Global Production and Demand for Sorghum and Millet to the Year 2000

James G. Ryan and M. von Oppen*

Abstract

The present status of production of sorghum and millet in the seven semi-arid tropical regions and the world is shown, together with the contribution from these crops to total calorie availability and consumption.

Future yields are projected from past trends and taking into consideration estimates of the impact of ongoing and planned research and extension efforts; also future demand is projected, taking into account income and population growth rates.

The projected supply and demand are compared. Two scenario analyses, one at the all-India level and the other at the global level, are presented, projecting sorghum and millet production, consumption, and prices into the year 2000.

Issues are raised concerning the possibilities and requirements for improving the projected situations. Various strategies are discussed, such as breeding for stability vs yield; maize vs sorghum; and fodder vs grain.

Résumé

Production et demande globales de sorgho et de mil jusqu'à l'an 2000 : Cette communication présente l'état actuel de la production de sorgho et de mil dans chacune des sept régions tropicales semi-arides et dans le monde, ainsi que la contribution de ces cultures à l'apport et à la consommation des calories.

Les projections des rendements sont établies à partir des tendances dans le passé et d'estimations de l'impact des activités, en cours ou prévues, de recherche et de vulgarisation. Les projections de la demande tiennent compte des taux de croissance démographique et du revenu.

Suit une comparaison des projections de l'offre et de la demande. Sont présentées deux analyses, l'une au niveau indien et l'autre au niveau global, présentant les projections de la production, de la consommation et des prix du sorgho et du mil jusqu'à l'an 2000.

Sont soulevées des questions concernant les possibilités et les impératifs pour améliorer les pronostics. Diverses options sont étudiées : phytosélection visant soit à stabiliser le rendement, soit à l'accroître; culture du maïs ou du sorgho; culture pour le fourrage ou le grain.

* Economics Program, ICRISAT, Patancheru A.P., India.

International Crops Research Institute for the Semi-Arid Tropics. 1984. Agrometeorology of Sorghum and Millet in the Semi-Arid Tropics: Proceedings of the Internationa) Symposium, 15-20 Nov 1982, ICRISAT Center, India. Patancheru, A.P. 502324, India: ICRISAT.

Sorghum and millets[1] are staple cereals in the diets of most of the 750 million people living in the semi-arid tropics (SAT) of the world. Those relying on these cereals often consume up to 700 g of them per capita per day. At this level of consumption, sorghum and millet provide the bulk of dietary energy and protein, particularly for consumers in Africa and India. Such people are amongst the poorest in the world, with annual per capita incomes generally less than U.S.$100, and farmers who grow these crops market only about 10 to 20% of their production, which is primarily subsistence-oriented. The future production performance of these two crops will hence directly affect the welfare—perhaps the very existence—of the most disadvantaged people in the world.

The income of people living in semi-arid tropical regions is both low and unstable largely because the agroclimatic environment of the SAT is marginal for crop production; indeed, this is the major reason sorghum and millets are grown there. Both crops have a comparative advantage in such marginal regions, and research that aims at increasing and stabilizing their production will both generate a major welfare or equity improvement and enhance the productivity of scarce resources in the SAT. Research on the agrometeorology of sorghum and millet can play a key role in providing the basis for this much-needed increase in productivity and stability.

This paper provides background information required for planning research to achieve these objectives. The current world and regional food situation is first discussed, together with projections to the year 2000. The present and future status of sorghum and millet production and demand are then addressed, with emphasis on the SAT regions most likely to be at risk by the turn of the century. The implications of the projected differentials in feed versus food demand growth for coarse grains are also presented. Likely sources of future increases in production of sorghum and millet are then identified, with particular emphasis on possible yield scenarios and their research and policy implications.

The Current World Food Situation and Recent Trends

World agricultural production grew at an annual rate of 2.2% per year from 1971 to 1980 (FAO 1981). With world population growing somewhat less than this at 1.85% per capita, world food output was able to improve marginally by 0.5% per year, during the same period (World Bank 1982). However, these trends mask some significant differences in agricultural production performance between regions (Table 1). Although the 90 developing countries analyzed by the FAO (1981) achieved higher growth rates of agricultural production (2.9%/year) than did the developed countries (1.4-2.1 %/year), the much higher population growth rates in the former (2.6%/year) eroded most of their production gains. This was especially true in Africa, where the 2.7% per annum growth in population led to an annual decline of 1.1 % in per capita food output (World Bank 1982). The countries of West Asia, where population is growing at the rate of 2.6% per annum, experienced no growth in per capita food output during the 1970s. East Asia had a l.4% per annum increase; Latin America, 0.6%.[2]

If similar trends in production and population continue for the next 20 years, the FAO (1981), in its publication *Agriculture: Towards 2000,* projects that demand growth in 90 developing countries (2.9%) will exceed projected agricultural production growth (2.8%). The imbalance will be greatest in Africa and in West Asia (Table 1). Self-sufficiency in cereals in the developing countries would decline from 91 % in 1979 to 83% in 2000, again with the situation being much worse in Africa and West Asia than in other regions (Table 1). The 90 developing countries (including China) are projected to have a cereal deficit of 165 million tonnes by 2000, compared with 36 million tonnes in 1979. The most vulnerable countries could have a deficit of 77 million tonnes, or more than three times their 1979 deficit of 22 million tonnes. These countries are least able to pay for cereal imports, as they are generally net importers, have low incomes, and are land-locked or island countries.[3] The FAO con-

1. Refers to all millets, including pearl millet *(Pennisetum americanum).* finger millet *(Eleusine coracana).* foxtail millet *(Setaria italica),* and barnyard millet (*Echinocloa crusgalli).*

2. The FAO refers to East Asia as the Far East and to West Asia as the Near East. We choose to use the Asian nomenclature throughout the paper even when referring to FAO's data for the Far and Near East.

3. Cereal self-sufficiency will probably decline faster in the middle-income than in the low-income developing countries; however, this gap will probably be filled by greater trade in the middle-income countries as they increase commercial cereal imports.

Table 1. Selected indices and projections of world agricultural development.

Index	World total (124 countries)	Developed market economies (26)	Developed centrally planned economies (8)	Developing countries (90)	Latin America	Africa	East Asia	West Asia	Low income	Middle income
Annual growth in agricultural production 1971-80 (%) [a]	2.2	2.1	1.4	2.9	3.2	1.4	3.1	3.0	2.3	3.5
Projection of trend per capita calorie consumption in 2000 [a,b]	na	na	na	2369	2698	2306	2208	2848	2174	2693
Population growth (%)										
Projected trend 1980-2000 [a]	1.7	0.6	0.7	2.4	2.6	3.0	2.1	2.6	2.3	2.6
Actual 1970-80	1.85 [c]	0.8 [d]	0.8 [d]	2.6 [e]	2.8 [e]	2.7 [e]	2.5 [e]	2.6 [g]	2.1 [d]	2.4 [d]
Agricultural demand projected trend growth 1980-2000 (%) [a]	na	1.2		2.9	3.0	3.4	2.6	3.2	2.7	3.1
Annual food output growth per capita 1970-80 (%) [d]	0.5	na	na	0.4 [f]	0.6	-1.1	1.4 [f]	0.09 [f]	-0.3	0.9
Agricultural production projected trend growth 1980-2000 (%) [a]	na	1.1-1.5		2.8	3.0	2.6	2.7	2.8	2.6	3.0
Cereal self-sufficiency 1975-79 (%)	na	na	na	91	98	75	95	82	92	90
Trend projection to 2000 [a]	na	na	na	83	87	56	93	67	86	79

Continued

Table 1. *Continued.*

Index	World total (124 countries)	Developed market economies (26)	Developed centrally planned economies (8)	Developing countries (90)	Latin America	Africa	East Asia	West Asia	Low income	Middle income
Sources of added crop output (%) in FAO scenarios [a]										
Arable land	na	na	na	26	55	27	10	6	na	na
Cropping intensity	na	na	na	14	14	22	14	25	na	na
Yield	na	na	na	60	31	51	76	69	na	na
Arable area in use 1975 (%) [a]	42 [g]	na	na	40	25	30	79	63	45	34
Share of irrigation in arable land (%) [a]	na	na	na	14	7	2	25	23	18	9

a. Source: FAO (1981).
b. Requirements are fixed at 2295 per capita per day for all 90 developing countries; the range is from 2484 for East Asia to 2236 for West Asia.
c. Calculated from population data in FAO (1980).
d. Source: World Bank (1982).
e. From 1963-75 only.
f. The World Bank refers to these as All Developing Countries, Southeast Asia, and South Asia, respectively. The country coverage of FAO and the World Bank in the regions is also different.
g. Source: Hopper (1976).

cludes (FAO 1981, p.26): "It is probably unrealistic to think that food aid, which in 1978-79 had still not reached the current target of 10 million tonnes, could bridge the larger part of this gap." Even if these projected cereal deficits were filled, the FAO estimates there would still be almost 600 million undernourished people in the developing countries.

In various projections to the year 2000, the FAO (1981) indicates that expansion of arable land will provide just over one-quarter of the additional crop production in the 90 developing countries. This will be concentrated largely in Latin America and Africa, where the expansion in arable area to sustain food production growth will disturb the ecological balance and alter the agroclimate, Higher yields will be responsible for the bulk (60%) of future crop-production increases and greater cropping intensity will contribute the rest (14%), Irrigated areas could provide almost 50% of the projected expansion in crop production 1980 to 2000, but 84% of the total arable area will remain nonirrigated at the end of the century and supply 59% of total crop output, much of which will be sorghum and millets. Most of the irrigated land will be in the low-income, land-scarce countries of East and West Asia.

Trends in Sorghum and Millet Production

Sorghum and millet together occupy more than 100 million hectares of the world's cropland, from which about 100 million tonnes of grain are produced (Table 2). Although the SAT countries have more than two-thirds of the world's harvested area of sorghum and millet, they contribute only about half of the world's total production, because of low yields. Semi-arid tropical Asia and SAT sub-Saharan Africa are the world's major sorghum-growing regions, representing about one-third and one-quarter of the total area, respectively. The centrally planned economies (CPEs) are the third most important sorghum producers; and with more than one-third of the area and 40% of the production, they represent the most important millet region. The countries of SAT Asia (35% of the area and 30% of the production) and SAT sub-Saharan Africa (28%, 24%) are the only other major millet-growing zones.

In sub-Saharan Africa, Nigeria is the major sorghum producer, followed by the Sudan, Ethiopia, Upper Volta, and Chad (Fig. 1). Of the major producers of sorghum, the West African Sahelian countries generally have the lowest yields. In India, which grows about half the SAT sorghum, the state of Maharashtra is by far the largest producer, with Andhra Pradesh and Karnataka each producing only about one-third of Maharashtra (see Fig. 2, Sivakumar et al., these Proceedings). Sorghum yields are generally much higher in south India than in the northern states.

The foremost millet producers in sub-Saharan Africa are Uganda, Mali, Nigeria, Senegal, and Niger (Fig. 2), with the highest yields attained in Uganda and Mali, and the lowest in Niger. In India, Rajasthan leads in terms of area sown to pearl millet but it has by far the lowest yields (see Fig. 3, Sivakumar et al., these Proceedings). Gujarat produces most of India's pearl millet, due largely to its high yields, which result from the extensive use of irrigation on summer crops on the lighter soils of that state. Yields in Tamil Nadu are also high, but total production lags behind that of Maharashtra.

Growth Rates

Sorghum

The world area of sorghum currently exceeds 50 million hectares but has been growing at only 0.33% per annum or by 170 000 ha (Table 3). Over the past 20 years, yield increases of around 28 kg/ha per year (2.47%) have enabled production to grow by more than 1.6 million tonnes annually, representing a compound growth rate of 2.8%. The SAT less developed market economies (LDMEs) had a production growth of 3.67% per annum, primarily as a result of a 3.11% annual increase in sorghum yields (Fig. 3). This enabled production to increase by almost 1 million tonnes a year. The fastest-growing sorghum-producing zones within the SAT LDMEs in the last 20 years were Latin America (12%), eastern Africa (2.7%) and Asian countries other than India (2.7%) (Table 4). However, in the last 10 years sorghum growth rates have markedly declined in these three zones and in southern Africa and West Asia. Indian and West African growth rates substantially increased in the 1970s. The fastest-growing region is the non-SAT LDMEs, where sorghum area has expanded by 75000 ha/year (8.2%), yield by 34 kg/ha per year (3.62%), and production by 134 000 tonnes (11.8%) (Table 3). However, this performance began from a very low base. In spite of a steady decline of

Table 2. Area, production, and yield of sorghum and millet in various regions of the world (Annual average 1975-1979).[a]

Region	Sorghum Area (000 ha)	Sorghum Production (000 tonnes)	Sorghum Yield (kg/ha)	Millet Area (000 ha)	Millet Production (000 tonnes)	Millet Yield (kg/ha)
Semi-Arid Tropics (SAT)						
A. Developed market economies						
Oceania	482	965	2002	31	27	871
Subtotal (A)	482	965	2002	31	27	871
B. Less developed market economies						
Sub-Saharan Africa	13027	8761	673	15077	8515	565
North and Central America	1509	3903	2586	-	-	-
South America	2433	6642	2730	237	297	1253
Asia	17878	12382	693	19123	10669	558
				(12163)[b]	(5960)[b]	(490)[b]
Subtotal (B)	34847	13688	909	34437	19481	566
				(27477)	(14772)	(538)
Total SAT (A+B)	35329	32653	924	34468	19508	566
				(27508)	(14799)	(538)
Rest of the world						
C. Developed market economies						
Sub-Saharan Africa	341	405	1188	22	15	682
North and Central America	5721	19446	3399	-	-	-
Asia	4	13	3250	3	4	1333
Europe	148	576	3892	11	23	1917
Oceania						
Subtotal (C)	6214	20440	3289	36	42	1167

Continued

Table 2. *Continued.*

Region	Sorghum Area (000 ha)	Sorghum Production (000 tonnes)	Sorghum Yield (kg/ha)	Millet Area (000 ha)	Millet Production (000 tonnes)	Millet Yield (kg/ha)
D. Less developed market economies						
Sub-Saharan Africa	667	788	1181	863	1290	1495
North and Central America	326	379	1163			
South America	272	608	2235			
Asia	16	14	875	231	247	1068
Europe						
Oceania	-					
Subtotal (D)	1281	1789	1397	1094	1537	1405
E. Centrally planned economies	9475	11812	1247	18403	13987	760
Subtotal (E)	9475	11812	1247	18403	13987	760
Total rest of the world (C+D+E)	16970	34041	2006	19533	15566	797
World (A+B+C+D+E)	52299	66694	1275	54001 (47041)	35074 (30365)	650 (645)

a. Includes China. b. In SAT Asia the figures in parentheses refer to pearl millet only. All figures outside parentheses refer to all millets.

150 000 ha (-1.52%) in the area of sorghum grown each year since the early 1960s, the centrally planned economies have increased their annual production by 200000 tonnes (1.94%) due to a 37 kg/ha per year increase in yields (3.5%).

Millet

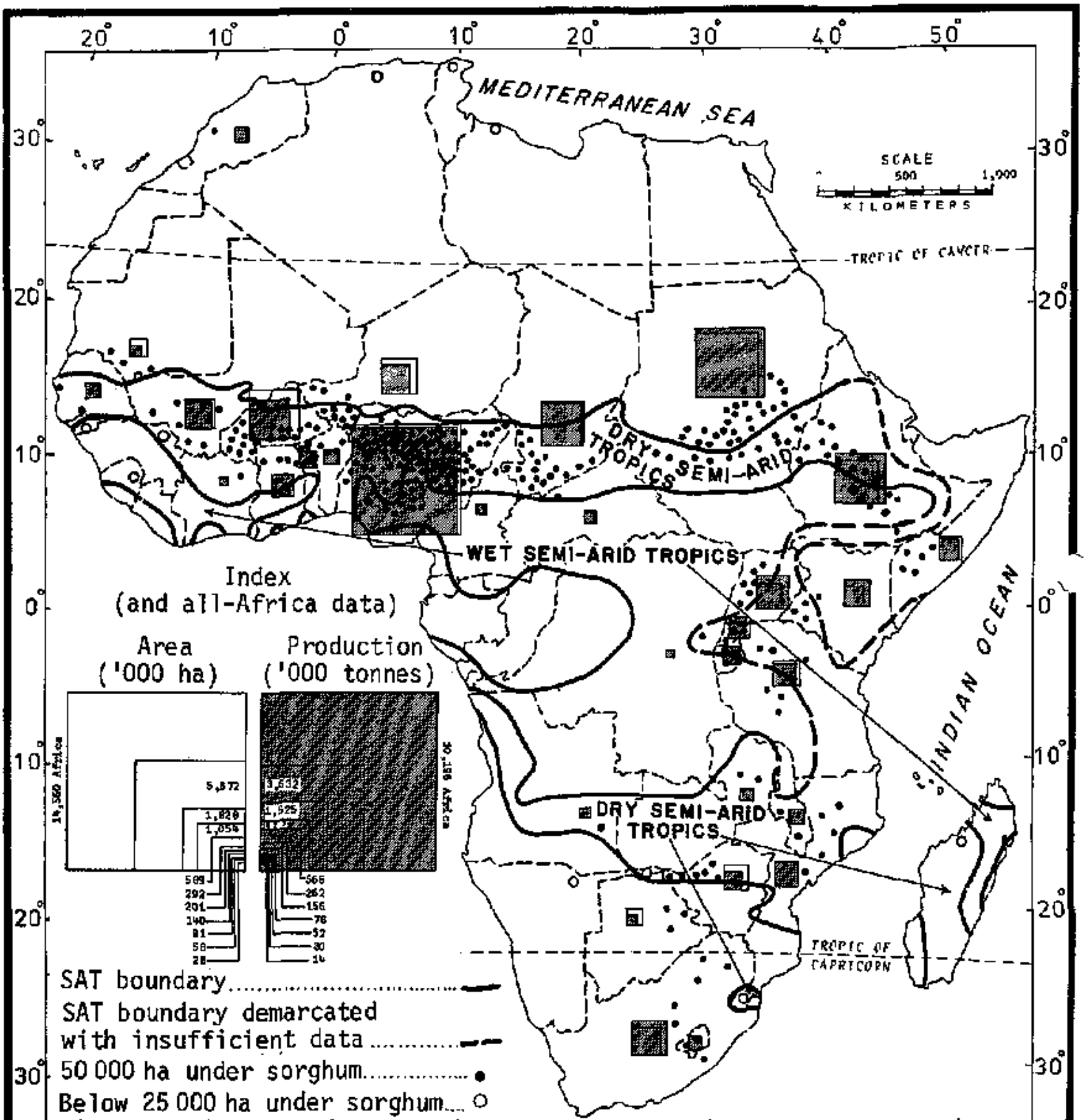
In the 1960s and 1970s (Table 3) world millet production grew by only 0.9%, or 250000 tonnes, annually. Yields increased less than 9 kg/ha per year and simultaneously area sown to millets declined by 300000 ha (-0.62%) per year. The CPEs had a better yield record (2.75%) than the SAT LDMEs, where yields were virtually stagnant (0.8%). However, because millet area declined by 343000 ha per year (-1.75%) in the CPEs, production rose by only 135 000 tonnes (1 %) (Fig. 4). In the SAT LDMEs a 0.35% annual increase in area, combined with a small yield increase, led to production growth of 1.15% (150 000 tonnes). The SAT LDME countries in Latin America had the highest millet production growth in the last 20 years (3.9%), followed by those in eastern Africa (2.9%) (Table 4). In all zones of the SAT except India, millet production has grown much faster (or declined less) in the 1970s than in the 1960s. The non-SAT LDMEs have had a drastic decline in millet production.

In the next section we match these historical production trends with various projections of growth in the future demand and production of coarse grains, with emphasis on the developing countries where problems of food imbalances loom largest.

Demand and Supply Projections

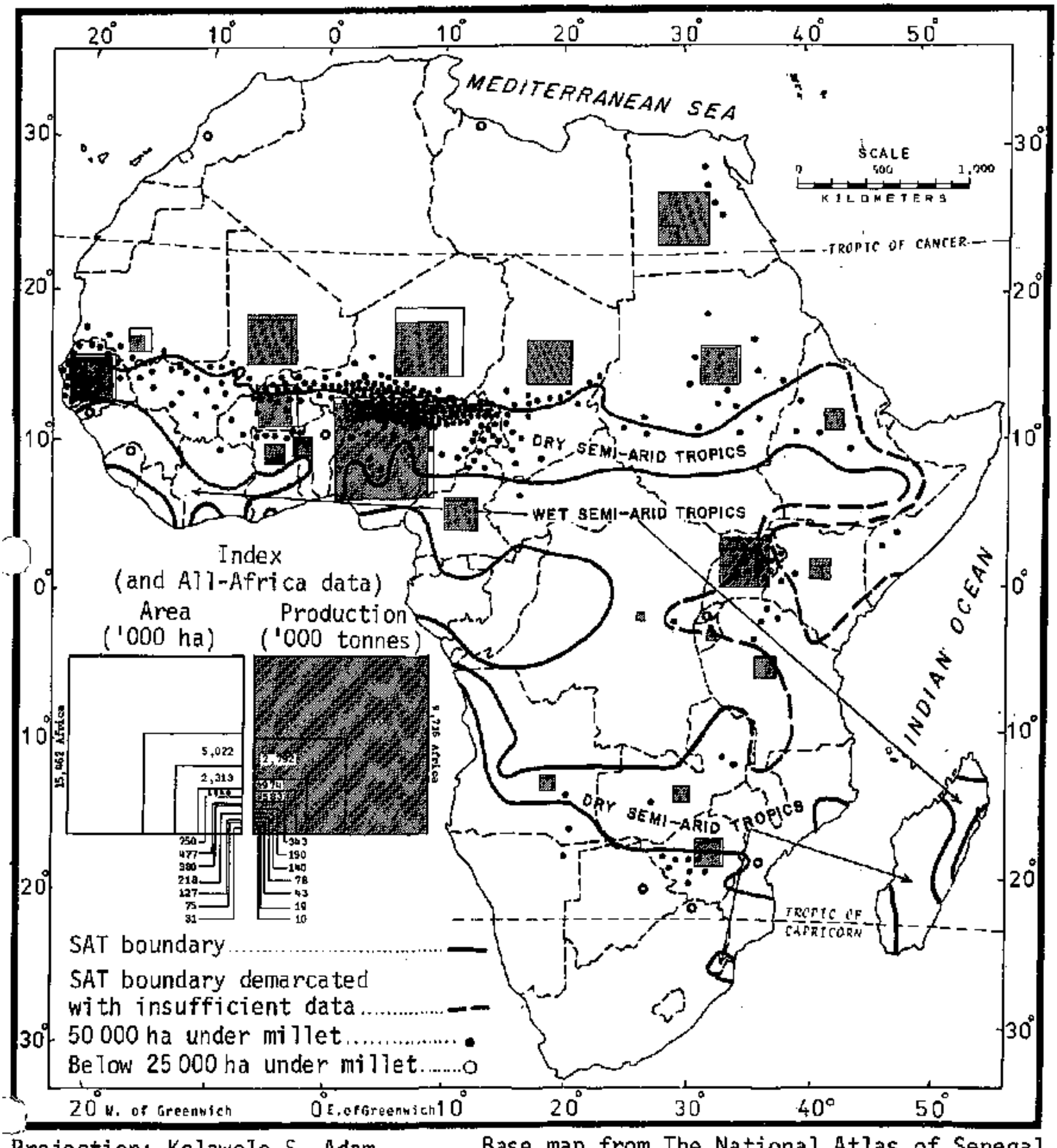
World demand for coarse grains is projected by Aziz (1976) to rise by 2.5% a year from 1970 to 2000 (Table 5). This is much less than the annual growth rate of sorghum production in the 1960s and 1970s (2.8%), but far in excess of that of millet (0.86%). On a worldwide basis, therefore, there may not be an imbalance in sorghum demand and supply but there may be in millet, particularly in the non-SAT countries, where millet production has been declining by more than 2% per year (Table 3 and Fig. 4).

The major deficit regions for sorghum and millets in 2000 would appear to be the SAT LDMEs (Table 5). Sorghum production in this region has grown at 3.67% per year since the early 1960s, and coarse grains are projected to grow by 3.45% to 2000,



Projection: Kolawole S. Adam Base map from The National Atlas of Senegal
Prepared by M.N.S. Bose, ICRISAT, Patancheru, A.P., India.
Sources: FAO Monthly Bulletin of Statistics 1981 4(12). World Agricultural Atlas. ICRISAT Agroclimatology Subprogram progress report 5 (1980-81).

Figure 1. Sorghum distribution, area, and production in Africa.



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Sources: FAO Monthly Bulletin of Statistics 1981 4(12). World Agricultural Atlas. ICRISAT Agroclimatology Subprogram progress report 5 (1980-81).

Figure 2. Millet distribution, area, and production in Africa.

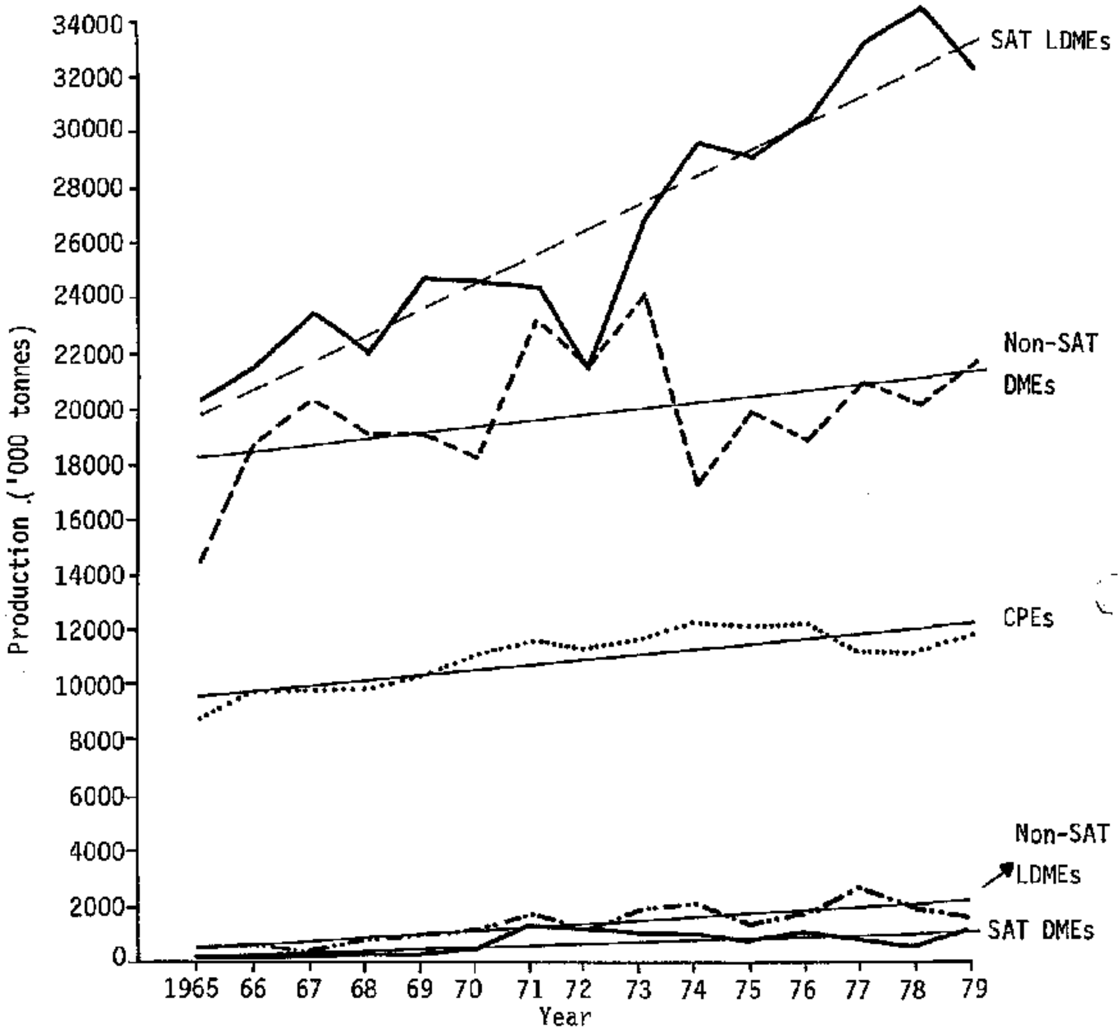

Figure 3. Sorghum production in five regions of the world.

using the FAO's more optimistic scenario, and at 2.78% using a more pessimistic one. These figures compare with those for projected demand growth generally in excess of 3.5%.

Examining more recent sorghum growth trends for the zones within the SAT, it appears that the major shortfalls in production may occur in West Asia, southern and eastern Africa, and Asia, other than India (Fig. 5). It would appear that the deficit in SAT millet production may be far greater in the future than that in sorghum production. In the past 20 years, millet production has grown by only 1.15% per year in the SAT LDMEs, far below projected coarse grain demand. In the last 10 years millet production in all SAT zones except Latin America has also grown at rates well below future demand growth (Fig. 6).

The non-SAT LDMEs would not appear to have the prospect of deficits in sorghum in 2000, but they would in millets. The non-SAT developed market economies (DMEs) must dramatically alter their production trends if they are to avoid substantial coarse grain production deficits in 2000.

The major source of growth in future demand for coarse grains—particularly in the LDMEs and especially among those with the lowest incomes—

Table 3. Linear trends and compound annual growth rates of sorghum and millet: 1961-65 (average) to 1979.[a]

Region	Sorghum: Linear trend equations: Intercepts	Sorghum: Regression coefficients (t-value)	Sorghum: R^2	Sorghum: 1979 trend value	Sorghum: Annual compound growth rate (%)	Millet: Linear trend equations: Intercepts	Millet: Regression coefficients (t-value)	Millet: R^2	Millet: 1979 trend value	Millet: Annual compound growth rate (%)
A. SAT developed market economies (DMEs)										
Area	193	27.8 (3.4)	0.47	603	8.70	26	0.579 (1.07)	0.08	35	1.67
Production	273	62.0 (3.8)	0.52	1203	10.90	29	0.061 (0.10)	0.00	30	0.24
Yield	1496	39.5 (2.4)	0.31	2089	2.20	1079	-13.2 (-1.4)	0.13	881	-1.43
B. SAT less developed market economies (LDMEs)										
Area	32415	189.8 (3.6)	0.50	35262	0.56	26556	93.7 (1.81)	0.20	27962	0.35
Production	18755	985.9 (8.9)	0.86	33543	3.67	12689	153.6 (1.81)	0.20	14993	1.15
Yield	585	24.6 (9.5)	0.87	954	3.11	477	3.99 (1.59)	0.16	537	0.80
C. Non-SAT DMEs										
Area	5941	27 (0.91)	0.06	6346	0.47	56	-1.81 (-3.88)	0.54	29	-3.8
Production	17993	237.9 (1.74)	0.19	21561	1.30	52	-1.47 (-1.6)	0.16	30	-2.2
Yield	3013	27.2 (1.59)	0.16	3420	0.83	842	13.8 (1.3)	0.11	1049	1.6

Continued

Table 3. *Continued.*

	Sorghum					Millet				
	Linear trend equations				Annual compound growth rate (%)	Linear trend equations				Annual compound growth rate (%)
Region	Intercepts	Regression coefficients (t-value)	R^2	1979 trend value		Intercepts	Regression coefficients (t-value)	R^2	1979 trend value	
D. Non-SAT LDMEs										
Area	405	75.4 (5.1)	0.67	1536	8.19	1790	-50.8 (-6.2)	0.75	1028	-3.76
Production	328	133.6 (6.27)	0.75	2332	11.81	2142	-41.0 (-4.2)	0.58	1527	-2.37
Yield	1126	33.9 (1.17)	0.10	1645	3.62	1184	18.1 (2.8)	0.37	1455	1.39
E. Centrally planned economies (CPEs)										
Area	11790	-149.0 (-3.0)	0.40	9555	-1.52	23444	-342.9 (-4.2)	0.57	18299	-1.75
Production	9400	205.2 (5.28)	0.68	12477	1.94	12709	135.2 (2.1)	0.25	14737	1.00
Yield	761	36.7 (11.1)	0.90	1311	3.46	525	18.63 (5.66)	0.71	804	2.75
F. World										
Area	50724	171.2 (1.88)	0.21	53293	0.33	51872	-301.3 (-2.8)	0.38	47353	-0.62
Production	46749	1624.6 (10.4)	0.89	71118	2.8	27621	246.4 (2.1)	0.26	31318	0.86
Yield	922	27.95 (11.5)	0.91	1341	2.47	528	8.86 (4.53)	0.61	661	1.49

a. Area in 000 ha, production in 000 tonnes, and yield in kg/ha. Calculated by ICRISAT using FAO data tapes at IFPRI.

Table 4. Annual compound growth rates (%) of sorghum and millet production in the less developed semi-arid tropical regions.

Crop	India	West Asia	Other Asia	Eastern Africa	West Africa	Southern Africa	Latin America
	Region						
Sorghum							
1961-65 (av.) to 1978	1.64	-3.11	2.65	2.68	0.67	2.04	12.0
1968-70 (av.) to 1979	5,26	-4.5	0.35	0.75	4.71	-0.31	8.75
Millet							
1961-65 (av.) to 1978	1.81 (1.32)[a]	-5.0	-1.14	2.88	1.01	-0.51	3.87
1968-70 (av.) to 1979	1.83 (0.58)[a]	6.60	0.99	3.20	1.68	-0.01	9.50

a. Pearl millet only.

Table 5. Summary of trends and projections of growth in demand and production of coarse grains (%/year).

Source	Developed market economies (DMEs)	Less developed market economies (LDMEs)	Low-income developing countries	All other developing countries	Centrally planned economies (CPEs)	World
	Region					
		Demand				
World Bank[a] (1977)		3.6				
Aziz (1976)[b]						
Food	0.52	2.49			1.16	1.92
Feed	2.16	5.30			2.74	2.72
Total	2.14	3.50			2.12	2.50
FAO (1971)[c]		2.74				
FAO (1979)[d]						
Food		2.41	2.28	2.55		
Feed		5.65	7.40	5.54		
Total		3.81	2.70	4.30		
		Production				
FAO (1981)[e]						
Scenario A		3.45				
Scenario B		2.78				
Ryan and von Oppen (1982)[f]	SAT / non-SAT	SAT / non-SAT				
Historical 1961-65 to 1979						
Sorghum	10.86 / 1.30	3.67 / 11.81			1,94	2.80
Millet	0.24 / -2.2	1.15 / -2.37			1.00	0.86

a. Projection up to 1985.
b. Projections from 1970 (actual) to 2000.
c. Projections from 1980-90.
d. Projections from 1975-2000 for barley, maize, millet, sorghum, and other cereals (except rice and wheat) using the optimistic scenario A in FAO (1981).
e. Projections for 1975-79 to 2000 for millet, sorghum, and other cereals (except rice and wheat).
f. Compound growth rates computed from the data files at the International Food Policy Research Institute, Washington, DC, USA.

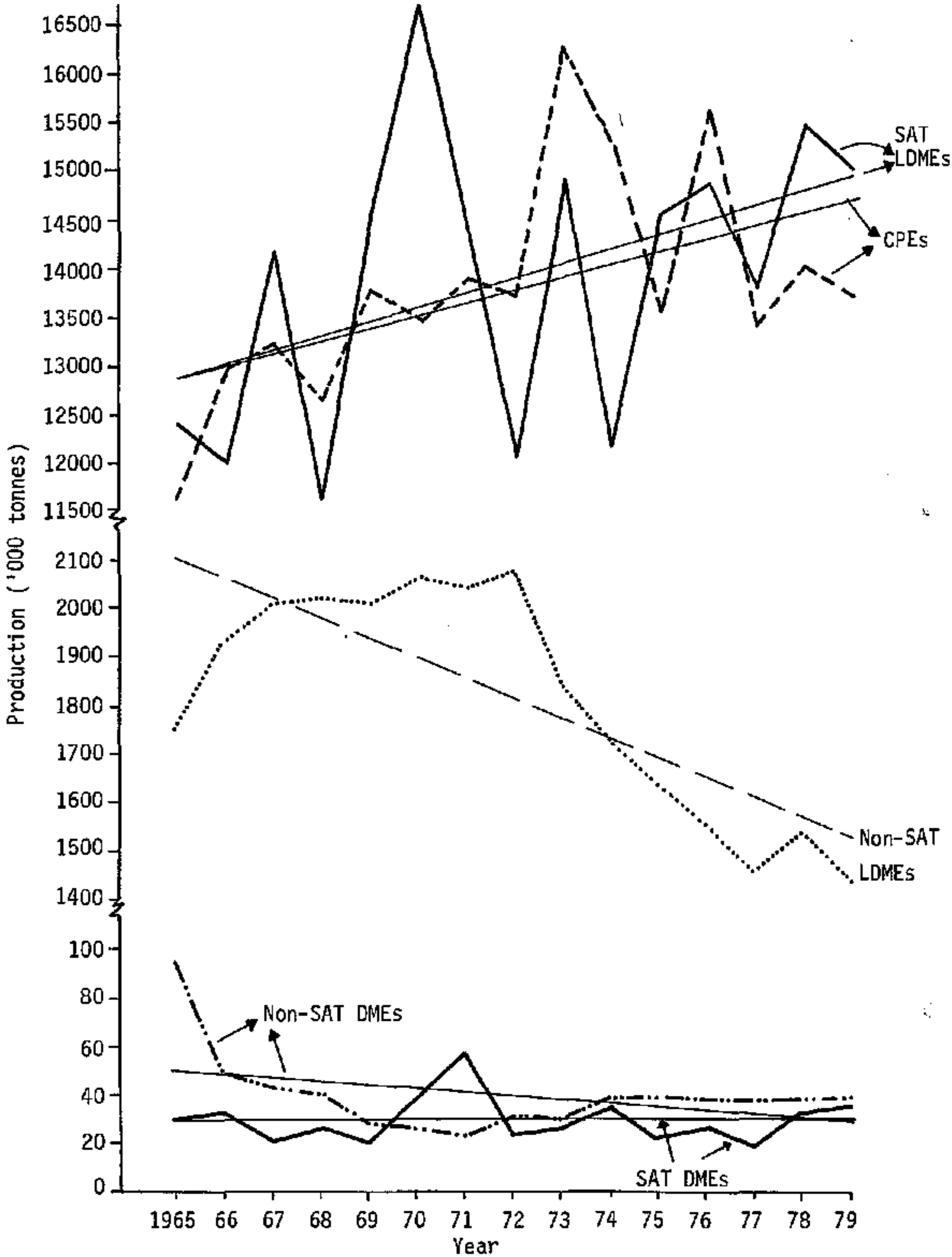

Figure 4. Millet production in five regions of the world.

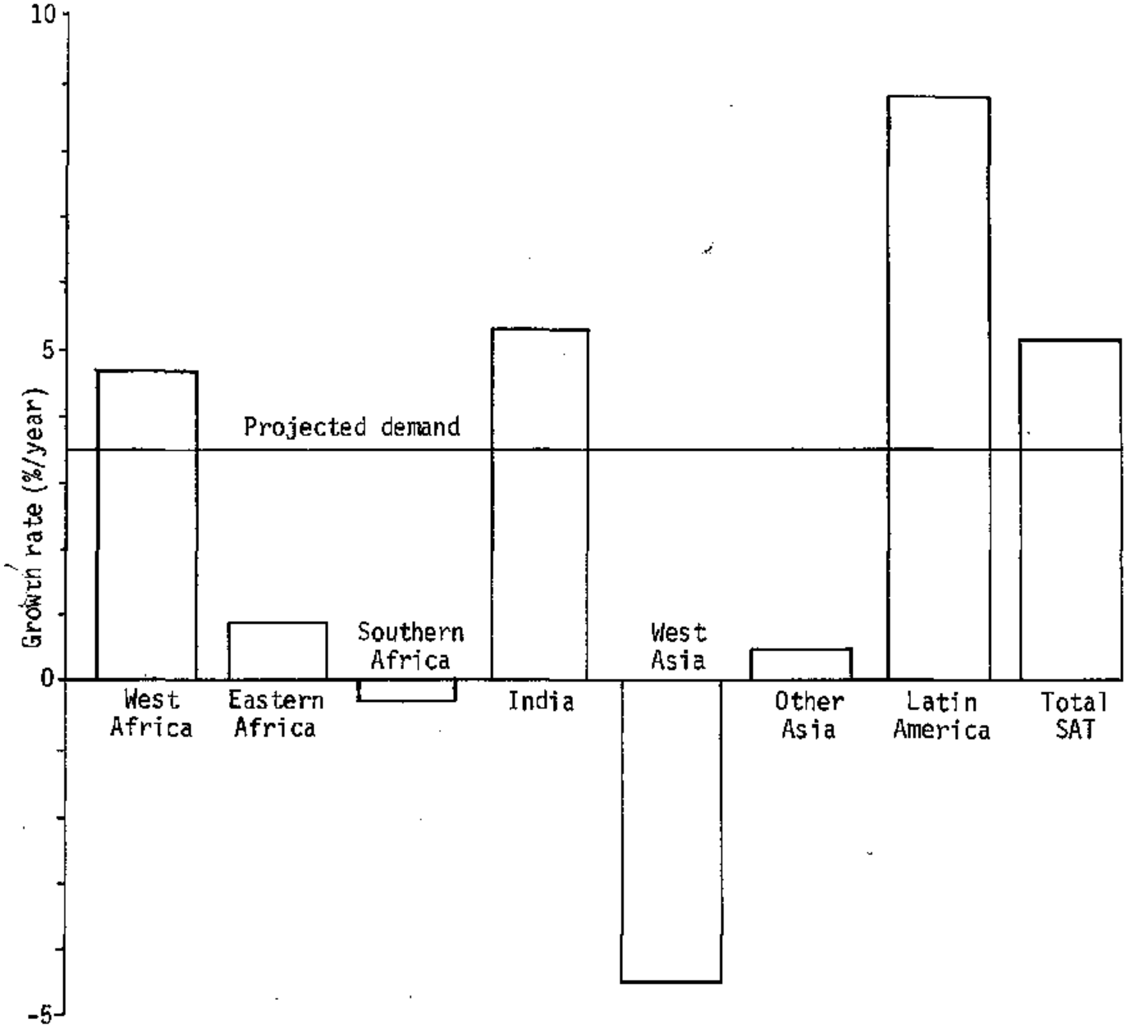

Figure 5. Growth in sorghum production 1968-70 to 1979 and projected demand to the year 2000 (%/year).

is likely to be their use for animal feed. Both Aziz (1976) and the FAO (1979) project that LDME demand for coarse grain feed will grow by around 5.6% per year compared with less than 2.5% for human food. In 1975, feed demand in 90 developing countries represented 19% of total domestic consumption of sorghum, millet, and other cereals, except rice and wheat. By 2000, the FAO (1979) projects that this figure will rise to 32%, with the proportion consumed directly by humans declining from 70 to 56%.

Sorghum and millets have considerable value in a traditional farming system as a source of fodder, fuel, and building material. In modern economies the vegetative growth of these plants in dry areas might be increasingly exploited through the breeding of special fodder varieties, sugar varieties for ethanol production, or other varieties for special technologies.

It seems clear from the above analysis that the developing countries within ICRISAT's mandate region will experience either increasing shortages of sorghum and millet at present prices or, more likely, at much higher prices, and will have large

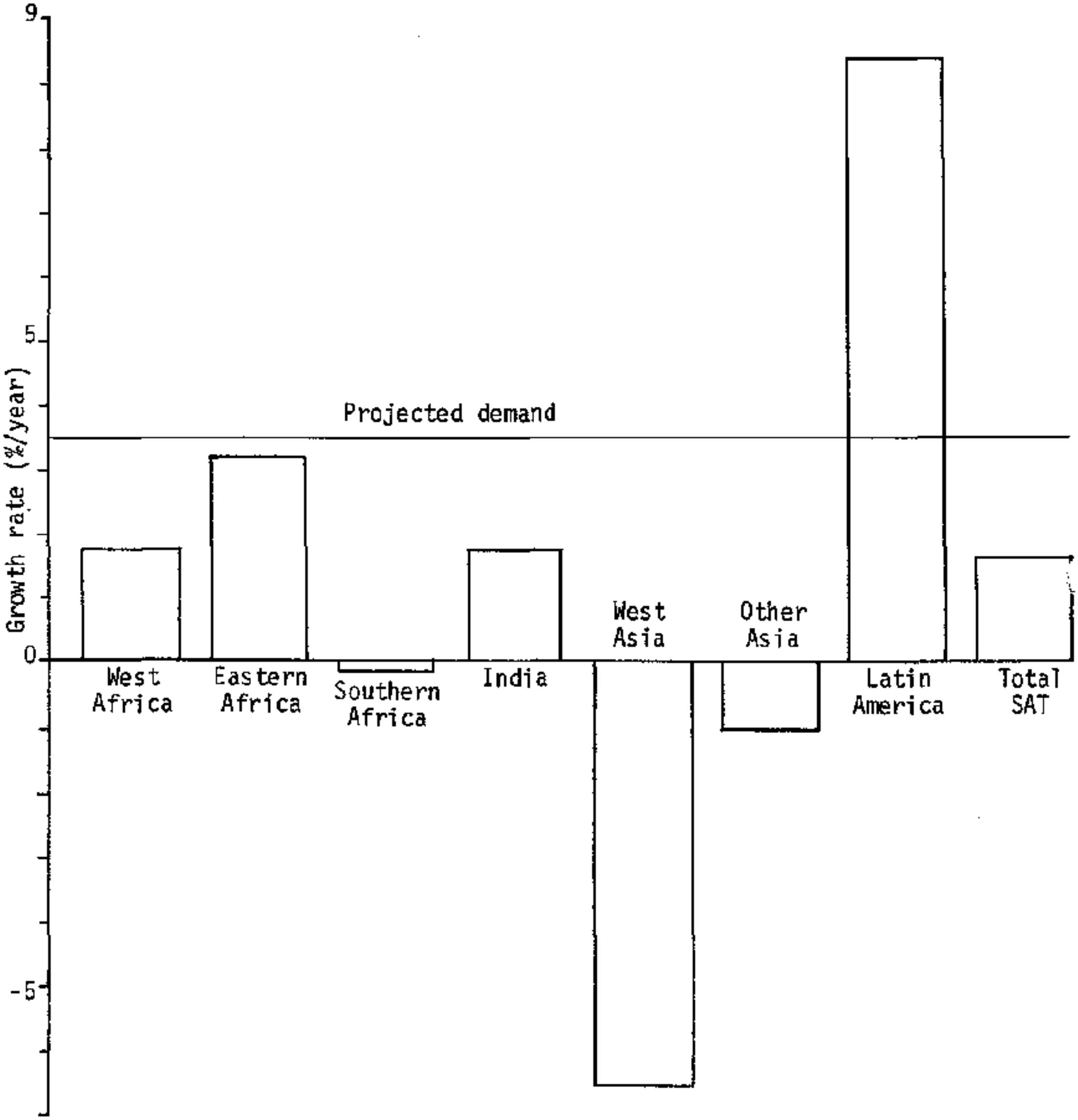

Figure 6. Growth in millet production 1968-70 to 1979 and projected demand to the year 2000 (%/year).

numbers of low-income people with unmet food needs. This will result partly from increasing competition between feed and food uses for the coarse grains in developing countries. Even by 1990 (commercial) food import gaps for sub-Saharan Africa are predicted to range from 9 to 21 million tonnes (USDA 1980). In addition, food grains needed to bring diets up to a minimum calorie consumption level of 2300 kcal/person per day are estimated at between 9 and 13 million tonnes. Hence, in sub-Saharan Africa the food and nutrition problem will involve questions of both production and distribution.

If the developing countries are to address their projected food deficit problems effectively, then greater attention must be paid to agricultural

Table 6. Arable land areas currently and potentially in use in developing countries.[1]

	90 developing countries	Region: Africa	Latin America	East Asia	West Asia	Low-income countries	Middle income countries
Potential arable area (million ha)	1843	676	693	335	139	846	997
Arable area in use (% of potential)							
1975	40	30	25	79	63	45	34
2000[2]	50	39	39	87	67	53	47
Arable area (ha) in use per capita of population							
1975	0.37	0.64	0.54	0.23	0.47	0.30	0.48
2000[2]	0.25	0.39	0.45	0.15	0.26	0.20	0.34

1. Source: FAO (1981, p. 66).
2. Using FAO's optimistic scenario A.

research and development. In this manner their self-sufficiency ratios can be improved and they may even generate exportable surpluses of agricultural products in which they have a comparative advantage (Thompson 1982). This strategy would help finance measures to overcome future cereal deficits and to encourage further development of the countries' economies. The World Bank (1982) specifically refers to the need for increased research in the hitherto neglected areas of rainfed crops, root crops (cassava), and coarse grains (sorghum and millet), so as to boost productivity in humid and semi-arid areas—particularly those in sub-Saharan Africa.

Sources of Future Production Growth

As mentioned earlier, the bulk (60%) of projected crop production increases in developing countries to 2000 is expected to derive from yield increases (Table 1). This will apply especially to the countries of West and East Asia, where population densities are high. Less than 10% of their production growth will be generated from expansion in the arable land area, as they already utilize more than two-thirds of their potentially arable land. The balance will come from increases in cropping intensity, particularly in West Asia. In sub-Saharan Africa, where less than one-third of the potentially arable land is at present cultivated, expansion of arable land is projected to contribute only 27% of future crop production growth. Surprisingly, the FAO (1981) expects yield increases to provide more than half of the future production increases in Africa and cropping intensity 22%. These two figures seem quite high,[4] especially when the share of irrigated land is only 2%. We would expect the relative contribution of area, intensity, and yield in Africa to be about the same as that projected by the FAO for Latin America, namely 55, 14, and 31%, respectively. These projections by the FAO (1981) would imply that more than 60% of the potentially arable land in Africa and Latin America would remain uncultivated (Table 6) in 2000.

Expansion of sorghum and millet production in regions relatively abundant in land, such as sub-Saharan Africa and Latin America, will involve further reduction in forest areas, possibly affecting the agroclimate, In such areas agroclimatologists can play a significant role in monitoring and predicting the likely effects of this on crop production. However, in West and East Asia, where yield and cropping intensity will be the major sources of production growth to the year 2000, the types of questions posed for agroclimatologists will be different, relating more to land-saving types of technological changes rather than the land-using types more relevant in Africa and Latin America. In the words of the World Bank (1982, p.39):

> Many still largely traditional farming systems that were sustainable with a low density of population are becoming increasingly

4. From 1961 to 1980, yield and intensity increases together contributed only 50% to production growth in West and eastern Africa (World Bank 1982, p. 57); in India they contributed 87%.

> strained by, and vulnerable to, the pressure of rising population, Spectacular environmental damage exemplifies the consequences of this pressure as land-hungry cultivators push into the tropical forests, up the hillsides, and across drought-prone, semi-arid savannah.

Location-specific technologies are needed to help ensure that production gains are achieved without unacceptably compromising the environment's ability to sustain production and population in the long run. As stated in the World Development Report (World Bank 1982, p.63):

> While irrigation has many advantages, the fact remains that rainfed areas constitute 80 percent of the developing world's cultivated land and support nearly two-thirds of its farmers. Yield increases still depend on the subtle interaction between soil, water, seeds, and sunlight, but the process is not as well understood under rainfed conditions as it is with irrigated land.

Agroclimatologists could render invaluable assistance in the formulation of research and development strategies by mapping zones where sorghum and millets (of various genotypes and phenotypes) could be grown with assurance. These could then be overlaid with maps describing projected population densities and unused arable land to indicate where land-using versus land-saving approaches would be relevant. The FAO's emerging crop suitability classification based on soil and water status in its agroecological study seems to be a step in the right direction (FAO 1979).

Other research areas such as weather forecasting to improve crop planning and yield stability remain important challenges for agroclimatological researchers. In conducting studies and analyses of the SAT, they should be aware of basic agroeconomic differences between regions: in high-potential areas researchers should strive for product-maximizing strategies, while in marginal areas output stability may be more appropriate.

The World Bank (1981) has enunciated a clear policy of selection of agricultural development project sites in sub-Saharan Africa, primarily on the basis of agricultural potential. This translates into those areas with good soil and adequate rainfall. The major challenge facing researchers in the future will be the more marginal areas, especially those in Africa:

> In the less-favored agricultural areas, development efforts had to fall back on traditional or slightly improved varieties of millet and sorghum, cowpeas, and traditional types of maize. The accumulated results of research are limited here. Also, the more marginal the ecological conditions, the more a variety needs to be adapted to the very specific conditions of the zone. Thus, tradeoffs have to be made between yield increases and drought resistance, and agricultural research has not yet succeeded in producing varieties adapted to these special conditions. (World Bank 1981, p.71).

The research strategy in Africa should emphasize measures that increase labor productivity—in particular, the use of farm implements, ox-draw;. cultivators, winnowers, threshers, and equipment aimed at reducing women's labor (mills, improved and accessible water supplies). Research aimed at enhancing land productivity should be concentrated especially in those regions where land is becoming a constraint and where potential for yield increases exists.

As yield increases have been the major source of production growth of crops, especially in the more densely populated regions of the developing world, it is instructive to examine yield scenarios used by various agencies concerned with projections of sorghum and millet production. The FAO (1979) projects that yields of millet, sorghum, and other cereals in the developing countries will rise from an average of 740 kg/ha in 1375 to 1200 kg/ha in 2000 (Table 7). This represents a 64% increase. The largest yield growth is projected for East Asia (69%) and the lowest for West Asia (47%). ICRISAT's projection of historical yield trends of a mean of 25 kg/ha per year for the SAT LDMEs (Table 3) gives a yield of more than 1400 kg/ha—well above the 1200 kg figure of the FAO's optimistic scenarios. However, projecting historical yield trends for millets of 4 kg/ha per year amounts to a yield of only 600 kg/ha in 2000.

In a poll we conducted, principal scientists in the cereal programs at ICRISAT, using Delphi techniques, at current levels of funding, projected sorghum and millet yields for India and Africa in farmers' fields in the year 2000 (Table 8).

The scientists were asked to provide their own

Table 7. Yield levels (kg/ha harvested) of sorghum, millets, and other cereals[1] used by FAO in its projections[2] for developing countries.

Year	Region				
	90 developing countries	Africa	Latin America	East Asia	West Asia
1975	740	630	2010	580	890
1990	990	790	2540	800	1090
2000	1210	940	3010	980	1310

1. Except wheat, rice, maize, and barley.
2. Source: FAO (1979).

Table 8. Projected yields (kg/ha) of sorghum and millet in farmers' fields to the year 2000.

Year	Sorghum		Pearl Millet	
	India	Africa	India	Africa
1990	1240	950	770	610
2000	1450	1100	950	770

Source: Results of a poll of principal scientists in the Cereal Programs at ICRISAT.

best estimates but, of course, they might have been influenced in their judgment by other estimates. The results from this poll confirm that yield projections in Table 7 are well within the range of possibility as seen by cereal breeders at ICRISAT The ICRISAT scientists also believe that yields in on-farm tests of new elite cultivars and practices for sorghum in 2000 could be more than double those being obtained by farmers now, with new genotypes in variety trials yielding more than three times what farmers would be achieving in their fields.

Increases in crop yields and production as a result of research and development may be accompanied by increased variability of production. For example, in non-SAT DMEs with current sorghum yields of over 3400 kg/ha, production variability is more than 80% (Table 3).[5] In contrast, although SAT LDMEs have much lower yields of around 950 kg/ha, they also have a much lower production variability of 13%. The same relationships however do not appear to hold for the millet regions.

In an analysis of the sources of instability in India's foodgrain production, Hazell (1982) found that after the mid-1960s the coefficient of variation of total foodgrain production increased from 4 to 8%. Most of the explanation was the increase in crop yield covariances of different crops in the same and in different states, and an increase in the variability of crop areas sown, which are now more positively associated with yields. About three-quarters of the increase of 2307% in India's pearl millet production variance between the two periods can be attributed to increases in interstate production covariances. Most of the rest is accounted for by variance increases in only three or four states, especially in Rajasthan. Of the 139% increase in the variance of India's sorghum production, 90% is attributable to Maharashtra state, probably largely a result of the disastrous 1972/73 drought.

5. Production variability is measured here as the dispersion around the linear trend, or 100 (1 -R^2), where R^2 is the coefficient of multiple determination of linear trend lines fitted from 1961-65 (average) to 1979.

Hazell postulates that the improved seed and fertilizer technologies have probably had less of a role in this than changes in weather patterns and the more widespread use of irrigation and fertilizers at a time when the supplies of these inputs were less reliable. In such circumstances he doubts the value of research strategies aimed at developing less risky technologies (e.g., disease-, insect-, and drought-resistant cultivars) for individual crops as a means of stabilizing India's total cereal production, as this will not address the covariance problem. Policies to stabilize supplies of fertilizers and electric power for irrigation pumps might be more effective. These conclusions require further research before they are used to formulate policies. Agroclimatologists must play a major role in such studies if the relationships between weather patterns and production are to be quantified.

Conclusion

To the year 2000, it seems that for the world as a whole there will be a balance between the growth in demand and supply of all agricultural products. This also applies to sorghum. But world demand growth for coarse grains is expected to far exceed projected increases in world millet production. Sorghum production in the developing countries of the semi-arid tropics is projected to grow faster than demand, although some regional imbalances will arise; however, major deficits of millet are projected for most regions.

Of the SAT regions, sub-Saharan Africa will probably have the largest coarse grain deficits by the end of the century, due primarily to the high population growth rates that will continue up to that time. India should have no difficulty meeting projected sorghum demand growth if the annual sorghum production growth rate of the 1970s (>5%) can be maintained. However, millet production (particularly pearl millet) has been growing more slowly in India of late, and unless this changes there will be large deficits by 2000.

All these scenarios imply that there will be need for a steady increase in research and development on sorghum and millets in the marginal areas in which they are grown in the semi-arid tropics. The World Bank (1981) recognizes this need, which is greatest in sub-Saharan Africa:

> More intensive research should be launched which aims at finding technologies appropriate to these mainly arid and semi-arid regions. Until this technology is discovered, these areas should be provided with basic economic and social infrastructure which will eventually enable the local population to make use of future opportunities. (World Bank 1981, p.52).

In planning this research effort agroclimatologists can play a key role through base-data analysis to delineate zones where breeders, soil scientists, agronomists, and others can develop improved sorghum and millet genotypes, phenotypes, and practices. Such analysis and mapping should involve overlaying present and projected population densities in order to identify where technologies need to be more of the land-saving (labor-using) versus the land-using (labor-saving) type. Mapping of regions by agroclimatologists according to the degree of riskiness of crop production can assist in the design of food security policies. Relating the extent of intercropping practiced by farmers to such measures can also be valuable in designing research strategies in cropping systems.

Yield increases will play a major role in the future growth of sorhgum and millet production in the developing countries, especially in the more densely populated region of Asia. Recent yield trends will have to be substantially improved, particularly for millets in Africa, if major food deficits are to be avoided. Even if increased yields generate greater production instability, this may be an acceptable price to pay for greater general availability of food grains. This danger could be reduced, however, if yield stability could also be improved simultaneously through incorporation of drought, pest, and disease resistance or tolerance; indeed, this may be a prerequisite to adoption of production-increasing technology. However, it may not completely insulate SAT countries from production variability, Measures designed to stabilize consumption through appropriate storage and international trade policies may be more effective in alleviating the consequences of residual instability in food-grain production.

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