and improvement of cropping systems for small farmers in Central America is unequalled by any other institution. As coordinator of the regional sorghum research network, the Comision Latinamericano de Investigadores en Sorgo (CLAIS), LASIP maintains excellent contact with NARSs, private companies and institutions, and farmers of the region. LASIP's technical assistance and specialized training backed up by ICRISAT Center is unrivalled.

The ICRISAT-LASIP I CLAIS collaboration has led to the training of 62 scientists in In-Service and Visiting Scientist categories at LASIP in Mexico and ICRISAT Center, India. An additional 77 scientists have received training in short courses.

For the 1990s, demand for sorghum (mainly as feed) is expected to grow at an annual rate of not less than 3.9%, and this production increase will have to come from marginal areas, especially in the larger countries of Mexico, Argentina, Brazil, Colombia, and Venezuela, as fertile soils are being increasingly utilized for intensive production of high-value food crops. The smaller countries will continue to use low-input, cost-reducing technologies that must be sustainable on small and intermediate farms.

ICRISAT's Medium Term Plan will respond to the need to obtain disease resistance in sorghums for the Latin American region and to develop cultivars that are adapted to the acid soil savannas of South America.

The Agro-socioeconomic Environment

At present, Latin America and the Caribbean (LAC) suffer from high external debt, fiscal deficits, hyperinflation, and unemployment, leading to decapitalization and recession. To overcome these, countries have cut subsidies, curtailed imports, and attempted to increase exports through drastic currency devaluations. Goverment antipoverty programs have been aimed more at the urban poor than at the rural poor. Agrarian reforms have made little change on land ownership. Economies have become more urban and industrialized, while the majority of the rural population—still having limited access to land, credit, inputs, markets, etc.—has remained poor. Coffee, bananas, beef, tobacco, cotton, sugar, soybeans, and vegetable oils are important export earners while cereals and dairy products are important imports (Janssen et al. 1991; Wiggins 1991).

Several countries (notably Ecuador, Jamaica, Mexico, Venezuela, Chile, and Argentina) have embarked on reforms such as restructuring their public sectors, deregulating their financial systems, reducing the protectionism of trade regimes, and reducing barriers to foreign investment. These reforms are aimed at achieving macroeconomic stability as well as enhancing allocative efficiency in both the public and private sectors (World Bank 1990).

The large countries of the region including Mexico, Brazil, Venezuela, Colombia, and Argentina are expected to intensify commercial farming on fertile soils with a high level of inputs. Smaller countries will continue to use low-input, cost-reducing technologies that must be sustainable and technically and economically attractive to small and intermediate farmers within a strategy of technological development in equilibrium with ecological and edaphological limitations predominant in the distinct ecosystems (IICA 1991; Wiggins 1991; Janssen et al. 1991; Pineiro 1989).

Rural population has been increasing rapidly and subdivision of small holdings with plots of less than 1 ha has increased in the region, especially in Mesoamerica. Of the total population of the LAC, 35% was below the poverty line in 1982. Increasing rural poverty has resulted in a migration to urban areas which in 1990 had 70% of the region's 440 million people. Overall, 62% of rural families live below the poverty line and 34% live in destitution (Hurtado 1986; Wiggins 1991).

The Physical Environment

Geology and soils

Mesoamerica. Mesoamerica consists of Mexico and Central America, including Hispaniola and the Caribbean islands, and occupies an area of about 2.5 million km^2 between the latitudes of 7°N and 32°N. Folding, faulting, and volcanic activity around the Precambrian platform underlying the Gulf of Mexico built up the present-day landscapes of southern Mexico and Central America. Central America comprises relict fragments of the terminal parts of two major continents and these have been plastered over and joined together by marine sediments. Volcanic activity and mountain chains add further diversity to the present-day landscape. The Caribbean islands are an integral part of the Central American region, since they were once joined to it in the Antillean geanticline.

A continuous series of rugged mountain ranges with volcanic peaks above 3000 m places severe restrictions on agriculture but extensive breaks in these mountains give way to arable basins and valleys in inland elevated areas and narrow fertile plains derived from volcanic ash on the Pacific and Caribbean coasts. The arable elevated areas (Fig. 1) include mostly shallow eroded Cambisols (FAO-UNESCO 1975; Bridges 1979) with slopes greater than 30% (and as high as 70%) on hillsides where run-off and erosion are high and water-holding capacity is low.

Acid effusive rocks and their associated tuffs and agglomerates, together with crystalline limestones, are widespread. In some areas, there are blankets of subaerial volcanic ash and

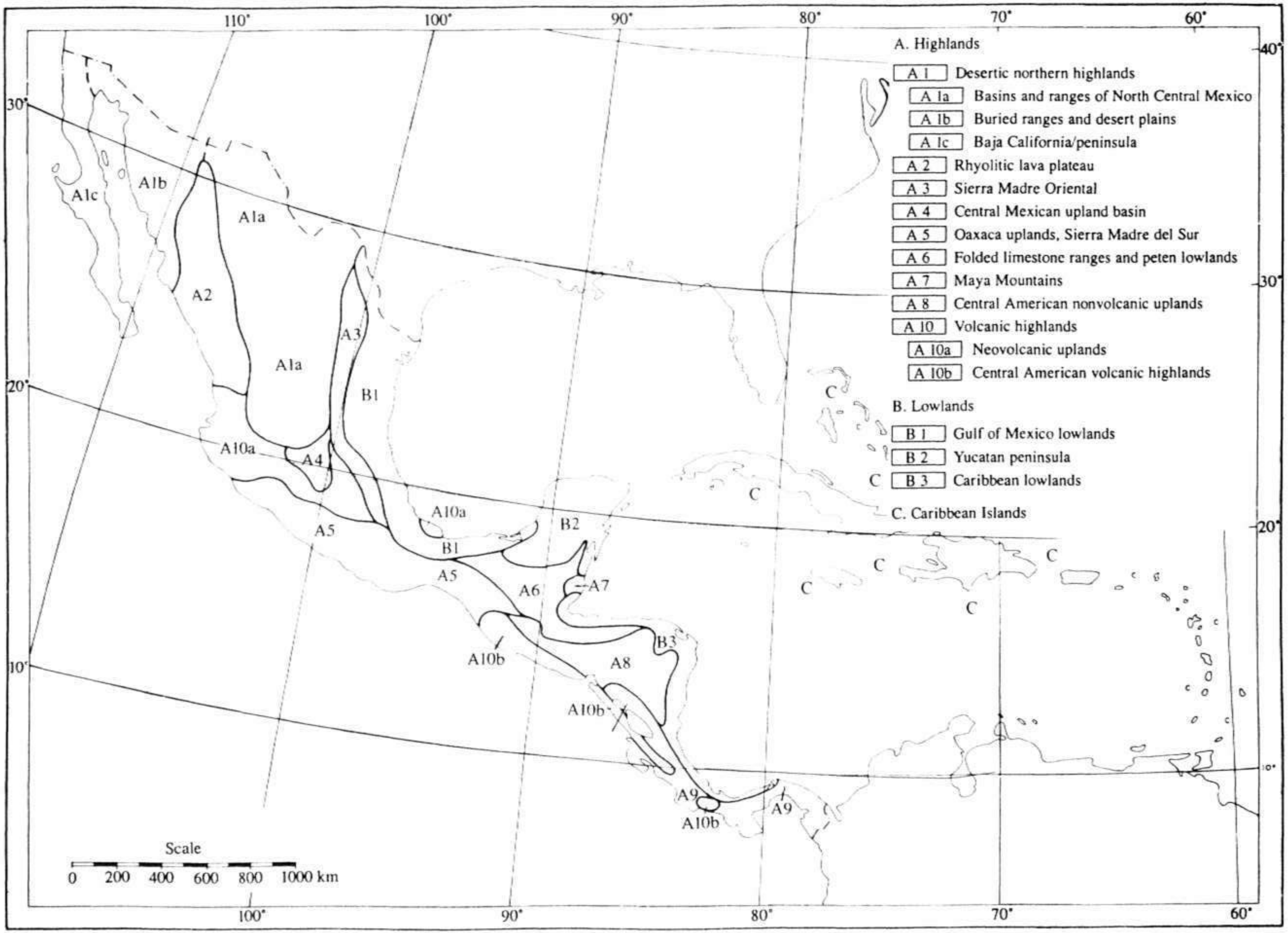


Figure 1. Broad soil regions of Central America and the Caribbean. **Source: FAO-UNESCO 1975.**

aeolian deposits. Sorghum areas are characterized by Cambisols, Luvisols, and Vertisols. Potential areas for sorghum in the Mexican highlands consist mainly of Kastanozems and Xerosols.

The soil erosion problem, which is complicated by semi-arid conditions, is due to removal of vegetative cover and a long history of cultivation under poor conservation techniques. For these reasons, many of the soils are found in their lithic phases except in the flat valley bottoms.

South America. South America can be divided into three major structural elements: lowlands, uplands, and Andes (Fig. 2). Lowlands refer to the three principal drainage systems: the Amazon, Orinoco, and Paraguay basins. The uplands cover the ancient Guianan, Brazilian, and Patagonian shields. The Andean mountain ranges include the entire system of mountains and foothills that dominates the western part of the continent.

The lowlands contain Ferralsols under equatorial rain forest and Acrisols under savanna vegetation. In areas considered suitable for sorghum from an agroclimatic point of view, there are wide expanses of Cambisols, Phaeozems, Luvisols, Kastanozems, Fluvisols, and Xerosols.

The upland areas and Andean mountain ranges and foothills suitable for sorghum are characterized by Arenosols, Lithosols, Luvisols, Cambisols, and Andosols.

Topography and climate

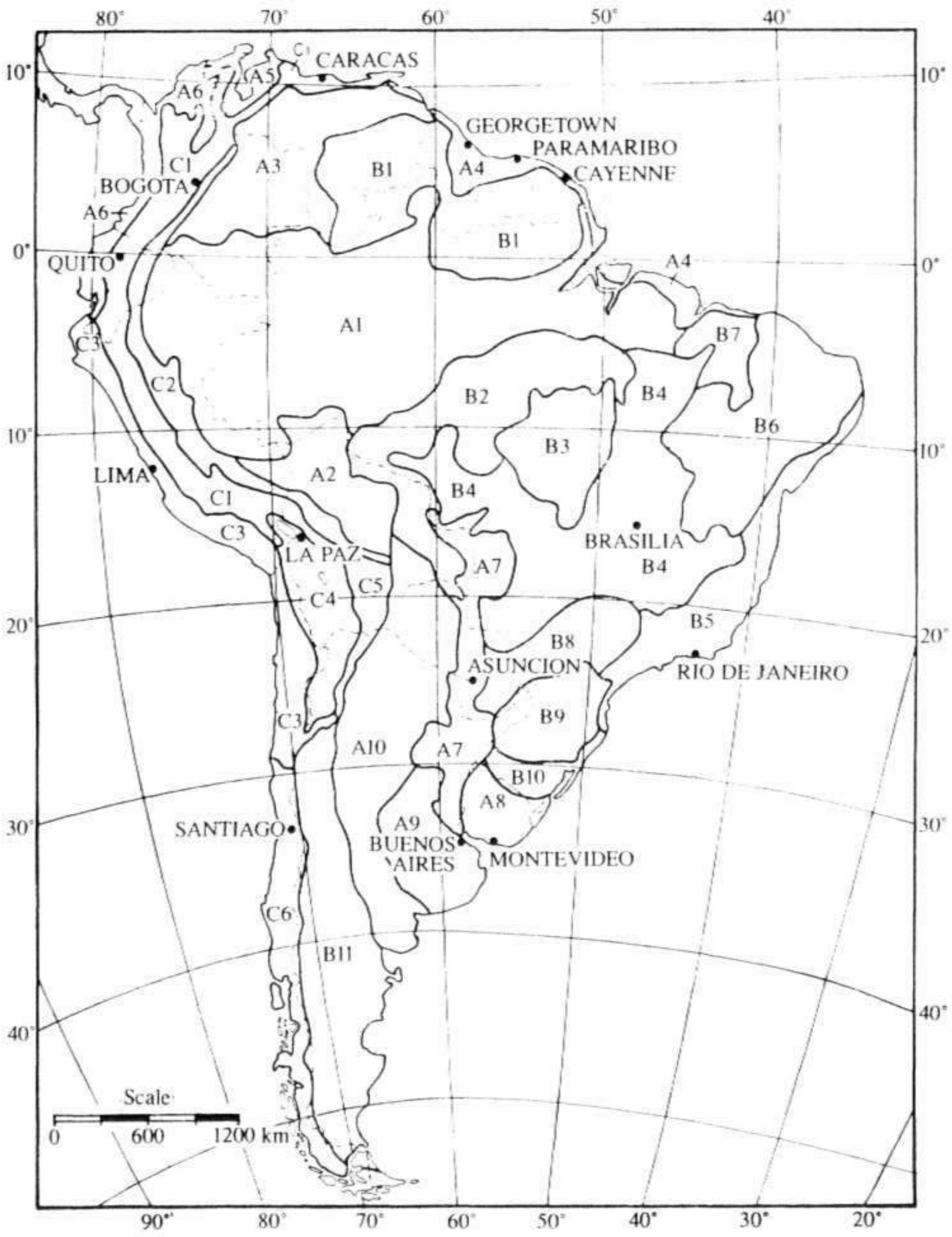
Mesoamerica. Because of the mountainous nature of the terrain standing as a barrier between two major oceanic weather systems, changes from one climatic type to another are abrupt. The northern and northwestern parts of the land bridge fall strongly under the influence of continental air movements from the high pressure centers of the North American continent. Dry seasons are more prolonged and pronounced along the Pacific side of the land bridge while the Atlantic lowlands are subject to irregular periodic invasions of cold fronts from the North American continent from October to March.

Going inland from the coast, the land rises, rainfall generally increases, and temperatures fall, culminating in a zone of cool, damp highlands well exemplified in Mexico and Guatemala. The climates of the interior uplands, highlands, and valleys are varied and include humid and dry subtropical climates, warm temperature climates, cold temperate climates, and desertic upland climates (northern Mexico). Many interior valleys experience subdesertic conditions along the valley floor.

The semi-arid highlands of Mexico consist of three extensive plateaus characterized by waste-filled basins surrounded by high mountain ranges or lower hills (Mosino Aleman and Garcia 1974). The Central Plateau, where sorghum has a good potential, has an elevation between 1600 and 3000 m and is rich in volcanic ash. Over the plateaus the blocking and diversion of upper air currents by extensive mountain ranges greatly affects precipitation and temperature distribution. Between 1600 and 2000 m the mean annual temperature is 12-16°C with that of the coldest month (Jan) being 4-13°C and that of the warmest month (Aug) 14-24°C; absolute minimum temperature within this zone is -5°C or less (FAO-UNESCO 1975). In this zone night-time frosts are common from September to April. Mean monthly evaporation exceeds mean monthly precipitation throughout the year. Most of the central plateau receives between 200 and 400 mm of rainfall per year (Mosino Aleman and Garcia 1974).

The Caribbean islands are subject to the influence of the southeast trade winds with the windward coasts being drier than the leeward coasts; the central mountains receive more rain than coastal areas.

Throughout Mesoamerica there is a marked bimodal rainy season from May to October, which is very variable in absolute amount and distribution of rainfall (Hawkins 1982). Rainfall is concentrated heavily in May/June and September with a dry spell of 2 to 7 weeks (known as the *canicula)* in July/August. A marked dry season with only 5% of the annual rainfall



A. Lowlands

- A 1 Amazon basin
- A 2 Bolivian lowlands
- A 3 Orinoco basin
- A 4 Atlantic coastal lowlands
- A 5 Maracaibo basin
- A 6 Pacific coastal lowlands
- A 7 Paraná/Paraguay basin
- A 8 South Brazilian and Uruguayan lowlands
- A 9 Argentinian pampa
- A 10 Chaco and peripampa

B. Uplands

- B 1 Guyana uplands
- B 2 Forested Amazon uplands of the Brazilian Shield
- B 3 Central Brazilian depression
- B 4 Central Brazilian cerrado uplands
- B 5 Atlantic uplands of Brazil
- B 6 Northeastern Brazilian uplands
- B 7 Transitional tablelands of Northeast Brazil
- B 8 Central southern Brazilian uplands
- B 9 Southern Brazilian planaltos
- B 10 Southern Brazilian and Uruguayan prairies
- B 11 West and South Argentinian uplands

C. Andean mountain ranges

- C 1 Northern Andes
- C 2 Eastern ranges and foothills
- C 3 Western ranges and foothills
- C 4 Andean altiplano
- C 5 Central eastern Andes
- C 6 Southern Andes

Figure 2. Broad soil regions of South America. **Source: FAO–UNESCO 1975.**

occurs during November to April Mean annual rainfall in inland areas varies from 300 mm to 1200 mm and the number of dry months from 0 to 8; on the Caribbean coast the average is more than 3000 mm and is about 1500 mm on the Pacific coast.

In general, average annual temperatures range from about 25-30°C at sea level to about 17-24°C at 750 m above sea level but the variation in altitude has a strong influence on temperature. This is particularly true in Mexico, Guatemala, and Honduras where areas below 800 m have a tropical climate; in areas between 800 and 1800 m the climate is subtropical with temperatures of 24-27°C during the day and 16-21°C at night.

South America. The Andean chain of mountains consists of a series of complex ranges that parallels the north coast of Venezuela and the entire west side of South America. These mountains prevent winds from the South Pacific anticyclone from entering the interior of South America or permit them to do so only after extracting their moisture on windward mountain slopes. This results in an elongated rain shadow zone that extends east from Bolivia and south to Tierra del Fuego. The Andean barrier also produces extraordinarily high orographic rainfall on the windward slopes of the Pacific coasts of Colombia and southern Chile. A secondary group of variations is produced on a regional level by the Andes with highland basins (Colombia) and high plateaus (Peru and Bolivia) affecting the wind systems.

The Brazilian shield collects orographic rainfall that keeps the coastal strip humid throughout the year. The wetter zones between Sao Paulo and Rio de Janeiro and from Victoria to Baia, are covered by dense tropical forests. In northeastern Brazil a group of uplands causes the southern trade winds to reach the interior of the state of Rio Grande do Norte as dry air. Dynamic warming helps create an arid climate in this area. North of the Amazon, the Guiana highlands block the northeast trade winds and produce a dry winter condition on their high leeward slopes. The Patagonian plateau and the Sierras de Cordoba in Argentina have an effect on general air circulation.

In addition to the four mountainous areas, three major lowlands affect circulation on the continent. The greatest of these is the Amazon Basin between the Guiana and Brazilian highlands. The combination of orographic uplift at the inner edges of the basin and constant convection throughout makes this a moist region all year long. North of the Amazon Basin are savanna lowlands, which include the *Llanos* of Colombia, Venezuela, and Guyana. South of the Amazon Basin are the lowlands of Mamore, Chaco, and Pampa, which have an arid climate on their western side close to the Andes.

The larger part of the east coast of South America is bathed by the warm south equatorial current that provides moisture to the trade winds. On the west coast, the Humboldt current and the warm *El Nino* bring heavy rains to coastal areas.

Temperature differences result from altitude and exposure. In the lowland tropics (0 -100 m) temperatures range from 24°C to 30°C. Between 1000-2000 m, the range is 18-24°C and between 2000-3000 m, 12-18°C. Annual rainfall across South America ranges from 4200 mm on the Chilean coast to 10 mm in the Chilean Atacama desert. In the tropical areas, annual rainfall is closer to 1000-2000 mm. Variations in exposure can also bring variations in precipitation, wind, and heating at the surface. Precipitation values generally increase upslope wherever orographic effects are important. Maximum values tend to occur on windward slopes near the lower *tierra templada* elevations. Leeward slopes may be quite dry due to rainshadow effects and dynamic warming.

The Sorghum Production Environment

Areas, productivity, and production

Sorghum *(Sorghum bicolor)* is the fifth most important cereal worldwide in terms of area, yield, and production. It is grown on approximately 45 million ha on a global scale with a production of 60-70 million t. In many developing countries, particularly in Africa and Asia, yields range from 0.5 to 0.7 t ha^{1}, while in developed countries and some developing countries of Latin America yields range from 3 to 5 t ha^{-1}. The average yield worldwide is 1292 kg ha"^{1} (FAO 1992).

World production expanded from 40 million t in the early 1960s to over 70 million t in 1981 but has since dropped back to 58 million t in 1991 (FAO 1992). The cultivation of the crop under stressful conditions such as the semi-arid tropics accounts for the large variation in its production statistics (Maunder 1990).

The area under sorghum production has declined substantially in Africa, Latin America, and Asia during the last decade. Production, however, has remained essentially stable because farmers increasingly grow improved cultivars associated with improved farming practices. The crop has shown the smallest increase in production among the major cereals at 2.4% for the 20-year period from 1961-65 to 1981-85 (Maunder 1990). Inadequate price and marketing structures together with high costs of production inputs and physical/biological constraints result in sorghum being considered a subsistence crop in many developing countries.

The areas suitable for sorghum in Latin America are shown in Figures 3a and 3b; feed-use trends are shown in Figure 4 and production trends in Table 1. Mesoamerica and South America account for 15.3% of the world sorghum production, with Mexico having 49.3% of the production in the Latin American region, Argentina 25.4%, Colombia 8.3%, Venezuela 7%, Central America 5.6%, and Brazil 3.1% (FAO 1992). Thirty years ago essentially no sorghum was grown in South America and only about 100 000 ha were grown in Mesoamerica. Today, Mexico cultivates almost 1.5 million ha of sorghum, Central America approximatly 0.5 million ha, and South America 1.5 million ha, often in areas too dry, and on soil too acid for successful maize *(Zea mays)* cultivation. The annual production of sorghum in Mesoamerica is about 4.9 million t, of which Mexico alone

Table 1. Sorghum production trends for the world and the Americas, 1979-1991.

	Area harvested ('000 ha)				Yield (kg ha^{-1})				Production ('000 t)			
	1979-81	1989	1990	1991	1979-81	1989	1990	1991	1979-81	1989	1990	1991
World	45 071	44 904	40 516	44 702	1 452	1 316	1 399	1 292	65 521	59 113	56 677	57 763
No. and Central America	7 236	6 606	5 925	5 771	3 404	3 214	3 555	3 398	24 696	21 231	21 060	19 609
Costa Rica	20	3	2	2	1 808	2 278	1 634	1 500	35	6	3	3
Dominican Republic	6	20	8	8	2 939	2 522	2 588	2 575	18	50	21	17
El Salvador	126	120	129	50	1 155	1 250	1 242	1 324	145	149	161	163
Guatemala	39	58	53	83	2 049	1 470	1 643	1 600	80	85	87	80
Haiti	158	165	100	1 380	762	807	680	700	121	133	68	70
Honduras	61	65	79	83	816	948	1 033	1 125	49	62	81	93
Mexico	1 491	1 620	1 820	1 380	3 343	3 090	3 285	3 164	4 991	5 004	5 978	4 367
Nicaragua	51	50	46	40	1 560	1 545	1 658	1 750	80	77	76	70
USA	5 273	4 493	3 678	3 974	3 618	3 479	3 959	3 704	19 157	15 632	14 562	14 720
S. America	2 476	1 378	1 341	1 467	2 705	2 265	2 649	2 781	6 854	3 120	3 543	4 081
Argentina	1 866	597	688	676	2 928	2 278	2 930	3 330	5 641	1 360	2016	2 251
Brazil	81	165	133	181	2 105	1 465	1 708	1 501	172	241	228	272
Colombia	220	239	273	257	2 219	2 910	2 848	2 878	488	695	777	738
Peru	14	10	5	10	3 292	3 528	2 702	3 055	46	37	13	31
Uruguay	56	38	26	28	1 874	2 069	2 268	3 174	112	79	59	90
Venezuela	227	289	176	275	1 606	2 063	2 141	2 240	36	559	376	616

Source: FAO 1992.

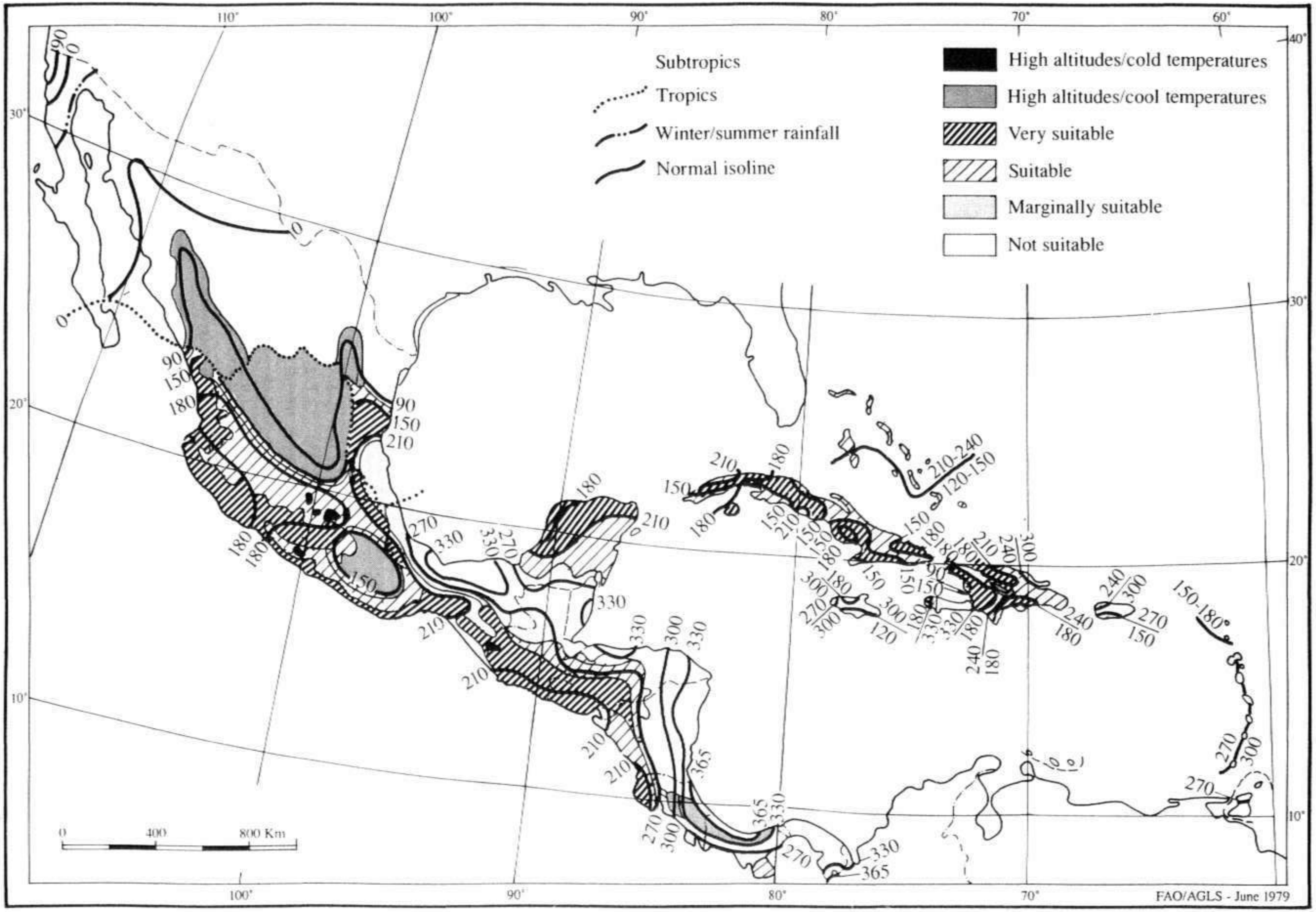


Figure 3a. Generalized agroclimatic suitability assessment for rainfed production of sorghum in Central America and the Caribbean. (Figures indicate length of growing period in days.) **Source: FAO 1981.**

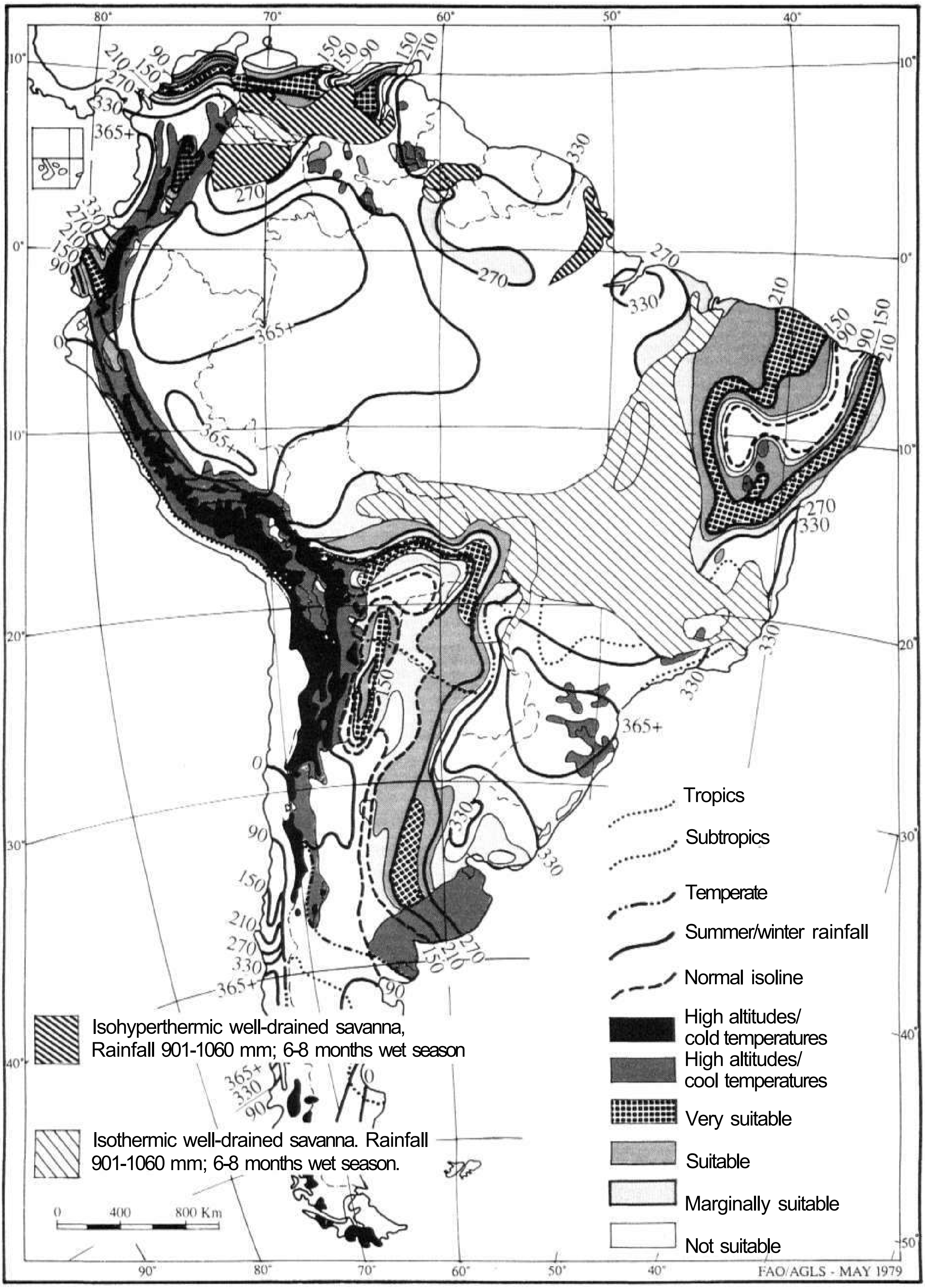
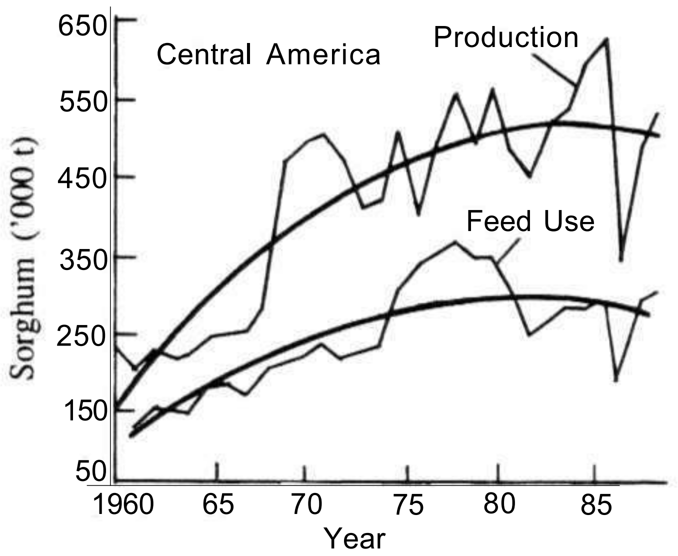
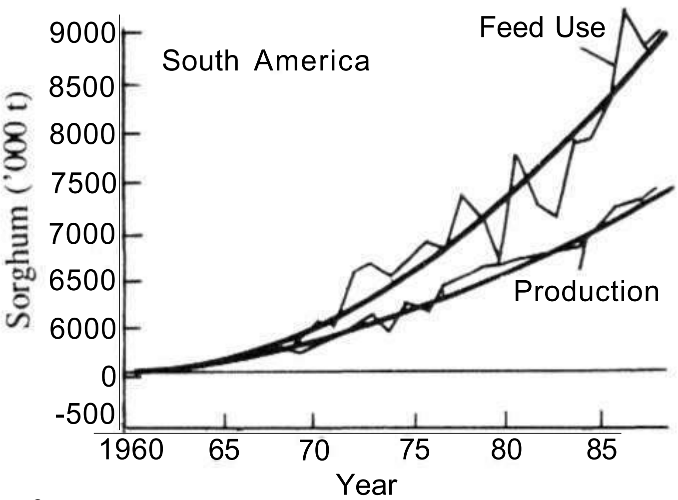


Figure 3 b. Generalized agroclimatic suitability assessment for rainfed production of sorghum in South America. (Figures indicate length of growing period in days.) **Source: FAO 1981.**



R^2 = 0.75
R^2 = 0.71



R^2 = 0.98
R^2 = 0.94

Figure 4. Sorghum production and feed-use trends in Latin America. **Source: de Wet 1991.**

produces 90%. Approximately 496 000 t of sorghum (10% of Mesoamerican production) are produced in Central America on 406 000 ha with an average yield of 1222 kg ha^{1}. Of this, about 51% is produced on small subsistence farms giving an average yield of 890 kg ha^{1}. The small farmers (about 5 million) grow mainly food-type, unimproved, photoperiod-sensitive genotypes *(maicillos criollos)* that are tall, leafy, susceptible to diseases and pests, and require 6 to 7 months to mature. The other 49% consists of improved varieties and hybrids grown mainly for feed on intermediate to large farms in the Pacific coastal regions and inland fertile valleys. Overall, sorghum production has grown at the rate of 0.9% annually over the period 1966-1989 while harvested area has grown by 1.2% annually. In Mesoamerica, sorghum genotypes having ICRISAT germplasm are grown on about 120 000 hectares and produce some 250 000 tons of grain (Table 2); this production generates US$ 40 million of gross income. These dual-purpose genotypes are also an important source of forage after harvesting of the grain.

Sorghum production in Mexico peaked at around 6 million t in 1985/86 on an area of approximately 2 million ha, but recent increases in the cost of production and relatively low-priced sorghum grain available in the USA have caused a 25% reduction in sorghum area. This scenario is likely to worsen as Mexico joins a free trade pact with the USA and Canada. Many marginal areas of the Mesoamerican region can be used for sorghum production if cheaper improved seed and other resources could be made available to small and intermediate farmers. Mexico alone has a potential of 450 000 ha of cold highland valleys and 1.4 million ha of semi-arid lowlands stretching from the Pacific coast to the Yucatan Peninsula on the Caribbean Sea.

Sorghum is cultivated in South America by small farmers as well as large farmers who grow hybrids (mainly imported from the USA) that average 2.80 t ha^{-1} under low inputs. Argentina, Venezuela, Colombia, and Brazil are the primary sorghum-producing countries of South America but the area in Argentina, the main producer, has dropped from 2 million ha 5 years ago to 676 000 ha at present, due to increasing production and transport costs, and soybeans displacing the sorghum belt westward into more arid, lower-yielding areas. Brazil offers considerable opportunity for expansion such as in the arid northeast or the tropical acid soils of the *Cerrados* region, which is similar to the savannas of Venezuela and Colombia. The tropical acid-soil savannas constitute an abundant potential agricultural resource in Latin America. It is estimated that these savannas cover an area of some 300 million ha of which 200 million ha

Table 2. Sorghum releases based on materials identified or bred by the ICRISAT Latin American Sorghum Improvement Program (LASIP).

Country of release	Genotype name	Pedigree	Genotype origin	Area under commercial production (ha)	Yield ($t\ ha^{-1}$)
1. El Salvador (1976)	CENTA S-2	Selected from crosses of materials from Chapingo	CIMMYT	5 600	3.2
2. Mexico (1978)	VA 110	Selected from crosses of materials from E. Africa	CiMMYT/INIA/LASIP	4 500	3.5
3. El Salvador (1980)	CENTA SS-41	ATX623 x Sweet Sudan	INTSORMIL/LASIP/ CENTA	6000	21 (Dry wt.)
4. El Salvador (1983)	ISIAP Dorado[2]	[(GPR 148 x E-35-1)4-1 x (CS 3541 deriv.)] 1-1	1CRISAT/CENTA	10 000	3.5
5. Honduras (1984)	Tortillero 1	Selection from CS 3541	India via ICRISAT	200	2.5
6. Honduras (1984)	Catracho	ATX623 x Tortillero 1	INTSORMIL/LASIP	4 500	3.9
7. Guatemala (1985)	Mitlan 85[2]	Selection from M-90975	ICRISAT/LASIP	5 000	3.5
8. Honduras (1985)	Sureno	[(SC 423 x CS 3541) x E-35-I]-2-5	ICRISAT/LASIP	5600	3.0
9. Nicaragua (1985)	Nico-Sor (T-43)[2]	Selection from ICRISAT SEPON 1977 Yield Trial	LASIP/CLAIS	5000	3.4
10. Honduras (1986)	ISIAP Dorado[3]	[(GPR 148 x E 35-1)-4-1 x (CS 3541 deriv)]-1	ICRISAT/LASIP	8000	3.9
11. El Salvador (1987)	Agroconsa I	ATX625 x M-90362	INTSORMIL / ICRISAT/ LASIP	3 800	3.2
12. Mexico (1987)	Blanco 86[2]	[<GPR 148 X E-35-1)4-1 X (CS 3541 deriv.)]I-I	ICRISAT/LASIP	3 000	3.7
13. Mexico (1987)	UANL-1-87[2]	ICSV 112(SPV475)	ICRISAT/LASIP	160	3.6
14. Mexico (1987)	UANL-I-287[2]	Selection from M-90362	ICRISAT/LASIP	200	3.5
15. Cuba (1987)	ISIAP Dorado	I(GPR 148 x E-35-1)4-1 x (CS 3541 deriv.)] 1-1	LASIP/CLAIS	200	3.8
16. Mexico (1989)	Costeno 201[2]	Selection from M-62641	ICRISAT/LASIP	1 400	3.5
17. Mexico (1989)	Pacifico 301[2]	SPV 475 (ICSV 112)8	ICRISAT/LASIP	200	3.0
18. Mexico (1990)	Tropical 401[2]	Selection from M-90812	ICRISAT/LASIP	100	3.6
19. Mexico (1991)	PP290	Introduction from Sudan	LASIP	2000	3.5
20. Guatemala CB(1989)	H-887 V1	TAMU x ICRISAT	Genotype unknown	2 226	5.0
21. Guatemala CB (1989)	H-887 V2	TAMU x ICRISAT	Genotype unknown	5 396	4.5
22. Guatemala CB(1989)	H-887 V	TAMU x ICRISAT	Genotype unknown	10 553	4.6
23. Nicaragua (1990)	Pinolero I[2]	ICSV 112(SPV-475)	ICRISAT/LASIP	3 500	3.0
24. Guatemala (1990)	1CTA Jutiapa[2]	Selected from Criollo Peloton	Honduras/CLAIS/ LASIP	3 500	4.0
25. Mexico (1991)	Istmeno[2]	Selection from M-91057	ICRISAT/LASIP	5000	3.6
26. Costa Rica (1992)	Escameka	Selection from M-90362	ICRISAT/LASIP	2 500	3.8
27. Panama (1992)	Alanje Blanquito	Selectiom from ISIAP Dorado	ICRISAT/LASIP	100	3.6
28. Paraguay (1988)	ISIAP Dorado	[(GPR 148 x E-35-1)4-1 x (CS 3541 deriv.)] 1-1	ICRISAT/CENTA/ LASIP	1 000	2.5
29. El Salvador (1992)	ES 727	CENTA S-1 x Criollo Sapo	LASIP/CLAIS	4000	3.0
30. Mexico (1992)[1]	Morelos 513	(M-90322 x M-90812)bk-3-I-I-bk	LASIP	60	5.0
31. Mexico (1992)[1]	Zapata 516	[(NSA-935-6 x 77CS1) x M-90378] x R 6956-	LASIP	120	5.0
32. Mexico (1992)'	Xalostoc 502	[SEPON-78bk x TX954062 x CS 3541)-47-I]x (77CS1 x TX 2735)bk-2-1-1[4]	LASIP	84	5.5
33. Mexico (1992)[1]	Mapaztlan 522	C-21 X [(TX 954063 x CS 3541)-3 x M-90378]bk-1	LASIP	144	5.0
34. El Salvador (1993)[1]	ES 726	Selectiom from M-90894-1-1	LASIP/CLAIS	300	4.0
35. Nicaragua (1993)[1]	ICSV-LM 86513	(M-90322 x M-90812)bk-3-1-1-bk	LASIP/CLAIS	200	5.7
36. Colombia (1993)[1]	ICA-Yanuba	(Information pending from ICA, Colombia)	LASIP/CLAIS	-	4.5
37. Colombia (1993)[1]	HE 241	(Information pending from ICA, Colombia)	LASIP/CLAIS		
			Total	119 203	

1. Release pending.
2. Released in collaboration with LASIP Agronomy Project S-122(89)IC.
3. ISIAP Dorado is grown on some 20 000 ha in Egypt (J.W. Stenhouse, personal communication, 1992).
4. Continued selections.

are under extensive cattle grazing on native pastures, and at least 5 million ha are currently used for crop and intensive livestock production (Rivas et al. 1991). Sorghum is a promising cereal for agro-pastoral systems on the savannas. Acid soils development will depend on generation and adoption of low-cost technologies that are sustainable, and technically and economically suitable; and whether, in a scenario of increasing input costs, the savannas can compete with areas closer to the market. The development path also depends on research on developing varieties (by biotechnology or conventional breeding) and new production systems that can efficiently utilize these environments (IICA 1991). Another important potential area for sorghum in South America is the semi-arid Chaco region of northern Argentina, Paraguay, and southern Bolivia.

Utilization

World feed use of sorghum has risen from 15 million t to 40 million t over the past 25 years—an average growth of 4% per annum. Mexico's feed use rose from 0.5 million t to 8.0 million t over the period from 1961-65 to 1981-85 while Argentina's rose from 0.9 million t to 2.6 million t over the same period (Maunder 1990). In South America, demand for sorghum consumption increased by over 3% annually. CIAT (1991) has predicted that in the 1990s, demand for sorghum (mainly as feed) will grow at an annual rate of not less than 3.9%, and that this production increase will have to come from marginal agricultural areas as fertile soils are being increasingly utilized for production of high-value food crops. Sorghum is replacing maize as animal feed, as the demand for maize as human food increases because of rapid population growth. At the same time, the demand for animal feed is increasing (Fig. 4) as demand for meat and dairy products increases because of population movement from rural to urban areas.

The majority of the sorghum grown in Mexico and South America is used as animal feed. Only in Brazil, Paraguay, and Uruguay has the use of some sorghum for bread been reported.

In the Mesoamerican region the most important food crops are maize, beans, sorghum, and rice. In Mexico, Costa Rica, Panama, and the Dominican Republic, the lowland Pacific coastal plains, and the cooler highland areas along the isthmus of Central America, hybrid brown sorghum (most of the seed imported from the USA) is monocropped on large farms for animal feed. In the other countries of the region (including Haiti), about 31 to 100% of the sorghum is grown on small subsistence-type farms of 5 ha or less, mainly in multiple cropping systems with maize, beans, and cassava. The small farmers (about 5 million) plant sorghum (photoperiod-sensitive Creole landraces and, recently, improved photoperiod-insensitive food types) as a precaution against failure (due to drought) of the food staple maize. If the maize fails, sorghum takes its place in direct human consumption. Generally, about 15 to 20% of the sorghum produced by these small farmers is consumed by the farmers themselves while the rest is fed to their animals or sold in the village markets. Sorghum foods, which are prepared wholly from sorghum or sorghum mixed with maize or wheat, include *tortilla* (unleavened bread), *atole* (porridge), *tiste,* and *pinol.*

Although global consumption of sorghum as food has stagnated, there are considerable regional differences. However, in Latin America the global status quo can be applied. Likely reasons are urbanization, time and energy required to prepare food from sorghum, inadequate domestic infrastructure, poor marketing and processing techniques, unstable supplies of food-type grain, and the lack of readily available products such as sorghum flour compared with other foodstuffs. This stability in consumption is reflected in that at the rural level where 100% of sorghum use as food takes place.

Stress dimensions

Stress dimensions for the sorghum production environments are outlined in Table 3.

Table 3. Stress dimensions for the sorghum production environments in Latin America.

Stress	Country	Location
Low temperature	Mexico	Highland valleys
	Guatemala	Northern highlands
	Ecuador	Andean foothills
	Bolivia	Andean foothills
Drought	Mexico	Northern semi-arid zones Isthmus Tehuantepec Yucatan Peninsula
	Guatemala	SE intermediate zones
	Honduras	S (Choluteca) and W (Comayagua) areas
	El Salvador	N, E, and W areas
	Nicaragua	Central area N and S
	Costa Rica	Guanacaste region
	Panama	Azuero Peninsula
	Colombia	N coast
	Venezuela	SW areas
	Brazil	NE semi-arid region
	Argentina	Chaco semi-arid region and Pampas of Patagonia
	Bolivia	Chaco semi-arid region
	Paraguay	NW Chaco semi-arid region
Acid soils	Colombia	Llanos
	Venezuela	Llanos
	Bolivia	N Llanos
	Brazil	Cerrados region
	Panama	Rio Hato
Alkaline soils	Mexico	Morelos, Central Plateau
Downy mildew	Mexico	NE and Central
	Guatemala	SE region
	Honduras	Comayagua
	El Salvador	All regions
	Argentina	Central belt Cordoba
	Venezuela	All regions
Anthracnose	All countries especially Nicaragua, Panama, Argentina, Brazil and Venezuela	
Leaf spots	All countries	
Grain molds	All countries especially wetter areas	
Macrophomina	Panama	All sorghum areas
	Venezuela	All sorghum areas
	Colombia	All sorghum areas
	Mexico	NE zone
Midge	All countries	
Stem borer (Diatraea)	All countries	
Fall armyworm	All countries	
Head bugs	Mexico All South American countries	
Green bugs	All countries	

Farming systems

In Mexico, Costa Rica, Panama, the Dominican Republic, the Pacific coastal regions of Central America, and South American countries, sorghum production is mainly on large farms greater than 20 ha. The crop is grown mainly in monoculture from hybrid seed imported from the USA or from varieties developed in the region. Generally, the crop is grown under a low level of inputs except in the northern and central *bajio* regions of Mexico where irrigation and fertilizers are applied. In the Central American and Caribbean (Guatemala, Honduras, El Salvador, Nicaragua, and Haiti) inland areas (Figs. 5 and 6) of intermediate altitude (500-1000 m) sorghum is intercropped with maize and beans in several spatial and chronological arrangements as summaried in Figure 7. A brief description of the main systems follows.

Maize + sorghum in simultaneous association—System S,. Maize + local creole photoperiod-sensitive sorghum are sown at the same time in the same row or with sorghum in the interrow during May when the rainy season becomes established. The two crops grow together competing with each other as the sorghum remains vegetative. The vegetative growth of the sorghum varies with the particular spatial arrangement used; if the arrangement affords more light, nutrients, and moisture to the sorghum, it grows more vigorously and competes more with the maize thereby lowering the yield of the latter.

The maize attains physiological maturity at mid-August and is doubled over below the ear thereby undergoing moisture loss during storage in the field. Under reduced shading and competition, the sorghum plant then begins to grow

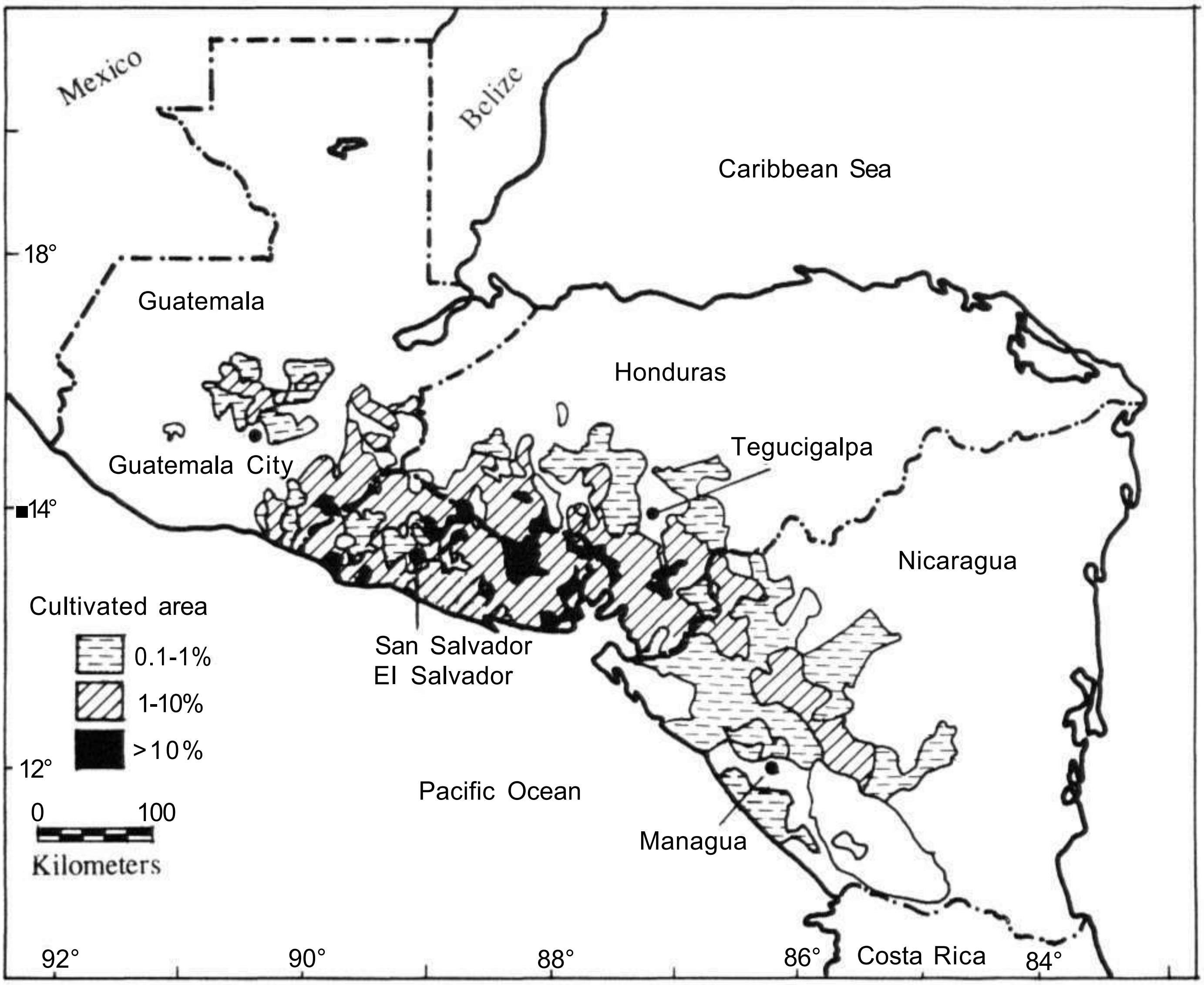
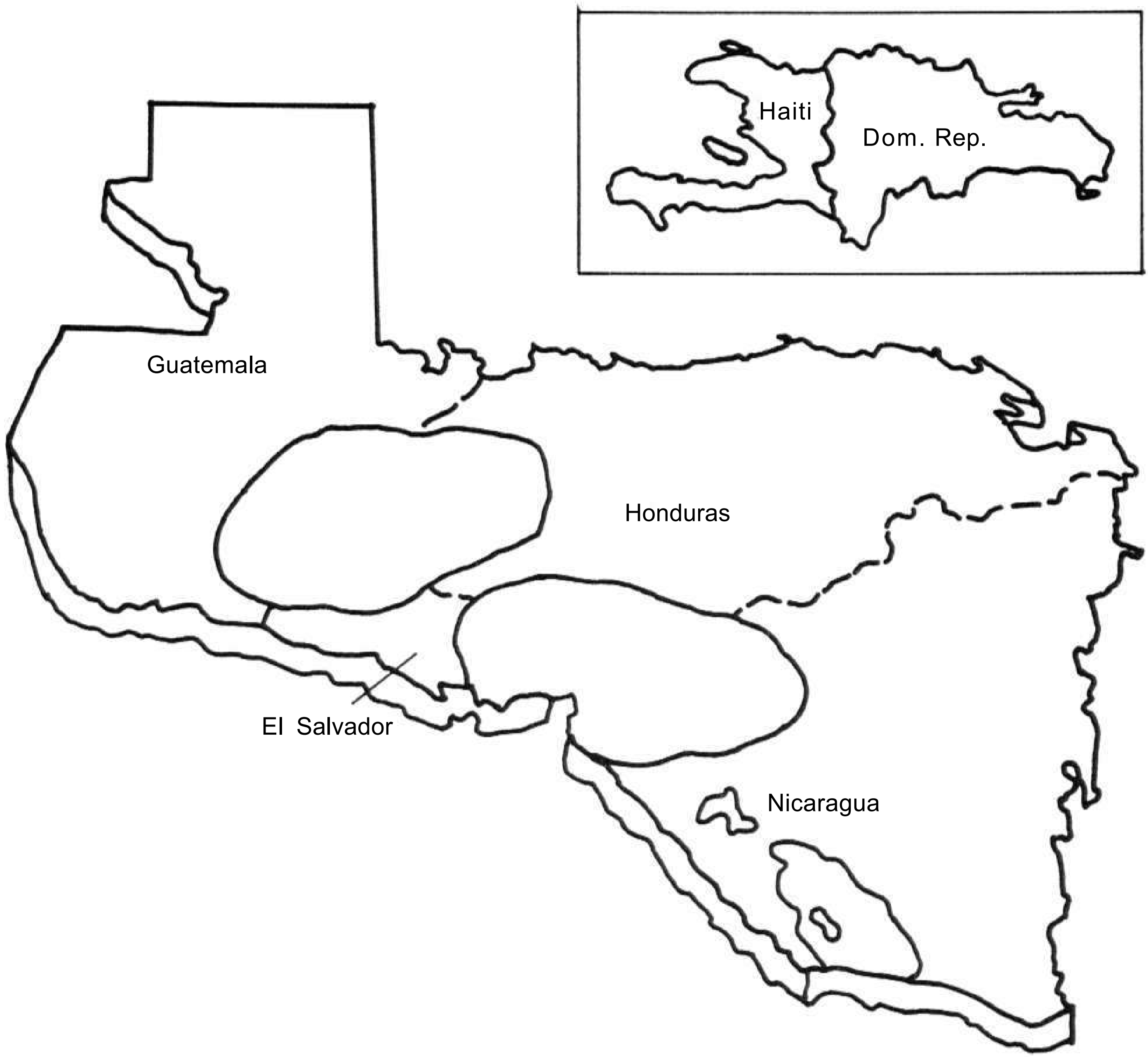


Figure* 5. *Areas of sorghum/maize intercropping in Central America. **Source: Hawkins 1984.**



	Guatemala	Haiti	Honduras	El Salvador	Nicaragua
Area (km^2)	108889	277000	112088	20935	118358
Population (million)	6.6	5.9	3.4	4.4	2.5
Per capita income (US$)	1067	272	540	599	939
Production (t)	74000	120000	57000	133000	96000
Sorghum area (ha)	61000	165000	62000	116000	65000
Area intercropped (%)	72	100	90	97	31
Mono crop yield (t ha^{-1})	1.82	0	1.17	1.33	1.64
Intercrop yield (t ha^{-1})	0.98	0.73	0.89	1.14	1.10

(Shaded portions on the map represent areas where sorghum is intercropped with maize and beans on small holdings.)

Figure 6. Sorghum production in five countries in Central America and the Caribbean.
Source: World of Information 1981; International Association of Agricultural Economists 1969; FAO 1982; Hawkins 1984a.

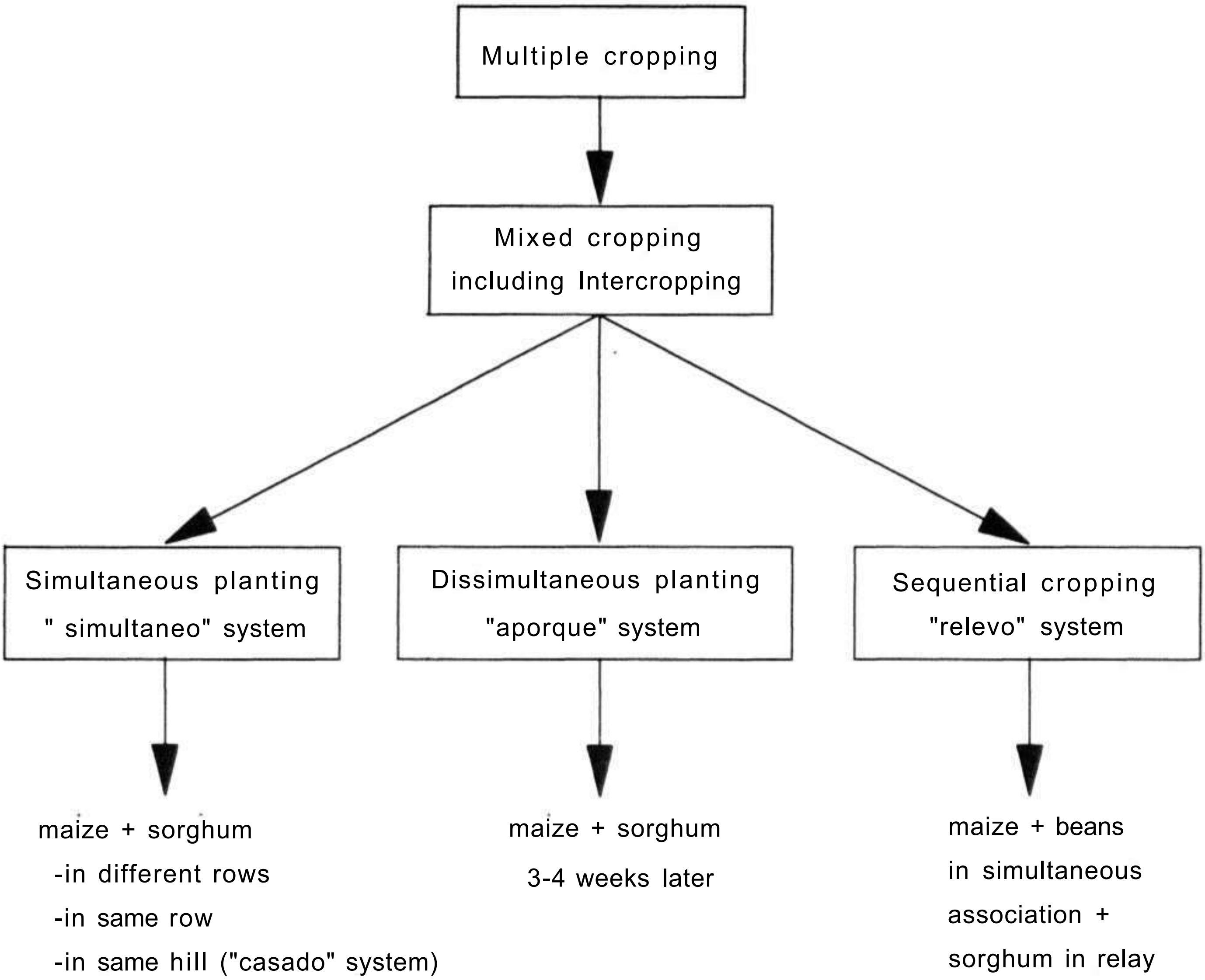


Figure 7. The main types of sorghum multiple cropping systems utilized on small farms in Central America and the Caribbean.

rapidly as the second peak of the bimodal distribution of rainfall provides further impetus. The sorghum receives its photoperiodic flowering stimulus from the shorter days of early October, flowers in November, matures in December, and is harvested together with the maize during December/January, or the maize may be harvested sooner according to the needs of the farmer.

A variation of this system in which the maize and sorghum seeds are sown in the same hill (*casado* system) is very important on steep hillsides where poor fertility dystrochrept soils are dominant and cultivation practices are difficult because of the lithic nature of the soil, shrub vegetation, and rugged terrain. In this variation of the system, interspecies competition is maximized. Sowing of the two crops at the same time causes interspecies competition to be very high and maize yields are consequently the lowest of all the systems,

Paul et al. (1985) demonstrated that net returns to farmers using this system of maize/sorghum in simultaneous association were so low that its use should be discouraged. However, farmers find the practice of sowing all their crops at the same time very convenient. Although they realize that maize yields suffer because of the competition from sorghum, they prefer to have the sorghum well established before the onset of the *canicula* (drought period) in order to ensure a sorghum grain harvest in case the maize crop fails due to drought.

Maize + sorghum at ridging-up *(aporque)*—System S_2. Maize is planted in May and local Creole photoperiod-sensitive sorghum is sown in the interrow about 22 to 28 days later, when the maize is cultivated and ridged-up for weed control and a second dose of nitrogen fertilizer is incorporated, if this is applied. The system then continues in the same manner as system S_1 described above but offers the advantage of letting the maize grow without competition for 3 to 4 weeks at the beginning of the cycle. Paul et al. (1985) observed a 46% increase in maize yield because of the reduced competition from sorghum. They also found a 41% decrease in sorghum yield because of it being planted so late; it suffers from severe competition from the more developed maize plant and also is less prepared in terms of root establishment to face the *canicula* of July/August. Martinez et al. (1986) obtained an investment return of 166% by using this system in three municipalities of Guatemala. Paul et al. (1986) found that the maize/bean competition for N and soil moisture was an important factor in the success of the system.

Maize and bean in simultaneous association + sorghum in relay—System S_3. Maize and bean *(Phaseolus* sp) are planted at the same time in May, the beans are harvested in August, the maize then doubles over, and nonphotoperiod-sensitive improved sorghum is planted in early September in the interrow. The maize is harvested in October and the sorghum in December. This system makes maximum use of the land surface, affords the maize a low level of competition, and allows the sorghum to grow as a monocrop, Paul et al. (1986) found that the maize-bean competition for N and soil moisture was an important factor in the success of the system. Martinez et al (1986) obtained an investment return of 166% by using this system in three municipalities of Guatemala.

Constraints

The main constraints to sorghum production in Latin America are summarized in Table 4.

Table 4. Main constraints to sorghum production and use in Latin America.

Discipline	Constraints
Breeding	Lack of screening techniques for biotic stress Lack of field plot uniformity Lack of germplasm with early maturity, high yielding ability, and tolerance to several important stresses, especially acid soils, drought, cold, midge, stem borer, and grain mold Lack of bird-resistant food-type germplasm
Physiology	Drought (physiological and edaphological)—due to poorly distributed and erratic rainfall and eroded soils Acid soils (Brazil, Colombia, Venezuela, Bolivia, and Panama) Alkaline soils (Mexico) Low temperature (Mexico, Guatemala, Honduras, Ecuador, and Peru) Poor tropical adaptation in genotypes used on large farms Photoperiod in introduced germplasm Low yielding ability Poor plant types
Entomology	Midge, stem borer, fall army worm, head bugs, green bugs, storage insects, and birds
Pathology	Fusarium, anthracnose, leaf spots, downy mildew, grain molds, and bacteriosis
Agronomy	Poor cultural practices (poor control of planting density and weeds, low level of inputs) and lack of equipment especially for planting and harvesting Unproductive cropping systems
Others	Poor marketing and credit facilities; inadequate seed production technology including lack of infrastructure for seed handling and storage; high input costs; lack of food technology; lack of good quality grain for food and food products; lack of trained personnel and extension of generated technology; high seed cost; and poor land tenure

The Sorghum Research Environment

The National Agricultural Research Systems (NARS)—strengths and weaknesses

Mesoamerica. ICRISAT has trained scientists from all sorghum-producing countries of this region at the In-Service and Visiting Scientist level, and has helped set up sorghum programs within the NARS of each country. Mexico has an adequate scientific staff in most disciplines but no funds for operational research and this has led to a very low-key collaboration between the Latin American Sorghum Improvement Program (LASIP) and the Instituto Nacional de Investigaciones Forestales y Agropecuarias (INIFAP, the Mexican NARS) during the past 5 years. The Central American and Caribbean countries suffer from inadequate staffing, poor infrastructure, low salaries, lack of capital equipment, and low operational budgets, although recent financial assistance from the European Economic Community (EEC) since 1990 has greatly improved the situation for basic grains research in Central America. There is a great need for training at the MS, PhD, Visiting Scientist, and Research Fellow levels in these small countries.

South America. Brazil holds the lead in staff strength with 10 PhDs and 10 MS-level scientists based at the maize and sorghum research facilities in Belo Horizonte. However, as with the other countries, low salaries and a poor operational budget place severe restrictions on output. Argentina's sorghum program based at Manfredi (Cordoba) employs seven PhDs in breeding, entomology, and pathology, and nine MS and BSc technicians. The program oversees research in 11 states distributed thoughout the sorghum region and is backed up by 3 Research Centers within the national program. Training is required in South America at the Visiting Scientist and Research Fellow levels.

ICRISAT-LASIP comparative advantage

1. Germplasm development for biotic and abiotic stresses (cold, drought, acid soils, diseases, pests) and of food genotypes especially for semi-arid (marginal) tropical areas.
2. Varietal development for small and intermediate farmers.
3. Sustainable agronomy/cropping systems research for small farmers.
4. Coordination of regional sorghum efforts through research networking.
5. Specialized training in sorghum through ICRISAT Center.
6. ICRISAT germplasm and collaborative research on pearl millet with Argentina and the savanna countries of Colombia, Venezuela, Bolivia, and Brazil.
7. Spillover of acid soil and cold-tolerant research results to ICRISAT programs and NARSs in Africa, Australia, and Asia.

Other research and development players

International Sorghum/Millet Collaborative Research Support Program (INTSORMIL). With one staff member in Colombia and one in Honduras under bilateral agreements with those countries, INTSORMIL interacts with Latin American countries through the Comisi6n Latinoamericano de Investigadores en Sorgo (CLAIS) network and collaborative arrangements with Brazil, Paraguay, Mexico, and El Salvador. INTSORMIL concentrates on on-station research with the *maicillos criollos* (local photoperiod-sensitive landraces) in Honduras and on acid soil tolerance in the Colombian *Llanos.* This Collaborative Research Support Program (CRSP) institution offers MS and PhD training at U.S. universities under its Title XII project. It also offers short specialized courses to Latin American scientists and focuses on international meetings on various aspects of sorghum research.

INTSORMIL, unlike ICRISAT-LASIP, is not an entirely regional institution and does not focus on applied research nor technology transfer—its priorities are in basic research. ICRISAT-LASIP can (and has in the past) benefit enormously from collaboration with INTSORMIL scientists in the region and in the USA. However, there needs to be a more formal agreement on collaboration than in the past.

The private sector. In almost every country private companies, mainly in sorghum seed production, are available to collaborate in at least a small way in training and support of regional trials in breeding and agronomy. However, ICRISAT-LASIP is required to do quite a lot of leg-work in order to tap this resource.

Regional institutions. The International Institute for Cooperation in Agriculture (IICA) in Costa Rica is the agricultural cooperation arm of the Organization of American States. With respect to sorghum, IICA coordinates the efforts of the Central American Basic Grains Program (BGP), which is a US$ 12 million, 4-year project (1991-94) financed by the EEC for agronomic technology development and transfer in maize, sorghum, rice, and bean. Under this program, each of the six Central American countries receives about US$ 30 000 per year for sorgum research. The BGP also assists the countries to attend the CLAIS network meetings and to participate in regional training programs organized by CLAIS.

In South America, IICA also coordinates the Andean zone (Venezuela, Colombia, Ecuador, Bolivia, and Peru) cooperative program on agricultural research (PROCIANDINO), the southern cone (Brazil, Paraguay, Uruguay, Chile, and Argentina) program of PROCISUR, and the tropical savanna program for Venezuela, Colombia, Guyana, Brazil, Bolivia, Ecuador, and Peru called PROCITROPICOS. There is a sorghum research and training component within these programs in each of the participating countries, but coordination of this component across South America is lacking. CLAIS has attempted to work with these programs and future collaboration appears promising.

The Central American Center for Tropical Agricultural Research and Training (CATIE) in Costa Rica, the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) in Mexico, and the Centro Internacional de Agricultura Tropical (CIAT) in Colombia offer collaboration to the CLAIS network in training and technology development (maize and bean components in sorghum-based cropping systems).

NARS/ICRISAT-LASIP collaboration

LASIP's relationship with NARSs are based upon the following activities of the LASIP staff:

1. Continually introduce and evaluate germplasm accessions; the best of these are provided to NARSs.
2. Implement regional trials and nurseries for yield, good agronomic traits, and food quality through the CLAIS network and through informal bilateral agreements with individual countries. The materials that enter these trials and nurseries are from national, regional, and international programs; in this way, NARSs receive a constant inflow of materials from other NARSs and other parts of the world.
3. Carry out agronomic research in farmers' fields in collaboration with NARS scientists, develop cooperative research linkages with farming systems research teams in NARSs, and assist in the planning and execution of on-farm cropping systems trials up to the technology transfer stage.
4. Assist NARSs in the process of technology transfer and obtain feed-back in order to develop technologies relevant to small and intermediate farmers in the SAT.
5. Training of NARS scientists in In-Service, Visiting Scientist, and In-Country training programs. There is also one-on-one in-field contact between LASIP staff and NARS scientists during research execution. Also, assisting NARS scientists to be trained at ICRISAT Center and at other institutions of higher learning within and outside of the region.

6. Act as an expert group on breeding, agronomy, pathology, entomology, physiology, seed production, food technology, seed quarantine, and regional policies on agricultural research, etc. Also, disseminate information on these topics to NARS scientists upon request.
7. Assist NARSs in the planning and review of their own research programs vis-a-vis CLAIS research and LASIP-NARS collaborative research. Also, offer technical assistance to NARSs on sorghum research.
8. Coordinate the activities of the CLAIS network and in this way maintain a leadership role in NARS research activities. The annual CLAIS workshop enables LASIP-NARS discussions on all aspects of sorghum research. Scientists from the USA and ICRISAT Center also attend this workshop and this gives NARS scientists an opportunity to interact with them on various topics.
9. Assistance at the annual workshop of the Central American Cooperative Program for the Improvement of Food Crops and Animals (PCCMCA), which is held in a different Central American country each year. LASIP staff assist NARS scientists to participate in this workshop and to present their research results. The PCCMCA workshop is also the main forum for the presentation of CLAIS research results. LASIP staff use this meeting to interact with NARS scientists on topics of mutual interest.

A special relationship exists between LASIP and its host country, Mexico, where the national program, INIFAP, has collaborated with LASIP since 1977, when ICRISAT's presence in Latin America was initiated with the sole objective of developing cold-tolerant food-type sorghums for the Mexican highlands. INIFAP's cold-tolerant program has run parallel to LASIP's over the years and has remained very close both in breeding and agronomy. LASIP has also collaborated with INIFAP since 1983 in the southern lowlands where INIFAP has released five ICRISAT varieties from this cooperative work. Important cropping systems research involving sorghum, groundnuts (*Arachis hypogaea),* beans, henequen (*Agave fourcroydes),* pigeonpea *(Cajanus cajan),* and soybean has been carried out in the Pacific coastal region and the Yucatan Peninsula. Lack of funding during the past 5 years has forced INIFAP to curtail a large part of its research work, and while LASIP maintains a good collaboration, this is kept to a minimum until INIFAP again finds it possible to increase its research activities.

Trainees and Visiting Scientists at LASIP's headquarters at CIMMYT and at ICRISAT Center select improved germplasm to take back to their countries. LASIP maintains improved germplasm in its cold storage facilities in sufficient quantities to provide seed to NARSs upon request.

CLAIS network

NARSs began in Central America during the 1940s with the assistance of the Rockefeller Foundation. In 1977, ICRISAT established its Latin American program based at CIMMYT. One breeder (1977) and one agronomist (1982) were assigned to the program.

During the annual PCCMCA meeting in Guatemala in 1982, Central American scientists, together with the LASIP staff, decided to form a group to establish sorghum research strategy more efficiently. This was the origin of CLAIS. The first meeting was held in Guatemala [at the Instituto de Ciencia y Technologia Agricola (ICTA) offices] and INTSORMIL was invited to attend together with representatives of NARSs from Guatemala, Honduras, El Salvador, Mexico, Nicaragua, Costa Rica, Panama, Haiti, and the Dominican Republic. In 1988 Jamaica and Trinidad were incorporated into the group. Since 1982 the Team Leader of LASIP has served as general coordinator of CLAIS under mutual agreement by the member countries.

In 1991, South American countries were invited to participate in the Eighth Annual CLAIS meeting held in Panama. By common agreement among all CLAIS members present at this meeting, the network was expanded to include 10 countries of South America (Fig. 8) and ICRI-

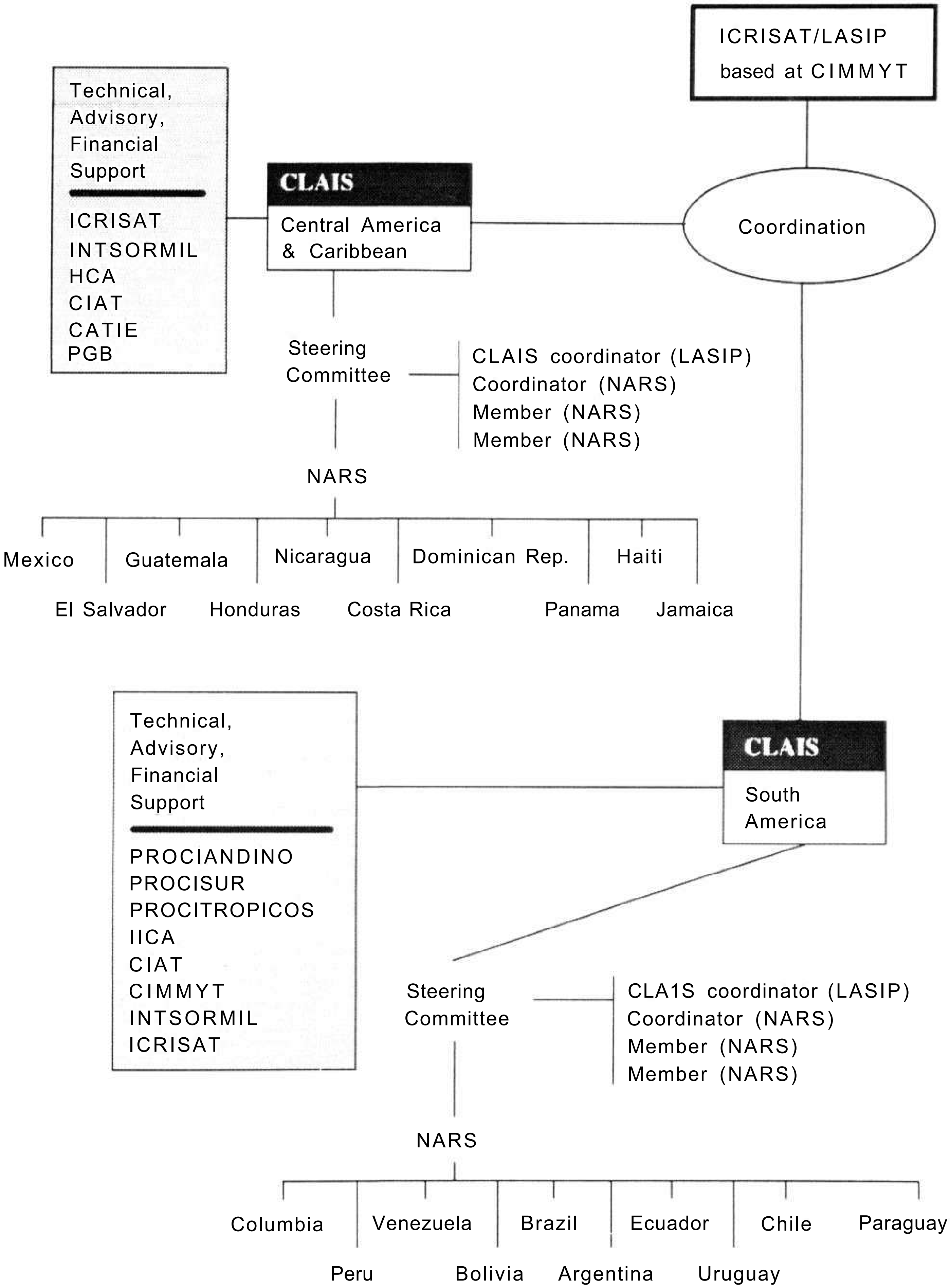


Figure 8. Operational structure of the LASIP-coordinated sorghum research network for Latin America and the Caribbean.

SAT-LAS IP was retained as the institution in charge of coordinating the two subprograms (Central America and South America) of CLAIS.

The first meeting of the CLAIS Subprogram South America was held in Campinas, Brazil, in October 1992 and was financed by ICRISAT, AGROCERES, the Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA) in Brazil, INTSORMIL, and a private seed company from Colombia.

CLAIS does not have legal status and operates through a common agreement among participating NARSs. In 1984, nine Directors of NARS of CLAIS-member countries signed a letter of intention establishing the coordination among the CLAIS Central American members. A similar letter was signed in 1992 establishing the South American coordination.The general objectives of the CLAIS network are to:

1. Solve problems of sorghum production in Latin America and the Caribbean on small and intermediate farms.
2. Identify constraints to sorghum production in the region.
3. Plan and implement joint projects among network member countries. Such projects must focus on national and regional priorities.
4. Strengthen linkages among participating NARSs and between NARS and international institutions working with sorghum.
5. Improve the research and extension capacities of CLAIS-member countries so as to better serve farmers.
6. Assist NARSs in seed production of improved sorghum cultivars.
7. Promote alternatives in the marketing and utilization of sorghum grain, such as in mixtures of sorghum flour with that of wheat and maize for the preparation of food products.

Achievements of CLAIS

1. Sorghum production in the Mesoamerican region has increased some 8.5% during the period of CLAIS, although in some countries such as El Salvador, Costa Rica, Haiti, and Mexico production has dropped because of political and economical reasons.
2. Breeding by ICRISAT-LASIP in collaboration with NARS members of the network has resulted in the release of 19 varieties and 5 hybrids (with 7 other varieties and 1 hybrid due for release in 1992/93), which are grown on approximately 97 000 ha in 10 countries. These cultivars were selected from regional trials within the network; each year advanced varieties and nurseries are sent to 29 locations in 17 countries in Mesoamerica and South America.
3. Research in cropping systems has identified and evaluated the main sorghum-based cropping systems used by farmers in Mesoamerica, Various ICRISAT genotypes have been evaluated in these systems and the principal factors affecting their performance have been identified. Recommendations have been made on appropriate plant populations and fertilizer applications within the systems. New systems, which include bean, groundnut, cowpea *(Vigna unguiculata),* soybean, pigeonpea, chickpea *(Cicer arietinum),* and henequen, have been designed and evaluated in several areas of the region.
4. Since 1982, 62 scientists (40 In-Service and 22 Visiting Scientists) have received training in breeding and production of sorghum and other ICRISAT mandate crops at LASIP in Mexico and at ICRISAT Center in India due to the ICRISAT/CLAIS collaboration. An additional 77 scientists from 14 countries of Latin America have received 1-week short courses on sorghum breeding and production, through CLAIS organization and financing. The majority of these scientists form important ICRISAT-NARS-CLAIS links in the region; these links are the most important factor in the activities of CLAIS.
5. CLAIS has held 10 annual meetings for regional sorghum scientists from NARSs and private institutions of Latin America. These meetings have enabled revision, planning, and discussion of regional sorghum research and have served as a base for cooperation among CLAIS-member countries and with

the international sorghum community. This activity has improved the quality of research of the NARSs and has led to better access to information on sorghum research production both at the regional and international levels.

The future of CLAIS. The CLAIS network is underfunded (Table 5). Important projects in training (MSc, PhD, and specialized short courses), physiology, pathology, entomology, food technology, seed production, and socio-economics are frozen from lack of funds. While ICRISAT finances the annual meetings and some international cultivar testing, and the BCG of Central America finances some agronomic research directly to NARSs, CLAIS requires annually about US$ 100 000 in additional funds for projects in Central America and about US$ 120 000 for projects in South America.

In future, the CLAIS network will continue to address problems of germplasm improvement, technology development and transfer, and training of scientists and technicians. ICRISAT-LASIP should continue to provide superior germplasm and assist NARSs in technology development and transfer, training, and coordination of the network.

The Policy Environment

Medium Term Plan

The ICRISAT Medium Term Plan 1994-98 calls for LASIP to be based at CIAT in Cali, Colombia, and to collaborate with INTSORMIL as well as with CIAT and ICRISAT Center. There are two themes incorporated in the plan for LASIP. One relates to the improvement of sorghum foliar disease resistance for Latin America and is proposed to be core-funded. The other is the adaptation of sorghum to the acid soil savannas of Brazil, Colombia, and Venezuela and is projected to be carried out in close collaboration with the CIAT ecoregional natural resource management capability as a complementary funded exercise.

Table 5, Financing of the CLAIS network in 1992.

Source	Purpose	US$
ICRISAT	for the annual meetings:	
	CLAIS Central America	5 000
	CLAIS South America	14 500
ICRISAT-LASIP	for operations (direct and indirect)	5 000
ICRISAT-LASIP	for coordination and supervision of projects (indirect)	8 000
ICRISAT-LASIP	for regional trials (indirect)	5 000
Basic Grains Program (IICA-EEC financed)	for NARS agronomic research 6 countries in Central America)	30 000
Basic Grains Program	(IICA-EEC financed) for NARS scientists' assistance at CLAIS annual meeting (Central America)	13 000
PCCMCA	private seed companies for support to NARS scientists' assistance at CLAIS annual meeting (Central America)	4 000
PCCMCA	private seed companies for support to NARS' testing of commercial hybrid seed	6 000
NARS	for their own field operations	10 000
INTSORMIL	for support of their scientists' participation at CLAIS annual meeting	2 000
Total		**102 500**

The details of these research themes are available in the ICRISAT Medium Term Plan document (ICRISAT 1992).

External Program Review

The Technical Advisory Committee (TAC) external review of ICRISAT in 1991 (TAC Secretariat 1991) concluded as follows:

Latin America. Of the 1.8 million ha of sorghum grown in Mexico, the white-grained sorghum types suitable for human consumption occupy such a small area that it does not appear in the statistics. ICRISAT established a base at CIMMYT in 1977 and through its research network, LASIP, emphasized the white-grained sorghum. The national program, INIFAP, made available land for experiments, has undertaken quality assessments, and has trained students in quality assessment methods. LASIP presently includes an agronomist who serves as Team Leader and sorghum breeder, and an associate breeder.

As a result of the coordination between ICRISAT and INIFAP, in 1982 seven Central American and Caribbean countries formed the regional research group on sorghum (CLAIS).

ICRISAT has made available germplasm producing a grain suited to human consumption and with adaptability to the tropical environment. The supply of germplasm has been greatly appreciated in Latin America. Workers from the regional network have been invited to participate in conferences and seminars held in Latin America and ICRISAT has financed some of the participants. Help has also been given with training and publishing. In 13 years, LASIP has trained 51 scientists in its 3-month in-service training project and has provided facilities to 22 visiting scientists for training and research. This training has impacted on the productivity of the scientists.

The following suggestions were received with regard to Mexico, which the EPR Panel wishes to pass on:

1. Introductions of millet and sorghum into Mexico will come from other Latin American countries. The Panel has been advised that the phytosanitary regulations need to be reinforced for these introductions.
2. The ICRISAT/INIFAP agreement for training should be continued. Graduate training has been dramatically reduced in Latin America and aid is requested by the national program for scholarships for sorghum researchers.
3. Mexico has 0.5 million ha of land in the highland valleys capable of growing white-grained sorghum, and continued support from ICRISAT is needed in order to develop varieties for this area.

The Panel notes that ICRISAT intends to maintain a modest effort in Latin America. It also noted the nearness of the USA with advanced sorghum programs, and the presence of multinational companies, which supply the bulk of the hybrid varieties. It further notes that there are large SAT areas in Latin America.

The CLAIS network. Active since 1982, this network is coordinated by ICRISAT from CIMMYT. There are nine Central American and Caribbean country members in addition to Mexico. The focus is on improving white-grained sorghum for human consumption. CLAIS seems to be central to the work of ICRISAT in Central America. We understand that there have been problems resulting from the wide range of capability among the national research systems involved, but that these are said to have been resolved. Close collaboration with INTSORMIL is suggested in the reports we have. ICRISAT strategy suggests shifting attention to sorghum as an industrial crop in South America, which would presumably mean a reduction in its already small investment in CLAIS as presently constituted.

LASIP-IHR outcome

Highland projects

1. It was felt that enough cold tolerance at anthesis is already incorporated into the germ-

plasm base. However, there is a need to measure climate, soil, and plant variables where advanced cold-tolerant lines are being evaluated so as to better understand the genotype x environment interaction.

2. INIFAP (Mexico) feels that ICRISAT-LASIP's future work in the highlands should address agronomic work in the evaluation of advanced varieties. LASIP should work jointly with INIFAP in this effort.

Intermediate and lowland projects

1. There is a need to better identify ecosystems within this environment.
2. Stress hot-spots should be better utilized by the breeding program: Cuyuta, Guatemala, for grain mold and foliar diseases; Comayagua, Honduras, for downy mildew; La Honda, Panama, for macrophomina; Rio Hato, Panama, for anthracnose; and Poza Rica, Mexico, for midge.
3. More germplasm (especially for drought, acid soil, and foliar diseases tolerance) should be introduced from IC, ICRISAT African programs, and Texas A & M University in order to widen LASIP's germplasm base.
4. High imported hybrid seed cost necessitates action by LASIP in assisting NARSs in the development of superior parental lines for hybrid seed production.
5. LASIP's comparative advantage over private seed companies is in the improvement of white-grained varieties for the region and this should be the main focus of LASIP's breeding efforts. However, superior red and brown-seeded lines should also be developed for areas where birds are a serious problem.

Photoperiod-sensitive sorghums. Improvement should focus on grain and forage quality and leaf diseases while reducing plant height to about 50 cm from the normal height of 3-6 m. Since INTSORMIL is working in Honduras with these *maicillos criollos* and focuses on reduction of plant height, hybrids, and yielding ability, LASIP's work should complement INTSORMIL's while bearing in mind that LASIP's mandate is regional while INTSORMIL's is bilateral with Honduras.

Breeding and agronomy efforts with the *maicillos criollos* should be based in the cropping systems and harsh mountainside environments where they are utilized.

There is a need for more introductions of photoperiod-sensitive landraces from West Africa.

International testing

1. The reduction of our international testing within the CLAIS network to three trials, namely, advanced varieties, varietal nursery, and hybrid parental lines, has cut down on work volume and cost.
2. The PCCMCA commercial hybrid testing has been placed in the CLAIS network in Central America.
3. The movement of germplasm must continue to honor government regulations and quarantine restrictions.

On-farm agronomy research. Within a climate of budgetary restrictions more attention will be paid to defining target areas and locating them where easy access can be achieved.

Training. LASIP should continue training at the 4-6 week visiting scientist level since this promotes better LASIP/NARS collaboration, which is essential in achieving impact.

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Sorghum and Millet in Asia

T.G. Kelley and P. Parthasarathy Rao[1]

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Sorghum and Millet in Asia

T.G. Kelley and P. Parthasarathy Rao

Abstract

Relative to other cereal crops in Asia, sorghum (Sorghum tricolor) *and millet* (Pennisetum glaucum, Eleusine coracana, *and* Setaria italica) *have fared poorly during the last three decades. Yield growth has been slow, area and production have declined, and consumption has fallen off dramatically. The shift away from these coarse cereals is not the result of supply constraints, but rather a consequence of rising incomes and changing food preferences. Sorghum and millet are inferior foodgrains, consumed largely by the population in the geographical regions in which they are grown. The scope for arresting or reversing these trends depends on the development of alternative uses. Here the potential for sorghum, in animal feed, starch, and other industries, appears to be better. The key to realizing this potential is significant and sustainable increases in yield that can ultimately translate into lower grain production costs.*

*Reduced competitiveness of sorghum and millet—the result of slow growth rates in productivity and low producer prices—has pushed these crops onto the more marginal lands across Asia. Because of their adaptability to drier and less fertile conditions, sorghum and millet have a comparative advantage over maize (*Zea mays) *and other competing crops in these environments. Scientists should therefore focus on drought-tolerant, moderate yielding cultivars, and on crop management practices with low to moderate inputs under rainfed conditions. Developing cultivars and crop management practices for more favorable environments (e.g., under assured rainfall or irrigation) would be justified only in situations where sorghum and millet are likely to be competitive against higher-valued crops. There are specific regions in India where rainy season* (kharif) *sorghum and pearl millet fit this model.*

While an overall assessment of the production and research environment of sorghum (*Sorghum bicolor)* and millet (*Pennisetum glaucum, Eleusine coracana,* and *Setaria italica)* in Asia was the assigned topic, the authors have narrowed the focus of the paper considerably to trends in production and consumption. The driving forces behind these trends, future projections for supply and demand, and implications for research are examined in some detail.

Asia produces 31% of the world's sorghum and 51% of the world's millet. Most of the output is concentrated in the Indian subcontinent. Relative to other cereals in Asia, sorghum and millet rank fifth and sixth behind rice (*Oryza sativa),* wheat (*Triticum* spp), maize (*Zea mays),* and barley (*Hordeum vulgare).* Of approximately 860 million t of cereals produced in Asia annually, 33 million t (4%) are sorghum and millet. Those figures alone, however, underestimate the importance of these two coarse grains in specific regions in Asia. Often referred to as 'poor man's crops', sorghum and millet are produced and consumed mainly by the rural poor. In India, small farmers devote a higher proportion of their land to sorghum and millet than large farmers do (ICRISAT VLS Survey 1989/90, unpublished data). Earlier diet surveys attest to a similar pattern with respect to consumption of coarse grain cereals (Ryan et al. 1984). Nevertheless, their relative importance has declined over time.

Crop research needs should be assessed in the context of current and future market forces.

Understanding past trends in area and production of sorghum and millet and their causal factors should provide some insight into future trends in supply and demand. This in turn characterizes the demand for new crop technology.

The first section of this paper examines the performance of sorghum and millet relative to other cereals in Asia during the last two decades. Trends in area, production, and yield are estimated for major producers and for the region as a whole. In the second section, we look at changes in food and feed consumption and reflect on shifting demand and possible implications for these crops. The third section takes a closer look at regional shifts in area under these crops in India. Many of these changes relate to loss of competitiveness due to either lack of consumer demand or lagging productivity. Supply and demand projections to the year 2000 are presented and discussed in the fourth section. The last section concludes with a summary and implications for future research.

Production, Area, and Yield

Agricultural research in rice, wheat, and maize led to impressive gains in productivity of those crops during the last 20 years (Table 1). Yield gains in sorghum and millet have been considerably lower. For the region as a whole, average yields of sorghum increased by 280 kg ha^{-1} (37%) and millet by 70 kg ha^{-1} (10%). This pales in comparison to yield increases in rice, wheat, and maize of 1200 kg ha^{-1} or more, which resulted in considerable expansion in area. Area increases and higher yields combined to sustain the upward trend in production of rice, wheat, and maize (Fig. 1). In contrast, production of sorghum and millet has been virtually stagnant. Closer examination reveals a recent declining trend in production for these crops.

Rates of growth in production of sorghum, positive during the 1960s and 1970s, fell sharply during the last decade (Fig. 2). [Unless otherwise stated, all growth rates mentioned have been calculated as compound growth rates (CGR), using the semi-log equation, log y - a + bt + e, where y is the dependent variable of interest, t is time, and e is the error term. Thus, CGR - (antilog b) - 1]. A low growth rate in productivity (0.6% per year) and a negative growth rate in area (-1.9%) resulted in declining production of sorghum in the 1980s (-1.3%). The downward trend in production of millet came

Table 1. Changes in cereal crop yields in Asia.

Crop	1969-71 (t ha-')	1989-91 (t ha^{-1})	Net increase (t ha^{-1})
Rice	2.35	3.59	1.24
Wheat	1.15	2.35	1.20
Maize	1.65	3.20	1.55
Sorghum	0.75	1.03	0.28
Millet	0.73	0.80	0.07

Source: FAO 1992.

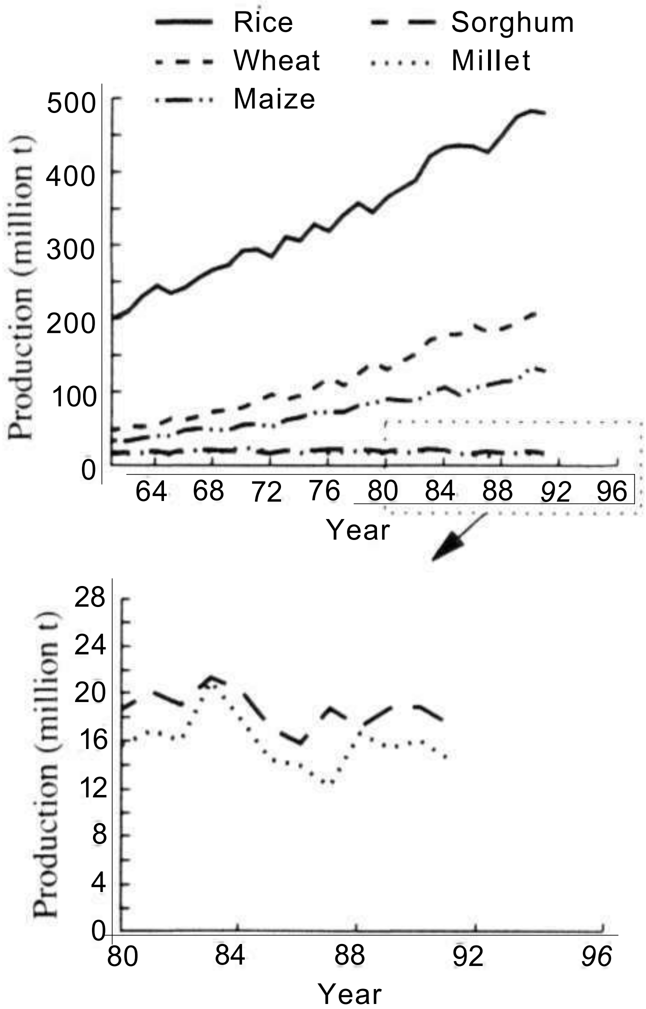


Figure 1. Cereal production in Asia.
Source: FAO 1992.

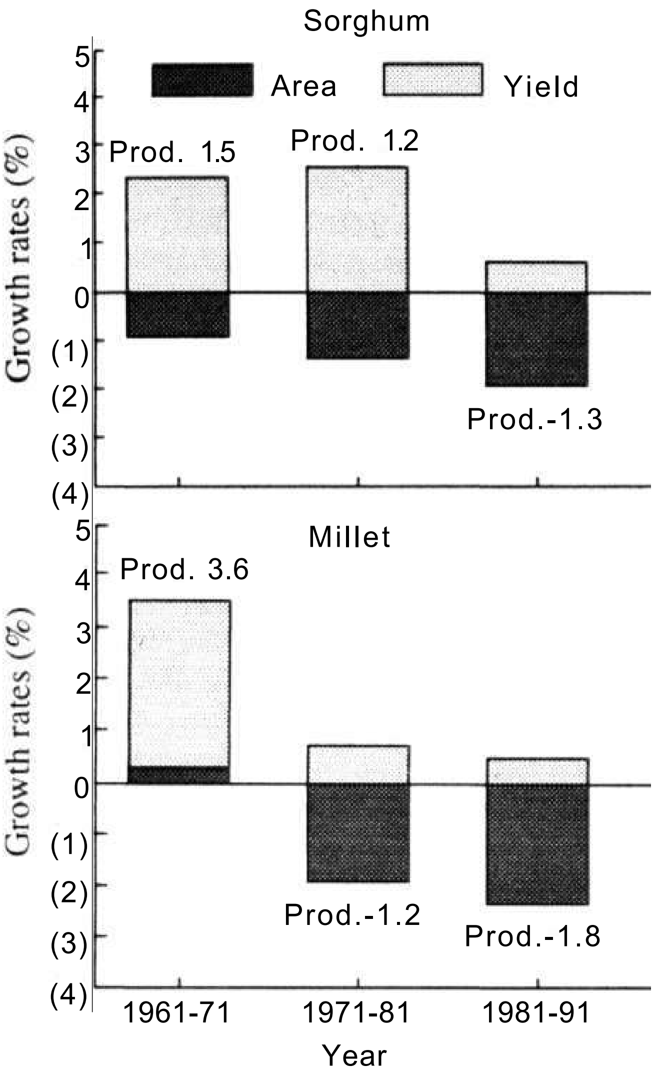


Figure 2. Area, yield, and production growth rates for sorghum and millet in Asia.
Source: FAO 1992.

even earlier. After impressive gains in production and productivity during the 1960s, growth rates in production turned negative. As with sorghum, a significant reduction in area accounts for this trend. For Asia as a whole, we thus see a decline in area planted to sorghum and millet during the 1970s and 1980s, and a decline in production during the 1980s. Yet these average figures mask important trends and determinants of trends within individual countries, not all of which are so discouraging.

Sorghum

Table 2 provides information on sorghum production, area, and yield for the major producers in Asia: India, the People's Republic of China, Yemen, Pakistan, Thailand, and Australia. India produces 11.6 million t annually (64% of the total), second only to the USA in world production. After wheat and rice, sorghum is the third most important cereal crop in India and thus plays a key role in the lives of millions of people. In some specific regions of peninsular India, it is the most important cereal crop. Though area under sorghum in India has declined over the last 30 years from 18.5 to 15.0 million ha, it is still sown to an area five times as large as in

Table 2. Sorghum area, production, and yield (average of 1987-91) and compound growth rales by country.

					Annual compound growth rates (%)								
					Area			Production			Yield		
Country	Area ('000 ha)	Production ('000 t)	Yield (kg ha^{-1})	% Production to Asia	1961-71	1971-81	1981-91	1961-71	1971-81	1981-91	1961-71	1971-81	1981-91
Asia	17875	18015	1010	100.0	-0.9 **	-1.4**	-1.9**	1.5*	12	-1.3	2.4**	2.6 **	0.7
India	14990	11590	775	64.3	-0.5	0.0	-1.3 **	-0.4	4.7 **	0.0	0.0	4.6 **	1.4
China	1700	5440	3200	30.2	-2.5 **	-7.1 **	-6.1 **	3.8 **	-2.6 **	-3.6 **	6.4**	4.9 **	2.6**
Yemen	505	420	830	2.3	-1 9 **	-4.5 **	-2.9 **	-1.7**	-0.6	-3.5	0.2	4.0*	-0.7
Pakistan	410	240	580	1.3	0.2	-2.7 **	1.1	2.4 **	-3.6 **	1.4	2.2**	1.0 **	0.2
Thailand[1]	175	220	1275	12	19.6*	13.4**	-5.1 **	15.2	6.3 **	-3.3	-3.7 **	-6.3 **	1.9 *
Others[2]	100	110	1100	0.6									
Australia	595	1235	2080		13.2 **	-1.6	-4.3 *	14.3 **	-1.8	-2.0	0.9	-0.2	2.4

1. For Thailand growth rate during 1960s based on data from 1964 to 1971 only.
2. Others include countries with less than 1% production to Asia.
** Significant at P = 0.05.
* Significant at P = 0.10.

Source: FAO 1992.

all other Asian countries combined (Table 2). Low yields—less than 0.8 t ha^{-1}—account for the discrepancy between India's share of sorghum production (64% of the total) and area (84% of the total) in Asia. China, the next largest producer in Asia, has the highest productivity with yields averaging 3.2 t ha^{-1}. It produces just under half of India's total production on a ninth of the area. Australia, a neighbor to the region, produces 1.2 million t annually.

Growth rates in area, production, and yield are also shown in Table 2. During the 1970s and 1980s, sorghum area declined in almost all countries. In China, 3.5 million ha were shifted out of sorghum cultivation. High growth rates in productivity helped mitigate the loss in area, though production still declined at the rate of 3.6% per year. China's growth rate in yield has fallen from 6.2 to 4.5 to 2.4% per year during the decades of the 1960s, 1970s, and 1980s as sorghum moved from the flat and fertile southern regions of the country to the dry, sandy, and alkaline regions of the north (Qing-Shan 1991). This exemplifies a typical pattern across many countries in Asia: where sorghum has remained competitive in the more marginal environments it is better adapted to dry and low-fertility conditions (compared to maize, for example). The particular advantage of sorghum (and millet), a low status 'poor man's crop', in lesser endowed regions has been documented previously (Jodha 1973; Jodha and Singh 1982; Kelley et al. 1992). In India, yield growth rates fell from 4.6% per year (1970s) to 1.4% (1980s). However, this cannot be explained as a shift to more marginal areas. Instead, as will be shown later, sorghum has been more competitive in the more favorable zones (higher production environments) than in the marginal ones.

For the whole region, growth rates in productivity during the 1980s were only 0.6% per year. One might question how yield growth rates in Asia could be so much lower than in either India and China, two countries which comprise 95% of Asia's production. The effect of rapidly declining area in China, a country with average yields significantly above the Asia average, accounts for this seeming anomaly. Despite positive growth rates in productivity for India, China, and Australia (the three largest producers in the region), productivity gains were not sufficient to raise production levels. Only India was able to keep production from actually falling. Loss of sorghum crop area is the driving force behind these production changes.

Millet

For millet the story is much the same: India dominates the picture for production and area, and China for yield (Table 3; millet in China is

Table 3. Millet area, production, and yield (average of 1987-91) and compound growth rates by country.

					Annual compound growth rates (%)								
					Area			Production			Yield		
Country	Area ('000 ha)	Production ('000 t)	Yield (kg ha^{-1})	% Production to Asia	1961-71	1971-81	1981-91	1961-71	1971-81	1981-91	1961-71	1971-81	1981-91
Asia	18980	14820	780	100.0	0.3	-1.9**	-2.4 **	3.6**	-1.2	-1.8	3.2 **	0.8	0.5
India	15405	9680	630	65.3	0.7 **	-0.7	-1.6 **	2.8*	1.0	0.0	2.1	1.7	1.7
China	2420	4360	1800	29.4	-0.2	-6.1 **	-6.8 **	5.0 **	-3.7 **	-5.3 **	5.2**	2.5 **	1.6
Nepal	190	200	1075	1.4	6.5 **	0.2	5.8 **	9.0 **	-1.3 **	8.0 **	2.3 **	-1.5 **	2.0**
Pakistan	460	190	405	1.3	-1.6	3.2 **	-1.2	-1.7	-2.8 **	-3.6 *	-0.1		-2.4 **
Myanmar	165	130	790	0.9	1.4	1.9**	-0.2	2.0	9.3 **	0.2	0.6	7.3 **	0.4
Others[1]	340	260	770	1.8									
Australia	40	40	1000		3.3	-2.6	2.0	2.0	-4.9	1.8	-1.3	-2.4	-0.2

1. Others include countries with less than 1% production to Asia.
** Significant at *P* = 0.05.
* Significant at P = 0.10.

Source: FAO 1992.

mainly foxtail millet; in India, pearl and finger millet; in Nepal and Myanmar, finger millet). Other major producers in Asia are Pakistan, Nepal, and Myanmar. Again, for almost all countries we observe a recent decline in area (except for Nepal).

China has been losing millet area at the rate of about 6.5% annually since 1970. But because yield growth rates have been somewhat lower than for sorghum (1.5% per year in the 1980s), production of millet in China has fallen more sharply (-5.3% per year). Falling productivity growth rates for both millet and sorghum in China suggests less importance attached to these crops compared to others. In India and Pakistan, growth rates in area have not fallen quite as fast, but were still negative. In Pakistan, yield growth rates were negative in the 1980s (-2.4% per year) and contributed to a fall in production at the rate of 3.6% per year during the 1980s. In India, however, yield improvement has offset the declining area and production actually rose by 1.0% in the 1970s and was stagnant during the 1980s. Since more than 60% of the millet production in Asia, and 75% of the area, is in India, this is rather significant. While productivity growth rates for the major millet producers were not impressive, they were nevertheless positive and significant for all countries but Pakistan. But as for sorghum, the declining trend in area under millet cultivation is the driving force behind stagnant and recently falling levels of production in Asia. Some of the factors influencing this trend will be examined in the next section.

Consumption and Utilization

Sorghum

Sorghum utilization patterns in Asia are in a dynamic phase (Table 4). The traditional method of consumption—as a food grain staple (e.g., *roti,* porridge, or mixed with rice)—is geographically localized in the regions where it is grown.

Utilization in the growing regions will continue to dominate its use for some time, particularly in India, Pakistan, and Myanmar. However, sorghum is increasingly being used as a source of feed for livestock and poultry and there is considerable interest for sorghum in starch, beer, and liquor production (Subramanian 1991). In China, about a third of the sorghum grain produced is already used in making alcoholic beverages (Qing-Shan 1991). It is also expanding as a fodder crop, particularly as the demand for milk and meat products continues to rise in Asia. India, Pakistan, China, and Australia have considerable area under sorghum and sorghum-sudangrass hybrids (Kelley et al. 1992).

Table 5 shows per capita consumption of sorghum, relative utilization as food and feed, and amount of exports from and imports to Asia from 1971 to 1988. Consumption of sorghum as a food grain declined from 8.9 to 5.0 kg $year^{-1}$ per capita. Of all sorghum consumed in Asia, an increasing proportion is being used in the feed sector (45%, up from 32%). In absolute terms, sorghum feed use rose from 7.5 to 9.5 million t from 1971 to 1988. In 1960, only 2.1 million t of sorghum were used as animal feed in Asia, thus the big surge in feed use occurred in the 1960s. Annual growth rates in sorghum feed use during the 1960s, 1970s, and 1980s were 17.8, 3.1, and 1.4%, respectively. In terms of per capita availability, sorghum use in livestock and poultry feed fell slightly, from 5.0 to 4.3 kg $year^{-1}$. Total consumption (food + feed), therefore, fell from 13.9 to 9.3 kg $year^{-1}$ per capita. In comparison, per capita consumption of rice in Asia rose from 133 to 147 kg $year^{-1}$; and for wheat from 53 to 76 kg $year^{-1}$.

Table 4. Sorghum utilization pattern in Asia.

Utilization	Countries
Food grain and straw	India, Pakistan, Myanmar, China
Feed grain	Japan, China, Thailand, Taiwan, S. Korea, India
Industrial uses: starch, liquor	China, India (potential)
Green fodder	Australia, India, Pakistan, China, Iran, S. Korea

Table 5. Annual per capita consumption of sorghum, feed use, imports, and exports in Asia (including Australia), 1971-91.

3-year average	Per capita food consumption (kg year^{-1})	Per capita total consumption[1] (kg year^{-1})	Feed use (% of total consumption)	Total imports (million t)	Total exports (million t)	Net imports (million t)
1971-73	8.9	13.9	36.0	n.a.[2]	n.a.	n.a.
1974-76	10.5	15.3	30.9	3.6	0.7	2.9
1977-79	9.4	14.4	34.9	6.6	0.7	5.9
1980-82	7.2	11.6	38.4	5.1	1.0	4.1
1983-85	6.6	11.4	43.1	5.6	1.4	4.2
1986-88	5.0	9.3	45.9	5.3	1.4	3.9
1989-91	n.a.	n.a.	n.a.	4.7	0.8	3.9

1. Includes use as feed.
2. Not applicable.

Source: USDA 1988; FAO 1992.

Table 6. Annual per capita consumption of millet, feed use, imports, and exports in Asia (including Australia), 1971-91.

3-year average	Per capita food consumption (kg year^{1})	Per capita total consumption[1] (kg year^{-1})	Feed use (% of total consumption)	Total imports (million t)	Total exports (million t)	Net imports (million t)
1971-73	11.0	11.4	3.3	n.a.[2]	n.a.	n.a.
1974-76	9.1	9.5	3.8	0.1	0.1	0.0
1977-79	8.7	9.0	3.2	0.1	0.1	0.0
1980-82	7.6	7.8	3.4	0.1	0.0	0.0
1983-85	7.9	8.2	3.7	0.1	0.0	0.0
1986-88	5.9	6.2	4.3	0.0	0.0	0.0
1989-91	n.a.	n.a.	n.a.	0.0	0.0	0.0

1. Includes use as feed.
2. Not applicable

Source. USDA 1988; FAO 1992.

Despite this decline, Asia is a net importer of sorghum, principally because of Japan and Taiwan. Imports to Asia have risen from 3.6 to 4.7 million t since the mid-1970s. Several countries in Asia export sorghum: China, Australia, and Thailand together exported about 800 000 t annually during recent years, down from almost 2.0 million t earlier of exports. Falling exports are a result of rising competition from the domestic livestock and poultry markets.

Millet

For millet, less information is available about utilization patterns. The traditional uses—grain consumed as *roti,* or gruel, and the straw fed to livestock—still predominate. And like sorghum, consumption is geographically localized in the regions where millet is grown. Data presented in Table 6 show that, indeed, millet goes mainly into human food use; very little (less than 5%)

goes to feed use. Exports and imports are negligible, suggesting low demand for this commodity on the world market. Per capita consumption of millet in Asia has dropped more than for sorghum—from 11.4 to 6.2 kg year^{-1} since 1970. What accounts for these grim trends and what can be said about the future?

Demand constraints

Demand for millet (almost exclusively) and sorghum (to a large extent) relies on traditional food uses. And though these crops are staple cereals in many parts of Asia, their relative importance is declining as they are gradually replaced by other, more preferred cereals such as rice and wheat. This shift in preference and consumption will continue.

On the price side, sorghum has the lowest world market prices of the major cereal grains (Fig. 3). Millet prices (from India) are roughly similar (Fig. 4). These prices reflect the lower preference by consumers. Delgado and Reardon (1991) present macro- and micro-level evidence from West Africa that indicates that shifts in consumption patterns, from sorghum and millet to other cereals like rice and wheat, are driven not by price changes but by income-urbanization effects. Data from FAO for a few selected countries in Asia confirm that sorghum and millet are inferior goods. Income elasticities of demand were negative, ranging from -0.40 to -0.20 (M. de Nigris, FAO, personal communication, 1993). Data from India from the last two rounds of the National Sample Survey (NSS) also indicate that sorghum for human food is an inferior good (Walker 1990). Using NSS data, he found that between 1977/78 and 1987/88, average All India rural consumption fell from 20.9 to 12.0 kg per capita per year; All India urban consumption dropped from 8.9 to 5.5 kg. It should be noted that expanding the availability of subsidized wheat and rice has also accelerated the trend in declining per capita consumption of sorghum. As real incomes rise consumers eat less sorghum and more of the preferred grains. Only in the rural areas of some

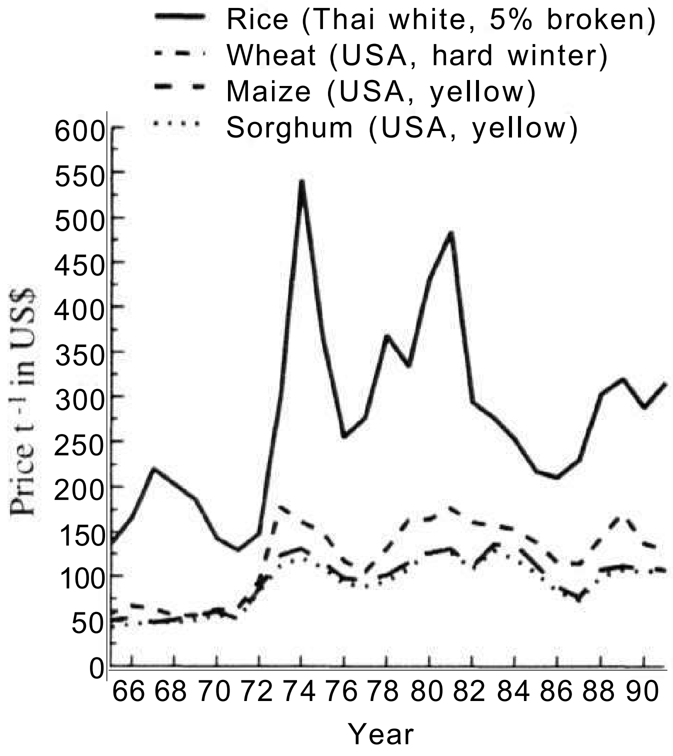


Figure 3. World market prices of selected cereals. **Source: FAO production yearbook (various years).**

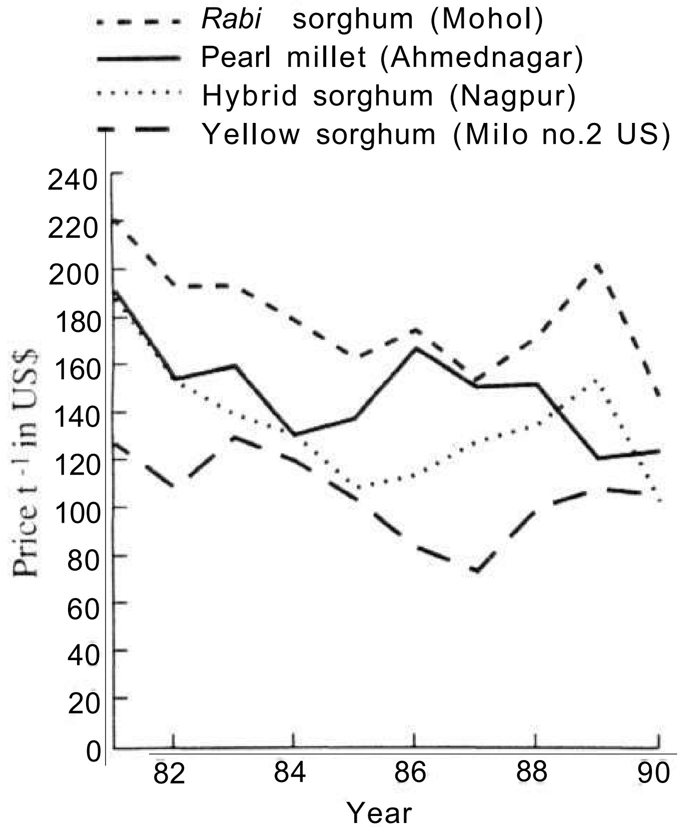


Figure 4. Sorghum and pearl millet prices, India. **Source: India: Directorate of Economics and Statistics. Bulletin on food statistics (various years); FAO production yearbook (various years).**

selected areas of India (e.g., Maharashtra) does sorghum have a positive expenditure elasticity, i.e., consumers purchase more sorghum with increased income. An analysis by Radhakrishna and Ravi (1990) shows that cereals other than wheat and rice have the lowest expenditure elasticity coefficient of any major commodity group for rural consumers, and the only negative expenditure elasticity coefficient for urban consumers. Based on their projections, the annual growth rate in per capita demand for cereal grains such as sorghum and millet is -0.45, but projected growth rates in total demand are still positive (1.0 to 1.2% a year) because of population growth. All other commodity groups (milk products, meat, pulses, oilseeds, and fruits and vegetables) have positive growth rates.

The message is clear. Unless other uses for sorghum and millet can be found or expanded, their importance to the Asian consumer (and farmer) will continue to diminish. Use of sorghum for extracting starch is still in its infant stages in India, but prospects for substituting sorghum for maize in poultry feed are much better and more immediate (Kelley et al. 1992). Although maize accounts for the bulk of feed-grain consumption in the poultry-industry, many layer and broiler producers in Andhra Pradesh—the leading poultry-producing state in India—are already substituting up to 40% of the maize component in the diet (personal communication, M.P. Seshaiah, President, AP Poultry Federation). The future of sorghum in starch or poultry feed depends on the long-term sorghum-maize price differential. The same is true for millet. While studies have confirmed its superior nutritive value in the diets of livestock and poultry (Sullivan et al. 1990; Andrews et al. 1993), it is yet to be used commercially in Asia to any significant extent.

Sorghum and Millet in India: Case Studies in Competitiveness

To understand the relative position of sorghum and millet in a dynamic setting, it is useful to outline a few principles of structural change. As new production technologies are developed and made available to farmers (e.g., high-yielding cultivars and improved crop and soil management practices), the relative profitabilities of various enterprises change. Shifts in profitability differentials are brought about by two dynamic forces: changes in technical input-output relationships and changes in relative output prices. Producers respond to both these forces and shift their production resources to those enterprises that reduce per unit cost of production. Thus, changes in commodity prices and in per unit cost of production of specific commodities (relative to other commodities) determine their competitiveness. In the case of sorghum and millet, technical change in and relative price changes of competing crops such as maize, sunflower (*Helianthus annuus),* pigeonpea *(Cajanus cajan),* wheat, chickpea *(Cicer arietinum),* and groundnut (*Arachis hypogaea),* determine how competitive sorghum and millet are over time.

This analysis is restricted to India, for the simple reason of data availability.

Sorghum

In India, sorghum is cultivated in two distinct seasons: rainy or *kharif* and postrainy or *rabi.* Almost all *kharif* and about 90% of *rabi* sorghum is cultivated under rainfed conditions. For purposes of analysis, sorghum in each season is treated separately—for several reasons. First, their products (grain and fodder) are qualitatively different, as reflected in their respective prices [e.g., *rabi* (white) sorghum grain commands, on average, a 30 to 40% higher market price than *kharif* (yellow or hybrid) sorghum]. Second, productivity and area changes over time have differed for these two sorghums and the causal factors associated with those changes require separate analysis. Finally, the regions in which each are primarily grown are distinct.

Kharif sorghum. Since 1966/67, the area under *kharif* sorghum in India has declined by 2.1 million ha. Most of this has been replaced by higher-valued cereal, oilseed, and pulse crops.

National figures, however, obscure regional changes that have taken place over time. In some regions, area under *kharif* sorghum has actually increased; in others, it has declined dramatically. On the map in Figure 5, major *kharif* sorghum growing districts (121 in total) have been identified according to changes in area during the last 20 years. [1988 is the last year for which district-wise data on *kharif* sorghum is available. The comparison covers the period 1966/67 (2-year average) to 1986-88 (2-year average). *Kharif-rabi* sorghum break-up for 1968 to 1970 was not available, hence the choice of 1966/67. Data for 1987 was purposely not used as it coincided with a major drought in India, hence the use of 1986-88]. The map indicates that, with the exception of a pocket in central Maharashtra (MAH) and a few scattered districts beyond, most districts saw a significant reduction in area under *kharif* sorghum. By state, the big losers were Andhra Pradesh (AP), Karnataka (KN), Gujarat (GJ), and Madhya Pradesh (MP). AP and KN together lost 820 000 ha, replaced directly or indirectly by groundnut, sunflower, pigeonpea, maize, and cotton *(Gossypium* spp) (AP only). GJ and MP also lost more than 400 000 ha each: major gainers were maize, mustard *(Brassica campestris),* pigeonpea (GJ only), castor *(Ricinus communis)* (GJ only), wheat (MP only), and chickpea (MP only). Looking across India, it is only a handful of districts—ten in MAH and three in MP—where acreage under *kharif* sorghum increased significantly, i.e., by more than 10 000 ha.

☐ Relatively unchanged

■ Declined by >10 000 ha

▒ Increased by > 10 000 ha

Figure 5. Changes in* kharif *sorghum areas in India, 1966/67 to 1986-88 in major sorghum-growing districts.

Of the 62 districts where sorghum area has declined significantly, 34 had yield growth rates below 2.0% per year. Some of these low productivity growth districts had negative growth rates; the majority were positive but below 1.0%. The other 28 had yield growth rates above 2.0%. High (above 2.0%) and low (below 2.0%) productivity growth districts where sorghum area declined are shown in Figure 6. For obvious reasons sorghum has not remained competitive in those districts where productivity has been low or negative. More interesting is the case where districts had respectable yield increases but sorghum acreage still fell. A group of districts in the southwestern part of the Deccan Plateau (mainly Karnataka) fall into this category. High growth rate in yield was not sufficient to keep sorghum competitive there.

Sorghum, it must be remembered, is still a noncommercial crop in many areas. Farmers allocate land to sorghum in accordance with their own family requirements. This is not true everywhere, but in places like Karnataka, high yields resulted in shrinking crop area as farm families were able to meet their consumption requirements from a smaller area of land. Also, sorghum consumption requirements fell as incomes rose. In the five high productivity growth districts of Karnataka where yield growth averaged 2.6% annually, sorghum production actually declined. Cropped area declined at the annual rate of 3.4%. The potential for raising production was clearly there, i.e., the land and the technology were available. But neither farm household nor market demand was sufficient to keep enough land in *kharif* sorghum to maintain production levels. Shrinking area under a crop, therefore, is not in itself an indictment against a particular crop or the rate of progress in yield improvement. It is possible to make significant gains in productivity and still witness declining area (reduced competitiveness of that crop) or even falling production. When looking at long-term changes, consumer demand plays a key role.

Of the remaining 59 *kharif* sorghum growing districts in India, 20 saw their *kharif* sorghum acreage increase significantly, while 39 were relatively unchanged. Of those 39, only 11 had high productivity growth rates. Thus, the majority of the relatively unchanged districts had low productivity growth rates. At first glance, this does not seems to fit the pattern above: low productivity resulting in decreased area due to loss of competitiveness. Indeed, there are even a handful of districts (five) where the area under *kharif* sorghum increased despite low productivity growth. This may be explained by the patterns of subsistence farming where, if productivity is stagnant over time, farmers have to keep about the same amount of land under sorghum if they want to maintain production levels. If their goal is to maintain per capita production levels, they will have to increase the area under sorghum at the rate of population growth. This has rarely happened. Generally, production has failed to keep pace with population. That is, the differential between the yield growth rate and the rate of decline in area has rarely exceeded the population growth rate. This is particularly so in the declining sorghum area districts. This means that per capita production—and very likely consumption as well—has declined since the mid-1960s, an observation consistent with all-India level consumption data.

Of the 20 districts in which area under *kharif* sorghum increased by 10 000 ha or more since 1966/67, 10 are located in Maharashtra (Fig. 5). Those 10 had a high average annual growth rate

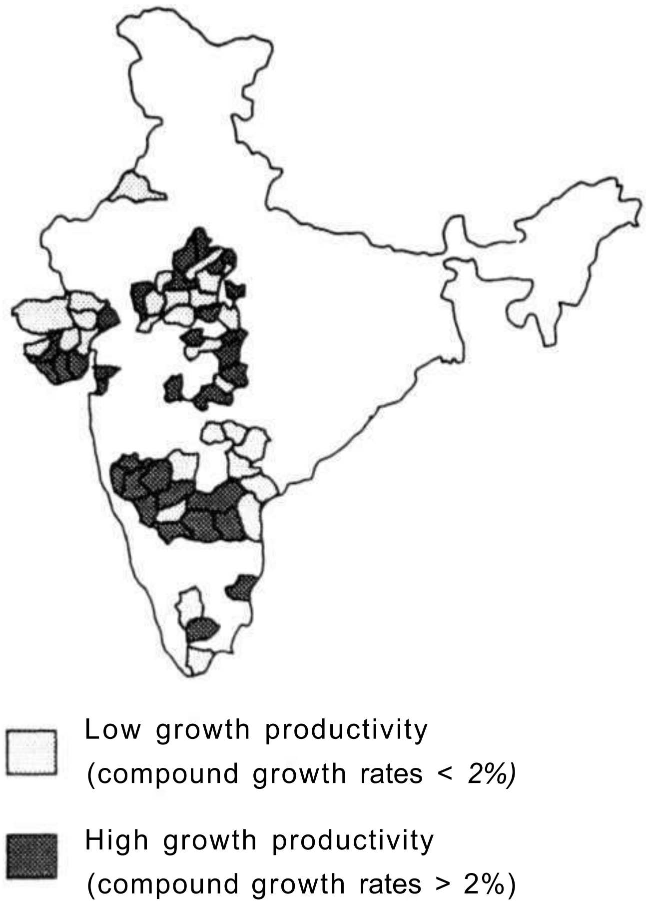


Figure 6. Changes in* kharif *sorghum productivity in districts in India that declined in sorghum area by more than 10 000 ha (1966/67 to 1986-88).

in—yield 4.7%. Because they represent a more favorable environment (deep, black soils in an assured rainfall zone), modern cultivars were better adapted there and hence more widely adopted. In fact, Maharashtra has the highest sorghum HYV adoption rate in India, approaching 70% of the total area. Yield levels are about 30 to 40% higher than the All India average. (Very limited adoption of HYVs in AP explains why productivity growth rates have been so low there.) It appears that this is one region in India where sorghum production has clearly moved beyond the own-farm subsistence stage and entered mainstream commercial production. Production growth rates averaged 7.5% per year in these 10 districts in Maharashtra, well above population growth rates. Even in the four adjoining districts, where area declines were significant, production growth rates averaged 3.8%. It is here—perhaps only here—in the Marathwada and Vidharba regions of peninsular India—that sorghum has maintained its competitiveness. This challenges the widely held perception of sorghum as a low-cost, low risk option which 'encourages its concentration in regions, districts, or even plots characterized by natural resource deficiencies—low fertility and paucity of moisture' (Jodha and Singh 1982, p. 349). High growth rates in productivity have translated into lower per unit production costs, despite relatively low producer prices. A positive correlation (r = 0.46) between yield growth rate and area growth rate is observed for this group. Farmers responded by putting more land under sorghum. We emphasize, however, that this was the exception, not the rule. For the relatively unchanged districts, the correlation coefficient was positive but not as strong (r - 0.21). For the declining-in-area districts, the correlation was slightly negative (r = -0.14), not unexpected. In general, sorghum yields have not improved rapidly enough to offset lower demand and lower relative prices, resulting in over 2.1 million ha of *kharif* sorghum lost to other crops.

Let us look more closely at the concept of competitiveness. Technical change and relative changes in commodity prices together determine an individual crop's competitiveness over time. In the case of sorghum at the national level, growth in average yield (a proxy for technical change) has lagged behind other competing cereal crops such as wheat, rice, and maize, but there are some regional exceptions, as already noted. It has lost ground in the market place as well: sorghum prices, for reasons already mentioned, have failed to keep pace with competing commodities—cereals, pulses, and oilseeds alike. Separately or together, these two factors have weakened sorghum's competitiveness over time, translating into reduced area under sorghum cultivation. This is illustrated in Figure 7. Using data from the Bulletin of Food Statistics (India: Directorate of Economics and Statistics 1991) and Area and Production of Principle Crops in India (India: Directorate of Economics and Statistics 1992) trends in crop prices, yields, and area indices have been estimated. This was done for three crops, *kharif* sorghum, wheat, and pigeonpea for the period 1971 to 1990. Trends were estimated using 1971 as the base year.

The results are consistent with the theory that changes in area under cultivation are positively related to growth in productivity and to own commodity price. For *kharif* sorghum, the average annual (linear) decline in cultivated area was 0.7%. This compares with wheat, which increased at 1.3%, and pigeonpea, which increased at 2.2%. Commodity price trend effects appear to dominate. Pigeonpea averaged a mere 0.3% annual linear increase in yields during this period but maintained a 1.2% rise in real prices. This translated into a high rate of growth in cultivated area. Area under wheat cultivation also increased, but for another reason. While the linear rate of decline in the wheat price trend was less than for sorghum (-2.5 vs -3.5%), it was rapid technical change in wheat production, i.e., higher growth in productivity and ultimately lower per unit production costs, which translated into positive growth in cultivated area. The combination of falling real sorghum prices and relatively poorer yield performance over time has reduced *kharif* sorghum's competitiveness. A more thorough analysis using time series cost of cultivation data is presently under way to examine more closely area responses to price and yield movements.

It is not likely that the price trend for sorghum will change markedly. Real prices of sorghum grain will continue to decline over time. If *kharif* sorghum is to maintain its present competitive status in India, higher rates of growth in productivity—relative to competing crops—must be forthcoming.

***Rabi* sorghum.** *Rabi* sorghum area has declined by 0.8 million ha, less than for *kharif* sorghum, but still considerable. Important *rabi* sorghum growing districts have been identified according to patterns of increasing and decreasing area

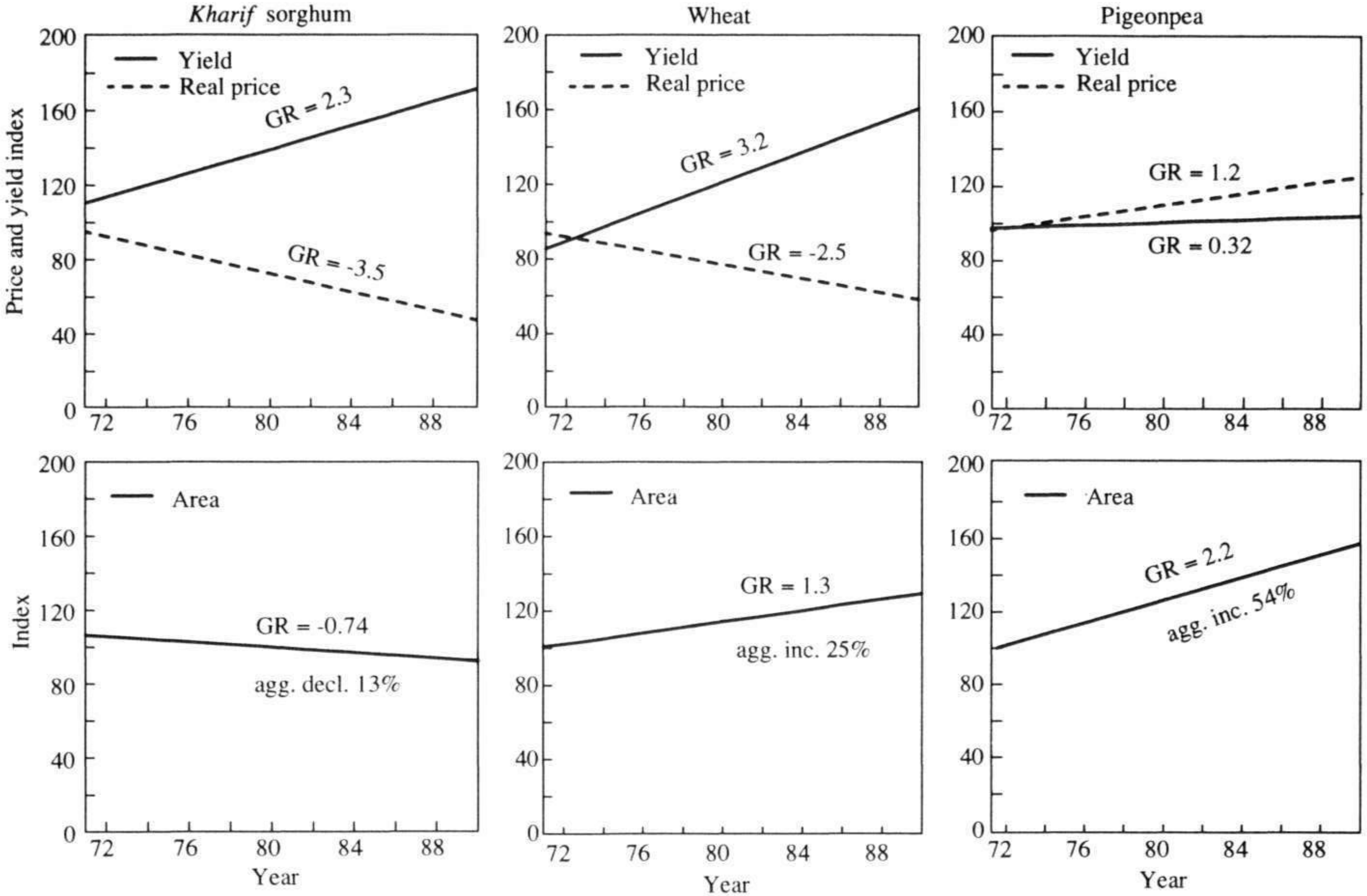
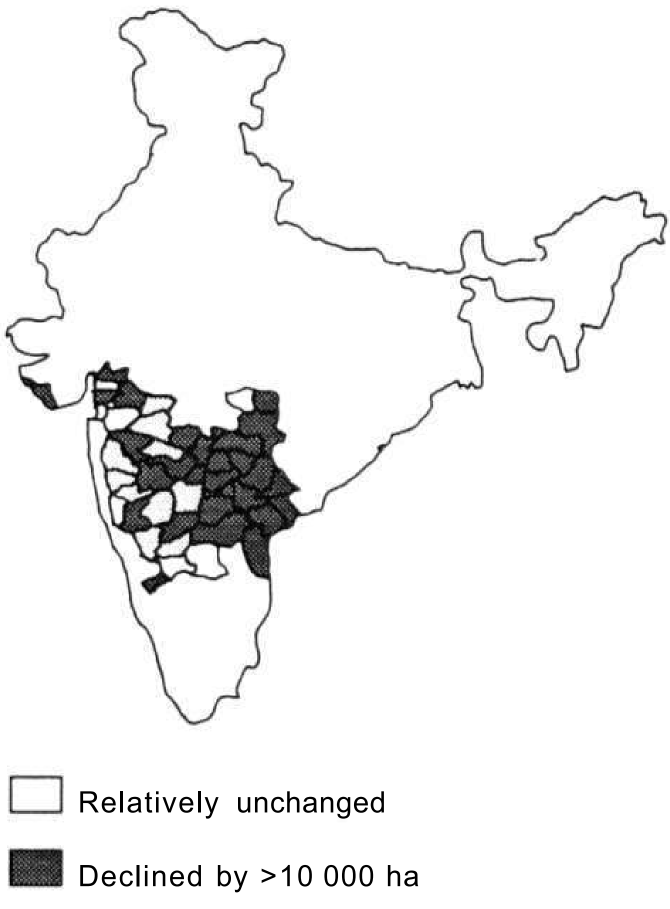


Figure 7. Trends in crop prices, yields, and area indices (1971 = 100) in India, 1971–90.
Source: India: Directorate of Economics and Statistics 1991, 1992.

over time (Fig. 8). Once again, districts that have lost more than 10 000 ha far outnumber those which have gained that much. Of the 44 districts identified, 28 (primarily in AP but also scattered in MAH and KN) decreased, 10 (mainly in MAH and KN) increased, and 6 remained relatively unchanged. An interesting pattern is observed in Figure 8: those districts that lost sorghum area are located primarily, but not entirely, in relatively more favorable production environments, i.e., in the more dependable rainfall zones (Kelley 1992). *Rabi* sorghum has moved out of the relatively higher rainfall areas (above 800 mm) and into the lower ones (less than 800 mm). Also, in these relatively higher rainfall districts irrigated area expanded more rapidly during the last 20 years, e.g., eastern AP. This deserves a little more explanation.



Relatively unchanged

Declined by >10 000 ha

Increased by > 10 000 ha

Figure 8. Changes in* rabi *sorghum area in India, 1966/67 to 1986-88, in major sorghum-growing districts.

Yields of *rabi* sorghum are considerably lower than for *kharif* sorghum (0.6 vs 0.9 t ha^{-1}, respectively). The reason for lower yield levels is the more difficult environment in which the *rabi* crop is normally cultivated: it is sown after the cessation of the monsoon rains once the soil is dry enough to cultivate. The crop must then rely on a limited and receding soil moisture regime to carry it through to harvest. In the relatively more favorable environments, *rabi* sorghum (like *kharif* sorghum) has been replaced by higher-valued cereal, pulse, and oilseed crops. But in the more marginal production environments, where low and variable grain yields are frequently observed, *rabi* sorghum has remained competitive. So although large areas of *rabi* sorghum went out of production in many favorable regions of AP (650 000 ha vs 375 000 ha for *kharif* sorghum), area under *rabi* sorghum in KN—a drier, more arid environment—actually increased by 125 000 ha (vs *kharif* sorghum, which fell by 445 000 ha). In 6 of the 10 districts that show an increase in area, yields significantly rose (by more than 2.0% annually).

There are at least three reasons why *rabi* sorghum experienced comparatively less reduction in area during the last 20 years. First, there are relatively few economically viable opportunities for crop substitution in the major *rabi* sorghum growing areas, i.e., in low rainfall, marginal environments. Using 10 years of data from Shirapur, Maharashtra, Kelley (1992) calculated that *rabi* sorghum accounted for about 95% of the postrainy season cropping and had higher benefit-cost ratios than alternative crops such as chickpea, linseed *(Linum usitatissisum),* and wheat. Also, Jodha and Singh (1982) showed that the proportion of plots planted to coarse grain cereals (mainly sorghum and millet) increased in low rainfall years. *Rabi* sorghum is particularly well-adapted to the harsher environments characteristic of the dry semi-arid tropics. For this reason, adoption of modern cultivars of *rabi* sorghum has been very limited.

Second, there is a preference for white sorghum grain *{rabi)* over yellow *(kharif).* Demand, as reflected in a smaller price decline (in real terms), has remained relatively stronger over time. Figure 9 illustrates the nominal price differentials for *rabi* (white) and *kharif* (yellow) sorghum. Note how these prices have diverged in the recent past. Lower prices for *kharif* indicate poorer grain quality characteristics, which translate into even lower expenditure elasticities. Indeed, in much of the *rabi* sorghum tract, sorghum is a preferred cereal, as reflected in its consistently high price. For example, in Shirapur village of Maharashtra during 1992, the price spread for wheat was Rs 5.00 to 6.25 per kg of grain; for white sorghum it was Rs 5.45 to 7.00 per kg of grain (ICRISAT VLS price schedule, unpublished data 1992).

Third, *rabi* sorghum is prized as much for its fodder as for grain. A major objective in cultivating *rabi* sorghum is generating sufficient quantities of good quality fodder to carry milk and draft animals through the year. The scope for tractorization is limited within the *rabi* sorghum growing region (Walker and Ryan 1990)—farmers will have to rely on bullock for field preparation and cultivation well into the next century. Even in years when 'crop failures' do occur, or grain yields are abysmally low, farmers are able to harvest some fodder for their animals. In normal years, the value of fodder can be quite high also. Using data from an ICRISAT benchmark village in the heart of the *rabi* sorghum belt of Maharashtra and Karnataka, Kelley et al. (in press) calculated that fodder's contribution to the total value of production ranged between 34 and 59% over a recent 10-year period. In the *rabi* sorghum belt, sorghum straw is the staple diet for draft and milk animals during many months of the year. Because of higher incomes and increased demand for milk products in India—hence increases in the derived demand for fodder—sorghum straw prices have more than kept pace with inflation. Indeed, the relative value of sorghum straw to grain has doubled in the last 20 years: *rabi* sorghum grain-to-straw price ratios fell from 6:1 to 3:1 (Kelley et al. 1993).

Pearl millet

Since 1966/67, almost 0.9 million ha of pearl millet have gone out of production. If we exclude Rajasthan (RAJ), the only state in which area under pearl millet increased, the total area lost is more than 1.4 million ha. Figure 10 shows

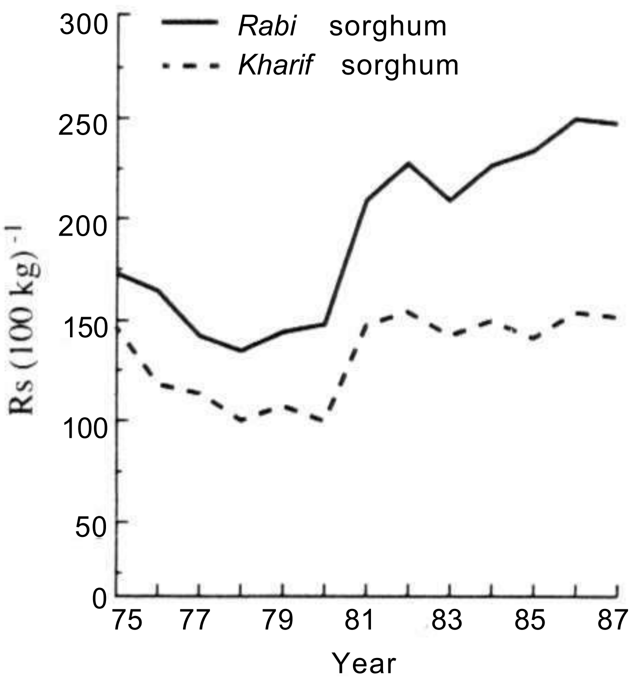


Figure 9. Wholesale prices of sorghum in Hyderabad, India. **Source: Bureau of Economics and Statistics (various years).**

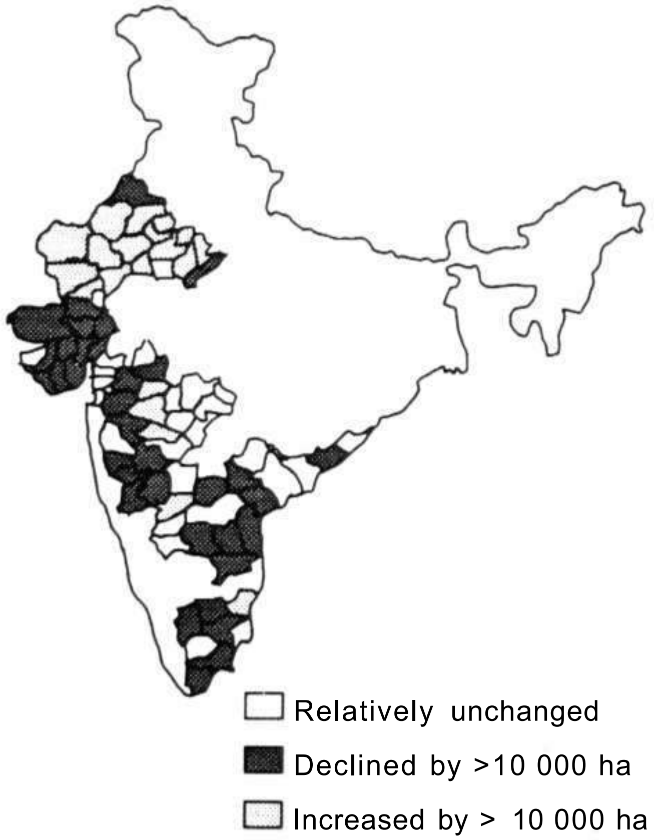


Figure 10. Changes in pearl millet area in India, 1967/68 to 1986-88, in major pearl millet growing districts.

the major regions where pearl millet has declined in importance: GJ, AP, and Tamil Nadu (TN) are the major losers. In GJ alone, 400 000 ha were taken out of pearl millet production. Interestingly, these areas all have fairly high modern cultivar adoption rates—from 60 to 90%. Also, GJ and TN were the states that had the largest absolute and relative increases in yields over this 20-year period. Again, increased productivity did not translate into expanding area. With production stagnant in GJ and TN, despite high growth rates in productivity, per capita consumption fell dramatically. As in the case of *kharif* sorghum, static demand in a low preference cereal explains the trend, which resulted in falling real prices a strong disincentive to farmers who are not subsistence-oriented.

Success in pearl millet crop improvement in these areas must not be measured in terms of increasing competitiveness over time (expanding area under pearl millet) or in terms of gains in total value of production. Decreasing area under pearl millet may itself indicate success if basic cereal needs are now met on a proportionately smaller area of cultivated land. This frees land for other, higher valued crops. Pearl millet appears to have served this role in the higher input production systems of GJ, AP, and TN (Bidinger and Parthasarathy Rao 1988).

The picture is different in RAJ where pearl millet has closer parallels to *rabi* sorghum. Most of the millet in this state is grown in the western part, a very dry, arid environment that includes the formidable Thar desert. Yields are low and extremely variable in this obviously risky production environment. Nevertheless, the area under millet in RAJ rose by more than 0.5 million ha since 1966/67. Three factors are important. First, as with *rabi* sorghum, there are few other crop (particularly cereal) alternatives. Thus, while yields in RAJ have improved slightly during the last 20 years (mostly in the eastern part where some modern cultivar adoption has occurred), production increases have been met mainly through area expansion. Second, in this region, there is a preference for millet as the major staple. Finally, pearl millet straw is highly regarded and valued in such production systems where livestock is at least as important as the crop component.

Supply and Demand Projections

What are the supply and demand prospects for the future? Assuming past performance serves as a good basis for predicting future trends (a topic addressed later), we estimated sorghum and millet production for major countries in Asia to the year 2000. These estimates are determined using growth rates based on recent production trends (1970 to 1991), according to the following compound growth rate equation:

$$Y_t = Y_0 \ (1+r)^t$$

or in natural log form,

$$\ln Y_t = a + bt + e_t$$

where Y_t is sorghum (or millet) production at time t, a = ln Y_0, b = ln(1 + r), r = compound growth rate, and e is the error term. Parameters a and b were estimated using historical time series data on production for individual countries. These parameter estimates were then used in projecting sorghum production to the year 2000.

To estimate consumption, we consider food and feed demand separately. Projections of population and income growth (weighted by income elasticity of demand) have been used to predict future food demand for sorghum and millet. Domestic income elasticities of demand are hard to come by. We have used estimates for Pakistan (-0.30) and India (-0.20) for sorghum and millet from FAO (1993) and have extrapolated the value from India to other Asian countries. This is probably a reasonable assumption, though it may overestimate slightly food demand for sorghum and millet in other Asian countries. Estimates of demand are thus determined using projections of population and income growth, weighted by the income elasticity of demand, according to the following equation:

$$D_t = D_0 \ (1 + d)^t + e_t$$

and $d = p + i^*n$

where D_t is sorghum food demand at future time t, D_0 is consumption at the 1986-88 level, d is the compound growth rate, p is the population growth rate, i is the income growth rate, and n is the income elasticity of demand.

Estimates of feed demand could not be calculated in a similar way because estimates of income elasticities of feed demand for sorghum and millet are not available. For predicting feed demand, historical growth rates in consumption were estimated using the reference period 1970 to 1988, this being the most current data available to us. A simple linear additive model was used here, as the compound growth rate equation gave unrealistically high estimates of feed consumption demand for several key countries.

$$D_t = a + bt + e_t,$$

where D_t is feed demand at time t, and a and b are parameters to be estimated. Results from this linear equation appeared more plausible.

Sorghum

Supply and demand projections for sorghum to the year 2000 are listed in Table 7. Values used to estimate projected demand are shown in Appendices I and II. Sorghum production in Asia is predicted to rise from its 1986-88 level of 17.6 million t to 19.9 million t in 2000. This falls far short of meeting the 4.8 million t increase in total demand, most of which is driven by rising feed demand. Substantial increases in imports (2.5 million t) over and above the current deficit of 4.3 million t are thus projected for Asia. This agrees with Ryan and von Oppen (1984) who predicted major shortfalls, in sorghum production in Asia other than India. Their sorghum demand estimates were based on FAO projections of sorghum feed demand increasing at growth rates of 5.6% per year, consistent with that observed during the 1960s and 1970s. Growth rate in feed use during the 1980s, however, fell significantly. Our estimates used considerably lower growth rates in feed use for sorghum to the year 2000 (1.7% for Asia), based on the 1971-88 observed growth rate. On the brighter side, increased demand offers favorable prospects for such exporters as Thailand and Australia, and may even lure in previously international market-shy countries like India.

Table 7. Domestic production and consumption of sorghum in selected Asian countries, present (1986-88) and projected (2000) levels.

		Present consumption (1986-88)					Projected consumption (2000)			
Country	Present production (1986-88)	Food ('000 t)	Feed ('000 t)	Food + feed ('000 t)	Surplus+ Deficit-	Projected production (2000)'	Food ('000 t)	Feed[2] ('000 t)	Food + feed ('000 t)	Surplus+ Deficit-
India	9489	8805	750	9555	-66	13743	10468	1339	11807	+ 1936
China	5495	1739	3806	5545	-50	4085	1799	5107	6906	-2821
N. Yemen	542	542	0	542	0	212	816	-	816	-604
Pakistan	222	162	59	221	+ 1	187	222	0	222	-35
Thailand	265	28	99	127	+ 138	377	30	119	149	+228
Australia	1432	25	685	710	+722	1045	29	854	883	+ 162
Japan	0	0	4040	4040	-4040	0	-	4325	4325	-4325
Israel	3	44	316	360	-357	0	52	158	210	-210
Taiwan	109	25	680	705	-596	265	24	1288	1312	-1047
Total	17557			21805	-4248	19914			26630	-6716

1. Based on observed growth rales in production from 1971 to 1991. For Taiwan based on production from 1984 to 1988.
2. Based on observed linear growth rates in feed use from 1971 to 1988.

Source: USDA 1988; FAO 1992.

Appendix I. Domestic consumption of sorghum in selected Asian countries, present (1986-88) and projected (2000) levels.

Country	Present COnsumnrinn 1986-88 (average) Food ('000 t)	Feed ('000 t)	Population growth %	Income growth %	Income elasticity of food demand	Annual growth in food demand %	Food demand projected to 2000 ('000 t)	Feed demand projected to 2000[1] ('000 t)	Food + feed demand projected to 2000 ('000 t)
India	8805	750	1.7	1.8	-.20	1.34	10468	1339	11807
China	1739	3806	1.4	5.7	-.20	0.26	1799	5107	6906
N. Yemen	542	0	3.7	2.5«	-.20	3.2	816	.	816
Pakistan	162	59	3.2	2.5	-.30	2.45	222	0	222
Thailand	28	99	1.3	4.2	-.20	0.46	30	119	149
Australia	25	685	1.4	1.7	-.20	1.06	29	854	883
Japan	0	4040	0.4	4.3	-	-	-	4325	4325
Israel	44	316	1.8	2.7	-.20	1.26	52	158	210
Taiwan	25	680	1.4	8.4	-.20	-0.28	24	1288	1312

1. Based on observed linear growth rales in feed use from 1971 to 1988.

Source: USDA 1988; World Bank 1992; M. de Nigris, FAO, personal communication, 1993.

Appendix II. Domestic consumption of millets in selected Asian countries, present (1986-88) and projected (2000) levels.

Country	Present consumption 1986-88 (average) Food ('000 t)	Feed ('000 t)	Population growth %	Income growth %	Income elasticity of food demand	Annual growth in food demand %	Food demand projected to 2000 ('000 t)	Feed demand projected to 2000[1] ('000 t)	Food + feed demand projected to 2000 ('000 t)
India	7863	467	1.7	1.8	-.20	1.34	9348	594	9942
China	4911	134	1.4	5.7	-.20	0.26	5080	116	5196
Pakistan	240	-	3.2	2.5	-.30	2.45	329	-	329
Nepal	139	-	2.5	0.6	-.20	2.40	189	-	189
Myanmar	117	-	2.1	-	-.20	1.98	151	-	151
Australia	-	15	1.4	1.7	-.20	1.06	-	30	30

1. Based on observed linear growth rates in feed use from 1971 to 1988.

Source: USDA 1988; World Bank 1992; M. de Nigris, FAO, personal communication, 1993.

India is projected to generate a surplus of 1.9 million t by the year 2000, as growth in production outstrips growth in demand. China, however, could become a major importer as production is projected to fall from 5.5 to 4.1 million t while demand is expected to increase from 5.5 to 6.9 million t, 95% of which is derived from feed use. In the past, China has drawn on its large stocks to meet the rising domestic and foreign demand (exports) for sorghum. Stocks are nearly exhausted now. Thus, China will either have to raise production (and reverse trends) or be prepared to import almost 3.0 million t of sorghum by the turn of the century—in which case it would go from being the major Asian exporter to being the second largest importer. Japan, which presently imports 4.0 million t, is, and will remain, Asia's largest importer of sorghum. Taiwan, which imports 0.6 million t, is projected to increase its imports to 1.0 million t. Thus, driven by the rising demand for sorghum feed, the market looks favorable for potential exporters. This, of course, presumes sorghum can remain competitive in price and quality with alternative feed grains, particularly maize.

Millet

Millet production and consumption projections to the year 2000 are shown in Table 8. Millet production is not expected to rise above its 1986-88 level of 13.8 million t. Demand, however, is projected to rise by almost 2.0 million t. Unlike sorghum, most of this is food demand. Use of millet for animal feed is still fairly limited in Asia, and unless trends change abruptly, its contribution to total demand is likely to remain small. This may seem surprising since millet, like sorghum, is an inferior food for most income classes. Yet population growth ensures that total food demand rises, at least in the short-to-medium term, even though individuals decrease their millet consumption as incomes go up.

India and Pakistan are projected to have relatively small deficits in millet, about 200 000 t each. But, as with sorghum, China is predicted to have a significant shortfall in production. Again, this is in general agreement with Ryan and von Oppen (1984) who predicted small deficits for India but rather large deficits for 'other Asia'. About 1.8 million t of millet imports will be needed to meet this largely food (not feed) requirement. Since world trade in millet is thin, this shortfall will probably be met through substitute coarse grains. Yet such a large shortfall could also drive prices high enough to stimulate increases in domestic production. Of the Asian countries, only Myanmar is projected to generate a surplus (300 000 t). Though small by regional standards, this is large relative to Myanmar's current production.

How valid are these projections for sorghum and millet? Estimating future production as we have done here assumes past trends in production to be reasonable indicators of future trends. This may or may not be valid. It assumes changes in sorghum productivity and price, relative to competing crops and commodities, to continue much as they have in the past. On the consumption side, it is possible that increasing incomes in Asia and the highly elastic demand

Table 8. Domestic production and consumption of millets in selected Asian countries, present (1986-88) and projected (2000) levels.

Country	Present production (1986-88)	Present consumption (1986-88) Food (' 000 t)	Feed ('000 t)	Food + feed ('000 t)	Surplus+ Deficit-	Projected production (2000)[1]	Projected consumption (2000) Food ('000 t)	Feed[2] ('000 t)	Food + feed ('000 t)	Surplus+ Deficit-
India	8329	7863	467	8330	-1	9737	9348	594	9942	-205
China	4983	4911	134	5045	62	3377	5080	116	5196	-1819
Pakistan	237	240	-	240	-3	141	329	-	329	-188
Nepal	139	139	-	139	0	213	189	-	189	+24
Myanmar	117	117	-	117	0	444	151	-	151	+293
Australia	29	-	15	15	+ 14	38	-	30	30	+8
Total Asia	13834			13886	-52	13950			15837	-1887

1. Based on observed compound growth rates in production from 1971 to 1991.
2. Based on observed linear growth rates in feed use from 1971 to 1988.

Sources: USDA 1988; FAO 1992.

for meat could stimulate a more rapid demand for sorghum feed than past trends alone would indicate. In this case, demand would be understated. Greater demand and higher prices would translate into higher than anticipated production in many of these countries. On the supply side, it is possible that yield breakthroughs in sorghum or millet could significantly raise production above that which has been estimated. Notwithstanding these qualifiers with various possibilities, these projections probably give us the best available figures for expected production and consumption of sorghum and millet in the year 2000.

Conclusions

The demand for sorghum and millet for food consumption is geographically localized to the regions growing them. However, even in these regions, sorghum and millet consumption continues to decline as these crops play out their roles as staple cereals in the diet of fewer and fewer people. This explains why per capita consumption of sorghum and millet in Asia has fallen precipitously since the early 1970s. The shift away from these coarse cereals is not the result of supply constraints, but rather a consequence of rising incomes and changing food preferences. Lack of consumer demand has had a depressing effect on prices which, while in the short run moderately encourages consumption, discourages production. (However, in the long run, as incomes go up, the effect is minimal). Lower producer prices have thus resulted in falling area and production of these cereals in Asia. The scope for arresting, perhaps even reversing, this trend depends on the development of alternative uses for sorghum and millet. Here the potential for sorghum (in animal feed, starch, and other industries) appears to be better. A condition for realizing this potential is significant and sustainable increases in yield that can ultimately translate into lower grain production costs. But even with progress in crop improvement, better technologies and improved quality characteristics (e.g., storability, higher starch fraction) may also be necessary. Ultimately, sorghum and millet must compete with maize for food demand in new preparations, and for industrial and feed demand.

Having identified demand as the limiting factor constraining growth in production of sorghum and millet, it may seem odd that the future projections of supply and demand in Asia indicate a widening shortfall in production to the year 2000. Presently, there is a large supply-demand gap in Asia largely because of strong demand for sorghum for feed use in Japan and Taiwan. This is expected to continue and even increase somewhat. A big change is occurring in China. Decreasing trends in sorghum and millet production and increasing trends in sorghum feed use translate into large supply deficits for that country, and ultimately for Asia at large. This increase will necessitate large scale increases in imports to satisfy demand. Of course, this depends critically on the competitive position of sorghum relative to maize. This, in turn, depends on the relative changes in production technology for these crops. In this respect, the situation in Asia is not fundamentally different from the situation in India. India, as already noted, is expected to generate a surplus in sorghum production. The potential, therefore, for exporting sorghum from India appears good, provided reductions in unit production costs can be achieved. Recall that the domestic price of sorghum is still well above international levels (Fig. 4).

Although technical change in sorghum and millet has lagged behind other cereal crops such as rice, wheat, and maize, contrary to general opinion, sorghum and millet, when compared to other major cereals, are by no means underprivileged, at least in India. Table 9 presents information provided by the Indian Council of Agricultural Research on the numbers of scientists in absolute and relative terms for major cereal crops in India. Based on these data, it would be difficult to justify increased investment in research on sorghum and millet. The expenditure on sorghum research, measured as a percent of the total production value of sorghum, is already six times larger than that of

Table 9. Major cereal crop research budgets relative to value of production in India.

	1991-92 research budget (million Rs)[1]		Total crop production value (billion Rs)	Research budget as a proportion of total value of production	
Rice	16.0	(264)[2]	284.2	0.56×10^{-4}	(0.93)[3]
Wheat	25.0	(162)	121.0	2.07×10^{-4}	(1.3)
Maize	12.5	(72)	17.3	7.23×10^{-4}	(4.2)
Sorghum	10.0	(59)	27.1	3.69×10^{-4}	(2.2)
Pearl millet	5.5	(40)	13.2	4.17×10^{-4}	(3.0)

1. Between 1991 and 1992 the Indian rupee ranged from 18.7-27 Indian rupees - US$ 1.00.
2. Number in parentheses refers to number of scientific staff associated with each crop.
3. Number of scientists per billion Rs value of production.

Source: Paroda 1992; India: Directorate of Economics and Statistics 1991. 1992.

rice, and more than one and a half times that of wheat. Millet receives seven times the resources of rice, and two times those of wheat. Maize receives the highest share of expenditure. Resources measured in scientists' man-years follow a similar pattern. Nevertheless, the lag in technical change, combined with its low preference as a food grain, has pushed sorghum and millet into more marginal environments. (*Kharif* sorghum in India is an exception.) There is, however, a bright side to the picture. The comparative advantage of these coarse grain crops is their adaptability to drier and less fertile conditions. Their low-input, low-risk characteristics give them a decisive advantage over maize and other competing crops. Nevertheless, because they are grown mainly in marginal environments under moisture stress conditions, average yields have remained low—though higher than yields that would have been obtained with other crops.

Recommendations for Sorghum and Millet Scientists

The important question with regard to sorghum research is, 'Which environments should be targeted by scientists when aiming to improve sorghum productivity?' If one accepts that sorghum's future production niche is in lower rainfall, poorer soil type areas, then the answer is clear—the focus should be on drought-tolerant, moderate-yielding cultivars, and on crop management practices with low to moderate inputs under rainfed conditions. In risky environments farmers are unlikely to invest or risk much. This is relevant for most of the sorghum grown in Asia and is particularly relevant for *rabi* sorghum in India. *Rabi* sorghum, as distinct from *kharif,* is increasingly being relegated to drier and more marginal environments where few viable crop alternatives exist. It is here where *rabi* sorghum is likely to be competitive for a long time, even with slow gains in productivity. If the more favorable grain and fodder price trends continue and if yield improvements in dryland *rabi* sorghum are not likely to be forthcoming, sorghum improvement scientists in India may want to focus their attention and resources on *rabi* sorghum production with supplemental irrigation (Walker 1990).

Developing cultivars and crop management practices for high-yield environments (e.g., assured rainfall or irrigation) would be justified only in situations where sorghum is likely to be competitive against higher-valued crops. There is good reason to believe *kharif* sorghum in India fits this model. Yield improvement and gains in area and production of *kharif* sorghum have been largest in some of the more favorable agroclimatic regions of the Indian SAT. The future competitiveness of *kharif* sorghum in India depends on closing the yield gap and improving the yield potential in more favorable environments. Area under *kharif* sorghum in less favorable regions has declined and will probably continue to decline as other higher-valued crops, also adaptable to these regions, replace sorghum. Thus, researchers should focus on production environments with higher production potential for *kharif* sorghum, if maximizing expected returns from research is the criterion for allocation of research resources. The probability of success in overcoming major constraints to higher yields in less favorable environments should be considered also. If prospects for removing those constraints are good (and can be estimated) a case should be made for allocating resources to them. Even small yield improvements resulting from overcoming a single biotic constraint, if distributed across several regions, could have large spillover benefits. The environments and conditions under which this would be the case should be clearly identified beforehand. But even in the more favorable environments, sorghum is likely to be replaced by other crops such as pigeonpea, maize, cotton, sunflower, and groundnut, unless breakthroughs in production technology are forthcoming. These are not the breakthroughs achieved under on-station conditions. Too often we hear that, 'Sorghum yields would double if farmers would just apply *x* kg of N, *y* kg of P, and exercise proper weed management/ No doubt sorghum yields would double by following that advice. But the pertinent question is, 'If farmers applied those same resources to other enterprises (e.g., to maize or vegetables), would the return on the investment be higher than from sorghum?' Improvements in sorghum yields must come about not simply through applying more resources, but through more efficient use of resources. New technologies must not only be adapted to farmers' conditions, but be economically attractive as well for farmers to adopt them. If breakthroughs should occur, which would significantly reduce per unit production costs, sorghum would remain competitive. Under this scenario, production would increase and prices fall, thereby encouraging sorghum substitution for maize in various industries, e.g., for starch, poultry and dairy feed, and breweries. This in turn ensures long-term demand for the commodity. However, even if sorghum were successful in partially replacing maize as a feed grain, the bulk of sorghum grain produced in India will still be directly consumed by humans for many years to come.

The situation for millet is somewhat akin to that of sorghum, yet it shows limited potential for diversification of use presently. In most countries in Asia, area and production of millet are declining rapidly, except for places like Rajasthan, which are heavily dependent on millet as a food staple and fodder, and where few crops can profitably replace it. Demand will continue to grow in such areas by virtue of population (human and animal) and income growth. Researchers should probably concentrate on those areas, and de-emphasize other marginal environments outside that zone as well as the more favorable millet-growing regions of the SAT (e.g., GJ, TN). To the extent that the potential for further gains in productivity can be achieved in more favorable environments with relatively low investment, these should be made. This would release land to other crops. Research for yield improvement in millet in high-production environments can be justified when productivity gains translate into reduced area under millet and increased area and production of higher value crops. In effect, productivity gains in millet facilitate production increases in other crops in which yield gains are more difficult to achieve.

Though it was not discussed in the paper, demand for forage sorghum in Asia has grown and will continue to grow as demand for meat and milk products increases. The area under irrigated and rainfed forage sorghum will likely expand to meet this demand. In cases where the demand for forage is strong, research should emphasize improved hybrid adaptation for the forage sorghums.

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About ICRISAT

The semi-arid tropics (SAT) encompasses parts of 48 developing countries including most of India, parts of southeast Asia, a swathe across sub-Saharan Africa, much of southern and eastern Africa, and parts of Latin America. Many of these countries are among the poorest in the world. Approximately one sixth of the world's population lives in the SAT, which is typified by unpredictable weather, limited and erratic rainfall, and nutrient-poor soils.

ICRISAT's mandate crops are sorghum, pearl millet, finger millet, chickpea, pigeonpea, and groundnut: these six crops are vital to life for the ever-increasing populations of the semi-arid tropics. ICRISAT's mission is to conduct research which can lead to enhanced sustainable production of these crops and to improved management of the limited natural resources of the SAT. ICRISAT communicates information on technologies as they are developed through workshops, networks, training, library services, and publishing.

ICRISAT was established in 1972. It is one of 18 nonprofit, research and training centers funded through the Consultative Group on International Agricultural Research (CGIAR). The CGIAR is an informal association of approximately 50 public and private sector donors: it is co-sponsored by the Food and Agriculture Organization of the United Nations (FAO), the World Bank, and the United Nations Development Programme (UNDP).

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