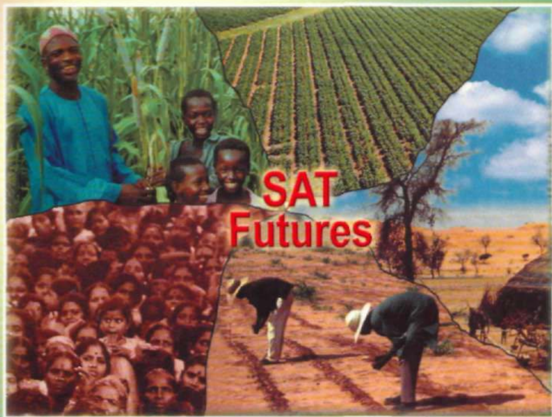

Future Challenges and Opportunities for Agricultural R&D in the Semi-Arid Tropics

International Crops Research Institute for the Semi-Arid Tropics

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Abstract

This publication reviews past trends, summarizes the major constraints to income growth, food security, poverty alleviation, and environmental sustainability, and identifies future R&D strategies and priorities for the semi-arid tropics (SAT). The study focuses on sub-Saharan Africa and South Asia, where poverty, food insecurity, child malnutrition, and gender inequalities are widespread.

ICRISAT's mandate cereals are becoming less important in household food budgets in Asia, but will remain staple foods of the poor in the driest areas, especially in sub-Saharan Africa. In addition, the anticipated growth in demand for livestock products will increase the derived demand for feedgrains, including sorghum and millet. Water will likely be the primary constraint throughout the SAT in the coming years. Research could focus on identifying genes that can improve water-use efficiency and drought tolerance. Other areas include crop and systems modeling, watershed management, and water policy. Poor soil fertility is another key issue, and could be addressed using an integrated soil, water, and nutrient management approach. Research to improve nutrient-use efficiency will be critical, especially in Africa. Research is needed on the extent, effects, and processes of land degradation.

Limiting the mandate to the current five crops may reduce ICRISAT's future ability to impact on the welfare of the SAT poor. A thematic, problem-driven agenda would be more appropriate. Future research and policy agendas must account for regional differences, in resource endowments, infrastructure, etc. For example, labor-intensive technologies would be appropriate for the poor in South Asia, and labor-saving ones for sub-Saharan Africa. HIV/AIDS is a serious constraint to labor availability in Southern and Eastern Africa, and must receive explicit attention in R&D strategies. ICRISAT's research agenda for the future could also include: village-level studies to better understand the apparent poverty-environmental degradation treadmill; reduction of marketing and transaction costs, especially in sub-Saharan Africa; strengthening the capacities of SAT farmers and national research systems with the aid of information technology; and development of gender-sensitive **technology** options.

Résumé

Recherche et développement agricoles aux tropiques semi-arides: défis et opportunités futurs. La présente publication examine les tendances antérieures, résume les principales contraintes à l'accroissement des revenus, à la sécurité alimentaire, à la réduction de la pauvreté et à la durabilité de l'environnement et identifie les stratégies et priorités futures en matière de R&D pour les zones tropicales semi-arides. L'étude porte essentiellement sur l'Afrique subsaharienne et l'Asie du Sud, où la pauvreté, l'insécurité alimentaire, la malnutrition des enfants et les inégalités entre les hommes et les femmes sont très répandues.

Les céréales qui font partie du mandat de l'ICRISAT deviennent moins importantes dans les budgets alimentaires des ménages en Asie, mais demeurent les aliments de base des pauvres vivant dans les zones les plus arides, notamment en Afrique subsaharienne. En outre, l'accroissement prévu en ce qui concerne la demande pour les produits d'origine animale augmentera la demande dérivée en céréales pour l'alimentation du bétail, dont le sorgho et le mil. Dans les années à venir, l'eau constituera probablement la principale contrainte dans les zones tropicales semi-arides. La recherche pourrait mettre l'accent sur l'identification des gènes susceptibles d'améliorer l'efficacité de l'utilisation de l'eau et la tolérance à la sécheresse. Les autres domaines de recherche sont: la modélisation des cultures et des systèmes, la gestion des bassins versants et la politique de l'eau. La faible fertilité des sols constitue un autre problème majeur auquel on pourrait faire face en adoptant une approche intégrée sol-eau-éléments nutritifs. La recherche visant à améliorer l'efficacité de l'utilisation des éléments nutritifs sera essentielle, notamment en Afrique. Il est nécessaire de mener des recherches sur l'ampleur, les effets et les processus de dégradation des terres.

La limitation du mandat actuel à 5 cultures pourra réduire la capacité future de l'ICRISAT à avoir un impact sur le bien-être des pauvres des zones tropicales semi-arides. Un programme thématique, basé sur les problèmes serait plus approprié. Les futurs programmes de recherche et de politiques doivent tenir compte des différences régionales en termes de dotation en ressources, d'infrastructures, etc. Par exemple, les technologies qui nécessitent une importante main d'œuvre conviendraient aux pauvres vivant en Asie du Sud et celles qui facilitent le travail seraient plus adaptées aux pauvres de l'Afrique subsaharienne. Le VIH/SIDA constitue une contrainte majeure à la main d'oeuvre en Afrique australe et orientale et doit faire l'objet d'une attention explicite dans les stratégies R&D. Le futur programme de recherche de l'ICRISAT pourrait également comprendre des études menées au niveau villageois pour mieux comprendre le lien apparent pauvreté-dégradation environnementale; la réduction des coûts de commercialisation et de transactions, notamment en Afrique subsaharienne; le renforcement des capacités des paysans des zones tropicales semi-arides et des systèmes nationaux de recherche avec l'aide des technologies de l'information; et le développement d'options technologiques tenant compte du genre.

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We appreciated the comments we received on earlier drafts of the paper from ICRISAT management and staff. Needless to say the content and conclusions in the paper are our responsibility and others cannot be implicated for any sins of omission and/or commission.

James G Ryan **Dunstan C Spencer**

Contents

Acronyms

ADB	Asian Development Bank
AEZ	agroecological zone
CGIAR	Consultative Group on International Agricultural Research
CIAT	Centro Internacional de Agricultura Tropical
CIMMYT	Centro Internacional de Mejoramiento de Maiz y del Trigo
DFID	Department for International Development, UK
FAO	Food and Agricultural Organization of the United Nations
GDP	gross domestic product
GMO	genetically modified organism
IADP	Intensive Agricultural Districts Program, India
IARC	international agricultural research center
IBSRAM	International Board for Soil Research and Management
ICAR	Indian Council for Agricultural Research
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFPRI	International Food Policy Research Institute
ILRI	International Livestock Research Institute
IPG	international public good
IPM	integrated pest management
IPR	intellectual property rights
IRRI	International Rice Research Institute
ISNAR	International Service for National Agricultural Research
IT	information technology
IWMI	International Water Management Institute
LAC	Latin America and the Caribbean
NARS	national agricultural research system (s)
NGO	nongovernmental organization
QOL	quality of life
R&D	research and development
SADC	Southern African Development Community
SAP	Structural Adjustment Programs
SAT	semi-arid tropics
SEA	Southern and Eastern Africa
SSA	sub-Saharan Africa
TAC	Technical Advisory Committee of the CGIAR
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
VLS	village-level studies
WANA	West Asia and North Africa
WCA	West and Central Africa
WTO	World Trade Organization

Summary

Background

This publication is the result of a study commissioned by ICRISAT. It analyzes future trends in agriculture in the semi-arid tropics (SAT) of the developing world, as part of the planning of a new vision and strategy for the Institute. The study reviews trends in SAT agriculture for the period 1960-2000; summarizes the major constraints limiting income growth, poverty alleviation, food security, and environmental sustainability now and towards 2020; discusses the implications for future research and development (R&D) strategies and priorities for the SAT; and examines possible roles for ICRISAT, national research systems, NGOs, and the private sector in implementing these R&D activities.

The semi-arid tropics cover parts of 55 developing countries. These areas have a population of over 1.4 billion, of whom 560 million are classified as poor. Of the total poor, 70% live in rural areas. The study focuses on two regions - sub-Saharan Africa and South Asia - where poverty, food insecurity, child malnutrition, and gender inequalities are widespread. For example, over 80% of the total SAT poor (and one-third of the total poor in the developing world) live in sub-Saharan Africa and South Asia.

Trends and opportunities in the SAT

Future trends in the semi-arid tropics - and correspondingly, research agendas - will be shaped by several factors. Population growth rates in the developing world have been declining in recent years, and this is expected to continue (projected growth rates for the period 1995 to 2015 are 1.4% per year). However, the absolute number of people - and of poor people - will continue to rise. Urbanization will increase rapidly; more than half the population in Asia and Africa will live in urban areas by 2025. Even so, poverty is expected to remain a primarily rural phenomenon for the next 25 years.

In developing countries as a group, the number and proportion of undernourished people has fallen in recent decades (currently 800 million, or 18% of the population). However, 17 of the 36 countries with low food consumption (per capita below 2200 kcal per day) are in the SAT. Malnutrition, especially among children, will continue to be a serious problem. In 2020 sub-Saharan Africa and South Asia will still have about 80% of the world's undernourished children; and within these regions, the incidence and extent of child malnutrition will be greatest in the SAT zones.

One major issue is the current and projected growth in the livestock sector. Demand for meat and milk in developing countries is projected to rise by 2.8% and 3.3% per year respectively to 2020; feedgrain demand is expected to grow at 2.4% per year. This anticipated growth represents an opportunity, particularly because most smallholder farming systems in the SAT are based on a mix of crops and livestock. The derived demand for livestock feedgrains (including ICRISAT's mandate cereals) represents another opportunity.

Consumption of animal products (milk, meat, eggs) is growing in importance in diets, even among the poor. ICRISAT's mandate cereals are becoming less important, but will remain staple foodgrains of the poor in the driest areas, where few alternative crops can be grown. For example, in India, the shares of sorghum and millet in the household food budgets of the poor fell 68%) in rural areas and 51 % in urban areas between the early 1970s and the early 1990s. Pulses represented a small (3-5%) but stable share. Consequently the ability of research on these crops to impact on poor consumers (through productivity gains leading to lower prices) has declined markedly. However, the anticipated growth in demand for livestock products will increase the demand for livestock feeds. This raises the issue of the value and desirability of a shift in ICRISAT's breeding emphasis to feedgrain sorghum and millet, away from the Institute's traditional focus on foodgrains, and how (or whether) such a shift would especially benefit poor consumers and producers of these crops.

In South Asia, relatively labor-using technological change and increased demand tor non-farm labor from rural industries with high labor/capital ratios would seem to be favorable to the poor. Labor-saving technological change will in general be better for the more affluent in this region.

In sub-Saharan Africa on the other hand, crop income is more important among the poor than among the more affluent, as is livestock income and remittances from emigrants. Crop production is viewed primarily as a subsistence activity, not as a source of cash income. Commercial crops and livestock are seen as keys to income growth for smallholder farmers. Non-farm income is more important for the non-poor. Thus, increased non-farm income opportunities and labor-saving technological change may be most appropriate for sub-Saharan Africa, particularly in view of rapidly growing fatalities from AIDS, and greater feminization of agriculture as men migrate to urban areas in search of wage labor.

Based upon the number of poor people in India (absolute numbers as well as proportion of poor in the total population), there may not be a strong case for different R&D priorities in the so-called high- and low-potential zones in rainfed areas. However, emerging evidence suggests that investments in roads and R&D in higher-potential areas generate much greater productivity gains and poverty reductions than in lower-potential rainfed areas. Notably, such investments in both types of rainfed areas generated greater benefits than in irrigated zones.

National research systems, particularly in South Asia but also in sub-Saharan Africa, have grown much stronger over the past 20 years, in terms of staff strength, skills, and experience. Agricultural research continues to be dominated by the public sector. Private sector research plays a limited but growing role in Asia, but very little in sub-Saharan Africa. Biotechnology and genetic improvement seem to be the private sector growth areas. Intellectual Property Rights, not only on genes but also on transformation processes and the like, does and will continue to constrain access by national public-sector and international organizations to proprietary technology. Opportunities for public-private partnerships do exist, but arc limited by commercial, biosafety, and associated public liabilities.

Irrigation growth rates are declining in South Asia: 2.1% per year from 1961 to 1971, 1.24% during 1981-90, and a projected 0.6% per year from 1995 to 2030. Projections are that SAT countries will be among the worst affected by water scarcity in the coming decades. It is thus imperative to improve water-use efficiencies in the SAT. This will open up new opportunities in genetic engineering of drought tolerance and water-use efficiency genes, including transgenic approaches involving both ICRISAT mandate and non-mandate crops.

Soil fertility is another key issue. Growth of fertilizer use has declined substantially in the 1990s in all SAT regions. In the SAT of sub-Saharan Africa, nutrient removal exceeds replenishment by a factor of more than three. Hence the importance of research to improve nutrient-use efficiency, especially in Africa. This should involve an integrated soil, water, and nutrient management approach. Much natural resource management research can be location-specific; it is therefore important to clearly specify an agenda that justifies international R&D.

Conclusions

Water. This will likely be the primary constraint throughout the SAT in the coming years. Research could focus on identifying genes (not only from current mandate crops, but also from other species) that can improve water-use efficiency and confer drought tolerance. The research agenda could also include crop and systems modeling, integrated watershed management, water policy, and institutional innovations in water resource trading, allocation, pricing, and management.

Species mandate. Limiting the mandate to the current five crops may reduce ICRISAT's future ability to impact on the welfare of the SAT poor. Several factors support such a conclusion: (i) the decline in importance of these crops as income sources and as components of the consumption basket of the poor, (ii) changes in the comparative advantage of commodity production due to globalization and liberalization, (iii) the increased importance of commercial crops and livestock in SAT farming systems, (iv) new developments in science, particularly biotechnology and information technology. A commodity approach to agricultural R&D will unduly inhibit ICRISAT and its partners in the future pursuit of their missions. In contrast, a thematic, problem-driven agenda would enable partners to play different roles according to their complementary advantages.

Livestock and feedgrains. The anticipated growth in the livestock sector in developing countries will create growth in the demand for feedgrains like sorghum and millet. There is hence a compelling case for ICRISAT to shift its emphasis in genetic improvement of sorghum and millet from foodgrain to feedgrain traits. A bioeconomic study of the value and desirability of this shift is required. Increased attention is needed on the integration of livestock in mixed crop-livestock systems, beyond the current emphasis on improving stover quality. Collaboration with the International Livestock Research Institute in this area could be productively enhanced.

Regional strategies. SAT countries in South Asia and sub-Saharan Africa have inherent differences in characteristics, which must be considered while defining agricultural R&D strategies. These include differences in resource endowments, infrastructure, and national research capacities; the nature and extent of poverty and malnutrition; roles of livestock in production and consumption; and causes and extent of land degradation. Correspondingly, the two regions may need different R&D strategies. The alarmingly high incidence of HIV/AIDS is a serious constraint to labor availability in Southern and Eastern Africa. This problem must now receive explicit attention in R&D strategies.

Socioeconomics and policy. ICRISAT must monitor changes in the external environment surrounding the SAT. This information will help inform future R&D strategies and priorities, and target efforts more effectively at the poor. One way to achieve this is by reviving village-level studies in both South Asia and sub-Saharan Africa. Issues such as the lines of causality in the apparent poverty-environmental degradation treadmill can only be fully understood at the level of the household and village.

Land degradation. Research is needed to understand the nature, extent, consequences, and trends in land degradation in the SAT. This should include the effects of soil loss and nutrient depletion on productivity, water pollution, salinity, and loss of biodiversity.

Postharvest technology and marketing. Research on reducing the high marketing and transaction costs in the SAT, especially in sub-Saharan Africa, is likely to have higher rewards than a focus on developing new postharvest and processing technologies for ICRISAT's mandate crops. The Institute can play a catalytic role in fostering the exploitation of new commercial opportunities for mandate (and non-mandate) crops. In the process, it is possible that technology options that have been available "on the shelf" for some time will suddenly become viable, especially if good partnerships exist among the public and private sectors, and farmers.

Balance between research and development. Strengthening the capacities of SAT farmers and national research systems with the aid of information technology will lead to significant rewards. ICRISAT can play a key facilitative role in the process of information delivery/exchange and training. Improved access to information technology will also enable SAT farmers to obtain real-time information on markets, prices, weather and pest and disease epidemic forecasts. This can further open new commercial opportunities and reduce the inherent risks of SAT agriculture.

Feminization of SAT agriculture. Increased seasonal and permanent male migration from rural to urban areas is leading to the feminization of SAT agriculture, especially in sub-Saharan Africa. This is accompanied by increasing labor scarcities. R&D institutions need to recognize the need for labor- and capital-saving technology options that are purposefully designed to be gender-sensitive.

Introduction

The primary purpose of this paper is to provide some background information and analysis on possible future trends and scenarios for the semi-arid tropics (SAT) of the developing world. It is intended these will be factored into the planning of a new vision and strategy for ICRISAT

The terms of reference for this study cover four topics:

- A review of trends in SAT agriculture for the period 1960-2000
- A summary of major constraints limiting income growth, food security, and environmental sustainability now and towards 2020
- A review of priorities for agricultural research and development (R&D) activities in the SAT towards 2020 in line with the CGIAR vision exercise
- A review of possible roles for ICRISAT, NARS, NGOs, and the private sector in implementing these R&D activities.

An extensive review of the literature provided the major input to the study, along with a compilation of relevant databases. Unfortunately, except for countries such as India, it was not possible from readily available national data to delineate statistics pertaining only to the SAT regions within a country. Countries were therefore classified as small, medium, or large based upon the proportion of SAT area in the total area (see Appendix). This enabled some separation of trends in largely-SAT countries versus countries where the SAT is a minor part of agriculture. We place particular emphasis on sub-Saharan Africa and South Asia, which are of primary concern to the Consultative Group on International Agricultural Research (CGIAR) in its current vision and strategy exercise.

The paper has four chapters. Chapter 1 is an introduction. Chapter 2 focuses on the various dimensions of poverty and food and nutrition security and how these might be relevant to future R&D priorities. It thus addresses primarily the second and third terms of reference. Chapter 3 analyzes recent trends and projections of a number of key parameters and draws inferences for the future. It thus focuses on the first and third terms of reference. The concluding Chapter 4 synthesizes insights from the earlier sections and derives **implications more specifically** for **ICRISAT** and its partners, as indicated in the fourth terms of reference. The paper ends with Appendices containing information on agroecological classifications and reports of meetings conducted as part of the broader SAT Futures exercise, and a comprehensive list of references.

Dimensions of Poverty in the SAT and their Implications

The CGIAR has always emphasized the improvement of nutrition and economic well-being of low-income people (TAC 1992, pp 9-13). More recently, measures of the locus, breadth, and depth of poverty have been more explicitly factored into the priority assessment (TAC 1996, pp 16-30). The new Goal Statement of the CGIAR is:

> *To reduce poverty, hunger, and malnutrition by sustainably increasing the productivity of resources in agriculture, forestry, and fisheries. (CGIAR 2000, p 2)*

Poverty alleviation has become a primary goal of overseas development assistance from both donor countries and international financial institutions.[1] It is thus appropriate that the nature and extent of poverty be an integral component of this study - indeed an overarching consideration in assessing constraints and opportunities. However, as Dalrymple (1999) reminds us, the CGIAR's pursuit of this goal should respect the comparative advantage of the Centers in producing international public goods, and recognize that poverty is basically a national responsibility. International agricultural research centers (IARCs) can and should, however, focus on poverty alleviation in defining their international agendas, in partnership with national agricultural research systems (NARS).

Understanding the determinants of poverty

The challenge before R&D institutions is to understand the underlying determinants of poverty and the pathways to its alleviation. The sustainable livelihoods approach to understanding poverty was highlighted in the 1997 UK Government White Paper on International Development (DFID 1997). It provides an analytical structure to help diagnose and design interventions to help the poor achieve preferred

1. Two reports were prepared at the G8 Summit in July 2000. These discussed poverty trends and issues, the international community's goals on poverty reduction, and the progress being made (AfDB et al. 2000).

livelihood outcomes. !t recognizes five capital assets on which these livelihoods depend; human, natural, financial, social, and physical. The poor use these interchangeably. Five ICRISAT Brainstorming Workshops were conducted in 2000 as a component of the SAT Futures exercise, and used this approach to identify the primary constraints and opportunities in the SAT. The outcomes of these workshops are described in the appendix.

Wiebe (1998) has used various indicators of these five assets. Data for sub-Saharan Africa and South Asia (Table 1) indicate that natural capital is a greater constraint in South Asia than in sub-. Saharan Africa but that the reverse is true for produced or physical capital and financial capital. There is not much difference between the two regions on the basis of social and human capital using these measures.

Along with adjustments to savings rates to better reflect the dissaving implied in natural resource degradation, economists have begun trying to better incorporate changes in resource quality and quantity into measures of income and wealth. Table 2 reflects World Bank estimates (1997) as reported by Wiebe. Per capita

Table 1, Selected livelihood capital asset indicators.

Indicator	Sub-Saharan Africa	South Asia	All low/mibdle income economies
Natural capital			
Cropland (ha/capita 94-95)	0-3	0.2	0.2
Cropland (% of total land area 94)	7	45	11
Cropland (annual % change in area 65-S9)	0.7	0.2	0.5
Physical capital			
Fertilizer consumption (kg/arable ha 92-93)	15	74	79
Mechanization {tractors/1000 arable ha 94)	1	14*	8
Social capital			
Health expenditures ($ per capita 90)	24	21	41
Democracy index {rank 94; least democratic = 1)	2	3	na
Human capital			
Population (millions mid 95)	583	1243	4771
Population growth (annual % change 90-95)	2.6	1.9	1.6
Adult literacy (% 95)	57	49	70
Life expectancy (years 95)	52	61	65
Financial capital			
Gross savings (% of GDP 95)	16	20	22
Genuine savings (% of GNP 93)	-1	6	9

na = data not available
' For all of Asia, not South Asia

Source:Adapted From Wiebe1998

Table 2. Sources of wealth.

indicator	Sub-Saharan Africa: Eastern and Southern Africa	Sub-Saharan Africa: West Africa	South Asia
'000 dollars per capita			
Natural capital	3	5	4
Physical capital	7	4	4
Human capital	20	13	14
Total wealth	30	22	22
Percentage of total wealth			
Natural capital	10	21	16
Physical capital	25	18	19
Human capital	66	60	65

Source: Wiebe 1998

Table 3. Total rural poor in developing countries, 1996.

	Number (millions)	% of total population
Arid/semi-arid	379	27
Rainfed	199	28
Irrigated	180	25
Humid/subhumid	500	25
Rainfed	259	25
Irrigated	241	25
Temperate/cool	116	24
Rainfed	89	51
Irrigated	27	9
Total rural	995 (75% of total no. of poor)	26

Source: Derived from TAC/FAO database as described by Gryseels et al. 1997, using Sere and Steinfield 1996 as described in Thornton et al. 2000

levels of these capital assets are similar in West Africa and South Asia. Total wealth per capita is highest in Southern and Eastern Africa, some 36% higher than the other two regions, largely because of better endowments of physical and human capital. In each region human capital represents around two-thirds of total wealth. Natural capital comprises a much larger share in West Africa and South Asia, while physical capital is more important in Southern and Eastern Africa.

The World Bank's Participatory Poverty Assessment Project (PPAP) provides useful information on the determinants of poverty and the pathways to its alleviation. PPAP employs participatory and qualitative research methods to understand the perceptions and experiences of the poor, and their interactions with institutions from the level of the state to the household. The project obtained information from 60,000 poor people from 60 countries (Narayan et al. 2000).

PPAP has revealed similarities in the experiences of the poor everywhere: hunger, deprivation, powerlessness, violation of dignity, social isolation, resilience, resourcefulness, solidarity, state corruption, rudeness of service providers, and gender inequity. The poor rarely speak of income but focus instead on managing assets - physical, human, social, and environmental - as a way of coping with their vulnerability. The main conclusions are:

- Poverty is multidimensional
- The state is largely ineffective in reaching the poor
- NGOs play a limited role, forcing the poor to depend primarily on their own networks
- Households are crumbling under the stresses of poverty
- The social fabric - the poor's only "insurance"- is unraveling.

Table 4. Total urban poor in developing countries, 1996.

	Number (millions)	% of poor	% of total population
Total urban poor	326	25	8
Total rural and urban poor	1321	100	34

Source: Derived from TAC/FAO database as described by Gryseels et al. 1997, using Sere and Steinfield 1996 as described in Thornton et al. 2000

Extent of poverty in developing countries

Using the TAC/FAO databases, it is estimated that in the mid 1990s there were about 1.3 billion people living below the poverty line in developing countries.[2] Some three-quarters of these were in rural areas (Tables 3, 4). The poor represent about one-third of the population of developing countries. Accordingto the World Food Summit (TAC 1997, p 24) since the 1970s the number of women below the poverty line has increased by 50% and the number of men by 30%. This means that women today account for over 70% of the 1.3 billion total poor. Jazairy et al. (1992, pp 273-274) estimate that women represent about 60% of the rural poor.

Of the rural poor, we estimate that around 380 million (38%) reside in the arid/semi-arid tropics (Table 3)[3] and another 500 million (50%) in the humid/subhumid tropics. Within each of these agroecological zones rainfed areas have slightly more poor people than do the more irrigated areas. A number of groups are vulnerable, including small farmers, the landless, women, and indigenous ethnic groups; but smallholder farmers and the landless represent more than 90% of those who are vulnerable (FAO 1996, p 1).

There are important differences between the arid/semi-arid tropics in Asia and sub-Saharan Africa. The former contains an estimated 237 million rural poor, i.e. three quarters of the total. Most of these reside in South Asia and some 62% of them are in the

2. Defined as those living on US$ 1 or less a day.

3. The TAC database gives combined figure* for arid and semi-arid zones.

more irrigated zones (Table 5). In sub-Saharan Africa on the other hand, 96% of the 79 million rural poor in the arid/semi-arid tropics reside in rainfed areas.

The UNDP human development index (HDI) for the 36 SAT countries was 0.56 in 1998, compared to 0.67 for non-SAT developing countries (calculated from UNDP various years).[4] Since 1975 the SAT countries have improved their HDI by 44%, compared to 33% improvement by non-SAT countries. In general the Latin American and Caribbean SAT countries have the best HDI, followed by the Asian SAT, with the African SAT the lowest (Fig 1). All SAT regions except Southern and Eastern Africa have been improving their HDI since 1975. The improvement in HDI was greatest in the six Large-SAT countries - 39% since 1975, compared to 29% for the Medium-SAT group and only 2% for the Small-SAT group. Thus, in the last quarter century, countries where the SAT dominates agricultural land area have fared much better in terms of progress in human development, than those where the SAT is less important.

The UNDP human poverty index (HPI) also shows greater poverty in the SAT HPI for the 36 SAT countries in 1998 was 32%, compared with 24% for all non-SAT countries.[5] HPI has fallen by almost 10% since 1995 in the SAT countries compared to an increase of more than 3% in non-SAT countries. In general, SAT countries in Latin America and the Caribbean have much better HPIs than SAT regions in either Asia or Africa (Fig 2). Southern and Eastern African SAT countries have improved (i.e. reduced] their HPI by 5% since 1995, which is marginally better than the Asian SAT (3%) and West and Central Africa (2%). The improvement in HPI has been greatest in the Small-SAT countries (18%), compared to 8% and 4% in the Medium-SAT and Large-SAT countries respectively. This is the opposite trend to that in HDI, where the Large-SAT countries fared better during this period.

The International Food Policy Research Institute (IFPRI) makes demand and supply projections for 37 countries and country groups and 18 major agricultural commodities (Rosegrant et. al. 1995, Pinstrup-Andersen et. al. 1997, 1999). They predict that in developing countries between 1995 and 2020 urban population will double to about 3.5 billion while rural population will increase only by 11% to 3 billion. Fifty-two percent of the world's population will live in urban areas in 2020, up from 38% in 1995.

Of the projected 1.9 billion increase in developing world population to 2025, some 90% will be in urban areas (Garrett and Ruel 1999). According to McCalla (2000), most of this growth will occur between the Tropics of Cancer and Capricorn, which form the borders of the SAT. Over half the populations of Asia and Africa, and over 80% in Latin America and the Caribbean, will live in urban areas by 2025. Garrett and Ruel (1999) examined urban poverty in eight developing countries. The proportion of poor who reside in urban areas increased in the past two decades in seven of the eight countries; the absolute numbers increased in five of the eight countries. For example in India, between 1978 and 1994 the number of rural poor fell by 7% from 268 to 249 million, while the urban poor rose by 18% from 64 to 76 million.[6] In 1978 the urban poor represented 19% of the total poor; in 1994 the figure rose to 23%. However, in spite of the high growth rates of urban poverty expected in

Table 5. Rural and urban poverty in the arid/semi-arid tropics of Asia and sub-Saharan Africa, 1996 (millions).

	Rural				
Region	Rainfed	Irrigated	Total	Urban	Total poor
Asia	89	148	237	149	386
South Asia	89	147	236	95	331
South East Asia	0	1	1	25	26
East Asia	0	0	0	29	29
Sub-Saharan Africa	76	3	79	32	111
Total	165	151	316	181	497

Source: Derived from TAC/FAO database as described by Gryseels et al. 1997, vising Sere and Steinfield 1996 as described in Thornton et al. 2000

4. HDI is determined from social indicators tor educational attainment, life expectancy, and per capita GDP. The higher the HDI the more advanced is the country or region with respect to human development indicators.
5. HPI is a deprivation index reflecting the percentages of: people not expected to survive to age 40, illiterates, those without access to safe water and health services, and malnourished children (UNDP 2000]. A higher HPI value implies greater deprivation.
6. Datt (1998) estimates that the incidence of both rural and urban poverty fell in India during the period 1951-94; by 0.86% pa in rural areas, 0.75% pa in urban areas.

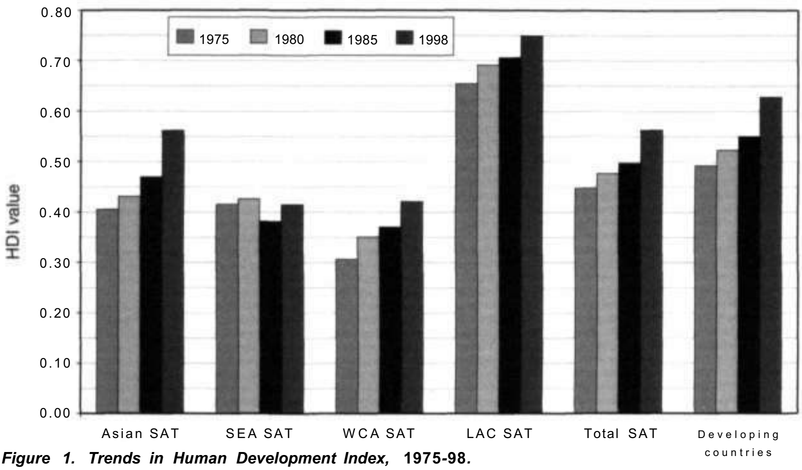

***Figure 1. Trends in Human Development Index,* 1975-98.**

Source: Calculated from UNDP Human Development Report 2000 using country populations (from FAOSTAT database) as weights

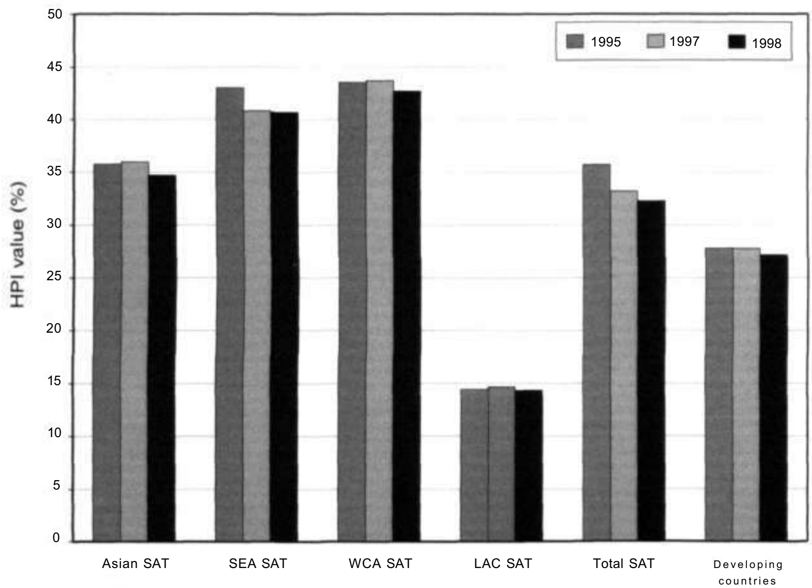

***Figure 2. Trends in Human Poverty Index,* 1975-98.**

Source: Calculated from UNDP Human Development Report (1998, 1999, 2000) using country populations (from FAOSTAT database) as weights the future, poverty will remain primarily a rural phenomenon.

A recent study by the Asian Development Bank (2000, pp 40-44) found that in many Asian countries the combination of high female involvement in agriculture and the large gender gap (in schooling, literacy, health, social participation, and agricultural wages) puts rural women at a disadvantage - not only vis-a-vis rural men, but also compared to urban women.

Food prices are very important for the urban poor as they purchase most of their food, increasingly in cooked/processed form, from street vendors. Every time a person moves from a rural to an urban setting, required market supplies must increase by a factor of two. This is because in rural areas people produce around 60% of their food supplies, purchasing only 40%. Those in urban areas depend on the market for close to 90% of their food needs (McCalla 2000).

In Accra in Ghana, Maxwell et al. (2000) found the poor spent more on street food (40% of their food budget) than the affluent (25%). Consequently, they may be more subject to nutritional diseases and food and water contamination. In contrast to the rural poor, the urban poor have diverse jobs and often engage in peri-urban agriculture. Structural adjustment has also tended to increase the number of "new" urban poor who have lost jobs in the civil service. Poverty, food insecurity, and malnutrition are growing rapidly in urban areas in Ghana.

Poverty and land potential

Gallup and Sachs (2000) have estimated that wet tropical countries have 27% and the dry tropics 42% lower productivity than temperate regions. Between 1961 and 1994, agricultural productivity has grown by 1.1% per year in the temperate zone, but fallen in the wet tropics by 0.6% per year and in the dry tropics by more than 1 % per year. Expenditures on agricultural research as a proportion of agricultural GDP in the dry and wet tropics are also about half that in temperate countries.

Gallup and Sachs question the wisdom of investing in R&D in the tropics, even though rates of return to research investments in the tropics have been shown to be higher than in other climatic zones. Their reasons are that tropical agricultural output is at least one-third lower than in the temperate regions when applying the same inputs. "This is a huge disadvantage, and throws into question the viability of an "agriculture-led" development strategy in the mostly agricultural tropics" (p 736). We will attempt to test this hypothesis in the following pages.

Is the breadth and depth of poverty greater or less in the so-called marginal areas compared to higher-potential areas? Pinstrup-Andersen and Pandya-Lorch (1994, pp 2-3, 16) maintain that, for developing countries as a whole, the numbers in absolute poverty are, to a large extent, in low-potential environmentally vulnerable areas. Citing Leonard (1989) they point out that of the 463 million people identified as the poorest of the rural poor in Asia, 57% live in low-potential areas.

A study commissioned by the CGIAR's Technical Advisory Committee (TAC) estimated that 630 million poor *(66%* of the total rural poor in developing countries) rely on marginal lands. The remaining 325 million depend on relatively favorable land (TAC 1997). The study recommended that the CGIAR sharpen its focus on poverty alleviation in setting priorities for marginal areas, which they defined as those with a high incidence of rural poverty subject to a relatively homogenous set of determining conditions. The TAC panel discarded biophysical productivity potential as an indicator of what the CGIAR ought to regard as marginal lands. Instead the term "marginal areas" was preferred. These were characterized as isolated, risky, and of low potential, where inhabitants have little political power and have been bypassed by R&D, such that the people are marginalized rather than the land. After much deliberation TAC has concluded that the evidence is inconclusive and neither confirms nor rejects the conventional wisdom that most of the rural poor are located in areas characterized by marginal lands and that marginal lands arc more susceptible to resource degradation (CGIAR 1999, p 6).

The situation in India seems different to that for Asia as portrayed by Leonard. Kelley and Parthasarathy Rao (1995) found there were significantly fewer absolutely poor people residing in the more marginal rural environments, i.e. districts with productivity less than Rs 500 per ha.[7] In other words the breadth of rural poverty in India is greater in higher-potential regions. This seems counter intuitive, but it is corroborated by Byerlee and Morris (1993, p 390) for wheat-producing areas in South Asia. But is the depth of poverty in India - the proportion of the population

7. The regression analysis showed that for every 1% increase in the proportion of total cropped land in a state classified as "marginal", the number of absolutely poor people fell by 380,000. This was after accounting for the effects of the absolute size of the state.

in poverty - greater in the more marginal environments? Kelley and Parthasarathy Rao found no statistical relationship between the proportion of marginal land in a region and the depth of poverty.

We updated the Kelley and Parthasarathy Rao analysis using more recent data and included the value of livestock products along with crop income in calculating land productivity and thus identifying marginal areas (Fig 3).[8] The results were similar (Table 6). There were fewer poor rural people in the more marginal districts.[9] The depth of poverty was slightly higher in the more marginal districts than in the favorable districts. Regression analysis showed that the elasticity of the breadth of poverty with respect to the gross value of agricultural production per net-cropped hectare was positive (0.62) and significant. This implies that for every 1 % increase in the productivity of land, the number of rural poor in that region increases by 345,000. Kelley and Parthasarathy Rao (1995) obtained similar numbers, reinforcing the conclusion that in India there tend to be more rural poor in higher-productivity regions.

Productivity growth in the marginal SAT districts has been significantly lower than in the more favorable ones during the period 1969-93 (Table 7).[10] This is in spite of faster growth in both fertilizer use per ha and in irrigation in the more marginal districts.

Income, food security, and nutrition

FAO (2000b) provides the most recent projections of agricultural growth scenarios to 2015 and 2030.[11] It is pointed out that although some 800 million

Table 6. Poverty in the Indian SAT, 1991-93.

Characteristics of region	Average gross value* of net cropped area (Rs ha^{-1})	No. of rural poor (millions)	% of poor in rural population
Marginal	5474	26.2	34.7
Average	9540	30.6	31.0
Favorable	18529	39.3	32.3
Total	10027	96.1	32.5

* Includes value of crops, small ruminant meat, and milk
Source: ICRISAT database

Table 7. Changes in the Indian SAT, 1969-71 to 1991-93.

Indicator	SAT region: Marginal	Average	Favorable
Productivity change (%)			
Crops	53(66)	68(84)	85(105)
Crops and livestock	58 (71)	68 (84)	88 (108)
Increase in fertilizer use (%)	484	411	355
Increase in percentage irrigation (%)	146	79	71

Productivity change measured by change in value of outputs per hectare of gross cropped area from 1969-71 to 1991-93 at 1991-93 constant prices. Figures in parentheses are on basis of net cropped area
Crops = cereals, pulses, oilseeds, and selected cash crops
Crops and livestock — crops plus milk and small ruminant meat
Fertilizer = increase in kg ha '
Source: ICRISAT database

8. Poverty data used for India is from Dreze and Srinivasan and not from the TAC/FAO database which was used for the international comparisons,
9. Gross value of production below Rs 5500 per ha of net cropped area in marginal areas, compared to over Rs 10,000 per ha in favorable districts.
10. Hazell and Fan (1998) also found that during 1970-94 the annual growth in land productivity in low-potential rainfed areas in India (1.88%) was lower than in either the high-potential (2.18%) or the irrigated regions (2.06%). They used ICAR agroecological classifications - including rainfall, growing period, and soil quality - to delineate the three regions. They also estimated that on this basis there were many more rural poor in the low-potential rainfed regions in 1993 than in the high-potential ones (59 vs 37 million). There were even more in the irrigated regions (73 million). Hence the methods used to classify regions by their land potential have a major bearing on estimates of the breadth and depth of poverty.
11. This is a partial equilibrium model, composed of single commodity modules and world market feedback leading to national and world market clearing through price adjustments. FAO emphasizes that specialists on countries and of many disciplines subjected the model projections to many rounds of iterative adjustments, particularly while analysing production growth and trade. The end-product may be described as a set of projections which meet conditions of accounting consistency and to a large extent respect constraints and views expressed by specialists in the different disciplines and countries. They are not "trend extrapolations", and the term trend or trend extrapolation is not appropriate for describing the projections.

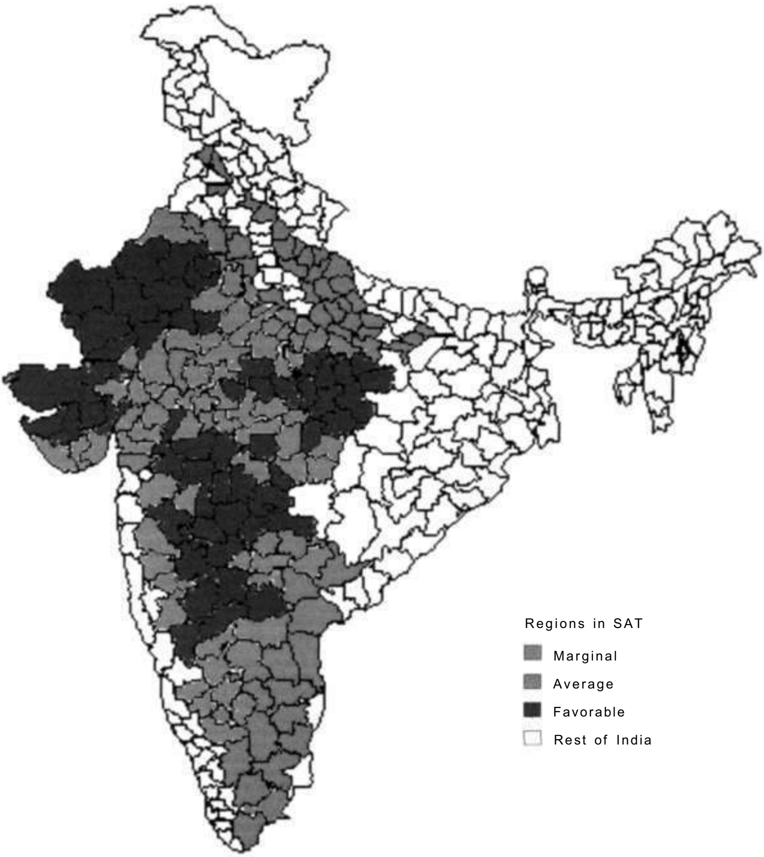

Figure 3. SAT regions in India based on total value of output (Crops+ fruits, vegetables+dairy+small ruminant meat), 1991-93.

persons in developing countries (18% of population) are currently under-nourished, the proportion of under-nourished has halved - in 1969-71 it was 960 million or 37% of the population. This change is partly because, over this period, developing-country population increased from 2.6 billion to 4.4 billion.

The world average of per capita food consumption[12] is currently 2760 kcal, 17% higher than in the mid 1960s. The gains reflect predominantly those of the developing countries (28% increase), given that industrial countries and transition economies already had fairly high levels of

12. Per caput food availability for direct human consumption expressed in kcal/person/day.

food consumption in the mid. 1960s. However, there are a number of countries where food security has not improved. There are 33 countries where per caput food consumption is under 2200 kcal. Of these, 17 countries (and 6 of the 18 Large- and Medium-SAT countries) are in the SAT.

FAO projections show that by 2015, and even more by 2030, per caput food consumption will have grown significantly (Table 8). Changes in the world averages will reflect above all the rising consumption in developing countries. More and more people will be living in countries with medium to high levels of food consumption. But the situation in sub-Saharan Africa will continue to be worrying, Of the 17 countries projected to stilt consume less than 2200 kcal/person/day in 2015, 12 will be in sub-Saharan Africa.

In the IFPRI projections to 2020, total income is expected to grow at 4.3% per year in developing countries. Higher growth rates in South Asia will result in a 140% increase in per capita income over the 25-year period, compared to only 28% in sub-Saharan Africa (Table 9). As a consequence of poor income growth, poverty is expected to remain pervasive in sub-Saharan Africa. Food availability is expected to increase marginally, remaining at the unacceptably low average of 2276 kcal per day compared to 2633 for South Asia, 3008 for LAC, and 2902 for the world.

FAO (2000b) uses food balance sheets at national level to assess the extent of undernourishment as measured by the proportion of the population falling below an Adjusted Average Requirement of 2600-2950 kcal per person per day, depending on the country and its population structure (age, sex, body weight). Their analysis shows that the incidence of undernourishment in sub-Saharan Africa has stayed around one-third of the population from the 1970s through the 1990s, but is projected to decline significantly towards 2030 (Table 10). In South Asia in contrast, incidence declined during the 1980s and 1990s and is projected to further fall to only 4% by 2030. But in 2030, there will still remain 165 million undernourished people in sub-Saharan Africa and 82 million in South Asia.

Child malnutrition is the most insidious manifestation of food insecurity. In 1995 there were an estimated 167 million malnourished children (underweight for age) in developing countries (Table 11). Of these, 86 million (51%) were in

Table 8. Per caput food consumption (kcal/person/day).

Region	1964/66	1974/76	1984/85	1995/97	2015	2030
World	2357	2429	2643	2761	2960	3100
Developing countries	2053	2145	2433	2626	2860	3020
Sub-Saharan Africa	2093	2093	2039	2188	2400	2580
Sub-Saharan Africa, excl Nigeria	2036	20S9	2054	2058	2280	2470
Near East/North Africa	2277	2574	2926	2983	3090	3170
Latin America and Caribbean	2392	2543	2685	2791	2950	3080
South Asia	2013	1977	2184	2424	2790	3040
East Asia	1953	2094	2544	2783	3020	3170
Industrial countries	2945	3065	3281	3374	3490	3550
Transition countries*	3222	3385	3378	2901	3170	3330

* Eastem European countries, Yugslavia, Commonwealth of Independent Slates, Baltic states
Source: FAO 2000, Table 2.2

Table 9. Projected income levels and growth in IFPRI model.

Region	Income growth (% pa), 1995-2020	Per capita income (1995 USS)	
		1995	2020
World	2.64	4807	6969
Sub-Saharan Africa excl South Africa	3.40	280	359
South Asia	5.01	350	830
Latin America	3.59	3590	6266
Developing countries	4.32	1080	2217

Source Pinstrup-Andersen et al. 1999

South Asia and 31 million (19%) in sub-Saharan Africa (Smith and Haddad 2000). South Asia has a much higher incidence of child malnutrition than sub-Saharan Africa, although the numbers have been decreasing in the former and increasing in the latter since 1970. According to FAO sub-Saharan Africa and South Asia will have 77% of the world's malnourished children in 2020, and remain the hot spots for child malnutrition and food insecurity. Similarly to the FAO projection, IFPRI projections to 2020 indicate that the number of malnourished children will continue to rise in sub-Saharan Africa, with incidence remaining about the same. Although an improvement is expected in South Asia, both absolute numbers and incidence will remain higher than in sub-Saharan Africa in 2020. According to Garrett and Ruel (1999) the urban share of malnourished children has increased in 11 of the 15 countries they examined, and their absolute numbers in urban areas increased in 9 of the 15.

The highest prevalence rates of child malnutrition and the largest numbers occur in the SAT (Table 12). There were an estimated 49 million malnourished children in the SAT in 1990 (Sharma et al. 1996). It has been suggested that one reason for the high prevalence rates is that land and labor productivity

Table 10. Actual and projected incidence of undernourishment in developing countries.

Region	1995/97	2015	2030
Sub-Saharan Africa	180 (33%)	184(22%)	165 (15%)
South Asia	284 (23%)	165 (10%)	82 (4%)
Developing countries	790 (18%)	576 (10%)	401 (6%)

Figures in parentheses show numbers as percentage of total population
Source: FAO 2000b, pp 19-22

Table 11. Trends in child malnutrition in developing countries.

Measure/Region	Change 1970-95	1995	Projected 2020
Proportion of children malnourished (%)			
South Asia	-23.0 pp	49.3	34.5-40.3
Sub-Saharan Africa	-3.9 pp	31.1	25.7-32.4
Developing countries	-15.5 pp	31.1	15.1-21.8
No. of children malnourished (millions)			
South Asia	-6.2	86.0	60.9-71.1
Sub-Saharan Africa	+ 12.9	31.1	43.3-54.6
Developing countries	-36.7	167.1	127.6-154.6

pp = percentage points
Projections to 2020 shown as expected range, depending on varying assumptions
Source: Smith and Haddad 2000

Table 12. Distribution of malnourished children by agroecological zone, 1990.

	Malnourished children	
Agroecological zone	%	Number (millions)
Warm semi-arid tropics	49.0	48.8
Warm subhumid tropics	36.4	20.6
Warm humid tropics	37.0	38.0
Cool tropics	26.0	8.1
Warm semi-arid subtropics (summer rainfall)	44.0	31.7
Warm subhumid subtropics (summer rainfall)	38.0	7.4
Warm/cool humid subtropics (summer rainfall)	19.0	10.0
Cool subtropics (summer rainfall)	23.0	10.6
Cool subtropics (winter rainfall)	17.4	8.2

Source: Sharma et al. 1996, p 10

have grown more slowly in the SAT than in most other agroecological regions. Some 38 million (79%) of the malnourished children in the SAT were in South Asia and 10 million in sub-Saharan Africa. In sub-Saharan Africa, child malnutrition was far more severe in the highland arid/semi-arid tropics than the lowland arid/semi-arid tropics. For example, prevalence of stunting (underheight) was 55% in the highlands and 27% in the lowlands, while prevalence of underweight children was 34 and 24% respectively.

A cross-country analysis indicated that to reduce child malnutrition in South Asia and sub-Saharan Africa, the top priorities are improved per capita food availability and women's education (Smith and Haddad 2000).[13] These priorities take account of the ranking of determinants by those with both the most potent impact on malnutrition relative to the existing range in each region, and by the most potential for impact based upon increases needed to reach desirable levels. Although the basic determinants of child malnutrition and future priorities are similar in the two regions, even if the determinants are brought to desirable levels, the enigma of a significant level (24%) of child malnutrition in South Asia would remain, compared to a virtual absence in sub-Saharan Africa.

The key issue arising from this work is the importance of per capita food availability in alleviating child malnutrition. It seems a necessary - but not sufficient - condition, and reinforces the value of R&D on crops that are important in the food baskets of the poor, especially in South Asia and sub-Saharan Africa. More will be said about this later.

In Maharashtra and Andhra Pradesh, the heartland of the Indian SAT, energy, iron, and Vitamin A are the major nutritional deficiencies in rural diets. This was the case in the mid 1970s and remains so in the 1990s (Chung 1998a,b, Ryan et al. 1984). Additionally, energy and iron intakes do not seem responsive to increases in income within a village context. The poor tend to purchase more expensive staples as their incomes increase. Cereal and pulse consumption is not responsive to increases in incomes. Hence, although sorghum and pigeonpea are currently significant contributors to beta carotene (a precursor of Vitamin A) in both Maharashtra and Andhra Pradesh villages, household income growth of the poor will not materially affect their intake of these nutrients from these sources. Fruit and vegetable consumption is responsive to income growth. As these are dense in micronutrients, they are more likely to materially improve nutrition than are the ICRISAT mandate crops, which have low micronutrient densities. Also supplementation, fortification, and nutrition education may address micronutrient deficiencies more effectively than attempts to genetically modify the ICRISAT mandate crops, even if modern biotechnology reduces the trade-offs in yield, yield stability, and protein content and quality, which were evident earlier with conventional breeding (Ryan 1976). Of course, if vitamin and mineral content can be augmented without unacceptable trade-offs in other desirable traits, this should be pursued. However, except in the few sorghum- and pearl millet-dominated systems in SAT India, there is simply insufficient consumption of these crops to materially improve micronutrient status; and even in such regions, overall coarse grain consumption is declining, as will be discussed later.

Growth in per caput food consumption is accompanied by significant changes in commodity composition, at least in the countries that experienced such growth (Table 13). Much of the structural change in developing-country diets was expressed as rapid increases of livestock products (meat, milk, eggs), vegetable oils, and to a smaller extent, sugar, as sources of food calories. These three groups together now account for 27% of total food availability for direct human consumption, up from 19% in the mid 1960s.

The historical evidence suggests that the growth in global agriculture has so far been more than sufficient to meet demand. FAO projections indicate that world consumption of coarse grains (maize, sorghum, millets, tef, etc.) should grow faster than that of other cereals, following the growth of the livestock sector. The shift of world consumption of coarse grains to the developing countries will continue and their share in total use will rise from 46% at present (and 34% 20 years ago) to 53% in 2015 and 57% in 2030. Much of the increase in consumption in developing countries will be for feed, a continuing trend in all regions except sub-Saharan Africa and South Asia, where food use will continue to predominate. FAO further point out that in the particular case of sub-Saharan Africa, coarse grains will remain the mainstay of food consumption. Production growth rates in sub-

13. Other (but less important) determinants were women's status relative to men's, and the health environment.

Saharan Africa were 3.3% p.a. in the past 20 years and 2.8% p.a. in the past 10 years. If these rates could be maintained - which is feasible according to their evaluation; they project a growth rate of 2.7% p.a, to 2015 - and given lower population growth, the region could raise annual per caput food consumption of coarse grains by some 10 kg, to 100 kg by 2030 (Fig 4). This will still fall short of what is needed for food security, but recall that there was no increase in the last 20 years. The FAO projections therefore provide a basis for increased investment in R&D for ICRISAT crops in sub-Saharan Africa.

With the projections of declining demand for sorghum and millet for direct human consumption in Asia, even among the poor, and the likelihood of rapidly growing demand for animal products, two implications arise for ICRISAT. First, there will be increased opportunities for research to better integrate crop-livestock systems, especially those of poor smallholders, which dominate the rural poor in the arid/semi-arid tropics and subtropics of South Asia (ILRI 2000, pp 1-9). In this agenda the dual-purpose characteristics of sorghum and millets can be more fully exploited, along with improved feed and nutrient cycling, and the excellent collaboration with the International Livestock Research Institute (ILRI) expanded. Second, there is scope for improving the feed quality characteristics of sorghum and pearl millet grain so they can become better substitutes for rnaize in the more intensive livestock feed sector than they are at present. This could reduce the 5-15% price discount they currently face. To what extent poor consumers (of animal products) and poor producers (of coarse grains) would benefit from such research is moot and must be carefully assessed before strategic decisions are made.

Table 13. Past and projected changes in commodity composition for major country groups.

Kg/person/year	1964/66	1974/76	1984/86	1995/97	2015	2030
Sub-Saharan Africa						
Cereals, food	117.0	115.0	113,0	121.0	133.0	143.0
Roots and tubers	192.0	192.0	170.0	192.0	198.0	198.0
Sugar (raw sugar eq.)	6.3	7.6	9.3	9,0	11.2	12.8
Vegetable oils, oilseeds and products (oil eq.)	7.7	8.0	8.3	9,4	10.9	12.6
Meat (carcass weight)	9.9	9.5	10.2	9.7	11.6	13.6
Milk and dairy, excl butter (fresh milk eq.)	28.0	28.0	32.0	30.0	33.0	35.0
Other food (kcal/person/day)	138.0	146.0	139.0	125.0	133.0	140.0
Total food (keal/person/day)	2019.0	2093.0	2039.0	2188,0	2400.0	2580.0
Latin America and Caribbean						
Cereals, food	116.0	123.0	132.0	133.0	139.0	142.0
Roots and tubers	89.0	79.0	68.0	65.0	63.0	63.0
Sugar (raw sugar eq.)	41.2	45.9	46.3	48.7	48.8	48.6
Vegetable oils, oilseeds and products (oil eq.)	6.2	8.0	11.0	12.2	14.3	16.2
Meat (carcass weight)	31.7	35.6	39.7	48,5	57.8	66.0
Milk and dairy, exel butter (fresh milk eq.)	80.0	93.0	95.0	109.0	119.0	128.0
Other food (kcai/person/day)	228,0	239.0	248.0	258.0	276,0	292.0
Total food (kcal/person/day)	2392.0	2543.0	2685.0	2791 .0	2950.0	3080.0
South Asia						
Cereals, food	145.0	142.0	154.0	169.0	186.0	192.0
Roots and tubers	13.0	19.0	19.0	21.0	26,0	30,0
Sugar (raw sugar eq.)	20.3	19.4	23.1	24,8	29.4	33.2
Pulses (raw sugar eq.)	15.3	12.8	12.0	10.6	9.1	8.0
Vegetable oils, oilseeds and products (oii eq.)	4.5	5.0	6.4	8.5	11.9	14.6
Meat (carcass weight)	3.9	3.9	4.3	5.5	8.2	11.8
Milk and dairy, excl butter (fresh milk eq.)	37,0	38.0	49.0	59.0	81.0	116.0
Other food (kcal/person/day)	82.0	84,0	99,0	121.0	143.0	158.0
Total food (kcal/person/dav)	2013.0	1977.0	2184.0	2424.0	2790.0	3040.0

Source: FAO 2000, Table 2.6

Sources of income of the poor

If poverty alleviation is to be a more explicit R&D goal, it is crucial to understand both the sources of income of the poor and how they spend this income. This will help identify intervention points with the best prospects for reducing poverty. To borrow from a recent World Bank (1999) study, the challenge is to move from counting the poor to making the poor count!

In villages in the heartland of the Indian SAT represented in the village level studies (VLS) conducted between the mid 1970s and mid '80s, per capita incomes were inversely related to the proportion of labor earnings (both on and off the farm) in total income (Walker and Ryan 1990). Income from trades, handicrafts, and transfers were also inversely related to per capita income, but not nearly as strongly as labor earnings. Crop and livestock income shares were positively related to per capita income and consequently were less important for the poor. There was a highly significant inverse relationship between the incidence of poverty and average per capita incomes among the 10 villages (Singh and Hazell 1989). On average the poor in these villages tend to be less educated, of lower caste, have larger families, more children, higher dependency ratios, fewer economically active workers, less wealth, and less access to land, especially irrigated land. The nonpoor are more educated, do not participate as actively in the labor market, and own more land than the poor. Improved education and wage increases from enhanced demand for labor were judged to be the most effective interventions to reduce the incidence of poverty.

Labor earnings had a stabilizing effect on household income even for those with land. Crop revenue contributed more to household income variability than to mean income in these Indian SAT villages. Those relying more on labor earnings were less prone to abrupt income shortfalls. The extent of stochastic poverty is high in the SAT. About two-thirds of the households in the VLS moved into or out of poverty at least one year during the 9 years of the study. A household had to be genuinely well off to avoid slipping into poverty in at least one year. As a result endemic poverty is hard to distinguish from stochastic poverty.

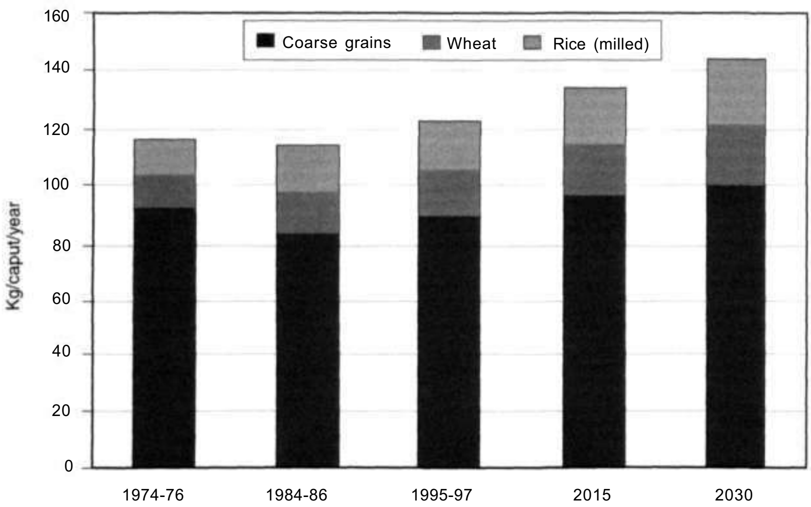

Figure 4. Per capita use of cereals in sub-Saharan Africa.

Source: FAO 2000b, Fig 3.9

It therefore seems that labor-using growth-promoting interventions will remain one of the most effective ways to enhance the incomes of the poor in the Indian SAT. Analyses show that irrigation investments in the more marginal environments represented by the Sholapur and Mahboobnagar villages had much more impact on the demand for labor than in the more assured rainfall villages in Akola. A 10%) increase in the proportion of land irrigated in the former regions results in a 3-6% increase in labor use per hectare, compared to only 0.6% in Akola. Additionally, the introduction of irrigated grapes in Sholapur had a significant effect on wages, as did technological change in labor-intensive rainfed cropping systems in Akola. Off-farm demand for labor placed added pressure on employment and wages for the poor in the less assured rainfall, marginal regions. This was less evident in the regions with more assured rainfall. In India as a whole Hanumantha Rao (1995), citing Bhalla et al. (1991), indicates that the rise in agricultural wages can be attributed mainly to a rise in demand for labor in non-agricultural activities, notably construction and services.

Overall in the VLS villages, the elasticity of household labor earnings with respect to increased labor demand was estimated to be 3.2. Thus, interventions that increase demand by 10%> will result in a 32% increase in household labor income. The elasticity of total household income with respect to increased labor demand is 1.3, which reflects the fact that labor earnings on average are only a portion of total income. However, this elasticity is quite high and reflects the potency of increased labor demand in the quest for reducing rural poverty.

In rural areas of Bangladesh the gains to be had from agricultural occupations of household heads in 1995-96 in per capita consumption compared to landless workers were (World Bank 1999):

Owner farmer	23%
Tenant farmer	18%
Worker in fisheries, livestock, forestry	16%
Agricultural worker with land	11%

The gains in non-agricultural occupations in rural areas were:

Petty trader/small business	29%
Executive, official, teacher	24%
Student, no work, retired	22%
Salesman, services, broker	22%
Transport, communication worker	20%
Servant, day-laborer	11%

Focusing on yield stability in a particular crop would seem to be a misguided means to reduce variability in household income and consumption. Reductions in yield variability for a given level of yield would not have contributed appreciably to dampening fluctuations in incomes for the panel of households in the continuous study villages. Variability in planted area reduces the value of reduced yield variability. Mean yields and profitability should remain the primary R&D objectives.

Unequal distribution of land contributes to skewed income distributions, but other sources of income serve to mediate this. In a panel survey in rural Pakistan Adams and He (1995) found that Gini ratios were 0.77 for land ownership and 0.38 for per capita income. Nonfarm income was the most important source of income, representing 30-34%. This was followed by agricultural income (23-27%). Nonfarm income was especially important for the poor, where it constituted 50% of income, more than twice the share of other sources and more than seven times the share of agricultural income. Livestock income was their second most important source (25%), followed by transfers (15%). Nonfarm and livestock incomes were the most important sources of reduced income inequality. Agricultural income accounts for the highest share (35-45%) of increased income inequality and cash crops like sugarcane, cotton, groundnut, and rapeseed/mustard accounted for much more of this than did food crops like rice and wheat. As in the Indian VLS, most poverty was transitory, with two-thirds of the poorest quartile not in that group after 2 years.

In Asia as a whole the ADB study (ADB 2000, pp 26-34) study indicates that the rural nonfarm economy accounts for 20-40% of total rural employment and 25-50% of total rural income. Formal manufacturing accounts for less than 20% of rural nonfarm employment. Most arises in service, trade, and household manufacturing activities. The agricultural-nonfarm regional income multipliers are such that for each dollar increase in agriculture's value added, there is an additional $0.5 to $1.0 increase in the value added of the nonfarm sector. More than two-thirds of this increment is due to household consumption linkages.

Diversification of income sources seems to be a growing feature in rural areas of the African SAT. Within agriculture increasing emphasis is being placed on livestock because of the perception that it offers higher and less variable returns than crop production. There is also diversification out of agriculture. Indeed farming systems in the African SAT are generally characterized as diversified crop-livestock systems. Most households also engage in various nonfarm enterprises, including trading, construction work, crafts, and wage employment.

In a review of 25 African studies, Reardon (1998) found that nonfarm income accounted for between 15 and 93% (average 45%) of total rural household income. Nonfarm income included wage employment, self-employment, and migration income. There is some evidence to suggest these shares arc increasing over time. In SAT areas most nonfarm activities occur in the dry season and the share of nonfarm income in total income is higher in the more marginal regions, mostly from more distant migration. It appears that in the studies reviewed by Reardon in Africa, the share of nonfarm income in total income for the upper tercile households is about double that in the lower tercile. Also, nonfarm earnings averaged about 10 times more than farm labor market earnings in the five studies where this comparison was possible. Poorer households supply most of the farm wage labor. Nonfarm income increases the inequality of the size distribution of income in marginal zones like the Sahel, but in more favorable regions such as the Guincan zone nonfarm income is an equalizing influence. Also, nonfarm earnings fluctuate more in areas with variable rainfall, which is a feature of the SAT. The implication is that one way out of poverty in SAT Africa is to enhance nonfarm income opportunities. Or perhaps it reinforces the need to emphasize more than in the past, the development of labor-saving agricultural technologies for the African SAT to free labor for more remunerative nonfarm activities?

Renkow (2000) concludes that where the data allow comparison of nonfarm income shares across production environments, there are no apparent systematic differences between favored and marginal areas of Africa and Asia. Overall, the empirical evidence on differences in the importance of nonfarm income to different income classes across agroecological zones is also mixed, according to Renkow. It will therefore be difficult to target R&D interventions to maximize their impact on poverty alleviation.

In the driest African environments, where wage employment opportunities are greatest, such as Botswana, the area planted to grain crops is declining.[14] But even in regions with fewer opportunities for off-farm employment, investments in crop production remain marginally competitive.

Most farmers primarily aim to produce enough grain to meet family food requirements. They are seeking to reduce the need to purchase food when stocks run out, and grain is most expensive - prior to the next season's harvest. Yet recent statistics from Zimbabwe suggest that 20-50% of these households fail in this quest in most years. These farmers then have to purchase a portion of their grain requirements or scale back consumption. In such regions, the common view of farmers as potentially in grain surplus needs to be replaced with the view of farmers as commonly grain deficit.

The reluctance to invest in crop production is further reinforced by the price variability and high marketing costs characterizing these environments. Traders do not have the capital to hold large enough inventories to offset extremes in production variability. And trading costs are increased by high assembly costs associated with the uncertainty of grain supply, and low density of farm populations. In consequence, farmgate prices tend to be lower than in higher rainfall zones.

Ultimately, in the driest parts of the SAT, it becomes cheaper to ship grain over long distances to overcome production deficits rather than buy locally produced grain. For example, imported maize is cheaper in northern Namibia than locally produced pearl millet despite the costs of shipping it over 1000 km. It is similarly cheaper for millers in Botswana to import sorghum from large-scale commercial farms in neighboring South Africa than to buy from local farmers.

Once family food supplies have been met, farm investments are next most likely to be allocated to livestock. This preference is confirmed, for example, in recent surveys in Zimbabwe (Fig 5). Livestock are perceived to offer higher returns to capital, as well as a source of ready cash for household purchases. In related studies, the value of crop stover fed to animals was 25-45% of the value of the grain in the farming system.

Recent surveys in southern Zimbabwe reveal that 50-75% of households in two SAT farming systems obtain cash from remittances, including salary and pension income (Table 14). This includes most female-headed households and many male-headed households with sons working off the farm. The majority of households also earn money from construction work, crafts, and working for others. In

14. We arc grateful to David Rohrbach for the African insights in the remaining parts of this section.

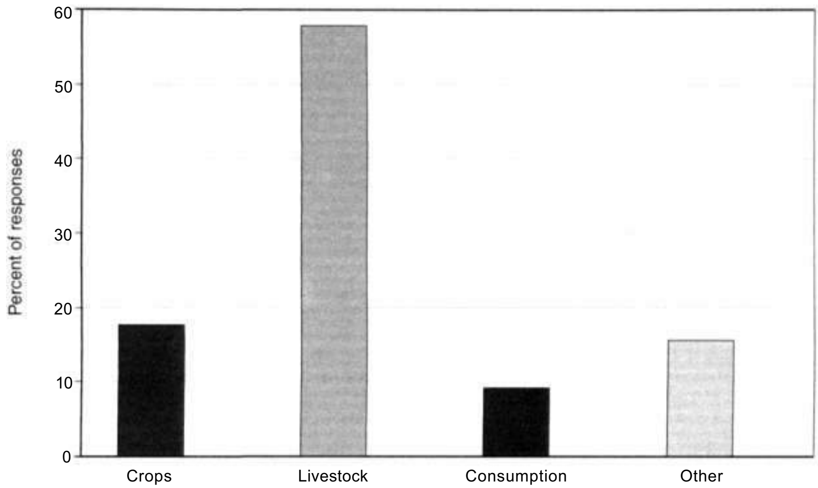

Figure 5. Primary investment targets of smallholder farmers in semi-arid areas of Zimbabwe, 1996.

Table 14. Percentage of SAT farm households obtaining cash income from alternative sources in two villages, Zimbabwe, 1998/99.

Region	Male or jointly headed	Female-headed (de facto)	Female-headed (de jure)
Gwanda (n = 105)			
Livestock	78.3	68.8	55.2
Remittances (incl salary)	56.6	75.0	65.5
Crafts	30.0	37.5	17.2
Labor	21.7	1S.S	17 2
Construction	20.0	6.3	3.4
Fruits and vegetables	16.7	25.0	51.7
Crops	11.7	18.8	17.2
Beer	0.5	0.0	6.9
Tsholotsho (n = 104)			
Livestock	55.1	33.3	22.7
Remittances (incl salary)	53.1	81.8	59.1
Crafts	22.4	21.2	22.7
Labor	22.4	27.3	22.7
Construction	20.4	12.1	13.6
Fruits and vegetables	16.3	21.2	22.7
Crops	28.6	12.1	13.6
Beer	20.4	21.2	18.2

contrast, only 10-20% of these households earn cash from crop sales. These include sales of small quantities of grain simply to obtain cash. Sales of fruits and vegetables are relatively more important for female-headed households without access to remittances.

In the same sample, remittances represent 40-50% of cash income among smallholder farm households (Table 15), and up to 75% of cash income for the 30-40% of households with the husband working off the farm. Livestock contributes 20-50% of cash incomes. In contrast, crop production contributes less than 5%.[15] In West Africa on the other hand, crop income is often more than 50% of cash income (Sanders et al. 1996). Though many female-headed households obtain cash from sales of fruits and vegetables, the income obtained is generally small.

While the numbers differ across SAT countries in Southern and Eastern Africa, the general trend is probably robust. Crop production is viewed as a subsistence activity whereas livestock production is viewed as a source of cash and savings. In much of Africa, investments in education are prioritized as a means of diversifying income by facilitating off-farm wage employment for children.

Few data are available to track changes in income and expenditure patterns across time. There is little doubt that the development of markets for specific cash crops like cotton and sunflower has stimulated cash investments in the production of these crops, and income growth. But these investments are more likely to be pursued in relatively higher rainfall zones, where market infrastructure is better developed.

In the medium term it seems likely that as the economies of SAT countries grow, labor will continue to shift out of agriculture. This shift will be most rapid in countries with significant areas with favorable rainfall or with large industrial sectors. Many small-scale farmers may retain their rural households as a source of subsistence for family members yet to migrate, or as a retirement destination.

One clue to the investment strategies of these households is whether cash remittances are being invested in agriculture, and crop production in particular. The evidence is mixed, and may depend as much on broader market conditions as the agroecology per se. But this is a key issue in the longitudinal analyses proposed in the revitalized ICRISAT village-level studies. There is some suggestion that farmers who earn cash income from crops like cotton are more likely to invest cash and labor in more intensified production practices for other crops also. If this can be verified then the

Table 15. Percentage of SAT farm household cash income derived from alternative sources in two villages, Zimbabwe, 1998/99.

% of household cash income drawn from	Tsholotsho n = 104	Gwanda n = 105
Livestock	14.2	35.3
Cash remittances (incl salary, pension)	34.5	29.9
Petty trade	14.9	18.9
Crafts	8.1	5.6
Labor	18.6	4.4
Construction	1.7	1.8
Fruits and vegetables	2.5	2.2
Crops	3.4	0.5
Beer	1.2	0.1
Mean total cash income (Z$/year)	13,627.4 (20,726.0)	15,295.3 (25,673.1)
Male-headed households	11,310 (16,462)	20,917 (31,964)
De facto female-headed households	21,313 (27,618)	15,004 (12,393)
De jure female-headed households	7232 (13,305)	3824 (2999)
Median total cash income (Z$/year)	5410	5800
Median total cash income (US$/year)	142	153

Numbers in parentheses are standard deviations

15. This does not include the value of home-produced food consumed by the farm households.

promotion of cash crops may be a more effective strategy for technology adoption on foodgrains, with subsequent impact on income growth.

Expenditure patterns of the poor

The other leverage point to influence the welfare of the poor is through the prices of important components of their consumption basket. Indeed agricultural research for development is significantly predicated on the linkage between productivity growth, reduced costs of production, and prices of commodities of value to the poor.

From 1972 to 1994, consumption of sorghum, pearl millet, and chickpea has fallen amongst the poorest 30% of the Indian population (Murthy 1997).[16] For the two coarse grains the decline has generally been faster among the urban poor compared to the rural poor. For chickpea the reverse is the case. Except for Haryana and Uttar Pradesh, pigeonpea consumption has been increasing. Edible oil consumption has also been increasing.

These trends have meant that the average budget shares for the rural poor for the two coarse cereals in ICRISAT's mandate have fallen from 13.6% in 1972-73 to 4.3% in 1993-94 (Table 16). This is a massive decrease in the share of what were staple cereals for the poor. Over the same period the share of coarse cereals among the urban poor fell from 7.4 to 3.6%. This decline in both urban and rural areas was not restricted to coarse cereals but also occurred with other cereals like rice and wheat, but not to the same extent. No doubt pricing and foodgrain procurement/ distribution policies in India, which continue to favor rice and wheat at the expense of sorghum and millets, have had some influence. However, as price and expenditure elasticities of demand for the latter are quite inelastic, as will be indicated later, it is unlikely that such policies were responsible for more than a minor portion of the decline.

It is evident that policy distortions such as cheap rice imports and fertilizer subsidies have had a negative impact on sorghum and millet consumption in Africa. However, ongoing efforts to remove such subsidies are not expected to change relative prices to such an extent as to have a major impact on consumption trends of sorghum and millet compared to rice, maize, and wheat.

To further highlight the changes in Indian consumption patterns: a recent adoption study in Tamil Nadu found that in 1975, 85-90%. of the pearl millet produced in the survey villages was consumed as food within the villages (Raniasamy et al. 2000). By 1996 only 5-30% was consumed within the villages as food, and 85% sold out of the producing areas, primarily as poultry feed. This development coincided with the widespread adoption of private sector pearl millet hybrids.

Table 16. Changes in average budget shares for the Indian poor, 1972-73 to 1993-94.

	Rural poor			Urban poor		
Commodity	1972-73 (%)	1993-94 (%)	Change (percentage points)	1972-73 (%)	1993-94 (%)	Change (percentage points)
Sorghum	9.5	2.7	-6.8	5.0	1.2	-3.8
Pearl millet	4.1	1.6	-2.5	2.4	2.4	0
Chickpea	0.7	0.7	0	0.6	0.6	0
Pigeonpea	1.8	1.9	+0.1	1.9	1.8	-0.1
Groundnut oil	2.1	na	na	2.7	na	na
ICRISAT crops (excl groundnut oil)	16.1	6.9	-9.2	9.9	6.0	-3.9
Edible oil	3.4	5.6	+ 2.2	5.8	6.0	+0.2
Other food*	59.4	58.2	-1.2	53.5	55.9	+2.4
Total food	81.0	70.7	-10.3	71.9	67.9	-4.0
Total non-food	19.0	29.3	+ 10.3	28.1	32.1	+ 4.0

na = data not available
* Food share minus ICRISAT crops (including groundnut oil in 1972-73 but not in 1993-94) minus edible oil
Source; Derived from Murthy 1997, pp B 18, 22

16. Murthy analysed the National Sample Survey data for the 10 states which have some semi-arid tropical and/or subtropical environments - Andhra Pradesh, Gujarat, Haryana, Karnataka, Madhya Pradesh, Maharashtra, Punjab, Rajasthan, Tamil Nadu, and Uttar Pradesh. Data for chickpea and pigeonpea are available only from 1987-88, not 1972-73. Also the chickpea data refer only to whole chickpea and not to chickpea flour, which may represent up to 80% of total consumption.

The budget share of chickpea among both rural ami urban Indian poor stayed tow and unchanged between 1972 and 1994. The share of pigeonpea rose marginally among the rural poor and fell among the urban poor, Figures for groundnut were not readily available; but for edible oils as a group, their share in the budget of the rural poor rose by 65%, but only 3% among the urban poor, during this period.

Overall food expenditure shares for the rural and urban poor have fallen by 10-3 and 4 percentage points respectively during the 21-year period examined by Murthy. Non-food expenditure shares of course have risen by the same amounts. An issue for ICRISAT is how to respond to the substantial decline in the shares of sorghum and pearl millet in the budgets of the poor in India. Compared to the situation when the Institute began its work in 1972, a given productivity change in these crops today will have a much smaller benefit to poor consumers. For the two pulses in ICRISAT's mandate, the relatively small changes in budget shares for the poor in the last 21 years indicate the prospects for impact have not changed markedly. However, their combined budget shares are so small (3-4%) that one must question whether research on these crops can materially improve the welfare of poor consumers. Indeed the current budget share for the two coarse cereals combined is also around 4%, so the same question applies to them. However, edible oils {presumably including groundnut) seem to be increasing their share of poor peoples' budget expenditures.

In only one of the ten states examined by Murthy did an ICRISAT mandate crop have the highest budget share among the poor. This was for the rural poor in Maharashtra (Table 17). Rice and wheat had by far the largest shares in all other states, except for edible oils in Gujarat. Their shares averaged more than three times that of the next highest commodity. This is borne out by the re-survey of the human nutrition status of VLS participants in Maharashtra and Andhra Pradesh by Chung (1998), Sorghum and pearl millet represented 22% of the per capita food expenditure of the poorest tercile in the Maharashtra villages and 6% in Andhra Pradesh. Surprisingly, the richest tercile in Maharashtra had a higher share of food expenditures on sorghum and millet (31%) than the poor in the same villages. In Andhra Pradesh the richest tercile had the same share as the poor (6%). Thus, while there are niches where sorghum is important in the expenditure pattern of the poor (and the less poor), this may only occur in one state in India. Nationally, coarse grains and pulses have become insignificant components of the budget expenditures of the poor. This raises an important strategic question: should ICRISAT focus on the production/consumption niches where the mandate crops are of primary importance to a limited number of poor, or broaden its horizons to the much larger numbers of poor who are becoming less dependent on the mandate crops, and identify new comparative and complementary advantages for ICRISAT in order to target this group?

What of the likely future trends in the consumption patterns of the poor for the ICRISAT

Table 17. Commodities with highest budget shares for the poor in India, 1993-94,

	Rural poor				Urban poor			
			Share for highest ICRISAT crop				Share for highest ICRISAT crop	
State	Commodity	Share (%)	Commodity	Share (%)	Commodity	Share (%)	Commodity	Share (%)
Andhra Pradesh	Rice	29.8	Pigeonpea	2.3	Rice	26.2	Edible oil	5.8
Gujarat	Edible oil	8.5	Pearl millet	5,9	Edible oil	10.3	Pearl millet	2.4
Haryana	Wheat	18.4	Edible oil*	3.8	Wheat	15,3	Edible oil	4.4
Kamataka	Rice	12.6	Sorghum	9.0	Rice	17.3	Sorghum	5,4
Madhya Pradesh	Rice	21.3	Edible oil	5.3	Wheat	13.6	Edible oil	6,2
Maharashtra	Sorghum	9.2	Edible oil	7.1	Wheat	8.4	Edible oil	7.4
Punjab	Wheat	14.8	Edible oil	5.8	Wheat	12.4	Edible oil	6,2
Rajasthan	Wheat	15.3	Pearl millet	5.3	Wheat	20,3	Edible oil	5,6
Tamil Nadu	Rice	32.2	Edible oil	4.7	Rice	26.1	Edible oil	4.5
Uttar Pradesh	Wheat	20.1	Edible oil	5.0	Wheat	19.3	Edible oil	5,0

* Separate date for groundnut oil not available for 19 93-94; Ineluded with all edible oil
Source: Derived from Murthy 1997, pp B 18, 22

mandate crops? Murthy (1997) has estimated the expenditure elasticities of demand from the NSS data reported in the preceding tables. These indicate the percentage change in expenditure of a commodity when total expenditure rises. For example an elasticity of 1 implies that the expenditure on that commodity will rise by 1 % upon a rise of 1% in the total expenditure of the household or individual.

Of the commodities Murthy examined, ICRISAT crops have the lowest average expenditure elasticities among the rural poor - all are less than 1, except for chickpea (Table 18). Among the urban poor the future demand picture is bleaker, especially for sorghum and pearl millet, for which the expenditure elasticities are negative. This means the urban poor will actually reduce their expenditures on these commodities as their total expenditures grow. Hence with the possible exception of chickpea, the other ICRISAT mandate commodities are regarded as inferior goods, even by the poor.

The price elasticities of demand for sorghum by the rural poor in India are estimated to be around -0.3, which is quite inelastic (Table 19). It implies that even if technological change results in lowered costs and prices, the rural poor are unlikely to increase consumption very much. If prices fall 10% for example, consumption would only rise by 3%. In some states the price elasticities were essentially zero and lower prices would result in no discernible increase in consumption by the poor.[17] The price elasticity of pearl millet (-0.9) is somewhat higher than for sorghum among the rural poor, but it remains inelastic and subject to the same arguments as for sorghum. For both sorghum and pearl millet the urban poor have essentially a zero price elasticity of demand, which implies an even more subdued effect of technological change on consumption of these coarse cereals by the urban poor than for the rural poor.

Both pigeonpea and chickpea have a price elasticity of demand for the poor around -1.0 (Table 19). This implies that lower prices due to technological change will result in a direct increase in consumption by the same proportion as their prices fall. In addition there is a real income effect operating to further enhance the consumption of pulses by a much higher proportion than income rises, and also much higher than for the coarse cereals.

In the years ahead, growing demand for animal products like meat, milk, and eggs in developing countries could well result in a substantial increase in demand for sorghum, and to a lesser extent pearl millet. Indeed this scenario is being described as a future Livestock Revolution (Delgado et al. 1999). Per capita consumption of meat in India is

Table 18. Average expenditure elasticities of demand for the poor in India, 1972-94.

	Rural poor*		Urban poor	
Commodity	Simple mean	Range	Simple mean	Range
Pulses	1.38	1.27 to 1.58	1.19	1.07 to 3.39
Rice	1.36	1.05 to 1.86	1.25	0.94 to 1.43
Wheat	1.21	0.79 to 2.06	0.89	0.47 to 1.75
Other food	1.20	1.11 to 1.30	3.21	1.12 to 1.31
Chickpea	1.18	0.83 to 1.53	1.25	0.90 to 1.60
Total non-food	1.12	3.03 to 1.23	1.11	1.02 to 1.22
Edible oil	1.11	0.82 to 1.30	1.15	0.86 to 1.34
Total cereals	0.75	0.65 to 0.85	0.59	0.48 to 0.69
Pigeonpea	0.70	0.47 to 3.05	0.73	0.52 to 3.08
Pearl millet	0.66	0.05 to 1.35	-0.10	-0.72 to 0.59
Groundnut oil	0.65	0.01 to 1.24	0.30	-0.35 to 0.89
Other coarse cereals	0.38	-0.19 to 0.83	0.11	-0.46 to 0.56
Sorghum	0.24	-0.17 to 0.71	-0.35	-0.76 to 0.32

* Derived from elasticities estimated for 10 states
Source: Murthy 1997, pp B *26*

17. This it not to say that poor consumers would not benefit from price-reducing tec hnological change in sorghum. Their real income would rise even if their consumption of sorghum remained unchanged (because sorghum price would fall). However, this real income effect is becoming less significant as the share of sorghum in budget expenditure has fallen, Indeed as sorghum expenditure elasticities are similarly small and often negative, little of the Increase in real income from lower sorghum prices will be spent on additional sorghum consumption.

Table 19. Own-price elasticities of demand for food commodities of the poor in SAT India*.

Commodity	Rural poor		Urban poor	
	Simple mean	Range	Simple mean	Range
Rice	-1.69	-1.21 to -2.56	-1.42	-1.03 to-2.16
Wheat	-1.55	-1.03 to-2.66	-1.00	-0.59 to-1.96
Sorghum	-0.33	+0.21 to -0.93	+0.48	+0.82 to -0.14
Pearl millet	-0.87	-0.07 to-1.65	+0,12	+0.86 to -0,65
Other coarse cereals	-0.50	+0.28 to-1.12	-0.12	+0.61 to -0.67
Total cereals	-0.99	-0.83 to -1.10	-0.74	-0.57 to -0.85
Chickpea	-1.19	-0.90 to-1.51	-1.06	-0.82 to-1.33
Pigeonpea	-0.94	-0.56 to-1.57	-1.04	-0.69 to -1.61
Pulses	-1.76	-1.65 to-1.98	-1.37	-1.27 to -1.57

* Refers to the 10 Indian states examined by Murthy. which comprise the semi-arid tropics and subtropies
Source: Murthy 1397, p B 35

projected to rise by 50% from 1993 to 2020 and for milk by 115%. For sub-Saharan Africa the corresponding figures are 22 and 30%, For India, Kumar (1996) projects future demand growth of 5.8% per year for meat, fish, and eggs and 4.09% for miik.[18] Presumably even the poor will benefit from this growth, as their expenditure elasticities for these products are more than double those for sorghum and millets as foodgrains (Murthy 1997), Also, expenditure elasticities for milk, milk products, and meat are positive and much higher than for any other commodity in both rural and urban India (Table 20). This compares with negative elasticities for wheat and coarse cereals. Additionaiiy, the very poor spend between 8 and 13% of their food budgets on these commodities, more than the shares of coarse cereals based on Murthy's (1997) analysis.

However, sorghum and millet wilt have to compete with maize in satisfying this prospective explosion in the demand for feedgrains arising from the anticipated Livestock Revolution. As indicated later in the discussion of trends and projections, until now maize has been preferred over sorghum as a feedgrain; sorghum usually sells at a price discount of 5-15%.[19] An issue for ICRISAT's strategic

Table 20. Demand patterns in India.

Commodity	Budget share (% of food expenditure) 1987/88				Expenditure elasticity	
	Rural		Urban		All India	
	Very poor	Rich	Very poor	Rich	Rural	Urban
Rice					0.06	0.01
Wheat	55.3*	30.8	44.5	19.3	-0.07	-0.09
Coarse cereals					-0.13	-0.18
Pulses	6.6	6.3	7.0	5.5	0.31	0.22
Milk and milk products	5.1	19.4	8.1	20.2	0.46	0.37
Oil	7.0	8.4	8.6	9.5	0.39	0.23
Vegetables	8.8	7.6	9.2	8.7	0.38	0.25
Fruits	1.1	3.6	1.8	5.9	0.44	0.36
Meat, eggs, fish	3.4	5.9	4.8	7.3	0.85**	0.63**
Sugar	3.3	5.2	4.2	3.9	0.14	0.06
Others	9.3	12.9	11.8	19.6	0.94	0.70
Non-food (% of total expenditure)	25.8	44.7	28.1	52.4	2.25	1.87

* Rice, wheat, and coarse cereals not calculated separately
** Meat only
Source: Kumar 1996

18. There seem conservative compared with actual 1980-92 growth rates which Kumar estimates as 14, 7, and 5% per year for meat, eggs, and milk rerpectlvely.
19. With the exceptin of the high quality rabi sorghum variety Maldandi M 35-1, a bold-seeded yellow grain type, which commands a premium of up to 70% over local sorghum cultivars and hybrids (Marsland and Rao 1999).

priorities is whether to shift the focus of the sorghum program to a feedgrain rather than a foodgrain emphasis. But before this is contemplated, several important issues must be resolved: the prospective benefits to poor consumers (of both sorghum and animal products that are produced from feedgrains) and producers, the preferred traits of sorghum for feed versus food uses, and the likelihood that the feed industry will respond to (and partly fund?) such an initiative. Is it feasible to reduce the price premium that feedgrain maize commands at present; to what extent will the poor share in the resulting benefits, compared to the feed and intensive livestock sectors?

Links between R&D, economic growth, and poverty[20]

There is now persuasive empirical evidence that absolute poverty in developing countries declines with growth in average incomes. Based on a study of 20 countries between 1984 and 1993, Bruno et al. (1998) estimate that a 10% increase in mean incomes led to a 20% decrease in the proportion of people living on less than $ 1 per day. Roemer and Gugerty (1997) found that GDP growth of 10% per year is associated with income growth of 9% for the poorest 20% of the population. In reviewing 95 country growth experiences, Deininger and Squire (1996) found a strong positive relationship between growth and poverty reduction in more than 85% of cases, whereas economic decline quite often hurt the poor disproportionately.[21] In their review of the Asian experience Rosegrant and Hazell (2000, p 100) concluded: "The countries that have been most successful in attacking poverty have achieved rapid agricultural growth and broader economic growth that makes efficient use of labor and have invested in the human capital of the poor."

Ravallion and Chen (1997) found that a 10% increase in mean standard of living could be expected to result in a 31 % drop in the proportion of people living on less than $ 1 per day. For higher poverty lines, the growth elasticity falls in absolute value. Deiningcr and Squire (1996) also found little relationship between growth and inequality change, although there are obviously losers and winners in the growth process.

Datt (1998) found that among Indian states, growth in mean consumption explained 87% of the reduction in the head count index of total poverty from 1951 to 1996. Only 13% was explained by redistribution, which did explain more of the changes in the depth and severity of poverty. "The more serious constraint on poverty reduction ... there just was not enough growth" (p 22). Changes in rural poverty accounted for 80% of the cumulative change in the national poverty count index. Intersectoral population shifts explained little.

It thus seems clear that a focus on growth-enhancing initiatives and on countries and provinces with large numbers of poor people will be conducive to poverty reduction. Some attention to interventions that redistribute income to the losers is appropriate also, but not to the exclusion of growth-enhancing investments. The jury is still out on whether an unequal distribution is more or less conducive to growth. More egalitarian countries may be more likely to respond to the need for reforms - land reform, improved credit access, investment in basic education - which will promote sustained growth and poverty reduction (Bruno et al. 1998).

The following discussion draws heavily on the Indian case, where the data are rich enough to enable economic analyses of the type required to measure intersectoral relationships. Ravallion and Datt (1996) show that in India, both urban and rural poor gained from rural sector growth. By contrast, capital intensive urban growth had adverse distributional effects in urban areas inimical to the urban poor and, importantly, had no discernible impact on rural poverty. Rural-urban migration also did not result in significant gains to the poor. They conclude (p 19): "Fostering the conditions for growth in the rural economy - in both the primary and tertiary sectors - must thus be considered central to an effective strategy for poverty reduction in India." Sectoral biases against the rural sector in pricing, exchange rates, and public investment are not conducive to growth, poverty alleviation, or reductions in inequality.

Perhaps of more significance is the strong evidence from Datt and Ravallion (1998a,b), using both state and household data for India, that indicate trend growth rates of farm yields per hectare were important in explaining differences in trend rates of reduction in poverty. By contrast, differences in trend growth rates of non-agricultural output (rural and urban) were not important. A large

20. This section draws heavily on Ryan et al. (1998).

21. This was painfully evident in 1997 when the economic crisis halted economic growth in most Southeast Asian countries.

share of the gains to the poor was from higher wages and lower prices resulting from the increase in yield. The long-run elasticity (10 years or more) of higher farm productivity on the head count index (breadth) of poverty was 1.0, whereas the short-term elasticity (1-2 years) was 0.2. There was no evidence these elasticities were falling over time. The gains also were not restricted to those near the poverty line but reached deeper. After controlling for yield trends, initial endowments of human and physical capital (e.g. higher irrigation intensity, higher literacy, lower infant mortality) all contributed to higher long-term rates of poverty reduction in rural areas.

The speed of the reduction in poverty from agricultural growth can be significantly retarded if there are concentrations in land ownership leading to uncompetitive markets in land and labor (Otsuka 1993, Gaiha 1995, Roemer and Gugerty 1997). Anti-poverty measures such as market-mediated land distribution, relaxation of tenancy regulations, and employment guarantee schemes can be important in enhancing the effect of growth on poverty reduction in rural areas. However, in Asia there is not enough land to redistribute to the poor. Labor-using R&D strategies also must be employed both within the agricultural sector and in nonfarrn rural enterprises to cater for this.

In India, Kalirajan (2000) found that states with initially a high share of income from the primary sector tended to grow faster than those with a lower share. However, the growth rates of states are converging to a lower level and there is a need to shift technological frontiers more rapidly. "Though technology played a crucial role in alleviating India's poverty trap in the 70s, its recent contribution to agricultural growth has not been impressive" (p 9).

Recent research by IFPRI (Fan et al. 1998, 1999a) found that expenditure on rural roads and R&D in India has had the largest impacts on both rural poverty reduction and agricultural productivity growth.[22] Government expenditure on education significantly reduces the number of people below the poverty line, as does expenditure on rural development. However, these investments have no discernible effects on productivity growth and hence do not provide a sustainable solution to the poverty problem. Investments in irrigation, soil and water conservation, power, and human health have small effects on rural poverty and no effects on productivity growth.

The IFPRI research in India by Hazell and Fan (1998) also examined the potential of alternative investments in irrigated, high- and low-potential rainfed areas to contribute to productivity growth and poverty alleviation. It shows that investments in rural infrastructure, agricultural technology, and human capital in many rainfed areas are now at least as productive as in irrigated areas and they have a much larger impact on poverty. They conclude that increased investments in rainfed areas could be a win-win proposition. The productivity impacts of agricultural technology investments as measured by the coverage of high-yielding varieties were similar in high- and low-potential rainfed regions (Table 21). The poverty impact was less than half in the low-potential areas. However, both types of rainfed areas generated greater impacts on poverty and productivity from investments in agricultural technology than in the irrigated regions. They found that markets, irrigation, and road investments had a larger impact in the low-potential areas.

Fan et al. (1999b) maintain that in India investments in irrigated areas have diminishing marginal returns and that it is now rainfed areas that yield the highest marginal returns from additional government investments in technology and

Table 21. Marginal impact* of investments in agricultural technology in different regions, India.

	Region		
Measure	Irrigated	High-potential rainfed	Low-potential rainfed
Returns to production (Rs ha^{-1} 1990 prices)	352	686	642
Returns to poverty reduction (persons 100 ha^{-1})	0	11	5

* As measured by coverage of high-yielding varieties. All coefficients significant at 5% level
Source: Hasell and Fan 1998

22. These results bar out the views of Hanumantha Rao (1995,1997) that investment in infrastructure, human resource development, and research and extension are emerging as the *matt* important canstrnints to growth in India, especially in less developed areas.

infrastructure. In contrast to Hazell and Fan (1998) who used state data and an agroecological classification, Fan et al. used an ICRISAT (1999) typology of farming systems and associated district data. The results were similar, except that the marginal rainfed regions had much lower impacts on productivity and on the poor than high-potential rainfed regions (Table 22).

In yet another analysis Fan and Hazell (2000) used the same ICAR (Indian Council for Agricultural Research) agroecological classification for India as the earlier study by Hazell and Fan (1998), with a different cut-off point. They used a cut-off point of 25% for classifying irrigated districts, while the earlier study used 40%. This resulted in approximately the same estimated number of rural poor in the low-potential regions as in the high-potential. In the low-potential rainfed regions the incremental effect of investments in agricultural technology on production were about 180% higher than in the high-potential ones, and on poverty reduction some 150% more. Again, both rainfed regions gave far higher production and poverty dividends than irrigated regions. Of course, agricultural growth in dry low-potential areas is unlikely to become a major factor in meeting national cereal needs; but as this research clearly shows, it will be important for redressing poverty and environmental problems for the large number of poor people who live in these areas (Byerlee et al. 1997). ICRISAT's current mandate for dry areas positions it well to contribute to the alleviation of such problems.

Ravallion and Woden (1998a,b) found in Bangladesh that poor areas are not poor because resident households have characteristics that inherently foster poverty. Rather, there appear to be structural differences to returns to given household characteristics, such as their education levels, in such regions. "Our results reinforce the case for anti-poverty programs targeted to poor areas even in an economy with few obvious impediments to mobility" (1998b, pp 19-20). Comparing average living standards in rural versus non-rural areas overstates the gains from switching, as often those in poor areas are poorly endowed with characteristics conducive to success in more profitable nonfarm activities. The Grameen Bank has tended to locate its branches where the gains favor the poor, whereas traditional banks were attracted to areas where the gains from switching to the nonfarm sector favor the non-poor. The World Bank (1999) found on balance that in rural Bangladesh the gains from switching from the farm to the nonfarm sector arc positive and large for the poor, implying that developing the rural nonfarm sector holds considerable potential for poverty reduction. However, the net elasticity of poverty reduction with respect to growth was still the largest in agriculture.

The Asian Development Bank conducted a major review of the problems, lessons, and prospects in Asia (ADB 2000). They concluded (pp 13-26) that:

- Agricultural growth is a prerequisite for economic development in general and rural development in particular
- To reduce poverty and improve the quality of life in rural areas, agricultural growth must be both pro-poor and environmentally sustainable
- Promoting growth of the rural nonfarm economy will greatly enhance the pace of rural development
- Efficient rural financial markets play a key role in promoting rural development
- It is necessary to ensure effective institutions for rural development

Table 22. Marginal effects of investments in agricultural technology* in India.

Region	Number of zones	Average land productivity (Rs ha^{-1} in 1994 prices)"	Added value of agricultural output per rupee invested (Rs ha^{-1} pa)	Reduction in number of poor per million rupees invested (persons Rs 1 million'^{1} in 1994 prices)
Rainfed				
Marginal	5	4670	5.04	0.92
Moderate potential	5	7121	8.79	3.95
High potential	3	13,383	16.21	11.18
Irrigated	1	12,455	4.64	0.76

* Agricultural technology as measured by coverage of high-yielding varieties
* * Includes crop and livestock income
Source: Fan et al. 199%

- To improve the overall quality of life in rural areas it is necessary to go beyond growth, poverty, and environmental considerations and directly address specific concerns of particular relevance to rural Asia.

Agricultural research is seen by ADB as a key element in enhancing agricultural growth, including both public and increasingly the private sector. Land- and water-saving innovations will be required in Asia, as most growth must come from already cropped land. Public sector research was seen to be particularly relevant to resource-poor areas, where the returns to research have historically been lower than in irrigated and high-potential areas. The private sector is seen as the major player in the latter regions. The premises underlying this public-private sector dichotomy seem to us to be flawed. For one thing Fan et al. have shown that research returns are often higher in the more marginal areas; for another, there are complementarities to be exploited between public and private sector research, even in low-potential marginal areas. Fortunately ADB seems to recommend that additional R&D resources be provided to both high- and low-potential rural areas, rather than seeing them as alternatives. Rosegrant and Hazell (2000, p 100) in the same ADB publication, argue that:

> *....on poverty and environmental grounds alone, more attention will have to be given to less favored lands in setting priorities for policy and public investments. The successful development of less favored lands will require new and improved approaches, particularly for agricultural intensification.*

The centrality of agricultural productivity growth to rural development in Asia is questioned by Bloom et al. (2000, pp 153-168) in the ADB study, who make a case for strengthening what they term quality of life (QOL) outcomes. While not denying the importance of increased agricultural productivity to income growth, they point out there are a myriad of non-income factors that influence QOL such as gender equity and better health and education. Improving QOL also stimulates economic growth.

Dynamics of Agriculture in the SAT

Population growth

The latest assessment of world population prospects by the UN (UN 1999) indicates that there is likely to be a drastic reduction in world population growth. The world population of 6.05 billion in 2000 is expected to grow to only 7.15 billion by 2015. Population growth rate peaked towards the end of the 1960s at 2.1% per annum, and fell to 1.35 by the late 1990s. Further deceleration is expected to bring it to 1% by 2015 and 0.3% by 2050 (Table 23).

Table 24 shows the population figures for the SAT regions. The Latin America and Caribbean (LAC) region is unique in that the majority of the population already live in urban areas, compared to one-third or less in the other SAT regions. By 2020, urban population is expected to comprise more than 80% of total LAC population, compared to 40-50°/) in the other SAT regions. The absolute number of people living in rural areas is expected to decline in LAC while continuing to increase over the next two decades in the other regions. These trends imply that the leverage of agricultural technologies and policies to impact on the welfare of the bulk of the

Table 23. Population growth rates (% per year).

	1967-97	1977-97	1987-97	1995/97-2015	2015-2030
World*	1.7	1.6	1.5	1.2	0.8
Developing countries	2.1	2.0	1.8	1.4	1.0
Sub-Saharan Africa	2.8	2.9	2.7	2.4	2.0
Near East/North Africa	2.7	2.7	2.4	1.9	1.4
Latin America and Caribbean	2.1	1.9	1.8	1.4	0.9
South Asia	2.2	2.2	2.0	1.5	1.0
East Asia	1.7	1.5	1.3	0.9	0.5
Industrial countries	0.7	0.7	0.7	0.3	0.1
Transition countries**	0.7	0.7	0.2	0.0	-0.1

* Countries with FAO Food Balance Sheets. These constitute 99.65% of world population
** Eastern European countries, former Yugoslavia, Commonwealth of Independent States, Baltic states
Source: FAO 2000b, Table 2.4

rural poor is expected to be much less in LAC than in other SAT regions.

The figures in Table 24 follow the general global trend, i.e. population growth rates have declined in the last decade, except in the SAT of West and Central Africa. The drastic declines in growth rates forecast for the next two decades (Table 23) reflect the projected effect of the AIDS pandemic on morbidity and life expectancy.

HIV/AIDS is having a devastating impact on the lives and livelihood of millions of people throughout the developing world. At the end of 1998, 95% of the estimated 33.4 million people living with HIV/AIDS were in developing countries, Africa remains the global epicenter, with 83% of all AIDS-related deaths to date, and nine out of ten new infections. Adult HIV/AIDS prevalence rates exceed 10% in 13 countries in Africa. In Zimbabwe, Botswana, Namibia, Zambia, and Swaziland 20-26% of the adult population aged 15-49 years is infected. Half the world's AIDS victims came from Southern and Eastern Africa, and the lifetime chances of dying from the disease there is now 40% (Caldwell 2000). In Zimbabwe and Botswana the chances are now 70%. The epidemic is increasingly recognized as a development crisis. Life expectancy is estimated to decline from 59 to 45 years in Africa and from 61 to 33 years in Zimbabwe by 2010. HIV/AIDS threatens food security and livelihoods of rural populations.

Compared to Africa, Asia has had a relatively low seropositivity rate, but the spotlight is increasingly shifting to South and East Asia. By the end of 1998 there were over 7 million infected people in Asia, and 4 million in India alone.

Semi-arid areas are particularly vulnerable because limited opportunities for earning cash income lead to high levels of mobility and migration in search of better opportunities, with attendant increases in the probability of contracting HIV/AIDS. This poses new challenges for agricultural R&D in these areas. At the household level the most immediate impact is on the availability and allocation of labor. Labor available for agriculture declines as patients fall ill and ultimately die. At the same time the labor of other household members is diverted from productive activities to care for AIDS patients, Studies from Southern and Eastern Africa show how affected households shift to crops that require less labor and are drought tolerant, Crop production will decline as a result of a reduction in planted area and the adoption of less labor-intensive farming practices. HIV/AIDS can lead to changes in land use and/or allocation of land to crops as a result of reduction in labor input. Affected households have been shown to re-allocate resources from cultivation of cash crops, choosing instead to allocate available labor to food crops for household subsistence needs. In some cases AIDS orphans have had problems retaining family land and other household assets.

AIDS normally claims the lives of people in then-most productive years, frequently leading to a loss of remittances. The number of *de jure* female-headed households, whose husbands have succumbed to the disease, is rising. The large numbers of children

Table 24. Current and projected population in the SAT.

		Total population (millions)				Urban population (%)			
Region*	Class	96-98	2000	2010	2020	96-98	2000	2010	2020
Asia	Large	962.3	1006.8	1152.3	1271.6	27	28	33	39
Asia	Small	62.0	67.5	82.9	98.9	29	30	37	44
LAC	Large	11.1	11.2	11.5	11.7	77	78	81	84
LAC	Medium	15.6	16.3	19.1	22.1	49	51	56	61
LAC	Small	305.2	318.7	363.5	404.1	77	78	81	84
SEA	Large	11.5	12.4	15.3	18.2	33	35	42	49
SEA	Medium	88.6	94.8	120.9	150.3	33	35	43	49
SEA	Small	140.4	154.7	206.2	268.2	22	23	29	35
WCA	Large	21.0	22.8	29.7	38.0	29	31	37	43
WCA	Medium	130.1	147.6	193.4	247.3	40	43	51	57
WCA	Small	33.0	35.8	47.0	60.6	34	36	42	48

* LAG = Latin America and Caribbean, SEA = Southern and Bacon Africa, WCA = West and Central Africa
Source; FAO statistical dstsbases, 1998

orphaned by AIDS ran the risk of delinquency, or are likely to face severe social problems.

There is a lack of empirical evidence on the macro-economic impact of HIV/AIDS. However, it is likely that the aggregate cost to these economies will be substantial. Investment currently going to agricultural research may have to be redirected toward medical research and hospital services. Investments will increase in social welfare funds for the support of the growing number of AIDS orphans.

All this implies the need to raise agricultural productivity by concentrating on developing and disseminating labor- and capital-saving technologies as well as drought-resistant crop varieties that stabilize yields. Increased attention needs to be given to targeting female heads of households. Research organizations also need to develop strategic partnerships with other development organizations to support diversification of income that offers better prospects for survival in semi-arid areas.

Gender balance in agricultural employment

Although the number of women in the SAT labor force has increased in line with increases in population, the share of women in the labor force has declined or remained constant in all regions except in the Large- and Small-SAT countries, where the proportion has increased. But the changes have been small and probably not significant (Table 25). What is more interesting is the shift towards non-agricultural sectors by both men and women. Generally the change has been greatest in the Large and Medium-SATs, which have fewer alternative agricultural options, than in the Small-SAT regions, with the greatest shifts in LAC. Also, the figures show that the female labor Force has shifted a bit more to non-agricultural sectors than the male labor force. Generally the figures on labor force participation support the picture of falling relative importance of the agricultural sector that emerges from examination of other statistics.

It should be noted that the global statistics do not reflect the fact that women are becoming increasingly responsible for overall farm management, especially following male migration, such as in the SAT of Southern and Eastern Africa. The increasing feminization of agriculture in some regions is mainly the result of seasonal or non-permanent out-migration from rural areas by males. In countries where this feminization is an important factor, agricultural policies, including those for technology development, need to take a priori consideration of any special needs of women. Such policies must take full cognizance of the possibility that female-headed households may have higher incomes than male-headed rural households because of remittances from migrant family members (Figs 6, 7). As indicated in Chapter 2 (Dimensions of Poverty), the increased incomes in the control of

Table 25. Distribution of total labor force in SAT regions.

								Non-agricultural labor force			
Region*	Class	Total labor force (millions)		Total male labor force (millions)		Total female labor force (millions)		% of male labor force		% of female labor force	
		1980	1995	1980	1995	1980	1995	1980	1994	1980	1994
Asia	Large	300	398	198	271	102	127	37	41	17	26
Asia	Small	19	28	11	17	8	11	29	34	19	21
LAC	Urge	A	5	3	3	1	2	70	60	90	92
LAC	Medium	5	6	3	4	2	2	40	49	53	62
LAC	Small	81	124	59	83	22	41	59	69	77	87
SEA	Large	3	S	2	3	1	2	37	42	15	19
SEA	Medium	26	38	15	22	11	16	28	30	8	11
SEA	Small	40	61	22	34	18	27	17	21	11	14
WCA	Large	7	10	4	6	3	4	16	20	S	9
WCA	Medium	35	51	22	32	13	19	45	54	38	50
WCA	Small	10	13	6	8	4	5	26	27	9	12

* LAC = Latin America and Caribbean, SEA » Southern and Bittern Africa, WCA = West and Central Africa
Source: World Bank 1997, 1998

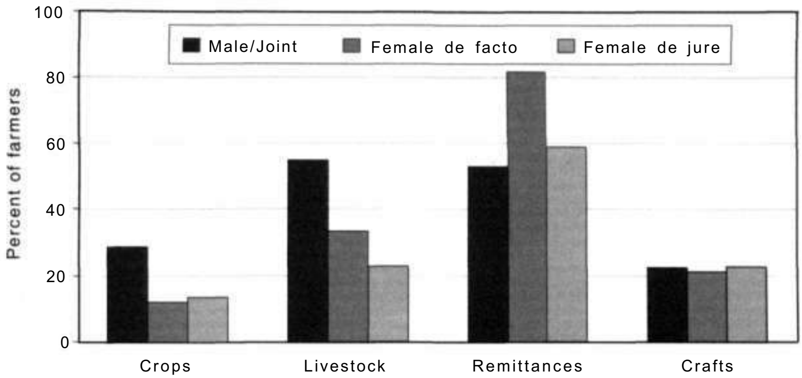

***Figure 6. Rural livelihood strategies are diversified: sources of cash income in male- and female-headed households, Tsholotsho, Zimbabwe,* 1999.**

Source: D, Rohrbach, **ICRISAT field surveys**

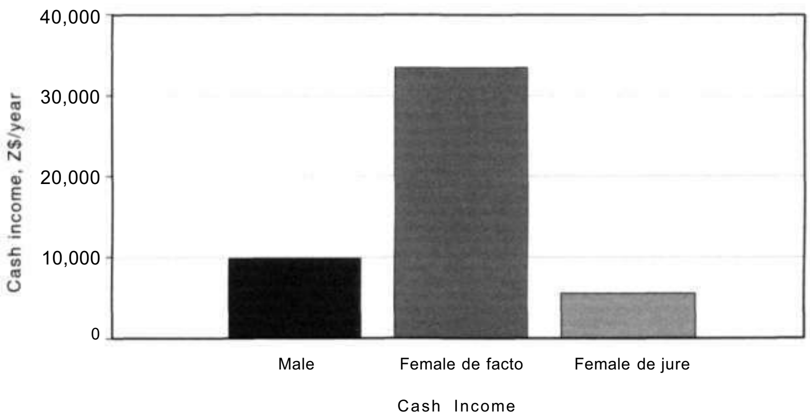

Figure 7. Female-headed households with husbands working elsewhere have more cash income to invest in crop production, Tsholotsho, Zimbabwe, 1999.

Source: D. Rohrbach, ICRISAT field surveys

women may have a significant positive effect on children's development in such communities. The phenomenon is therefore most likely an economically viable response to nonfarm opportunities in the changing dynamics in the SAT as well as other parts of the developing world.

However, the feminization of agriculture in Southern and Eastern Africa brings with it particular challenges for women. Women under usufruct title are usually assigned the poorest land. Because the title is insecure they do not invest, and have difficulty in obtaining credit. Women also are more illiterate than men, have poorer access to transport and markets, and poorer education, health, and nutrition. In view of these realities the task of agricultural research and extension institutions is even more challenging.

Changing importance of agriculture in SAT economies

Over the last three decades there has been a structural change in SAT economies, away from dependence on agricultural exports. The share of agriculture in total merchandise exports has declined significantly, except in Southern and Eastern Africa, where it has fluctuated between 40 and 50% (Fig 8). In Asia (India), the proportion declined from around 45% in the mid 1960s to 15% in the 1990s, while there has been a precipitous drop in West and Central Africa (Large and Medium SAT), from 85% to 15%.

Meanwhile, agriculture's share of imports declined from 45% to 5% over the same period in India, as the country became self-sufficient in food grains as a result of the Green Revolution, while the Large SAT in Southern and Eastern Africa has remained virtually self-sufficient throughout the last three decades (Fig 9). Agricultural imports account for roughly the same proportions of imports in the other regions: 20% in Large-SAT Latin America and Caribbean, 25-30% in West and Central Africa since the mid 1970s, and 10-20% in all Medium-SAT regions.

The implication is that SAT agriculture is more likely to be an import substituting, than an export industry. This will affect the prospects for ICRISAT crops, versus non-ICRISAT crops and livestock, as discussed later.

Irrigation and water scarcity

The rate of expansion of irrigation is slowing in developing countries, especially in Asia (Table 26). In India the scope for additional large-scale canal irrigation schemes is limited because the good and least-costly sites have already been developed. The marginal rates of return on further investments in irrigation are also diminishing, but returns from non-irrigation investments in rainfed areas are rising (Fan et al. 1999b).

FAO (2000b) project that the areas equipped for irrigation in developing countries will increase by 45 million ha or 25% over the next three decades (Table 27). This means that 22% of the land with irrigation potential not currently equipped will be brought under irrigation and that 60% of all land with irrigation potential would be in use by 2030. Expansion in irrigation will be strongest in absolute terms in the more land-scarce regions such as South Asia, East Asia, and the Near East/North Africa. Only small additions are expected in the more land-abundant regions such as sub-Saharan Africa and LAC, although the increase may be large in relative terms. The projected net increase in arable irrigated land of 45 million ha is less than half the increase over the preceding 34 years, and would be only 0.6% in terms of annual growth.

The International Water Management Institute (IWMI) estimates that 25% of the world's population, and 33%) of developing country population, live in regions that will experience severe water scarcity by 2025. Some one billion of the world's poorest people living in arid and semi-arid lands will be affected (Seckler et al. 1998).

Figure 10 shows that virtually all SAT countries in Africa fall into sub-group 2.1, i.e. countries that are expected to have enough water to meet their needs in 2025, but will need to produce more than twice their existing water supplies; or sub-group 2 (need to increase supplies 25-100%). This will require new water development projects which many countries will not be able to finance, in addition to the projected 50-70% improvement in water-use efficiency that is needed.

Table 26. Growth rates of irrigated area, 1961-90 (% per year).

Region	1961-71	1971-81	1981-90
Africa	1.81	3.96	2.22
Far East	2.15	2.53	2.18
China	2.65	1.83	0.39
India	2.06	2.56	1.08
All developing countries	2.17	2.09	1.24

Source: Pinstrup-Andersen and Pandya-Lorch 1994

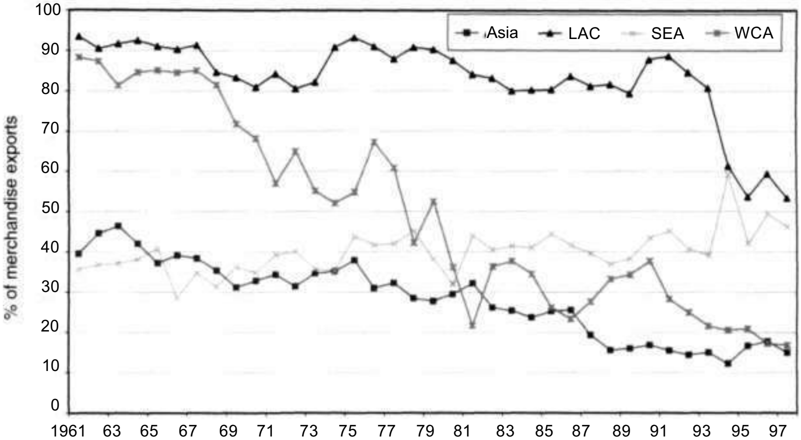

Figure 8. Share of agriculture value in merchandise exports, Large-SAT countries.

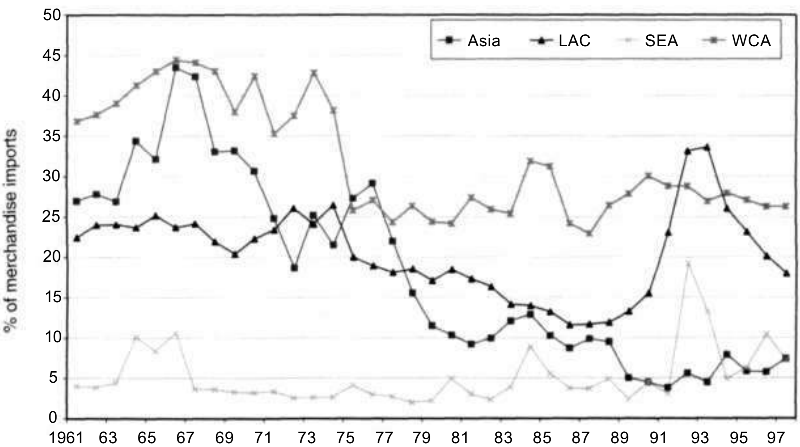

Figure 9. Share of agriculture value in merchandise imports, Large-SAT countries.

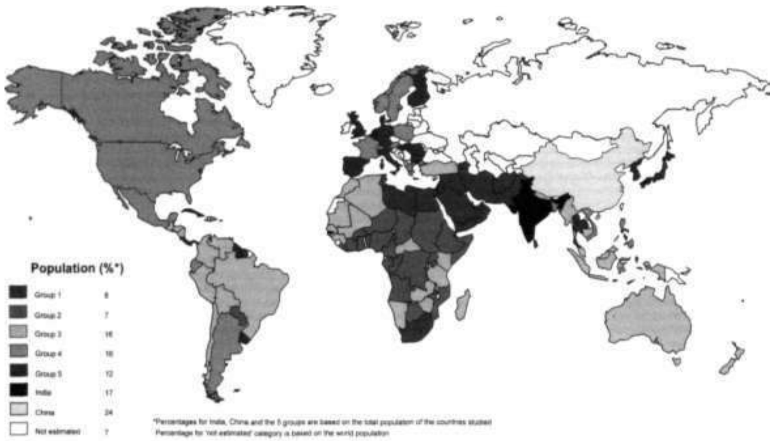

Figure 10. IWMI indicators of water scarcity in 2025.

Source; Seckkrer et al, 1998, Fig 1

Table 27. Irrigated arable land.

	Irrigated land in use (million ha)					Growth rate (% pa)		Land in use as % of potential		Balance (million ha)	
	1961-63	**1979-81**	**1995-97**	**2015**	**2030**	**1961-97**	**1995/97-2030**	**1995-97**	**2030**	**1995-97**	**2030**
Sub-Saharan Africa	3	4	5	6	**7**	2.1	**0.8**	**14**	**19**	**32**	**30**
Latin America	8	14	18	20	22	**2.4**	**0.6**	**26**	**32**	**50**	**46**
Near East / North Africa	15	18	27	30	**33**	**1.9**	**0.7**	**60**	**77**	**17**	10
South Asia	37	56	78	85	**95**	2.2	**0.6**	**55**	**67**	**64**	**47**
South Asia excl India	12	17	23	24	**25**	**1.9**	0.2	**82**	**89**	**3**	
East Asia	40	59	69	78	**85**	**1.5**	**0.6**	**62**	**76**	**43**	**27**
East Asia excl China	10	14	18	22	**25**	2.0	**0.8**	**40**	**52**	**29**	**23**
All above	103	150	197	220	242	**1.9**	**0.6**	**49**	**60**	206	160
All above excl China	**72**	105	146	164	182	2.1	**0.7**	**43**	**54**	192	156
All above excl China, India	47	67	91	103	112	2.0	**0.6**	**40**	**50**	134	113
Industrial countries	27	37	41			1.3					
Transition countries	11	22	25			2.8					
World	141	210	264			1.9					

Source: FAO 2000b, Table 4.9

The situation is likely to be worse in the Asian SAT, where Yemen and one-third of the Indian population are expected to experience absolute water scarcity. Projected use is expected to exceed 50% of annual water resources, and groundwater aquifers will be depleted and more polluted.

The IWMI studies further show that improvements in irrigation efficiency will not be sufficient to prevent the situation from worsening. As the price of water increases, agricultural water use will decline, with disproportionate impact on the poor. They also show that although technology improvements (better seed, increased fertilizer use, improved crop management) are expected to make a contribution, they will not go anywhere near being able to address the problem.

The implications of the projected water scarcity are that more water-efficient farm management systems will be needed, incorporating the use of drought-tolerant varieties, the choice of species with higher water-use efficiency, and the use of crop and simulation modeling for increased water-use efficiency. But even this will not be sufficient. SAT countries will need to devote more resources to increasing the supply of water. How much investment should be put into increasing water supplies relative to investment in development of new technologies will depend on the relative costs and chances of success. In the Asian SAT, which will face absolute water scarcity and depleted/polluted aquifers, the incentives to invest in water-conserving farming systems (irrigated and dryland] will be higher than in other SAT regions. There is good scope for achieving this in the Indian SAT, where around hall of farmers have holdings that are either wholly or partly irrigated. The Brainstorming Workshop with NARS partners at ICRISAT-Patancheru placed the highest priority on this type of research for ICRISAT (Appendix). ICRISAT leadership in associated policy and institutional analysis of effective interventions will also be required to address emerging water scarcity problems in the SAT.

Public and private irrigation schemes in many Asian SAT countries arc heavily subsidized, either by nominal water charges in canal schemes, or minimal electricity charges for the use of bore wells. To the extent that WTO processes regain momentum in the years ahead and subsidies are reduced for such inputs, it is imperative to economize on water use. Even though such measures are extremely sensitive politically, towards 2020 bold decisions will be required. If they are not made, alternative and less palatable means of rationing water will emerge, as it is clear the real economic value of water will rise, especially in the SAT.

This offers both a challenge and an opportunity for ICRISAT to focus squarely on the water constraint. This would involve both genetic enhancement to identify genes for improved water-use efficiency and drought tolerance, as well as water policy analysis and natural resource management research. In view of the advances in biotechnology enabling transgenic innovations, genetic enhancement need not be restricted to the current mandate crops but may be extended to other species with the required genes and water-use traits. This would provide more options because drought tolerance/resistance within species seems to come largely at the expense of yield potential, as plants have to invest more energy in roots or develop small, thick leaves with low transpiration rates but lower net photosynthesis.

Changing importance of ICRISAT mandate crops

It has been shown earlier that agriculture has become relatively less important in the SAT economies over the last three decades. Within the agricultural sector, what has happened to the ICRISAT crops? Table 28 shows growth rates of Laspeyre's indices and the changing shares of ICRISAT and non-ICRISAT commodities in agricultural GDP.[23] The figures show that with only a few exceptions, ICRISAT crops have been losing market share, i.e. SAT countries have become less reliant on them for their contribution to agricultural GDP.

The contribution of sorghum and millet has declined in all regions except in Large-SAT West and Central Africa, where value has grown at about the same rate as total crop value. The biggest drop in contribution has been in the Large SAT of Latin America and the Caribbean and Southern and Eastern Africa. Chickpea and pigeonpea shares have declined in Asia, the most important production region, although they have increased in Southern and Eastern Africa, where pigeonpea is increasing in importance from a very low base. Even for groundnut there has been a decline in market share over the last three decades.

By contrast, non-ICRISAT crops have increased market share over the last three decades. In the Large and Medium SAT, rice and wheat have gained significantly in market share in all regions, except for rice in Southern and Eastern Africa. The market share of cotton has increased significantly in Africa.

23. Where the ratios of the indices are greater than 1, the commodity's share of the value of crop or agricultural production is increasing, and is decreasing when the ratio is less than 1. Indices are calculated by Laspeyre's formulae. Quantities for each commodity are weighted by 1989-91 average international commodity prices and summed for each year, To obtain the index, the aggregate for a given year is divided by the average aggregate for the base period 1989-91.

Table 28. Relative annual growth rates of Laspeyre's index.

Region	Class	Growth rates 1961-98: All agriculture[2]	Growth rates 1961-98: All crops	Ratios of annual growth rates, individual crops compared to all crops, 1961-98[1] — ICRISAT crops: Sorg+Millet	ICRISAT crops: Cpea+Ppea	ICRISAT crops: Groundnut	non-ICRISAT crops: Rice	non-ICRISAT crops: Wheat	non-ICRISAT crops: Cotton	non-ICRISAT crops: Maize	Ratios of annual growth rates, subsectors compared to all agriculture, 1961-98: Inland fish 1961-97[3]	Livestock 1961-98
Asia	Large	2.91*	2.66*	0.22	0.15	0.59	1.03	2.06	0.86	0.83	1.71	1.26
Asia	Small	2.87*	2.77*	0.63	1.09	0.39	1.00	1.67	0.32	2.06	1.31	1.10
LAC	Large	0.58	1.03*	-7.44		-0.52	2.80			-0.33	40.83	0.19
LAC	Medium											
LAC	Small	3.37*	2.86*	3.74	-0.05	-1.27	0.55	0.54	-0.51	1.1	1.68	1.22
SEA	Large	2.28*	2.52*	-1.00		-0.62	-2.28	5.04	3.62	0.6	0.56	0.73
SEA	Medium	2.05*	0.72*	0.52	2.09	-3.01	-2.53	3.59	-3.21	2.17	1.10	1.33
SEA	Small	1.41*	1.21*	-1.00	0.16	1.72	3.26	-0.66	-1.13	2.05	2.90	1.56
WCA	Large	2.01*	1.69*	1.22		0.51	1.16		6.11	2.51	1.45	1.47
WCA	Medium	2.85*	2.70*	0.75		0.77	3.10	1.43	0.74	2.19	1.22	1.44
WCA	Small	1.69*	1.75*	0.57		-0.41	3.35	3.06	0.80	0.86	-0.83	1.18

* indicate significance at 5% probability level

1. Where ratios of indices are greater than 1, the commodity's share of value of crop or agricultural production is increasing, and is decreasing when ratio is less than 1. Indices are calculated by Laspeyre's formulae. Quantities for each commodity are weighted by 1989-91 average international commodity prices and summed for each year. To obtain the index, aggregate for a given year is divided by average aggregate for base period 1989-91.
2. All agriculture = crops + livestock.
3. Freshwater fishes in inland waters from FAOSTAT are considered as total inland fish. Export price of total fish catch of Mexico in 1989-91 is used to compute the total value of production. Laspeyre's index by country is calculated on this value and is aggregated into SAT groups using share of agriculture in GDP as weights. Agriculture commodities and livestock index from FAOSTAT

Maize has gained share in virtually all regions, compared to sorghum and millet. The implications for ICRISAT are clear - its mandate crops are becoming less and less important in SAT countries. The figures also clearly show the growth in livestock and inland fisheries, whose market shares have increased in virtually all SAT regions.

Overall in SAT India from 1970 to 1994 there was a shift away from coarse grains towards wheat, paddy, and oilseeds. The Indian SAT currently produces 87% of the coarse grains, 82% of the oilseeds, and 79% of the pulses (Gulati and Kelley 1999, p 10). It produces 54% of the total value of the major crops, and irrigation has been growing more rapidly in the SAT than in non-SAT areas. It now contains 58% of India's irrigated land (Table 29). Rainfed cropping in the Indian SAT has tended to move to more marginal areas, reflected in a decline in the areas under fallow, wastelands, and permanent pastures. Cropping intensity in the Indian rainfed SAT has increased from 1.09 in 1968-70 to 1.20 in 1992-94. Some 80% of the growth in gross cropped area in India's SAT can be attributed to crop intensification. Gulati and Kelley (1999, p 14) expect that while irrigation will continue to expand in the Indian SAT, the cropped area will still be predominantly rainfed in the foreseeable future.

Reflecting the pattern in the SAT generally in Table 28, the share of coarse cereals - particularly sorghum and millet - in India's gross cropped area has fallen dramatically in the last 25 years (Table 30). However, maize share has increased. The overall share of pulses has been steady during this period, with chickpea share falling and pigeonpea share rising. Oilseeds have almost doubled their share, dominated by sunflower, soybean, and rapeseed/mustard; groundnut share has not increased. Most of this expansion in oilseeds was due to the special Technology Mission on Oilseeds implemented by the Government of India in the 1980s and early 1990s. This involved price supports, import tariffs, marketing interventions, input subsidies, and intensive extension. Bhinde et al. (1998) have calculated that between 1971 and 1994, the production of 31 crops grew more rapidly than coarse cereals and pulses in India. Only five crops grew more slowly. The high flyers were fruits, vegetables, spices, and animal products. Horticulture now accounts for about one-third of the value of agricultural production, up from 15% in 1970-71. States with better irrigation tend to converge to higher rates of agricultural growth. Before the Green Revolution three-quarters of the growth of agricultural output in India was explained by growth in total factor inputs and only one-quarter by total factor productivity growth. After the Green Revolution the shares were reversed (Dholakia and Dholakia 1993).

Table 29. The Indian SAT.

Measure (%)	1968-70	1992-94
SAT share of gross cropped area	62	62
SAT share of total irrigated area	48	58
Share of SAT irrigated	18	23

Source: Gulati and Kelley 1999

There was a major increase in wheat area in the Indian SAT, virtually all due to the expansion in irrigation, as the area under dryland wheat fell by almost 2.4 million ha. Irrigated wheat displaced many crops including chickpea, minor pulses, sorghum, pearl millet, and groundnut. Most of this resulted from new access to irrigation in areas previously dominated by rainfed cropping.

Cropping patterns in India have changed from the early 1970s to the early 1990s. In both marginal and favorable districts, shares of the following crops in total gross cropped area fell sharply: pearl millet, and both *kharif* and *rabi* sorghum (Table 31). The shares of rapeseed/mustard and soybean rose significantly in both marginal and favorable districts. Cotton and groundnut shares fell in marginal districts but not in favorable ones, where cotton rose significantly. Chickpea share fell in favorable districts but rose in marginal ones. The shares of sunflower, safflower, and minor pulses increased in marginal districts but fell in favorable ones. For wheat, rice, and sugar there were substantial increases in shares in

Table 30. Share of crops in gross cropped area in India.

Crop	Share (%)	
	1968-70	1992-94
Sorghum	16.8	10.8
Pearl millet	12.0	8.7
Maize	2.7	3.0
Coarse cereals	34.7	24.3
Chickpea	6.0	5.3
Pigeonpea	2.1	2.5
Total pulses	15.9	15.7
Groundnut	6.7	*6.6*
Total oilseeds	10.4	19.3

Source: Gulati and Kelley 1999

favorable areas not matched in marginal areas. These three crops have a high proportion of their areas irrigated and this no doubt contributed to the differential productivity growth rates.

More than 90% of the reduction in sorghum area in India was in *kharif* sorghum. It was replaced by soybean and chickpea in the north; and by groundnut, paddy, and cotton in southeastern India. Pearl millet was largely replaced by sunflower, safflower, chickpea, irrigated wheat, and rapeseed/ mustard. Chickpea declined in the north largely because of expanded irrigation but increased its share in the west and south of the country. Pigeonpea expanded over most zones. Groundnut share rose in the south and fell in the north. It replaced finger millet, pearl millet, sorghum (both *kharif and rabi),* and cotton in some places.

Gulati and Kelley (1999, pp 37-66) found that for most crops, the extent of irrigation was the most important factor besides own or competing crop prices, in accounting for area increases. Decisions on how much area to plant seem to be driven by profit considerations and not by home consumption considerations. This was particularly true for commercial crops like cotton, wheat, maize and rapeseed/mustard; except in a few cases it was also true for sorghum, millet, chickpea, and pigeonpea.

In many districts in India, high-yielding sorghum cultivars and hybrids seem to be less remunerative than competing crops, Dayakar et at. (1997) calculated that the net returns per hectare from sorghum were on average only 29% (range 9-67%) of those from other crops. Respondents in the surveys conducted indicated they grew sorghum primarily for home consumption (grain and fodder) so profitability per se was not the primary consideration. Even in Anantapur and Akola districts, where large productivity growth has occurred, high-yielding sorghum varieties are still less competitive than alternative crops (37% of net returns per hectare of others, with a range of 18-67%). They postulate that had not household demand for sorghum held up, sorghum area would have declined even more. They suggest that future productivity growth in sorghum will not reverse the decline in sorghum competitiveness and area.

Production trends

Sorghum: Developing countries account for roughly 90% of the world's sorghum area and 70% of total output (FAO/ICRISAT 1996), Asia and Africa each account for 25-30% of global production. The biggest producers are USA, India, Nigeria, China, Mexico, Sudan, and Argentina.

Small-scale farming households grow much of the crop. Production in Africa is characterized by low productivity and extensive, low-input cultivation. Production is generally more intensive in Asia, where fertilizer and improved varieties are used more widely. In Africa and Asia sorghum is grown primarily for food, In contrast almost all production in developed countries is used in animal feed. Small quantities are used for flour, malt drinks and beer.

Global sorghum production fell by 0.7% per annum between 1979 and 1994 (Table 32). Production grew in Africa by 2.9% per annum but declined in most other parts of the world. Gross cropped area is expanding in Africa - from 13 million to 22 million ha between 1979 and 1994. However, global sorghum area fell by 0.2% per annum over the same period. Sorghum yields have increased in all regions except Africa, where yields fell 14% in the 1980s before rising again in the 1990s. In India yields vary significantly between

Table 31. Major changes (change in percentage points) in share of crops in gross cropped area in the Indian SAT, 1968-70 to 1992-94.

Marginal regions				Favorable regions			
Crop	Falling sheres	Crop	Rising shares	Crop	Falling shares	Crop	Rising Shares
Kharif sorghum*	-4.4	Sunflower	3.1	Chickpea	-4.5	Wheat	8.5
Pearl millet	-3.1	Soybean	2.3	Pearl millet	-3.8	Rapeseed/mustard	2.6
Cotton	-2.6	Rapeseed/mustard	2.0	Kharif sorghum	-3.4	Rice	2.4
Rabi sorghum	-1.2	Chickpea	1.7	Barley	-2.5	Cotton	1,4
Groundnut	-1.2	Safflower	1.5	Rabi sorghum	-2.4	Sugar	1.3
		Minor pulses	0.9			Soybean	0.9

* Kharif = rainy season, rabi =postrainy season

Sources:ICRISATdatabase,GulatiandKelley1999 regions depending on rainfall, soil type, and season. Yields of rainy-season sorghum are 2-2.5 t ha^{-1} in areas with deep soils and assured rainfall, but postrainy-season yields are less than 500 kg ha^{-1} in many low-rainfall areas. An important factor underlying yield trends is the adoption of hybrids, most widely in areas where sorghum is produced commercially and there are well-developed private seed industries. Falling yields in Africa, where sorghum is a food security crop, are a major concern.

Sorghum is moving on to more marginal lands in sub-Saharan Africa, and is being replaced by maize. Simultaneously, cheap rice and wheat imports discourage local sorghum and millet consumption. In Asia sorghum receives little price support compared to competing crops.

World trade in sorghum is strongly linked to demand for livestock products, dominated by feed requirements and prices. Only 6% of the 0.5 million tons traded globally is for food. Countries in Africa are the main importers. Competition between sorghum and maize is a key factor in feed utilization. In some countries sorghum is discounted in poultry feed because it does not give the preferred yellow egg yolk. However, the main advantage of maize is its greater productivity, resistance to birds, and strong consumer preferences.

Millet: Developing countries account for about 94% of the world's millet production. Global output is 28 million tons per year, of which pearl millet accounts for 15 million tons, foxtail millet 5 million, proso millet 4 million, and finger millet 3 million tons. The major producers are India (11 million tons), Nigeria (4.6), China (3.7), and Niger (1.9}. In most parts of the world millet is grown as a subsistence crop for local consumption - 95% of the crop is used as food in developing countries.

Worldwide, millet area has remained around 38 million ha over the last two decades but production has increased from 25.7 million tons in 1979-81 to 28.4 million tons in 1992-94 (FAO/ICRISAT 1996). In India millet area declined 1.8% per annum between 1979 and 1994, but yields rose 2.7% per annum. In Africa millet area rose 4.1% per annum, but yields declined 0.6% (Table 32). Millet yields are declining in Africa because of reduced fallows and movement into more marginal lands.

There has been little growth in millet consumption, whether for food or feed. There is little scope to expand feed use because of production fluctuations, poor infrastructure, little surplus after food needs are met, and high transport costs to animal feed centers. Only 1 % of millet production is traded internationally, but there is considerable intra-regional trade within West and Central Africa.

Groundnut: Groundnut is largely a smallholder crop grown under rainfed conditions in the SAT. Developing countries account for over 95% of world area and 75% of production. Asia accounts for 70% of global production and 60% of area. Africa produces only 21% of global production on 35% of area. The main producers are China (10.1 million tons), India (8.4), Nigeria (1.8), USA (1.7), Senegal (0.7), and Sudan (0.5 million tons).

During the past two decades groundnut area has expanded in Africa and Asia, increased marginally in developed countries, and declined sharply in Latin America and the Caribbean (Table 33). Overall,

Table 32. Sorghum and millet growth rates (% per year), 1979-94.

	Sorghum			Millet		
Region	Area	Yield	Production	Area	Yield	Production
Developing countries	0.1	-0.5	-0.4	0.3	0.4	0.6
Africa	3.9	-1.0	2.9	4.1	-0.6	3.4
Sudan	4.2	-0.9	3.3	2.7	-2.7	-0.2
West Africa	5.7	-1.2	4.5	4.7	-1.4	4.2
Central Africa	2.1	0.9	3.1	3.6	-1.3	2.3
Eastern Africa	-0.2	-0.6	-0.8	0.5	-0.1	0.4
Southern Africa	3.0	-2.2	0.7	5.9	-1.5	1.1
Asia	-2.6	1.5	-1.1	-2.4	1.5	-0.9
Near East	-2.8	3.2	0.3	-2.0	-3.1	-5.0
Far East	-2.5	1.4	-1.1	-2.4	1.5	-0.9
India	-2.1	1.7	-0.5	-1.8	2.7	-0.9
South America	-5.9	0.6	-5.4	-12.5	2.3	-10.5

Source: FAO/ICRISAT 1996

global area declined 1.3% per annum between 1979 and 1996, while yields increased by 1.9% per annum. Productivity improved in all regions, especially in Asia and Latin America and the Caribbean.

Table 33. Groundnut growth rates (% per year), 1979-96.

Region	Area	Yield	Production
Developing countries	1.4	2.1	3.5
Africa	1.3	1.1	2.4
Eastern and Southern Africa	-0.7	0.0	-0.7
West and Central Africa	2.4	1.3	3.7
North Africa	2.3	2.3	4.6
Asia	1.5	2.5	4.0
East Asia	2.9	4.5	7.4
South Asia	0.9	1.6	2.5
India	1.0	1.7	2.7
LAC	-3.7	1.7	-2.0
Developed countries	-0.4	0.7	0.2
World	1.3	1.9	3.2

Source: Freeman et al. 1999

In India 20% of groundnut is irrigated, and yields 1.6 t ha^{-1} compared to 0.9 t ha^{-1} in rainfed systems. Globally, production is growing at 3.2% per annum - more in developing countries - but less than competing crops such as soybean, palm oil, sunflower, and rapeseed. The private seed sector is not interested in groundnut because of large seed size, a low multiplication factor, and storage and viability problems. Some of these problems are amenable to breeding and could be considered as research priorities for ICRISAT.

Demand for groundnut in Asia has grown due to population growth; income growth and urbanization have increased the demand for convenience foods. Groundnut oil and meal compete well with other substitutes. Trade in oil and meal has fallen in the last 20 years, while confectionery trade has increased. Aflatoxin is an important factor in both food and stockfeed. Exports are concentrated in developing countries and imports in Europe, except for USA in confectionery groundnut.

Groundnut consumption is income elastic. In the last 10 years the proportion of food use in groundnut has increased in Asia and Africa, while the oil share has decreased. World utilization of groundnut meal increased 45% between 1979 and 1996, largely driven by Asia, where meal consumption has doubled. There was little change in Africa. Globally the share of confectionery use of groundnut increased from 75 to 83% between 1979 and 1996. It doubled in Asia, which now accounts for two-thirds of world confectionery groundnut consumption.

Exports of groundnut oil declined by 34% between 1979 and 1996. Most of this decline occurred in developing countries. The chief causes were policies taxing export crops in Africa, and increased domestic requirements in Asia. European countries account for 80% of global imports of groundnut oil. Groundnut meal exports also declined in developing countries over the same period. India is the largest meal exporter, followed by Gambia, Sudan, and Senegal. Together they account for 75% of total exports.

Chickpea: Joshi et al. (2000) show that chickpea area and yields in developing countries have grown in the last two decades. This expansion has mostly occurred outside of South Asia (Table 34). This has resulted in an increase in the Simpson Index of diversity from 0.40 in 1970-72 to 0.56 in 1996-98 (Ganesh Kumar 2000).[24] South Asia's share of world production has fallen from 81% to 75% over the same period. In the 1980s there was a substantial reduction in chickpea area (-1.1 % per year) but this was reversed in the '90s (2.9% per year). In West Asia and North Africa (WANA), the other major chickpea-growing region, area grew rapidly in the '80s (12.1% per year) but stagnated in the '90s (0.4% per year).

Currently 77% of chickpea is consumed as food and 11% as feed. In India 75% of chickpea is consumed as *dhal* or flour and 25% as whole seed. In recent years, feed use has been growing much more rapidly than food use (3.5 versus 1.5% per year). International trade in chickpea has slowed in the '90s and currently represents only 10% of the world trade in pulses. India is becoming a major importer. In 1980-82 it imported 4000 t; in 1996-97 the figure was 122,000 t. In the '90s India began to reduce import duties on chickpea from 35 to 10%. Europe is also increasing its imports of chickpea, for both food and feed use.

South Asia is projected to have a substantial deficit in chickpea in 2010, to the extent of 1.6 million tons. Africa will also have a deficit. On the other hand WANA, LAC, and Australia are likely to have trade surpluses.

24. The Simpson Index is calculated as I_k , where I_k is $\Sigma_m(S_{km}/100)^2$, and S_{km} is the share of crop k in country m. A variable 1- 1_k is created from the Simpson Index such that the more diversified is the production of a crop, the closer is the variable to unity.

Table 34. Compound annual growth rates for chickpea and pigeonpea, 1981-98.

Crop/Region	Area	Production	Yield
Chickpea			
Developing countries	0.7	0.8	1,6
South Asia	0.0	1.2	1.1
WANA	8.1	-1.6	6.4
Developed countries	7.2	1.8	9.2
World	0.9	0.9	1.8
Pigeonpea			
Developing countries	1.6	1.0	-0.6
Africa	0.9	2.2	1.4
Southeast Asia (Myanmar)	10.6	11.5	0.8
South Asia	1.3	0.6	-0.8
Developed countries	na	na	na
World	1.6	1.0	-0.6

na = data not available
Source: Joshi et al. 2000

Pigeonpea; India remains the dominant producer of pigeonpea, accounting for 86% of world production. Africa follows with 7%, then Southeast Asia 6%, and LAC 1%. As with chickpea, pigeonpea is becoming more of an international crop, with the Simpson Index of diversity rising from 0.20 in 1980-81 to 0.26 in 1996-98. The area has expanded in all regions in the past two decades although yield has been falling in the major producing countries (Table 34}. In the three decades to 1990, pigeonpea area in India grew at 1.1% per year. Since then it has declined slightly at -0.2% per year. During the expansion phase yields grew at 0.7% annually but declined by 0.4% per year in the '90s. Myanmar has rapidly expanded its area and production but with modest yield growth. A major portion of its production is exported to India.

Some 80% of pigeonpea is used as food and 9% as feed. Feed use has been growing at 1.3% per annum in the last 20 years while food use has grown only by 0-5% annually. International trade represents only 2% of total production with India and Venezuela the major importers. Production is projected to increase by 1 million tons by 2010 from 2.8 million tons in 1996-98. Myanmar and India will be the major contributors. India will drive the increased demand for pigeonpea in the next decade and will continue to be in deficit.

Oil crops: The FAO (2000b) study indicates that the oil-crops sector has recorded fastest growth of all sub-sectors of global agriculture, particularly in recent decades. In the 20 years to 1997, its growth rate exceeded that of livestock products, widely held to be the driving force of the world food economy. The major driving force on the demand side has been the growth of food demand in developing countries, mostly in the form of oil but also for direct consumption of soybean, groundnut, etc; as well as in the form of derived products other than oil.

It is expected that oil crops will be playing an ever-increasing role in raising food consumption and reducing undemourishment. However, given the lower growth rates of both population and per caput demand, FAO project that growth of aggregate food demand is likely to be well below that of the past {Table 35). The projected fairly buoyant growth in demand, coupled with still considerable production potential in some of the major exporters suggests that earlier trade patterns - rapidly increasing imports by most developing countries, matched by rapid export growth by the main exporters - will continue for some time.

Sources of growth in crop production

IFPRI projections are that the world's farmers will have to produce 40% more grain in 2020. Of the rise in global cereal production, 20% will come from area expansion, mainly in sub-Saharan Africa, and 80% from higher yields (Table 36).

Table 36. Sources of growth in cereal production (% per year) in IFPRI model.

Region	Total	Area expansion	Yield improvement
Sub-Saharan Africa	2.9	1.2	1.7
LAC	2.2	0.5	1.2
South Asia	1.5	0.2	1.3
Developing countries	1.7	0.4	1.3

LAC = Latin America and Caribben
Source; Pinstrup-Andersen et al. 1999

Agricultural production and research systems will be challenged to keep abreast of changing dietary preferences while generating technologies to improve crop yields in the coming years. Growth in cereal yield is slowing from 2.9% in 1967-82, to 1.9% in 1982-94, and is projected at 1.3% to 2020 by IFPRI.

FAO (2000b) projects a 57% increment in world crop production over the period 1995 to 2030, against 117% over the preceding period covering 1961 to 1997. Similar increments for developing countries as a group are 70 and 175% respectively.

Only in sub-Saharan Africa is the projected increment about the same as the historical one. Batter growth in developing countries, as compared to the world average, means that by 2030 these countries will account for almost three-quarters of world crop production, up from two-thirds in 1995/97 and just over half in 1961/63.

FAD point out that there are three sources of growth in crop production: (i) arable land expansion which, together with (ii) increases in cropping intensity, i.e. greater multiple cropping and shorter fallow periods, leads to an expansion in harvested area; and (iii) yield growth. About 80% of the projected growth in crop production in developing countries will come from yield increases (69%) and higher cropping intensity (11%, Table 37). The share due to intensification will go up to 90% and higher in the land-scarce regions of Near East/North Africa and South Asia. Arable land expansion will remain an important source of growth in many countries of sub-Saharan Africa, Latin America, and some countries in East Asia, although much less so than in the past.

The IFPRI and FAO studies indicate that, as in the past but even more so in the future, production increases will come mainly from intensification of agriculture - higher yields, more multiple cropping, and reduced fallow periods This will be true particularly in countries with appropriate agroecological environments and little or no potential for bringing new land into cultivation. Overall, for all the crops covered in the FAO study (aggregated with standard price weights), world yield growth rate over the projection period will be only half of the historical rate: 0.9% p.a. during 1995-2030 against 1.7% p.a. during 1961-97; and for developing countries, 1.0% and 2.1% respectively. This slowdown in yield growth is a gradual process, which has been under way for some time and is expected to continue in the future. In view of the fact that the impact of genetically improved crops in the SAT of sub-Saharan Africa has been limited by low soil fertility and rudimentary management practices, higher priority should be given to soil, water, and nutrient management research in future, even at the expense of further genetic enhancement (Ruttan 1991, Sanders et al. 1996).

Table 35. Food use of vegetable oils, oilseeds, and products (oil equivalent).

	Food use (kg/capita)					
Region	1964/66	1974/76	1984/86	1995/97	2015	2030
World	6.3	7.2	9.4	11	13.6	15.8
Developing countries	4.7	5.2	7.5	9.4	32.4	14.8
Sub-Saharan Africa	7.7	8.0	8.3	9.4	10.9	12.6
Near East/North Africa	6.7	9.4	12.2	13.4	14.7	16.2
Latin America and Caribbean	6.2	8.0	11.0	12.2	14.3	16.0
South Asia	4.5	5.0	6.4	8,5	11.9	15.3
East and Southeast Asia	3.4	3.4	6.2	8.6	12.2	16.1
East and Southeast Asia, excl China	4.9	5.3	8.4	11.1	13.6	14.6
Industrial countries	11.4	14.5	17.4	19.9	22.0	23.3
Transition countries	6.9	8.2	10.2	8.7	11.6	14.9
	Total food use					
	Million tons	**Growth rates (% pa)**				
	1995/97	1967-97	1977-97	1987-97	95/97-2015	2015-2030
World	62.9	3.8	3.5	2.7	2.3	1.9
Developing countries	41.9	4.9	4.6	3.8	2.8	2.2
Sub-Saharan Africa	5.1	3.4	3.3	4.4	3.2	2.9
Near East/North Africa	4.8	4.9	4,0	2,9	2.4	2.0
Latin America and Caribbean	5.9	4.7	3.5	2.2	2.2	1.8
South Asia	10.6	4.7	4.7	4,2	3.3	2,4
East and Southeast Asia	15.6	5.8	5.9	4,2	2.7	2,1
East asd Southeast Aria, excl China	6.5	5.6	5.4	3.5	2.3	2.0
Industrial countries	17.4	2.4	2.2	1.8	0.9	0.5
Transition countries	3.6	1.5	0.1	-2.8	1.5	1.6

Source:FAO 2000, Table 3.17

Agricultural diversification

The Brainstorming Workshop with NARS partners at ICRISAT-Patancheru regarded diversification as an important opportunity for smallholders in the rainfed SAT for a number of reasons:

- Risk diffusion leading to higher and more stable incomes
- Response to changing demand patterns away from cereals towards animal products, fruits, and vegetables
- A means of arresting resource degradation by creative changes in livestock-horticulture-crop systems to exploit synergism and economize on increasingly scarce water
- Reduction of the incidence and damage caused by pests and diseases.

Delgado and Siamwalla (1997) discuss whether diversification per se should be a means or an end in itself. Farmers will respond to price signals and technology options in ways that will sometimes result in greater diversification and sometimes will not. If (as we always assume) farmers are rational, then the final outcome presumably meets their own objectives and there may be little we can do about it, except to ensure policies are in place that mean the signals are the correct ones and there is a wide array of technology options available to them.

As globalization and trade liberalization proceed apace, it can be expected this will lead to more specialization - not less - at country and regional levels. Whether this will be translated into more or less specialization at farm level is arguable. However, as subsidies are removed on inputs such as water and electricity, there will be offsetting incentives for farmers to diversify out of water-intensive crops such as rice into those with higher water-use efficiencies. Infrastructure investments on roads, communications, and markets can be expected to enhance the prospects for greater diversification. Information technology may provide a special scope for diversification in remote SAT regions, Ib the extent that SAT areas receive a higher priority in these investments in future as a result of the convincing evidence from the work of Fan et al. of the win-win outcomes that are possible, then we may see greater diversification in South Asia at least. However, in sub-Saharan Africa, there is already a significant amount of diversification and further changes will depend on improvements in markets. Recent initiatives with date palm in the SAT of West and Central Africa provide an opportunity to examine the scope for perennial commercial crop diversification in this drought-prone environment.

In Africa the same households tend to be involved in both farm and nonfarm activities; in South Asia,

Table 37. Sources of growth in crop production (%).

Region	Arable land expansion (1)		Increase in cropping intensity (2)		Harvested land expansion (1+2)		Yield increases	
	1961-97	1995/97-2030	1961-97	1995/97-2030	1961-97	1995/97-2030	1961-97	1995/97-2030
Sub-Saharan Africa	41	25	24	13	56	38	35	62
Latin America and Caribbean	47	30	1	22	48	52	52	48
Near East/North Africa	14	13	15	20	29	33	71	67
South Asia	7	5	14	12	21	17	79	83
East Asia	26	5	-6	12	20	16	80	83
All developing countries	24	20	5	11	29	31	71	69
All developing countries excl China	24	23	12	13	36	35	64	65
All developing countries excl China and India	31	27	14	15	45	43	55	57
All developing countries - rainfed		21		11		32		68
All developing countries - irrigated		27		15		42		58
World	15		8		23		77	

Source: FAO 2000b, Table 4.2

households tend to specialize, even though households in the same village may have different economic functions (Delgado and Siamwalla 1997, p 135). They note that in rainfed agriculture in Africa diversification into nonfarm activities may be the most appropriate solution, but it may come at the expense of agricultural intensification. However, this would seem to ignore the added opportunities to use nonfarm income and remittances for additional farm investment. Intensification also probably implies less diversification of agricultural output, which will increase risks. They suggest that a mix of public and private institutional forms (e.g. contract farming and cooperatives) is probably appropriate in Africa to help promote diversification.

Livestock

Livestock demand and poverty[25]

The magnitude and significance of projected increases in demand for livestock products in developing countries over the next two decades have led Delgado et al. (1999) to describe the phenomenon as the coming "livestock revolution". While demand for meat in developed countries is expected to grow only marginally over the next 20 years, demand in developing countries is projected to grow at 2.8% per year. This will increase the annual demand for meat in developing countries from 89 million tons in 1993 to 188 million tons by 2020 (Delgado et. al. 1999). Two-thirds of the demand will be for pork and poultry (Table 38). Demand for milk is expected to increase even more than for meat. With a projected annual increase of 3.3% in developing countries, annual demand will increase from 168 million tons in 1993 to 391 million tons in 2020.

This large increase in demand is likely to improve the welfare of the poor. An estimated 678 million rural poor in developing countries (two-thirds of their rural poor) keep livestock. This large proportion indicates the importance of livestock to their livelihoods (Table 39). ILRI points out that the mixed crop-livestock systems prevalent in developing countries offer the best opportunity for public livestock R&D to have significant economic impact. This is because the value of animal products that would accrue from improved production and reduced costs is much greater in these mixed systems than in other systems (grassland and industrial). It is in these mixed crop-livestock systems that the largest numbers of rural poor work. For developing countries as a whole, the correlation is high between the economic importance of animal products in a livestock system and the number of poor living in that agroecological zone.

As indicated in Chapter 3 (Dynamics of Agriculture), the rural poor, especially women, derive a larger proportion of their wealth from livestock than do the relatively wealthy, with the possible exception of those in LAC (Delgado et al. 1999). Poor people in rural areas with little access to capital, have few opportunities to increase their income. The increasing demand for livestock products offers them opportunities to benefit from a rapidly growing market, using common-property resources such as communal grazing lands, forages from roadsides etc, and family labor.

Table 38. Regional projections of total demand and consumption of livestock products (million tons).

	Sheep		Beef		Pork		Poultry		Milk	
Region	1993	2020	1993	2020	1993	2020	1993	2020	1993	2020
East Asia	2	2	3	7	31	65	7	18	9	19
South Asia	1	3	3	8	0	1	0	2	69	201
Southeast Asia	0	0	1	3	3	7	3	6	5	11
LAC	0	1	10	18	3	6	7	14	46	77
WANA	2	4	2	5	0	0	3	6	23	51
SSA	1	2	2	6	1	2	1	2	14	51
Developing countries	6	12	22	47	39	81	21	49	168	391
Developed countries	4	4	32	36	38	41	26	34	245	263

LAC = Latin America and Caribbean, WANA = West Asia North Africa, SSA = Sub-Saharan Africa
Sources: ILRI 2000, Table 1.3, Delgado et al. 1999

25. This section mainly from ILRI (2000).

Table 39. Number and location of resource-poor livestock keepers by system.

	Category of livestock keepers who are poor (millions)		
Agroecological zone	Extensive graziers	Mixed rainfed	Landless
Arid or semi-arid	63	213	
Temperate, including tropical highlands	72	82	
Humid, subhumid and subtropical	-	89	
Total	135	387	156

Source: ILRI 2000, Table 1.2

Livestock production trends

Livestock numbers have increased significantly in all SAT regions for all categories of livestock over the last three decades (Table 40). However, with a few exceptions growth rates have been lower in the 1990s than in earlier decades, although they have remained significantly higher than population growth rates in sub-Saharan Africa and in the Medium and Small SAT of LAC and Asia (Table 41).

Of significance is the big difference in stocking rates (Table 42). For large ruminants (cattle and buffalo) it is over 15 Livestock Units[26] per hectare in the Large SAT of Asia (India), compared to about 2 LU per ha in LAC, and less than 0.2 LU per ha in Africa. By comparison, small ruminants (sheep and goats) have much higher stocking rates in WCA (about 0.06 per ha) than in LAC (0.01 per ha) and Asia (0.001 per ha), indicating the greater importance of small ruminants in the African SAT.

Table 42 also shows a significant increase in stocking rates of both large and small ruminants over the last three decades, putting increased pressure on the environment. However, this does not necessarily confirm that on a regional scale livestock are overgrazing and degrading arid rangelands, although there are definitely well documented cases of local significance. As pointed out by Ellis and Galvin (1994), arid and semi-arid ecosystems are more resilient than previously thought and the role of climatic factors has been consistently underestimated.

The FAO (2000b) projections accept that livestock is a major factor in the growth of world agriculture. The world food economy is being increasingly driven by the shift of diets and food consumption patterns towards livestock products. In developing countries, where almost the totality of world population increases takes place, meat consumption has grown at 5-6% p.a., and that of milk and dairy products at 3.3-3.5% p.a. in the last few decades. Aggregate agricultural output is affected by these trends not only through growth in livestock production (a major component of gross agricultural output), but also through linkages between livestock production and the crop sector which supplies feed (mainly cereals and oilseeds); and the important crop-livestock synergism in mixed farming systems (de Haan et al. 1998).

However, with regard to the prospects for the livestock sector the FAO predicts lower growth in world meat consumption. The forces that shaped the rapid growth of meat demand in the past are expected to weaken considerably in the future. Falling population growth rates are an important factor. So also is the natural deceleration of growth as consumption reaches fairly high levels in the few countries that dominated past increases: Brazil and China are expected to increase consumption in future at a lower rate than in the past, and significant increases in national meat consumption because of income growth may be precluded in predominantly vegetarian India. In Latin America and the Caribbean, excluding Brazil, the swing to poultry consumption is expected to raise the group's overall meat consumption average, but in sub-Saharan Africa economic prospects suggest that no significant increases in per caput meat consumption may be forthcoming (Table 43).

These prospects for changes in per caput meat consumption, in combination with lower population growth, suggest that the strength of the meat sector as a driving force of the world food economy will be much weaker than in the past, according to FAO. Thus, world aggregate demand for meat is projected

26. The Livestock Units (LU) used here can be regarded as World Livestock Units as they are based on the world average carcass weight of 180 kg for cattle and buffalo. These are from FAO (2000), except for Horses + Mules + Asses, and Camels, which are calculated as the ratio of the category to the cattle/buffalo carcass weight from the ILRI LU of 250 kg liveweight (1.0 for Horses + Mules + Asses, and 1.43 for Camels), ref. Jahnke (1980).

Table 40. Average livestock numbers ('000 world livestock units).

Region	Class	Large ruminants			Small ruminants			Poultry			Horses, Asses, Donkeys			Camels			Pigs		
		61-63	89-91	96-98	61-63	89-91	96-98	61-63	89-91	96-98	61-63	89-91	96-98	61-63	89-91	96-98	61-63	89-91	96-98
Asia	Large	135,515	169,910	180,219	3	11	12	630	1145	1215	28,082	37,001	43,499	798	875	886	0	0	0
Asia	Small	3387	5682	6309	0	0	0	60	81	95	1394	3139	3697	1154	1013	1073	0	0	0
LAC	Large	6117	5326	5114	18	31	25	17	31	22	5	5	5	12	43	19	0	0	0
LAC	Medium	2268	4212	4670	8	16	17	23	25	33	1722	873	1219	14	56	70	0	0	0
LAC	Small	35,839	72,338	74,584	798	1670	1770	279	415	407	43,117	57,440	57,327	89,784	229,691	253,626	0	2	3
SEA	Large	136	170	180	0	0	0	5	25	27	402	688	658	7	13	16	0	0	0
SEA	Medium	11,369	19,263	20,171	0	0	0	149	298	513	6512	16,572	30,091	7735	22,199	34,855	0	0	0
SEA	Small	16,973	27,312	29,427	320	542	491	224	240	247	23,168	24,763	7359	28,642	33,357	33,619	76	184	190
WCA	Large	224	414	485	152	596	730	31	105	129	157	554	643	3639	6882	7749	0	0	0
WCA	Medium	2791	7722	9079	398	664	677	72	361	435	2122	10,224	11,448	10,601	19,972	26,319	0	0	0
WCA	Small	2959	7311	8586	646	945	1147	104	129	166	610	643	671	10,448	7747	9144	0	0	0

LAC = Latin America and Caribbean, SEA = Southern and Eastern Africa, WCA = West and Central Africa
Source: FAOSTAT, 1998

Table 41. Livestock growth rates (% per year).

Region	Class	Large ruminants		Small ruminants		Poultry		Horses etc		Camels		Pigs	
		61-89	90-93	61-89	90-93	62-89	90-97	62-89	90-97	62-89	90-97	62-89	90-97
Asia	Large	1.71*	1.44	4.93*	3.15	2.39*	0.87*	1.05*	2.36*	0.05	0.14*	na	na
Asia	Small	2.11*	1.06*	na	na	1.16*	2.12*	3.43*	2.66*	-0.43	0.94*	na	na
LAC	Large	-1.65*	5.23	1.61*	0.39	1.12*	-4.25*	0.08	0.00	4.82*	-12.02*	na	na
LAC	Medium	2.99*	3.79	2.70*	0.67	-0.27	3.22*	-2.61*	3.97*	6.06*	3.88*	na	na
LAC	Small	1.74*	-0.42	2.37*	2.65*	1.33*	-0.47*	0.86*	0.09	3.64*	1.51*	1.22	5.96*
SEA	Large	1.89*	-7.13	na	na	3.86*	0.92*	0.72	-0.16	1.19*	3.13*	na	na
SEA	Medium	1.77*	0.26	na	na	2.59*	8.77*	3.48*	9.46*	3.78*	6.96*	na	na
SEA	Small	1.89*	2.13	2.41*	-1.74	0.12*	0.32*	0.05	-19.44*	0.25*	-0.14	1.77*	0.54
WCA	Large	2.22*	2.02	5.08*	5.91*	4.06*	2.79*	3.88*	2.10*	1.55*	1.70*	na	na
WCA	Medium	3.56*	2.63*	1.08*	-0.66	5.96*	2.76*	6.23*	1.50*	2.16*	4.08*	na	na
WCA	Small	3.17*	2.57*	0.82*	2.06*	0.43*	3.27*	-0.37	0.48*	-1.75*	1.90*	na	na

na = data not available
* indicates significance at 5% probability level
Source: FAOSTAT, 1998

to grow at 1.9% p.a. in the next 20 years, down from 2.8%) in the preceding 20 years. The reduction is even more drastic for the developing countries, from 5.5% to 2.8%. Much of this reduction is due to the projected slower growth of aggregate consumption in China, and to a smaller extent in Brazil. Remove these two countries from the developing countries aggregate and there is very little change in the growth of aggregate demand for meat, from 3.5% p.a. in the preceding two decades to 3% p.a. in the next two. All this reduction reflects essentially the lower population growth.

However, FAO predicts that there will be no slowdown in the consumption of dairy products (Table 44). Unlike meat, consumption of milk and dairy products has some way to go before its limits. Only a few developing countries have per caput consumption exceeding 150 kg in liquid milk equivalent (Argentina, Uruguay, some pastoral countries in the Sudano-Sahelian zone of Africa), and none of the most populous countries are in that class. South Asia, where milk and dairy products are preferred foods, has only 59 kg. The Livestock Revolution in the FAO projections is therefore mainly an increase in the growth rate of demand for milk products and poultry meat. Notwithstanding the projected slowdown in meat demand, it is expected that meat trade expansion will continue, and there will be a recovery in the dairy trade (Table 45).

Clearly the IFPRI projections of future prospects for livestock are more optimistic than those of FAO. This is primarily because IFPRI assumes that the same aggregate growth rate for meat demand in the past (2.8% per annum) will continue to 2020. The FAO projections on the other hand predict that the rate of growth will slow down to 1.9% per annum due to expectations that some major meat-consuming countries will reach a demand plateau and population growth will slow down. Both projections, however, assume continued high growth rates for poultry, pork, milk, and dairy products and so the overall scenario for livestock products is likely to be fairly robust.

Land degradation

Land degradation can occur as a result of depletion of soil nutrients, soil erosion, salinization, agrochemical pollution, and loss of vegetation. The result is a decline in the productive capacity of land.

Extent and causes

While there is much concern about the extent of land degradation, there is no satisfactory quantitative estimate of the degree of land degradation in the world. Existing estimates of the current global extent and severity of the problem should be considered indicative at best (Scherr and Yadav 1996). They show that except for forest and woodland, the proportion of land that is degraded is estimated to be more extensive in Africa than the other regions (Fig 11). Oldeman et al. (1991) assess that globally, about 15% of the land they mapped is strongly degraded. Water erosion was estimated to have accounted for 56%, wind erosion for 28%, chemical degradation for 12%, and physical

Table 42. Ruminants (large and small) numbers per '000 ha with permanent pasture.

		Large ruminants*		Small ruminants*	
Region	Class	1961-63	1991-93	1961-63	1991-93
Asia	Large	9667	15263	0.24	1.05
Asia	Small	207	358	0.00	0.00
LAC	Large	2943	2095	8.66	10.72
LAC	Medium	846	1757	2.98	6.32
LAC	Small	138	212	3.06	5.16
SEA	Large	155	205	0.00	0.00
SEA	Medium	49	79	0.00	0.00
SEA	Small	92	162	1.73	2.86
WCA	Large	19	36	12.81	58.43
WCA	Medium	40	120	5.65	9.23
WCA	Small	31	82	6.67	10.54

* Large ruminants weighted by 0.6 in Asia, 1.08 in LAC, 0.73 in Africa to convert them into livestock units
Small ruminants weighted by 0.06 in Asia, 0.08 in LAC, 0.07 in Africa to convert them into livestock units
Source: FAOSTAT, 1998

Table 43. Put and projected food consumption of meat (kg per capita carcass weight).

Region	1964/66	1974/76	1984/86	1995/97	2015	2030
World	24.1	27.4	30.7	34.7	40.0	44.0
Developing countries	10.2	11.3	15.5	23.1	30.0	35.0
Developing countries excl China	11	12.1	14.5	17.4	21.9	26.2
Developing countries exd China and Brazil	10.1	11	13.1	15.0	19.4	23.6
Sub-Saaaran Africa	9.9	9.5	10.2	9.7	11.6	13.6
Near East/North Africa	11.9	13,7	20.5	20.0	26.6	32
Latin America and Caribbean	31.7	35.6	39.7	48.5	57.8	66
LAC excl Brazil	34.1	37.5	39.6	41.8	50.2	57.4
South Asia	3.9	3.9	4.3	5.5	8.2	11.8
East Asia	8.7	10	17	33.3	47.2	55
Eaat Asia exd China	9.4	10.8	15.1	22.3	30.5	37.7
Industrial countries	61.5	73.6	81	86.5	93.0	97.0
Transition countries	42.5	60	65.8	49.4	61.0	69.0
Per caput meat by type						
World						
Bovine meat	9,9	11.0	10.4	9.6	10,2	10.6
Ovine and caprine meat	1,8	1.6	1.7	1.8	2.3	2.6
Pig meat	9.1	10.2	12.2	13.7	14.8	14.9
Pig meat exd China	9.7	10.8	11.3	10.2	9.9	9.8
Poultry meat	3.2	4.6	6.4	9.5	12.9	15.7
Developing countries						
Bovine meat	4.1	4.3	4.8	5.6	6.9	7.7
Ovine and caprine meat	1.2	1.1	1.3	1.7	2.1	2,5
Pig meat	3.7	4.1	6.5	9.7	11.5	11.9
Pig meat exd China	2.2	2.4	2.9	3.3	4.0	4.6
Poultry meat	1.2	1.8	2.9	6.2	9.5	12.4
Poultry meat exd China and Brazil	1.2	1.9	3.2	4.9	7.5	10.0

Source: FAO 2000, Table 3.10

Table 44. Past and projected consumption of milk and dairy products in liquid milk equivalents (kg per capita).

Region	1964/66	1974/76	1984/86	1995/97	2015	2030
World	74	75	78	76	82	91
Developing countries	28	30	37	42	53	67
Sub-Saharan Africa	28	28	32	30	33	35
Near East/North Africa	69	72	83	69	76	85
Latin America and Caribbean	80	93	95	109	119	128
South Asia	37	38	49	59	81	116
East Asia	4	4	6	10	14	19
Industrial countries	185	191	210	213	220	224
Transition countries	157	192	180	155	173	186

Source:FAO 2000, Table 3.9

degradation for 4%. Pinstrup-Andersen and Pandya-Lorch (1994) indicate that about half of land degradation in Africa is caused by overgrazing, and about one-quarter by agricultural activities. Deforestation and over-exploitation account equally for the balance. In contrast 40% of Asia's degradation is attributed to deforestation, with overgrazing and agricultural activities contributing about one-quarter each. Since country level data are not available, it is not possible to determine the extent of degradation in the SAT regions. It is only possible to infer that since extensive areas of permanent pasture exist in the SAT,

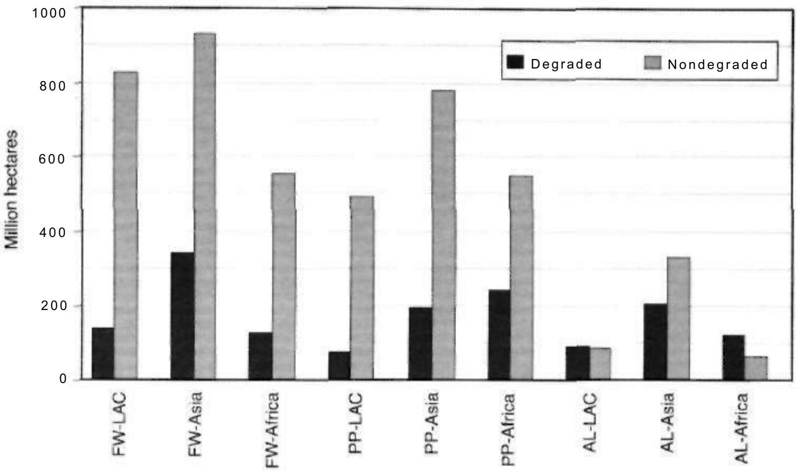

Figure 11. Land degradation by region and type of land use.

FW = Forests and woodland, PP = Permanent pasture, AL = Agricultural land
Source: Scherr and Yadav 1996

Table 45. Net trade in meat and milk/dairy products ('()()() tons).

	1964/66	1974/76	1984/86	1995/97	2015	2030
Region			Meat			
Sub-Saharan Africa	112	180	-59	12	390	-910
Near East/North Africa	-97	-337	-1437	-1213	2900	4720
Latin America and Caribbean	838	687	867	874	1710	2530
South Asia	-6	0	47	176	80	-310
East Asia	132	16	453	-237	-2470	-3630
	Milk and dairy products in liquids, milk equivalent (excl butter)					
Developing countries	-5310	-8743	-20046	-20711	-33450	-45,450
Sub-Saharan Africa	-520	-1250	-2785	-2178	-3800	-5250
Near East/North Africa	-753	-2031	-6757	-5048	-8800	-12,900
Latin American and Caribbean	-1879	2571	-5500	-6254	-8000	-7500
South Asia	-662	-553	1247	-572	-1850	-4800
East Asia	-1496	-2383	-3758	-6660	-11,000	-15,000
Industrial countries	-6920	8971	-18,421	18,491	-30,000	41,800
Transition countries	135	898	-1898	3142	-4000	4200

Source: FAO 2000, Table 3.14

the extent of degradation might be higher in the African SAT than in the SAT in Asia or LAC.

There are uncertainties about the likely extent and consequences of global warming on climatic change. It does seem that there will be regional differences in the likely impact but that overall the world's food security may not be imperiled. The extremes of climate may increase and there may be a general reduction of rainfall in the tropics and subtropics and increases in more temperate areas. This will have obvious consequences for the additional 2 billion people who will live between the Tropics of

Cancer and Capricorn in the next 25 years and the 1.3 billion poor who already live there (McCalla 2000).

Studies of the global impact of land degradation are as scarce as estimates of the extent of degradation. Crosson (1994), using the Global Land Assessment of Degradation results, estimated that there has been a 17% cumulative productivity loss between 1945 and 1990 as a result of land degradation. Dregne and Chou (1992) estimate the economic value of productivity losses due to degradation on rainfed cropland to be 10-12%. For sub-Saharan Africa, Lal (1995) estimated that yield reductions due to erosion in the past have averaged about 6%, with a range of 2-40%. These losses are much less than productivity gains during the same periods. However, in spite of land degradation it is estimated that the amount of potential cropland in sub-Saharan Africa is 2.4 times the amount of land now cultivated (Crosson 1995). In South Asia on the other hand the additional potential is the lowest of all regions at 28% of current cropland. Bringing such potential cropland into cultivation of course will involve considerable economic and environmental costs, including soil erosion and loss of habitat and plant and animal biodiversity. In addition, there will be growing demand for land to satisfy the rapid growth in urbanization. On balance Crosson concludes that developing countries cannot meet their future food requirements without unacceptable increases in the economic and environmental costs of land and water degradation. Increased reliance on imports from developed countries with excess land and water capacity will be required. This reinforces the value of further trade liberalization as a means of alleviating future land and water degradation in developing countries. Research agendas of NARS and IARCs should also focus more on increasing the effective supplies of land and water.

Nutrient depletion and fertilizer use

Bumb and Baanante (1996) cite research on nutrient depletion that suggests that 43.7 million hectares of land in LAC are moderately to severely degraded. This is 72% more than in Africa (25.4 million ha) and more than four times the figure for Asia (10 million ha). In many countries of sub-Saharan Africa, nutrient removal exceeds nutrient replenishment by a factor of three to four. Almost 90% of countries in Africa show annual depletion rates of N, P, and K in excess of 30 kg per ha per year (Pinstrup-Andersen et al. 1999). Traditionally long fallows, 10-15 years in duration, were used to restore soil fertility, but increased population pressures have reduced these in many countries. In some, continuous cultivation prevails. Compensatory measures to restore fertility have not occurred. Instead more deforestation has resulted in an attempt to rectify the situation, leading to a continual downward spiral of resource depletion. This process leads to poverty, hunger, and malnutrition with further environmental degradation (Pinstrup-Andersen and Pandya-Lorch 1994).

Many high-potential areas are degraded or suffer environmental stress. Scherr and Hazell (1993) doubt whether high-potential areas have the capacity to meet food needs in a sustainable manner. There is a body of opinion that agricultural intensification can rehabilitate degraded marginal lands but it needs to be different to methods employed in high-potential areas. Examples include diversification of cropping systems instead of intensive monoculture of annual crops, better integration of livestock and green manure into farming systems, and generation of reliable nonfarm sources of income (Pinstrup-Andersen and Pandya-Lorch 1994). According to the marginal lands study by TAC (1997), 23% of sub-Saharan Africa is classified as marginal for agriculture and 9% as favorable. In Asia the corresponding figures are 30 and 17%. Hence the focus in the CGIAR on marginal lands.

Historical and socioeconomic evidence suggests that farmers often actively respond to degradation by modifying their farming systems or practices and through land-improving investments. There seems to be an emerging consensus also that poverty per se is not a primary cause of resource degradation, although empirical evidence is mixed (Pachico et al. 2000). Table 46 shows that fertilizer use has increased significantly in all SAT regions, although application rates arc still extremely low, especially in Africa. The figures clearly show the effect of the Green Revolution in India in the 1960s and 1970s, and the downturn in growth rates following the Structural Adjustment Programs (SAP) in the 1980s resulting in negative growth rates in three of the SAT regions in the 1990s.

Without crop-specific data it is not possible to determine the effect of the trends in fertilizer use on land degradation in the SAT. More than half the countries in sub-Saharan Africa depend on fertilizer aid to meet all their fertilizer needs (Bumb and Baanante 1996). This makes them vulnerable to the vagaries of aid donors and trade liberalization. Also nitrogen dominates fertilizer use, leading to an inappropriate balance of phosphorus and potassium. However, despite the lack of quantitative data it is clear that land-improving investments are having an effect in the developing world (Scherr and Yadav 1996). This was also the general feeling in the Brainstorming Sessions with ICRISAT. The consensus was that while land degradation will continue it will not become more severe than at present, and in some countries may even be reversed. But the long-term economic threat of possible acceleration of soil degradation should not be taken lightly either (Scherr 1999). Furthermore, the drop in the post-SAP growth rates of fertilizer use calls for more efficient use of fertilizers and new technologies that promote such efficient use.

Mechanization

Inappropriate mechanization can lead to land degradation. Table 47 shows that the current level of mechanization is highest in LAC with 2-21 tractors per 1000 ha of arable land, and lowest in WCA with

Table 46. Fertilizer consumption (NPK) growth rates and average consumption for SAT regions (kg/ha arable land).

		Growth rates		Average consumption (kg/ha)		
Region	Class	1962-89	1990-97	1961-63	1989-91	1996-98
Asia	Large	11.44 '	3.45 '	2.84	75.53	97.40
Asia	Small	13.34 '	11.87 '	0.58	8.88	17.35
LAC	Large	2.10 '	-11.90	87.33	164.76	57.58
LAC	Medium	5.88 '	2.48 '	9.80	55.82	68.25
LAC	Small	8.27 '	2.33	10.68	70.50	85.44
SEA	Large	2.67 '	0.67	22,15	58.05	55.84
SEA	Medium	5.27 '	-6.78 '	2.10	8.47	5.79
SEA	Small	6.87 '	6.54 '	0.91	8.50	12.10
WCA	Large	4.93 '	6.22 '	1.81	5.82	10.66
WCA	Medium	20.77 '	-13,04 '	0.09	12.93	6.81
WCA	Small	7.82 '	7,96 '	0.40	2.53	3.82

' indicates significance at 5% probability level
Source.' FAOSTAT, 1998

Table 47. Average number of harvesters and tractors per million ha arable land in SAT regions.

		Harvester-Threshers			Tractors		
Region*	Class	1961-63	1989-91	1996-98	1961-63	1989-91	1996-98
Asia	Large	4	18	24	226	6084	9061
Asia	Small	91	337	737	165	1640	1272
LAC	Large	1213	2253	2002	9366	23,906	21,098
LAC	Medium	0	0	0	1630	1591	1559
LAC	Small	491	909	913	3210	12,338	12,182
SEA	Large	87	268	296	6620	6373	7888
SEA	Medium	8	64	69	1184	1524	1349
SEA	Small	42	35	41	501	1399	1581
WCA	Large	14	26	28	55	228	442
WCA	Medium	1	13	18	25	763	939
WCA	Small	1	2	3	7	90	81

* LAC = Latin America and Caribbean, SEA = Southern and Eastern Africa, WCA = West and Central Africa
Source: FAOSTAX; 1998

less than 1. Tractor use has increased 2-4 fold in LAC since the early 1960s, more than 10 times in Asia, but has hardly changed in Africa over the past three decades. There has generally been a reduction in the rate of growth of tractors and harvesters in the 1990s compared to earlier decades, and growth rates have in fact been negative in some SAT regions. The figures available do not allow any conclusions to be drawn on the effect of mechanization on land degradation. With regard to technology development in the SAT, they do indicate that cultivation systems continue basically to be manual in Africa, are becoming more mechanized in Asia, and are already reasonably mechanized in LAC.

Land tenure and property rights

There are still some unsettled questions about whether or not the lack of secure property rights discourages long-term investment in land and forests and induces mining of soils. Do farmers make investments in soil conservation and fertility management or do the returns from soil mining exceed the sum of discounted values of uncertain future income streams generated by these investments, such that soil mining is a superior strategy as population pressure increases?

The consensus in agricultural development literature is that usufructory land tenure systems that are still common in the SAT, particularly in Africa, arc not necessarily bottlenecks to agricultural development. Bruce and Migot-Adholla (1994) have summarized recent significant studies. There is clear evidence that customary tenure rights evolve toward stronger, more alienable individual rights as population pressure on land increases, technologies change, and agriculture becomes more commercialized (Place and Hazell 1993). However, there is not much correlation between possession of title and use of formal credit, no difference in the incidence of land improvements between operators with partial or complete transfer rights, and no significant relationship between land rights and crop yields. In fact there is a great danger that individual land titling by the state may encourage large speculative landholdings and rent-seeking behavior if not carefully managed and properly controlled.

Empirical evidence suggests that the most important characteristic of tenure security under indigenous systems is the ability to bequeath land. Therefore, government intervention is desirable only after removing the causes of tenure insecurity, such as inability to bequeath land and poor access to input and output markets. However, as productivity of land and natural resources increases, agriculture becomes more commercialized and less risky, and as population densities increase then appropriate registration efforts may bear positive results. This can lead to improved incentives for investing in measures to further conserve natural resources, including land.

Another unsettled question is whether or not liberalizing land markets results in a concentration of land assets in the hands of a few farmers when there are imperfect credit markets. For example, land can be concentrated among large-scale farmers with access to long-term finance even though these are more inefficient because there is often an inverse relationship between total factor productivity and farm size.

The challenge to institutions concerned with agricultural R&D in the SAT is to contribute to the empirical knowledge for designing appropriate property rights structures for improving natural resource management.

> *Poverty limits the opportunities for protecting and enhancing the environment because poor people have few options but to exploit the natural resource base in order to attain food security, and sometimes even to survive. Poverty also hinders efforts to manage population growth because for poor people children represent additional sources of income. The way forward is through sustainable agricultural and economic development aimed at broadly based poverty alleviation. New technology options must therefore be found to improve and sustain agriculture. (CGIAR 1994, pp 3-4)*

Mink (1993) points out that the poverty-environment nexus is especially pertinent as it works in both directions. He says the poor are the most vulnerable in terms of exposure to certain types of pollution, such as unclean water that carries infectious and parasitic. diseases. Environmental degradation also depresses the poor's income by diverting more time to routine household tasks such as fuelwood collection and by reducing the productivity of the natural resources from which the rural poor are most likely to wrest a living. The very poor, struggling at the edge of subsistence levels of consumption and preoccupied with day-to-day survival, have limited scope to plan ahead and make natural resource investments (e.g. soil conservation) that give positive returns only after a number of years.

Mink maintains that such short time horizons are not innate characteristics, but rather the outcome of policy, institutional, and social failures. As Hanumantha Rao (1995) puts it:

> *The poor are increasingly becoming the victims of natural resource degradation in the form of shortages of fuel, fodder, and drinking water, rather than being the perpetrators of such degradation, (p 13)*

According to Scherr (2000), few longitudinal studies have linked poverty and resource quality in agricultural systems. She suggests that international efforts are needed to collect intertemporal data integrating poverty, environment, and agricultural factors at community and landscape levels to confirm and quantify key relationships and identify relevant policies under a range of agroecological and socioeconomic conditions. Based on two criteria - number of poor agriculturally-dependent people and the scale of environmental risks - she suggests that priority for such research be given to densely populated marginal lands in the tropics and smallholder irrigation systems in Asia.

This apparent poverty-environment treadmill requires more detailed research at the village and household levels in a range of SAT environments to ascertain where the causalities lie and to identify the scope for policy and/or technological interventions to encourage desirable outcomes. Longitudinal village-level studies of the type conducted earlier by ICRISAT offer the best way to better understand these issues.

Evolution of NARS

In Africa, the number of research scientists has increased significantly since 1961 (Table 48). This has been accompanied by an increase in education levels and a reduction in the proportion of expatriates from 90% to 11% (Pardey and Alston 1995). Researchers in sub-Saharan African increased by 273% from the early 1960s to the early 1980s (i.e. 6.8% per year), compared to 211% in South Asia (5.8% per year). However, real spending per scientist in sub-Saharan Africa has fallen by 2.6%) per year since 1961, with the rate of decline accelerating during the 1980s. In contrast, expenditure per scientist has risen modestly in South Asia. As a result salaries consume about 60% of research expenditures in sub-Saharan Africa, and 51% in Asia and the Pacific.

In 1981-85 sub-Saharan Africa had 42 agricultural researchers per million economically active persons in agriculture; in Asia and the Pacific (excluding China) the figure was 66.[27] The number of researchers per million hectares of agricultural land in sub-Saharan Africa (7) was only one-tenth of that in Asia and the Pacific (69 excluding China). In both sub-Saharan Africa and Asia and the Pacific about two-thirds of scientists are allocated to research on crops, one-fifth on livestock, and roughly equal shares on forestry and fisheries. Donor funding represented 35% of total agricultural research expenditures in sub-Saharan Africa and 26% in Asia and the Pacific (excluding China).

There were few scientists working for SAT crops in Asia in the 70s, but the number has increased in the '90s. However, the number of scientists in Asian public research institutes is expected to remain at the present level for the next 10 years though the research capabilities of scientists are expected to increase due to the advanced training they are receiving. In addition to public research institutes, private seed companies are increasing their operation in many Asian countries, and often expanding research facilities. The rise of private sector research

Table 48. Agricultural research expenditures and personnel estimates, 1961-85.

	Total agricultural research expenditures (millions of dollars pa)			Total no. of researchers (full time equivalents)		
Region	1961-65	1981-85	Increase (%)	1961-65	1981-85	Increase (%)
Sub-Saharan Africa	149.5	372.3	149	1323	4941	273
South Asia	164.5	642.3	290	4337	13,502	211
Less developed countries	1093.6	3629.8	232	19,753	77,737	294

Source; Pardey et al. 1991, pp 414-421

27. Pardey et al. (1991, ppl97-308) did not provide data separately on South Asia for some of these variables.

requires complementarity in research targets and focus in Asian NARS. It also highlights the need for harmony and complementarity between public, private, and international institutions.

The future of NARS in sub-Saharan Africa largely depends on the size of the NARS, their institutional and organizational structure, the level and quality of resource endowments (human and capital resources), their research intensities in terms of quality and quantity, and their commitment to move towards more development-oriented research that will generate impacts and justify continued donor funding. Small NARS[28] are endemically spread too thin and are unlikely to be able to deploy enough human and material resources to allow them to function as well as the better research programs in large NARS (Gilbert et al. 1994). The role that IARCs could play with respect to NARS in small countries is crucial. For example, much of the research in staple food crops is done in association with international centers.

The viability of NARS will depend on the new role that IARCs could play. Given the dwindling funding (due in part to lack of impact) and the limited human resources available, NARS will have to build new partnerships with IARCs and research institutions in developed countries, and focus on R&D priorities that will generate impact.

Evolution of private/public sector R&D roles

In developed countries the share of private investment in agricultural R&D is rising, and it now represents about half of all agricultural research spending. In the '80s and early '90s public agricultural R&D spending in developed countries grew at 1.7% per year, compared to 5.1% per year for private R&D (Alston et al. 1998). However, in developing countries private investments are an insignificant proportion of the total (Pardey 1997), and are concentrated in a few large countries such as Brazil, Mexico, Argentina, and India. Private research expenditure is probably only 1% of public-sector research expenditure (Pray and Echeverria 1991). Research conducted by local companies seems to be more important in Asia than in Latin America. Private research expenditures in the seed and machinery industries are growing. In India private research accounted for around 7% of the total expenditures on agricultural research by 1990 (Evenson et al. 1999). Pray and Umali-Deininger (1998) estimate that in 1995 the private sector in India represented more than 16% of total agricultural research expenditure.

Traditionally the private sector focused on embodied technologies as exemplified by mechanical and chemical innovations where proprietary knowledge could be easily protected. Except for hybrid seeds, the private sector did not engage in biological technology. However, with the advent of biotechnology and the broadening of the scope of intellectual property rights into life forms, the private sector is becoming a major player in biological technology. Public goods are becoming further circumscribed. It is likely this trend will begin to gather momentum, even in developing countries, as a consequence of the WTO/TRIPS and the Convention on Biological Diversity. Some refer to this as the "life-science revolution" and question whether agricultural research will remain a public good (Oehmkeetal. 1999).

The differential growth of private-sector agricultural R&D in the European Union has been shown to depend crucially on the strength of intellectual property contract enforcement, the efficiency of bureaucracy, the strength of patent rights, and the stock of higher education capital (Alfranca and Huffman 1999). Many of these conditions arc lacking in developing countries and hence one might not expect to see a rapid growth in private-sector agricultural R&D in the near term. Indeed, if as Alfranca and Huffman found, large public-sector R&D tended to crowd out private-sector R&D investment instead of complementing it, there is a danger that overall research efficiency can be impaired. This reinforces the need for public-sector institutions to ensure they engage only in research that results in public goods.

Associated with these developments is the growth in public-private partnerships in the conduct of agricultural research and also in its funding and management. ICRISAT and other IARCs such as CIAT, CIMMYT, and ILRI are purposefully developing such partnerships. The motivations are primarily associated with the decline in public sector support for their research, but also because of the likelihood of enhanced impact. It seems clear there is a demand by the private sector for enhancing direct relationships with IARCs, which has proved

28. In West Africa for example, 9 of the 17 countries could be classified as small countries (less than 5 million people, 1980 census) where agriculture is the major employer and largest contributor to GDP

so effective in the past in providing parental lines for private companies developing sorghum and pearl millet hybrids. These relationships should be nurtured and encouraged in the future.

A major bottleneck in ICRISAT's work on genetic transformation will be in the availability of novel genes and effective promoters for gene expression due to Intellectual Property Rights (IPR) (Sharma and Ortiz 2000). Currently, most established or promising plant genetic transformation strategies are covered by patents owned by private biotechnology companies. These are hence already commercial barriers to exploitation of these technologies.

It is inescapable that private firms will want clear and unambiguous intellectual property rights to encourage them to make long-term R&D investments. Pray and Umali-Deininger cite studies which demonstrate this clearly. More recently, Sam Dryden, Chair of the Private Sector Committee of the CGIAR, has made a clear statement of the importance of IPR to the private sector for its collaboration with the CGIAR in genetic improvement:

- *In the age of biotechnology and IPR, the time honored and noble concept of "international public goods" (IPG) relative to genetically improved material is essentially obsolete and needs to be redefined.*
- *IPC - defined as freely available material with uncontrolled dissemination - is irreconcilable with proprietary technology, IPR, and responsible biosafety.*
- *The private sector is willing to license important proprietary technology for the benefit of CGIAR genetic improvement goals but only on a negotiated basis. As part of these negotiations it is essential to understand that the private sector cannot and will not share competitive technologies for incorporation in products that will be disseminated in an uncontrolled manner. To do so threatens disequilibrium in the commercial markets where these companies compete using their proprietary technologies.*
- *Further, the genetically improved products of today are different from the IPG of the past. Today's products are much more sophisticated, with powerful benefits, and are safe when used as directed but require responsible stewardship. The private sector cannot allow the public dissemination of its proprietary technology in ways over which it has no control. (Dryden 2000)*

This would seem to cast some doubt on the future viability of meaningful collaboration even where so-called orphan crops of tropical environments are involved, unless the Centers are willing to confer IPR on proprietary technology from the private sector. It has long been a rationale for embracing the private sector that they would be less concerned about IPR on the mandate crops of the CGIAR because they are of little commercial interest to them. From Dryden's statement it appears this assumption may be heroic. Even if the CGIAR agrees, the difficulties of enforcing compliance in developing countries may still deter the private sector from making proprietary technologies available to the CGIAR.

The Asian Development Bank (ADB 2000, pp 75-78) sees a continuing need for public-sector research, as the private sector will not have an incentive to work on "orphan crops", nor for poorer farmers and regions. Agroecological characterization can help facilitate the needed agroclimatic specificity of research and the complexity it implies. It will also enable a more decentralized approach both regionally and at farm level, with advantages in better linkages among the various actors. Technology will be more knowledge-based and location-specific in future and so must research and extension.

Related to the issue of IPR are those of biosafety and access to genetic resources. The 1992 Convention on Biological Diversity (CBD) reaffirmed national sovereignty over biological resources. The TRIPS accord under the WTO protocols also requires members to enact *sui generis* national legislation to protect plant varieties. These international covenants are beginning to hamper the free flow of plant germplasm across national boundaries and among the IARCs and NARS.

Fortunately some progress is being made on negotiating an International Undertaking that will include a multilateral system of facilitated access to plant germplasm, under the auspices of FAO. This would include the 30 crops in the genebanks of the CGIAR Centers. These negotiations have been characterized by sharp divisions between the South and Europe on the one hand, and the USA, Canada, Australia, and New Zealand on the other; but it is hoped that prudent and open stewardship of these invaluable resources will prevail.

Role of NGOs

Another feature of private sector research in developing countries is the increased involvement of multinational corporations and their growing concentration as a result of mergers and acquisitions. This is leading to disquiet, especially among some NGOs.

The role of NGOs in rural development has grown substantially in the last 15 years. A criticism of NGOs is that they lack the necessary scientific and technical expertise to complement their rapport with poor people at the grassroots level. For many NGOs, indigenous knowledge and empowerment of its owners are seen as the panacea for environmentally sustainable development and food security. These elements are crucial, but it is clear that in the face of the enormous food security challenges in the next 25 years, modern science must also be brought to bear. Indigenous knowledge and empowerment alone will not suffice in the future in the face of the unprecedented pressure of population and its demands on the natural resource base (Ryan 1995).

NGOs have a crucial role in the R&D process. OECD countries and agencies such as the World Bank have formally acknowledged this in recent years. NGOs offer the advantage of being closer to the beneficiaries and hence able to engage in people's participation in the development process by creating new social organizations for coordinated action and empowerment. Cernea (1993) maintains that creating social organizations is equivalent to creating new social capital, which is a strategic resource for development. NGOs also have a special concern for the poor and the environment. These attributes have led to their increasing influence on development policy, programs, and projects.

In a review of the Ford Foundation's association with the Intensive Agricultural Districts Program (IADP) in India, Staples (1992) found that all-India solutions to development challenges are not appropriate. It was concluded that sustainable development is crucially related to the participatory nature of the process. People will conserve forests, maintain irrigation systems, and innovate in farming systems if they are actively involved and have full rights to the product of their energies. To quote from Staples:

> *...the first two decades of development in India showed that national approaches like the IADP, or indeed most centralized, nation-wide development schemes, run into difficulties as they confront specific problems of local populations. NGOs often can demonstrate how best to organize people and deploy funds for poverty alleviation and resource management in the complexity and diversity of the Indian countryside.*

It would seem desirable for national and international R&D agencies to more explicitly involve themselves with NGOs in their natural resource management research agendas in future. This view was shared by participants in a workshop in Nairobi in Dec 1994 entitled "Listening to the people: Social aspects of dryland management". There is growing unease in some quarters, however, about the replicability and sustainability of some NGO-sponsored activities and their limited scientific and technical capabilities. The proliferation of NGOs in recent years is of concern, along with difficulties in accountability. Dependency of NGOs on government support, and in turn of the poor on NGOs for their livelihoods, is also a frequently repeated theme. There are even doubts being expressed about whether NGOs are always more cost-effective than governments, and their claim that they reach the poorest of the poor is not borne out (Siamwalla et al. 2000, p 176).

Trade liberalization

The WTO is currently addressing further rounds of trade liberalization and removal of protection and support for agriculture. Generally, developing countries impose a net tax on agriculture through trade restrictions, overvalued exchange rates, tariffs, and export taxes. Developed countries generally do the opposite, with extensive subsidies to agriculture. There arc exceptions to these general rules.

Prior to the Uruguay Round African agriculture suffered from a domestic policy bias - overvalued exchange rates, taxes on agricultural exports, and establishment of state or parastatal buying agencies that paid producers less than world prices. As a result Africa's share of world agricultural exports fell from more than 10% in the early '60s to less than 4% in the mid '90s (Mukherjee and Harris 1999). Some countries provided input subsidies but the net impact was a tax on agriculture, which benefited urban consumers. Since the early '90s a number of African countries have instituted structural adjustment programs which have effectively removed much of this policy bias against agriculture.

In Africa private marketing is on the increase for crops like rice, maize, cotton, groundnut, and livestock, where inter-regional trade is growing. Sorghum and millet do not seem to be participating as much in this growth. Commercial crops also dominate fertilizer use. Mukherjee and Harris feel the prospects for higher growth in Africa will come largely from new crops rather than traditional primary commodities. However, trade barriers, which were not removed in the Uruguay Round, may prevent this. Also, research suggests trade liberalization under the Uruguay Round, by itself, will have adverse terms-of-trade effects for sub-Saharan African countries, which are mostly net importers of food and manufactures.

India is the only Asian country (for which data arc available) which heavily taxes its agricultural sector. All others lend positive support to the sector (Noland 1999). Hence in this respect India resembles sub-Saharan Africa prior to 1990. As India liberalizes and opens both agricultural imports and exports, issues of sanitary and phytosanitary regulation, quarantine, and genetically modified organisms (GMOs) will loom larger on the national policy agenda and in relations with WTO.

In India domestic prices of agricultural products are generally below international levels, except for sugarcane and rapeseed-mustard.[29] Between 1988 and 1995 the implicit tax on agriculture based on support prices has fallen from 23 to 18%. Rice, wheat, and cotton are taxed while oilseeds and sugarcane receive support. Under the WTO/ Uruguay Round India is not required to reduce domestic agricultural subsidies as its aggregate measure of support to agriculture is negative. India needs to address only the tariffication of quantitative import restrictions, although it has postponed this for balance-of-payments reasons.

In June 1995 the import duty on pulses was reduced from 10% to 5%. Starting in 1995, duty on edible oils was progressively reduced, reaching 10% in July 1998. These reductions seemed to be largely to arrest inflation rather than in response to WTO obligations. However, it does appear that India is continuing to move down the path of trade liberalization and this will have significant effects on its production and trade patterns. Gulati and Kelley (1999) have identified crops for which India has a comparative advantage in production, to provide an indication of the likely changes in cropping patterns as liberalization proceeds. Their analysis shows that at the margin, India has a comparative advantage in wheat, rice, and cotton. Soybean and most coarse cereals fall within the non-tradable band, while most pulses have a marginal disadvantage. Most edible oils (groundnut, rapeseed-mustard, sunflower) suffer from a comparative disadvantage in an open economy. Liberalization should therefore lead to exportable surpluses of wheat, rice, and cotton, but higher imports of edible oils and pulses.

To the extent that liberalization is accompanied by lower input subsidies, with consequent price rises, there will be a shift in area away from fertilizer-intensive crops like cotton, rice, and wheat, to crops that currently use little fertilizer, such as the ICRISAT mandate crops. This will dampen the disincentive effect of increased imports of oilseeds and pulses on market prices of these crops. Byerlee et al. (1997) indicate that liberalization policies in India are sometimes creating new marketing opportunities for high-value crops and livestock in rainfed areas, but also worsening the terms of trade for some important rainfed crops, because of the removal of price supports and input subsidies and the greater exposure of farmers to markets.

A key strategic issue in the South Asian SAT: to what extent are the payoffs to incremental research investments on crops in which the region has a comparative disadvantage, less than on those where it has a comparative advantage? In other words, are the prospective productivity gains from research greater on crops where the SAT region concerned has a lower cost structure vis-a-vis competitors, than on those where it has not? In the case of rice and wheat, which are largely grown under irrigation in India, recent research implies that both productivity and poverty dividends from incremental investments in irrigation at the margin are much lower than in rainfed zones (Hazell and Fan 1998, Fan et al. 1999a,b, 2000). The plateauing of yields in experimental situations and the closing of the yield gap for rice and wheat arc further indications of the growing relative attractiveness of rainfed investments. Hence it seems that current comparative advantage in the production of different crops may not necessarily be a good indicator of the relative payoffs to incremental R&D investments on such crops vis-a-vis alternatives, which are currently produced at a comparative disadvantage.

New science

Developments in biotechnology are opening up new opportunities for genetic enhancement. These serve to reduce the erstwhile long research lags in conventional breeding and also increase the probabilities of research success. Both these parameters play a big role in determining the

29. Most of the discussion on India is taken from Gulati and Kelley (1999).

economic benefits from agricultural research; biotechnology thus has the potential to substantially increase the rates of return on investments in crop breeding. However, realizing this potential is not without its challenges. These include the potential risks to the environment and human health (biosafety), policy and ethical issues, the roles of the public and private sectors, the dominance of highly concentrated private sector firms which some fear will lead to a new dependency,[30] and intellectual property issues.

As the private sector in developed countries is investing billions of dollars in biotechnology there is a danger that developing countries will be left behind. As Sachs (1999) points out, unlike information technology and computers, life-science technologies have "ecological specificity" which can result in a profound imbalance in the global production of knowledge. He cites the example of the attempt to produce a malaria vaccine, which has not been successful because of a market failure. Private investors and scientists doubt that malaria research will be rewarded financially as it is primarily a problem of the poor in the tropics. He notes that historically "...there is scarcely one technology of significance that was not nurtured through public as well as private care" (p 18). The suggestion is for creativity to bridge the gap between human needs, scientific effort, and market returns in both public health and agricultural biotechnology, using private and public partnerships. Clearly IARCs can be effective vehicles for this, working as they are on orphan crops and tropical environments, which the private sector would not generally find attractive and hence which would not compete with their commercial markets (Serageldin 1999).

Intellectual property protection is an inescapable corollary of the embrace of biotechnology by NARS and the IARCs. The "life-science revolution" has meant the food-crop germplasm held in trust by IARCs has become suddenly more valuable (see section 3.10). This is challenging the "international public good" paradigm which has differentiated IARC products until now. It is leading to explicit consideration of defensive patenting to ensure the germplasm and the genes embedded in it remain in the public domain." Such initiatives are also being encouraged so that IARCs have bargaining chips to negotiate alliances with multinational companies (Serageldin and Persley 2000, p 11).

There are synergies between the advances in DNA sequencing, genome analysis, and computational biology (bioinformatics). The identification of genome sequences is facilitated by computer technology and their rapid and ready availability is similarly facilitated by information technology. Apparently 23 genome sequences are already available on the Internet and a further 60 or more are under way (Serageldin and Persley 2000, p 15). Drought and heat tolerance are governed by complex genetic determinants, which are often difficult to identify and manipulate by conventional breeding. Functional genomics and recombinant DNA technology offer the possibilities of exploiting interspecific genes through transgenic manipulation. Given the emerging constraints on water availability, the new sciences offer exciting new opportunities for ICRISAT to lead strategic research on these traits, which will offer complementary advantages to the NARS and the private sector in developing countries. Other applications with improved potential include pest and disease diagnostics and control, resistance breeding, quality and nutritional enhancement, and trait diversification.

Sub-Saharan Africa is perhaps not as equipped with scientific capacity to be able to capture the benefits of these new scientific advances as is South Asia. According to Johnson and Evenson (2000), sub-Saharan Africa in general does not have the infrastructure or the agroecological similarities to be able to benefit from scientific and technological spill-ins from developed countries. This helps explain why it has lagged behind all other developing regions in agricultural growth. Because of other differences - in resource endowments, the roles of livestock in production and consumption, scope for mechanization, nature and extent of poverty, extent and causes of land degradation and soil nutrient depletion - it appears that different R&D strategies are required in sub-Saharan Africa and South Asia.

Conclusions

The foregoing literature survey, data analyses, and stakeholder consultations, which were conducted by ICRISAT as a part of the SAT Futures exercise (see Appendix), have a number of implications for agricultural R&D strategies and priorities, which are

30. About six companies dominate what was an industry with many small companies (Serageldin and Persley 2000, p 10).

31. CIMMYT has recently announced a defensive intellectual property protection policy, according to a recent RAFI announcement.

discussed in this chapter. They arc preceded by a synthesis of the major findings.

In general it was found that the analyses of trends using the classification of countries as Large-SAT, Medium-SAT, or Small-SAT (based upon the proportion of their land masses which were SAT), did not add significantly to our understanding of features that are unique to the SAT per se. It had been hoped by separating out a group of countries which were largely comprised of a SAT environment, we would be able to capture the essence of SAT trends, as opposed to those of other agroecologies in the developing world.

Synthesis

The SAT is home to about 380 million rural poor and more than 180 million urban poor. Together these represent around 42% of the total poor in developing countries. Although there arc likely to be more poor people in the humid and subhumid areas of developing countries, it seems clear that the semi-arid tropics will continue to deserve priority by the international R&D community. It is in the SAT that the challenges of poverty and food and nutrition security will remain well into the new millennium, in spite of the generally optimistic outlook for the developing world as a whole. There are particularities about the SAT that require a special focus if these triple scourges are to be eradicated. These include the vagaries of the climate, the breadth, depth, and nature of poverty, the degrading natural resource base, poor infrastructure, neglect in national R&D priorities, and the dynamics of change in both demand and production patterns.

There seems to be a growing recognition of the special challenges and opportunities available in the SAT, which offer the hope of redressing the imbalance that has been evident in R&D investments in the past. This is predicated on increasing evidence that public investment in predominantly rainfed SAT regions in South Asia offer win-win outcomes in terms of both their impacts on sustainable productivity gains and in reducing poverty. Incremental investments in irrigation are now showing more modest returns and those on past investments are being eroded due to increasing salinity and land degradation. This is leading to a much slower growth rate of irrigated land in the last 20 years. Whilst irrigation is important in the SAT, especially in Asia, most of the land in the SAT in the foreseeable future will be rainfed.

The SAT countries of sub-Saharan Africa and South Asia are projected to be among the worst from the point of view of facing either absolute or severe water scarcity in the next 25 years. This means water will likely be the primary limiting resource in the SAT in the new millennium, especially in South Asia. This offers new strategic-opportunities for ICRISAT, which will be elaborated later in this chapter.

ICRISAT's mandate crops are becoming less and less important in the crop production economies of the SAT countries. Demand for sorghum and pearl millet as human food has been declining in the past 30 years relative to other cereals and food commodities. This is not only true at country levels, but is increasingly evident amongst both the rural and urban poor, especially in South Asia. The share of these cereals in the food budgets of the rural poor in SAT India fell from around 14% in the early 1970s to near 4% in the early 1990s. Pigeonpea and chickpea have maintained their food budget shares among the poor and groundnut has increased its share. But they still represent a minor share - 3% for the two pulses and 5% for groundnut. The implication is that productivity improvement in the ICRISAT mandate cereals, which leads to price reductions, have much less potential impact on both rural and urban poor than was the case when ICRISAT began its research in 1972. The low and sometimes negative expenditure elasticities of demand for these crops among the poor suggest that this situation will continue into the future. This raises important questions about the strategies and priorities that should be accorded to sorghum and pearl millet as foodgrains by ICRISAT in future, if the primary aim is to benefit the poor. There are even questions about the relevance of the two pulses to the poor in view of their low (even though stable) budget shares.

This is not to say that the gene pools of these crops held in trust by ICRISAT are less valuable. Indeed, the advances in science occasioned by the biotechnology revolution, including functional genomics and transgenics, open up new and valuable opportunities to exploit these gene pools for the benefit of other crops. This could represent a major comparative advantage of ICRISAT in future.

Recent growth and future projections of aggregate demand patterns suggest there will be a substantial increase in demand for animal products (meat, milk, and eggs) in developing countries towards 2020. There will also be a significant increase in edible oils, including groundnut, and a modest increase in pulses. Demand for confectionery groundnut will grow more rapidly than for groundnut oil and meal. Cereals demand growth will be constrained. Demand growth for coarse grains will be substantial, fed by the derived demand for feedgrains from the livestock revolution. Except in regions where sorghum and millet dominate production and consumption patterns, as in rural West Africa and Maharashtra and Rajasthan states in India, their use as foodgrains is expected to continue to decline. While the need for continued and even expanded germplasm conservation work is indicated, the question arises as to the continued need for IARC breeding programs for these crops. This is a particularly relevant question for South Asia compared to sub-Saharan Africa, given the relative strength of the Asian NARS compared to the African NARS.

Population growth in developing countries is slowing rather dramatically. From 2.4% per year in the '60s it has fallen to 1.7 in the late '90s, and is projected to fall further to 1% towards 2030. Sub-Saharan Africa growth rates will remain the highest in the developing world, even though they have been falling in recent years; towards 2030 it is projected to be 2% per year, compared to 2.7 in the '90s. Population growth in South Asia is estimated to fall from 2% in the '90s to 1% towards 2030.

Three underlying factors in population growth will have profound effects on SAT agriculture. The first is HIV/AIDS, which has been especially severe in sub-Saharan Africa. Aside from the human tragedy it represents, it is resulting in the increasing ageing of the rural labor force and an attendant labor shortage in a continent that in general already had a relative scarcity. The second factor is the spectacular increase in urbanization that is projected to occur in developing countries in the next 25 years. More than 90% of the increase of about 2 billion in the population of developing countries to 2025 will be in urban areas and the majority of the populations will reside there. In spite of this, poverty will still largely remain a rural phenomenon. However, dietary patterns will change as a result of the increase in urbanization, with more emphasis on diversified and processed and prepared foods. With the exception of groundnut, ICRISAT mandate crops will not be a primary feature of this change. Urban dwellers obtain a much higher proportion of energy from fats and sweeteners than do rural residents. They also consume more animal products. The third factor is the increased feminization of agriculture as a result of seasonal migration of male workers to seek off-farm employment, particularly in Southern and Eastern Africa, with implications for the demand for labor-saving technologies.

The major sources of income for the poor in rural areas of the SAT differ from those of the more affluent. In South Asia where rural poverty is closely associated with near or complete landlessness, farm and nonfarm employment, crafts, trades, and transfers are the primary sources of income. Crop and livestock incomes are more important sources lor the less poor. In sub-Saharan Africa it seems that after crop production, remittances and nonfarm income represent the next major sources of income for the poor; then follows income from livestock. Contrary to South Asia, there is little landlessness in sub-Saharan Africa, hence the importance of crop income to the poor in the latter. In fact nonfarm income is much more important for the more affluent rural inhabitants in sub-Saharan Africa. Agricultural R&D strategies aimed at benefiting the poor should therefore emphasize labor-using interventions in South Asia and labor-saving ones in sub-Saharan Africa. As most of the rural poor in the SAT own some livestock, a focus on improving the productivity of this component of their livelihoods in the face of rapidly expanding demand for livestock products projected for the developing world is also appropriate. Enhancing rural nonfarm enterprises and employment also offers significant benefits for the poor.

Globalization and trade liberalization are expected to continue to influence agricultural development in developing countries in the years to 2020, perhaps at a slower pace than might have been expected a few years ago. There is a growing consensus that lower tariffs, reduced subsidies for inputs such as fertilizers, water and electricity, rational commodity marketing driven by world prices, along with institutional reform, is a preferred development strategy. This will allow comparative advantage to drive the choices of farmers and potentially lead to more efficient use of scarce resources such as water and nutrients, with attendant benefits to the environment. The appropriate roles of the public sector in research, extension, health, education, infrastructure, and social welfare are being clarified. This is expected to reinforce investments in these sectors as governments withdraw from enterprises where the private sector has a comparative advantage.

However, although there is likely to be an increase in private R&D investment, it is not likely to reduce the need for public investment in the SAT. There will still be need for continued (and increased) public investment, partly because the private sector will not service smallholder farmers or non-commercial crops. Both sectors will co-exist, and should work in partnership. Indeed ICRISAT can and should play a catalytic role in bringing public and private sectors together with farmers where new commercial opportunities for ICRISAT crops emerge as a result of trade liberalization and market reforms. This will provide increased scope for technology adoption and R&D synergies.

Exciting developments in science such as biotechnology and information technology have the potential to greatly reduce research and adoption lags. In SAT agriculture these have been long because of the complexities, heterogeneity, and vagaries of the environment on the one hand and the poor infrastructure, policy biases, and governmental neglect on the other. For example cellular phones and digital radios offer the prospect of directly targeting remote and poor villages with marketing and technology information. With water becoming an even more binding constraint in the future, and the pervasiveness of other biotic and abiotic stresses in the SAT, new opportunities also arise for ICRISAT because of these new scientific tools. Functional genomics and recombinant DNA technology offer the prospect of making progress where conventional breeding had limited success by enabling the exploitation of interspecific genes in transgenic manipulation.

Intellectual property rights remain a major hurdle to enhancing partnerships between IARCs and the private sector. It seems the private sector views international public goods related to genetically improved material as irreconcilable with proprietary technology, IPR, and biosafety. Apparently no distinction is being made in this context between "orphan" SAT crops in developing countries and crops in developed countries. The CGIAR will have to clarify its policy on this issue before ICRISAT can formulate a clear strategy of collaboration with the private sector.

As in the past but even more so in the future, the mainstay of production increases will be the intensification of agriculture in the form of higher yields, more multiple cropping, and reduced fallow periods. Natural resource management research should hence focus on the development of improved integrated soil-water-nutrient management technologies and integrated crop-livestock management systems, including pest and disease control, using demand-driven participatory research methods.

There are still questions as to the degree to which natural resource management research on such topics is location-specific and whether it has sufficient international public good characteristics to justify major investments by IARCs. However, there is every indication that IARCs have a comparative advantage in aspects of resource management research that require application of new science. These include diagnostic research to explain the functioning of natural systems, and thereby facilitating the construction of system models. There is also a need for improved data and information on the extent, causes, and consequences of land degradation to help inform decisions at all levels, from the landscape to the plot.

NARS in recent years have built up their human capital but the levels of support per scientist have been declining in sub-Saharan Africa. Research investments per hectare of land, per farmer, and as a proportion of GDP in developing countries remain far below those in developed countries. NARS seek genuine partnership with IARCs on mutually agreed priorities. Most public sector NARIs are yet to formulate clear strategies and modus operandi for their relationships with the private sector. In this sense they face similar challenges to the IARCs.

Implications

In view of the above developments, the opportunities they provide, and ICRISAT's comparative and complementary advantages vis-a-vis partners and alternative suppliers, several important implications deserve consideration as the Institute positions itself for the future. We list these in no particular order of importance.

Water as an overarching concern

The increasingly precarious position of the SAT with respect to water availability in the coming two decades offers exciting new possibilities for ICRISAT, which respond to the challenge, the opportunities provided by new science, and the demonstrated comparative advantage of ICRISAT in both genetics and natural resource management.

The unique genetic resource collections of a group of species that have evolved in water-limited environments, combined with advances in functional genomics and transgenics, represent new frontiers for a genetic as opposed to a narrow "species" approach to the constraints of drought and the need for improved water-use efficiency. With a critical mass of scientific resources focused on these areas, ICRISAT could potentially become a hub for the identification and exchange of genes that confer these traits. While it would obviously focus on the mandate crops, it need not be restricted to them in the quest for the required genes. It could be both a leader and a catalyst for others. ICRISAT breeders and plant physiologists have already built up a body of knowledge and understanding of drought response of the mandate crops over the past 28 years, which means the research lags would be small.

Of course the quest for drought and water-use efficiency traits associated with certain genes may not be without trade-offs, and these would need to be assessed. Water use and productivity are generally correlated at a fundamental physiological level.

Water-use efficiency could also be the primary focus of ICRISAT's natural resource management research. This would include crop and simulation modeling, and watershed management using a holistic systems approach, again building on an accumulated comparative advantage. The heterogeneity of rainfed agriculture in the SAT and its inherent riskiness make the use of models particularly relevant as a complement to other R&D approaches. Models offer three cost-effective advantages:

- A means of extrapolating location-specific research to achieve technology spillovers
- An ability to assess the risks of alternative crop and technology options
- An ability to assess the likely sustainability of crop and technology options that are beyond the experience of farmers.

Watershed management research would enable the integration of crop-livestock-silviculture-horticulture options to be assessed in terms of water-use efficiency, soil conservation, and carbon sequestration. Combined with modeling it would represent a powerful focal point for international attention on the future water constraints that are going to operate at field, farm, watershed, catchment, and river basin levels. However, it should be recognized that previous watershed management R&D has not realized its promise. Widespread and demonstrable impact has not been evident. This implies that research on water policy and institutional innovations in water resource trading, allocation, pricing, and management are also likely to have high payoffs for ICRISAT, in collaboration with IFPRI and IWMI.

There is considerable evidence that there are high payoffs to be had from incremental R&D investments in the so-called marginal lower rainfall SAT regions in South Asia. This includes both sustainable productivity gains and poverty reduction. There are gains to be had in the higher potential, higher rainfall SAT regions also, but these are probably lower than in the more marginal areas. It certainly does not appear to be the case that the poor in marginal areas must migrate to higher potential areas if they are to move out of poverty. A focus on water-use efficiency would have particular benefits to the poor in marginal areas.

The species mandate

Several factors are impacting on the relevance and appropriateness of ICRISAT's species mandate :

- Decline in the importance of ICRISAT crops in the export and import economies of SAT countries
- Changes in relative competitiveness of different crops as a result of globalization and liberalization
- Rapid decline in the importance of sorghum and pearl millet in the food baskets of the poor and in cropping patterns in South Asia
- Increasing priority accorded to commercial crops and livestock compared to food crops in farm investments and intensification by poor farmers in sub-Saharan Africa
- The small contribution of food crop production to incomes of the poor in South Asia
- Developments in new science.

In view of these trends, ICRISAT is in danger of losing its leverage on the poor by limiting its focus to the five mandate species in its genetic enhancement work. As indicated in the preceding discussion on water, there is a strong case for a focus on genes of value instead of species. This extends to work on IPM and IDM (integrated pest management, integrated disease management) as well as water. Changing the commodity mix may be a more effective way to make the genetic progress desired than being restricted to the current five mandate species. It is also a preferred way to conduct systems research, which of course has not been restricted to the mandate species anyway, but has arguably limited its horizons. A current illustration of the limitations of a commodity approach to IDM is

Aflatoxin study in groundnut: Limitations of a commodity versus a holistic approach

A collaborative study involving the Indian NARS, the Natural Resources Institute in the UK, and ICRISAT has recently been initiated with the support of UK's Department for International Development. As we understand it, one aspect is to extend the previous work which has been primarily focused on aflatoxin contamination of the kernel, to the extent and causes of aflatoxin contamination of the haulms, and whether this is transmitted to milk after being eaten by cows and buffaloes. Apparently other feed sources for the animals were not to be a part of the study. This is disappointing, as even if the project finds ways of reducing or eliminating contamination in groundnut haulms, presumably problems will remain with other feeds and hence the milk will remain contaminated. The human health consequences, which are a major rationale for the project, may hence be minimal because of a single commodity approach.

Perhaps searching for a gene or genes from any species that triggers a color marker in groundnut haulms and kernels, as well as in the stover and grain of maize, sorghum, millet, and other species, once the toxins exceed permissible levels, may lead to more benefits for farmers, animals, and consumers. Such a marker would have the added advantage over current approaches, of turning a cryptic character into an evident one for users and buyers. This would allow non-contaminated produce to be clearly identified and a market premium established for the genetically modified products. Such a premium is important in order to create the. necessary incentives for farmers, traders, processors, and retailers to invest in aflatoxin control measures, whether they be resistant varieties, cultivation practices, or postharvest technologies. As the debate on organic foods and GMOs in developed countries illustrates, clear labeling is an imperative.

provided by the recently initiated study on aflatoxins, which is primarily focused on groundnut because of the current mandate (see box). Similarly, ICRISAT's IPM work might have had more impact had it explicitly focused on cotton-based systems, rather than pigeonpea. This narrow approach can mean many missed opportunities. A problem-oriented or thematic mandate would seem more appropriate now than a commodity or even agroecological one.[32]

Commercial crops like cotton, soybean, and other oilseeds offer opportunities for poor subsistence-oriented farmers to enhance incomes and access purchased inputs that can benefit both food and commercial crop productivity. These options should be a more explicit component of ICRISAT's horizons in future. It does not imply ICRISAT necessarily leads or plays a primary research role. Rather it could play a catalytic or facilitative role in bringing others who have a comparative advantage in these areas to engage in strategic research of particular relevance to the SAT

Livestock and feedgrains

While the precise extent of the growth in demand for livestock products is debated (significantly because of uncertainty over the degree to which meat demand in India will increase), it will grow much more rapidly than the demand for foodgrain staples in the years to 2020. The derived demand for feedgrains like maize, sorghum, and to a lesser extent pearl millet, pigeonpea, and chickpea will expand as a consequence. At issue is whether 1CRISAT should alter its genetic enhancement strategy from an almost exclusive focus on foodgrain uses of the mandate crops, to one that increasingly caters to their use as feedgrains.

The question is especially pertinent to sorghum, which already competes with maize as the major feedgrain. At present sorghum sells at a 5-15% price discount to maize. It has a lower total digestive nutrient content, is often moldy, and results in poorer quality eggs. Would poor SAT farmers and consumers gain from a strategic shift to genetic enhancement aimed at improving feedgrain sorghum quality attributes at the expense of the current focus? A bioeconomic study of the value and desirability of such a shift is required. The focus should be on whether sorghum can compete effectively with maize, and under what circumstances.

Related to the livestock revolution is the need to consider a more explicit research focus and enhanced investment in livestock and mixed crop-

32. Especially because the mandate crops are grown on large areas outside what is defined as the SAT.

livestock farming systems in the SAT. The predominance of the poor in such systems, the growing importance of livestock to their livelihoods, and the strength of future demand provide the primary rationales for this. Such a focus should build on the productive collaboration with ILRI in both sub-Saharan Africa and South Asia. It should move beyond a commodity focus centered on sorghum and millet.

The relative value of sorghum and millet stover as a proportion of the total value of production of these two crops has been consistently rising, compared to the value of the grain component. Research on grain/stover productivity and quality therefore remains a priority. Additionally, biomass from SAT farming systems in general will become increasingly valuable both as livestock feed and as a renewable energy source, leading to increased competition between these alternative uses. If alternative energy sources for SAT households do not become readily available, the potential for livestock in such systems will be constrained.

Different regional strategies

Except for the pervasive constraint of water, other constraints are somewhat more region-specific, with different priorities in sub-Saharan Africa and South Asia. Even with water, deficits towards 2020 are projected to be more severe in South Asia than in sub-Saharan Africa. There are also large differences between the two regions in terms of strength of the NARS, endowments of land, labor, and capital, extent and quality of infrastructure, roles of livestock in production and consumption, nature and extent of poverty, and the extent and causes of land degradation and soil nutrient depletion. For example, there is strong support for a high priority to be given to soil, water, and nutrient management research in sub-Saharan Africa, even at the expense of further genetic enhancement work.

The suggested research agenda - focusing on water and strategically important genes instead of species - has aspects with international public goods characteristics, which makes such an agenda relevant in both regions. However, the natural resource management and policy environments would seem to require diverse R&D strategies for the different regions.

Socioeconomics and policy

With the dynamics of the external environment surrounding the SAT, as described in this paper, ICRISAT will need to monitor this and use the information to refine R&D strategies, and assess priorities and impacts. It will be especially important to better understand the dynamics and determinants of poverty in the SAT and how ICRISAT can intervene. Greater and continuing attention to problem diagnosis against this background would seem appropriate.

Because of the growing significance of non-crop income among the SAT poor, there is a need to study what new opportunities there might be for ICRISAT to make a difference to their welfare, beyond the confines of its current commodity and agroecological mandate, and/or where others better equipped to do so might. Revival of the Village Level Studies in carefully defined SAT regions of sub-Saharan Africa and South Asia could be a unique way for ICRISAT to express its already demonstrated comparative advantage to lead in such studies. It also represents a complementary advantage vis-a-vis the NARS and other partners, who would be key collaborators. These studies would cover not only crop/livestock farming systems, household and village economies, but also the increasingly important aspects of migration, nonfarm rural employment and enterprise, and remittances. It would include assessment of how farm and nonfarm investments are evolving, and the opportunity costs of resources currently invested in agricultural systems vis-a-vis alternatives. ICRISAT's strategic contribution could be concentrated on evaluation of returns to alternative resource management strategies, rather than in the design and development of specific technologies. Questions include: how are income sources evolving; what are the trade-offs underlying investments in crops and livestock, and agriculture versus nonfarm enterprises; how do markets influence resource-use efficiency and the returns to production research; and what populations are being left behind.

The issue of improved ownership/access to land, water and other natural resources is important in the Asian and African SAT, and somewhat less so in West and Central Africa. As productivity of land and natural resources increases, agriculture becomes more commercialized; and as population densities increase there will be greater need for appropriate land registration. Policy research agendas should include land tenure and common property access studies, building on indigenous knowledge. The challenge for research and agricultural development institutions is to contribute to empirical knowledge for designing appropriate property rights structures for improving performance under different situations. There is good scope for further collaboration with IFPRI on this topic. This should include detailed research at the village and household levels over both space and time to better understand the causal factors in what is an apparent poverty-environmental degradation nexus. This would provide the necessary microeconomic foundations for the design of policy and/or technological interventions. The revived ICRISAT village level studies could provide a unique opportunity to examine these issues using participatory on-farm research.

Land degradation

There is need for more research on the nature, extent, consequences, and trends in land degradation in the SAT. Information appears to be very limited and sometimes contradictory. At best aggregate data are available and/or CIS mapping is based upon doubtful information. There is need for careful long-term field studies to complement satellite imagery and spatial analysis by others. This would include the productivity effects of soil loss and nutrient depletion, water pollution, salinity, and loss of biodiversity.

Postharvest technology and marketing

There would not seem to be significant reasons to change the priority which ICRISAT currently accords to postharvest technology research on its mandate crops. Projections indicate there is not likely to be growth in industrial uses of these crops. Any research by ICRISAT is unlikely to change that. Furthermore, the private sector is better positioned to assess the needs of the market, develop appropriate processes and new uses, and reap the rewards for their successful proprietary innovations. It does not appear that lack of postharvest technology constrains demand for the five crops. Indeed production research that makes them more price-competitive is more likely to benefit the rural and urban poor than a focus on postharvest technology, where a priori one would expect the beneficiaries would be traders, processors, wholesalers, and retailers. "Value-adding" means increased prices, and poor consumers usually do not benefit from price rises. The development of production, marketing, and postharvest innovations for commodities like fruits and vegetables might conceivably do more for the poor by stimulating their production and more widespread availability. This would improve both off-farm employment and nutrition among the poor.

The ICRISAT mandate crops experience high marketing and transaction costs as a result of poor infrastructure, especially in sub-Saharan Africa. Research which aims to reduce these costs can have high payoffs for the poor, both as consumers and as a source of earned income.

Additionally, there is emerging evidence that the opening up of new commercial opportunities provides a conducive environment for the adoption of technology options that may have been on the shelf for many years. The recent growth of pigeonpea exports from Eastern Africa to India is a case in point. As WTO trade liberalization proceeds, such opportunities are likely to increase. ICRISAT can play a catalytic role in bringing the private sector, farmers, and the public sector together to exploit such opportunities. Especially for poor SAT smallholders, improving commercial linkages with emerging agro-industries and in the process enhancing rural nonfarm employment potential, can help reduce poverty. ICRISAT would need to move beyond production research to play a catalytic role in this process in partnership with the public and private sectors.

Balance between research and development: role oflARCs

A perennial issue for IARCs is the appropriate balance between location-specific applied/adaptive research and more basic/strategic research on constraints that are important in many countries. Emphasis on the former is justified by the need to demonstrate impact and relevance to the poor and to provide feedback to the latter. Emphasis on the latter is rationalized on the grounds that the outputs are more likely to be international public goods and hence represent both a comparative and complementary advantage for the IARCs vis-a-vis partners and alternative suppliers.

IARCs need to play many different roles depending on needs, priorities, and comparative and complementary advantage vis-a-vis other R&D actors. These can range from leadership, primary, catalytic, facilitative, convening, custodial, and advocacy. The appropriate balance of effort will need to be established along the R to D (or discovery to delivery to impact) continuum.

There are many small NARS in Africa and they are endemically spread too thin and arc unlikely to be able to deploy enough human and material resources to function at the level needed over the next two decades. IARCs and regional research organizations will need to play crucial backstopping roles for such NARS.

The alleviation of human capital constraints also requires more effective partnerships among farmers and private and public sector research. Community approaches to enhancing human capital are needed, along with more intensive efforts to assess and refine technology options. To address human capital constraints, institutions addressing poverty need to work on improving literacy and basic education of the poor in order to empower them to better interact with other segments of society. Information delivery/exchange and training should also receive much consideration. Farmers should be provided with technical training (especially in resource allocation and management) as the SAT is expected to shift from extensive to more intensive production systems. Appropriate tools and methods need to be designed for information dissemination and to foster information exchange among farmers. Health delivery facilities must also be improved.

Advances in information technology (IT) will mean that technology and information exchange will become much more cost-effective and potentially available directly to SAT farmers; for example, cellular phones and digital radios in remote SAT regions. As literacy improves, farmers will make better use of the opportunity that IT provides. R&D institutions need to factor this into their strategies. Conceivably, SAT farmers could access IT to help array options and trade-offs in integrated natural resource management, and provide real-time information on commodity prices, seed availability, weather, and pest and disease epidemic forecasts. These could help diffuse the inherent risks of SAT agriculture and allow exploitation of new commercial opportunities. IT can also facilitate communication among farmers, researchers, extension staff, and policy makers, which can serve to enhance the value of partnerships.

Increased feminization: need for targeted technologies

Child malnutrition is the most insidious manifestation of food insecurity. The highest prevalence rates of child malnutrition and the largest numbers occur in the semi-arid tropics. To reduce child malnutrition further in South Asia and sub-Saharan Africa, the top priorities are improved per capita food availability and women's education. Furthermore, with increasing nonfarm employment and migration of men, there is a need to look at selective mechanization of both pre- and postharvest operations, as there is evidence of emerging labor scarcity even in South Asia. Small tools could be a component of this strategy so that labor displacement is minimized. This implies the need to raise agricultural productivity by concentrating on developing and disseminating labor and capital saving technologies as well as drought-resistant crop varieties that stabilize yields. Increased attention needs to be given to targeting female heads of households, as the proportion of such households is increasing due to increased male migration. Research organizations also need to develop strategic partnerships with other development organizations to support income diversification efforts.

Appendices

The semi-arid tropics

Using the TAC/FAO definition of the semi-arid tropics (TAC 1992), we classified a total of 55 developing countries which had some area of SAT within their borders (Table 49). The criteria for this classification were as follows:

- Length of growing period 75-180 days
- All months have a mean monthly temperature >18°C (i.e. the Tropics)
- Daily mean temperature during the growing period >20^{0}C.

The world map of the developing countries with SAT agroecological zones is shown in Figure 12. TAC refers to this zone as AEZ 1.

Unfortunately, for most countries data were not available separately for the SAT regions within each country. One exception is India, where the availability of district-level data allows us to differentiate the SAT from non-SAT areas. We do use such data on India in the study but in order to compare trends and projections in key statistics across different geographic regions, we had to rely on a suitable aggregation of country-level data only.

To help discern meaningful insights for the SAT we created three groups of SAT countries for each of four geographic regions. The first group comprised countries with a large proportion of SAT within their borders; the second were those countries with relatively less SAT area; and the third were those with small proportions. The logic was that national statistics on the Large-SAT countries would be dominated by what is happening in the SAT, whereas

Table 49. Developing countries with semi-arid tropical environments.

Country	Total area (km^2)	SAT area (km^2)	SAT area (%)
Angola	1,252,421	289,215	23
Argentina	2,781,013	5564	0
Bahamas, The	12,868	4610	36
Benin	116,515	35,401	30
Bolivia	1,090,353	256,863	24
Botswana	580,011	200,080	34
Brazil	8,507,128	641,160	8
Burkina Faso	273,719	214,068	78
Cambodia	182,612	9841	5
Cameroon	466,307	48,325	10
Central African Republic	621,499	30,241	5
Chad	1,168,002	362,853	31
Colombia	1,141,962	46,495	4
Cuba	110,443	83,945	76
Dominican Republic	48,445	16,615	34
Ecuador	256,932	35,379	14
Eritrea	121,941	27,091	22
Ethiopia	1,132,328	186,095	16
Gambia, the	10,678	10,678	100
Ghana	239,981	10,194	4
Guinea	246,077	7009	3
Guinea-Bissau	33,635	1145	3
Haiti	37,157	12,888	35
India	3,089,282	1,289,713	42
Indonesia	1,910,842	35,083	2
Jamaica	11,044	2458	22
Kenya	584,429	99,578	17
Laos	230,566	3716	2
Madagascar	594,856	131,391	22
Malawi	119,028	17,547	15
Mali	1,256,747	377,143	30
Mauritania	1,041,570	63,681	6
Mexico	1,962,939	107,508	5
Mozambique	788,629	359,753	46
Myanmar	669,821	86,194	13
Namibia	825,632	181,454	22
Niger	1,186,021	151,891	13
Nigeria	912,039	352,289	39
Paraguay	400,089	127,322	32
Peru	1,296,912	15,415	1
Puerto Rico	9063	1313	14
Senegal	196,911	166,129	84
Somalia	639,065	41,409	6
Sri Lanka	66,580	7878	12
Sudan	2,490,409	742,330	30
Swaziland	17,164	1759	10
Tanzania	944,977	308,230	33
Thailand	515,144	46,263	9
Togo	57,300	1086	2
Uganda	243,050	38,902	16
Venezulela	916,561	95,323	10
Vietnam	327,123	5126	2
Yemen	425,521	38,301	9
Zambia	754,773	258,532	34
Zimbabwe	390,804	262,311	67

Source: Derived from FAO databases by the ICRISAT CIS Unit

Source: FAO, Rome, Italy

Figure 12. The semi-arid tropics of the developing world.

SAT definition: Length of growing period 75-180 days
All months with monthly mean temperature, corrected to sea level, above 18° C

in Small-SAT countries non-SAT areas would dominate. Hence greater reliance should be placed on statistics from the Large- and Medium-SAT countries in each region than on the Small-SAT.

In grouping countries precise cut-off points based upon the portions of the countries defined as SAT were not used. Instead countries were broadly classified so that most cells of the matrix had entries. A total of 36 countries were thus classified, as shown in Table 50. Together these represent more than 90% of the developing world's SAT area. Only those 19 countries with a few percent of SAT agroecology were excluded from the classification. Unfortunately there are few Large-SAT countries; in most of the 55 countries identified the SAT occupies less than half the country's area.

Summary of outcomes of stakeholder consultations

Brainstorming sessions associated with this exercise brought together NARS collaborators and ICRISAT management and staff, including participants from national research and extension organizations, NGOs, farmers' organizations, the private seed sector, and universities. A series of meetings were held during 2000 - for Asia in Hyderabad, India (25 July and 10-11 Aug), Eastern Africa in Nairobi, Kenya (14-15 July), Southern Africa in Bulawayo, Zimbabwe (18-19 July), and West/Central Africa in Bamako, Mali (25 July).

The main purpose of these meetings was to discuss the future of the SAT and ICRISAT's future role. Discussions were organized around the Sustainable Livelihood Framework developed by the Department for International Development, UK (Farrington et al. 1999). The framework addresses the inter-relations between *livelihood outcomes, livelihood assets,* the *vulnerability context,* and *transforming structures and processes,* as well as their respective and combined roles in driving livelihood strategies. It shows that in order to alleviate poverty, five livelihood outcomes need to be addressed. These are: increase of income, increase of well-being, reduction of vulnerability, improvement of food security, and development of a more sustainable use of the natural resource base. Livelihood outcomes can be affected using five categories of livelihood assets (human, physical, social, financial, and natural capital) as discussed in Chapter 2.

Participants were first requested to rank livelihood assets in each region in terms of their importance as constraints in affecting poverty in the respective regions. Once the asset rankings were determined, participants discussed and ranked actions proposed for alleviating the constraints. Then the groups discussed their perspectives on what the SAT is likely to look like in 2020 and the dynamics of change. Finally participants were requested to brainstorm on the implications for

Table 50. Classification of countries into SAT regions and size groups.

Region	Large SAT	Medium SAT	Small SAT
Asia	India		Myanmar Yemen
Southern and Eastern Africa	Zimbabwe	Botswana Eritrea Mozambique Sudan Swaziland Tanzania Zambia	Angola Ethiopia Kenya Madagascar Namibia Uganda
Western and Central Africa	Burkina Faso Gambia Senegal	Benin Mali Nigeria	Cameroon Chad Mauritania Niger
Latin America and the Caribbean	Cuba	Dominican Republic Haiti	Bolivia Brazil Ecuador Mexico Paraguay Venezuela

ICRISAT and the changes needed if it is to effectively serve the SAT over the next two decades.

Constraints ranking

Although opinions expressed were diverse, and the results should be interpreted with caution, the groups were able to arrive at broad consensus about the importance of the different asset constraints. In the Nairobi and Bulawayo sessions the consensus among both ICRISAT staff and other stakeholder groups generally was that in Southern and Eastern Africa, natural capital, followed by financial capital, were the most constraining factors to poverty alleviation. Social capital, specifically government policy, was considered somewhat more important by ICRISAT's partners than by ICRISAT staff.

In the Bamako session participants ranked constraints for West and Central Africa differently. ICRISAT staff gave highest importance to human capital constraints, then successively financial, social, physical, and natural resource capital constraints. ICRISAT collaborators also ranked human capital constraints first, followed by financial and physical constraints, ending with social and natural constraints. Overall, for both ICRISAT staff and collaborators, social constraints ranked above physical constraints.

In the brainstorming at Hyderabad, the consensus was that the major constraint in Asia was natural capital. This included water, land degradation/soil health, and biodiversity. Then followed social and human capital. It was recognized that community action will be an increasing element in the management and conservation of natural resources and that indigenous knowledge is eroding. There is a challenge in improving technology exchange because of a communications gap (in both directions) between farmers and researchers.

Alleviation of constraints

Actions proposed for constraint alleviation were similar in the two sub-Saharan African regions. For *natural capital constraints* participants identified the need for two broad sets of actions. First is development of improved technologies using demand-driven participatory research methods. Specifically, since water and soil quality are the key limiting factors in most SAT environments, integrated soil-water management technologies are needed, as well as integrated crop-livestock management systems including pest and disease control, and biodiversity conservation. Which of these suggested actions is most important in a particular area would depend on the extent of degradation in a target area, and the primary objective of intervention. Second is improved ownership/access to land, water, and other natural resources. The issue was considered to be more important by participants in Southern and Eastern Africa than in West and Central Africa. Both groups recognized the importance of using indigenous knowledge in addressing issues of access to resources.

For *human capital constraints* (ranked highest in WCA), improvement of literacy and basic education was deemed crucial. Information delivery/exchange and training should also receive much consideration. Farmers should be provided with additional technical training - especially in resource allocation and management - as the SAT is expected to shift from extensive to intensive production systems. Increased literacy and basic education would facilitate this technical training. Appropriate tools and methods need to be designed for information dissemination and to foster information exchange among farmers. Health delivery facilities must also be improved.

For alleviation of *social/financial constraints,* participants identified the strengthening of community-based organizations as the first step towards poverty reduction, followed by diversification of household income sources (postharvest systems, increased remittances, etc), improved access to credit (rural financial institutions), and improved marketing systems/ policies for agricultural products. These issues, together with improvement of land tenure policies (agricultural reforms) are to be addressed within the context of decentralization currently under way in several West African countries. Policy dialogues need to be at the global, regional, and national levels. Policy analysis is vital to understand the bottlenecks and constraints to technology adoption and the improvement of livelihoods.

In Asia participants felt alleviation of *natural capital constraints* required a systems approach. Water constraints can be addressed under three headings:

- On-farm water management - physical facilities such as storage and conveyance; mechanical systems, including mulching and tillage; supplemental irrigation/water harvesting
- Water-efficient systems - within-system including watersheds, agroforestry, crops, livestock; within-plant including heat- and drought-tolerant cultivars and genomics

- Water policies - recognize water is a national asset rather than a personal one; pricing; utilization; abuse.

To tackle land degradation and problems of soil health requires a comprehensive research agenda covering many topics in both genetics and natural resource management. Indeed it was felt a balanced approach was necessary. It was not an either/or issue. The topics include soil erosion, soil nutrient replenishment, maintenance of the C:N ratio, balancing N-P-K, conservation and use of soil, plant and animal biodiversity, salinity/alkalinity tolerant cultivars, waterlogging, microflora and fauna, cropping systems options and diversification, bio-indicators of soil health and land degradation, soil pollution/contamination, land use planning, reclamation, management and zoning, soilborne diseases, and insects. There was no agreement on whether or not natural resource management research on such topics was location-specific and hence of limited scope for ICRISAT.

Alleviation of *human capital* constraints in Asia requires more effective partnerships among farmers and private and public sector research institutions. Community approaches to enhancing human capital are needed, along with more intensive efforts to assess and refine technology options in participatory modes.

Dynamics of change: sub-Saharan Africa

Trying to foresee what the sub-Saharan African SAT could look like in 20 years from now, participants identified several indicators for trend prediction as follows:

Demography (population growth, health-AIDS, urbanization)

In West and Central Africa, participants agreed on the following: (i) no significant change is to be expected in land/people ratios, (ii) no significant increase in the feminization of SAT rural populations as migration will affect men and women equally. By contrast, participants in Southern and Eastern Africa predict increased feminization of agriculture and an increase in land/people ratios, i.e. more land per capita because of urbanization, migration, and HIV/AIDS. Labor shortages will become more severe. As a result, livestock will become more important in the farming system, and the current practice of extensive (rather than intensive) agriculture will be reinforced. Cropping systems and crop preferences may change - thus, new crop and resource management technologies will be needed.

Climate change, desertification, soil degradation, water scarcity, pollution

Global warming should lead to greater climatic extremes in the SAT (increase in rainfall variability) and possibly a decrease in total rainfall. However, the effects are expected to be minimal at least within a 20-year time frame. The evolution of the rate of soil degradation is unclear. However, it was noted that the natural resource base is already degraded and needs to be rehabilitated. Participants believe that combined with expected improvements in infrastructure, the prospects for cash crops (groundnut, cotton, sesame, cowpea for livestock feed, vegetables, and livestock feed) will be improved, relative to coarse grains.

Privatization

Privatization is expected to result in rising investments (both private and public, although the latter need to be better targeted). On the whole participants believe that use of investments will become more rational. There will still be need for continued (and increased) public investment, partly because the private sector will not service smallholder farmers or non-commercial crops. Both sectors will co-exist, and should work in partnership.

Governance and decentralization

Increasingly better governance in SAT countries is expected to result in increased investment in poverty alleviation measures, and a strengthening of community-based and local organizations, leading to a reduction in conflicts.

Roles of NARS, IARCs, and other partners

NARS will continue to play a key role, with support from IARCs, but many other partners will become increasingly involved (NGOs, and recently the private sector) in rural development. Appropriate roles should be identified for each partner, in relation to their comparative advantages. The consensus of all stakeholders was that IARCs will need to be involved 20 years from now. But ways must be found to broaden and strengthen partnerships.

Crop/livestock competition

Competition between crops and livestock is expected to decrease through better integration and a "forage revolution" (intensification of forage production and decrease of transhumance), leading to increased livestock production and increased use of manure in cropping systems.

Dynamics of change: Asia

In the **Asian SAT** participants felt there were eight external influences which were likely to materially affect the strategic choices and priorities of ICRISAT towards 2020. They are discussed in descending order of importance, as gauged by participants.

Population growth, urbanization, migration

The trends in all these variables would place particular strains on SAT environments. Even though South Asia is approaching a transition in population growth rates, the absolute increases in population (and increasing urbanization) will place ever increasing demands on land and water resources. Off-farm income sources will grow, offering new opportunities for the poor in terms of risk diffusion and income enhancement, along with investment funds for agriculture.

New sciences (biotechnology, molecular biology, information science, space technology)

The major issues here are the roles and relationships between the private and public sectors. Discovery has traditionally been a public sector role and innovation a private one. However these distinctions are being blurred and Intellectual Property Rights (IPR) is a key dynamic in this milieu. IPR implies responsibilities as well as rights. Multinationals should be generous to the public sector NARIs in developing countries and the CGIAR should provide leadership to facilitate partnerships and debate. Is it possible that the CGIAR is placing too much emphasis on international public goods such that it reduces the prospects of enhancing private sector collaboration?

There was a view that scientists should be able to pursue transgenics, GMOs, and the like without the constraints that have been placed upon them by NGOs and environmentalists. NARS and IARCs are being overly cautious in this respect. Synergism should be exploited and a major focus on capacity building of partners will be important to fully exploit these opportunities.

Advances in IT and in its availability will mean that technology and information exchange will be much more cost-effective and potentially available directly to farmers via cellular phones and the like. We can also assume literacy will improve in the SAT, allowing farmer to make better use of the opportunity that IT provides. R & D institutions need to factor this into their strategies.

Rural poverty

Projections indicate that numerically, poverty will remain primarily a rural phenomenon towards 2020, despite the more rapid growth expected in both number of people and number of poor in urban compared to rural areas. As there will still be large numbers of poor people in the SAT towards 2020 the challenges for ICRISAT will remain formidable.

Food and nutrition insecurity

The pervasive nature of food and nutrition insecurity in the SAT, especially in South Asia, was highlighted. Projections are that child malnutrition will remain a problem in South Asia towards 2020, even if progress is made on overall food security and women's education, which are the major determinants of child malnutrition. It was noted that income growth does not necessarily alleviate human nutritional deficiencies, even if it goes a long way towards achieving food security.

Globalization, liberalization

The sense was this trend would continue towards 2020, with potentially profound effects on comparative advantages of different SAT regions. Coarse grains will be especially affected. Rainled agriculture will need to be more efficient, with products of higher quality, to compete effectively.

Rise of civil society, empowerment, breakdown

Increasingly, power is being devolved to local levels. This includes taxation powers and rights to acquire and use germplasm. Women are being empowered and with migration this is leading to increased feminization of agriculture. This may increase the scope for successful community action for management practices like IPM.

Changing demand patterns, diversification

Trends in consumption habits towards animal products, fruit, and vegetables will imply changes in R&D priorities in the SAT. More marketing research will be needed, including promoting ICRISAT' crops as health foods in niche markets. Maybe livestock and perennials will replace annuals? We should look at the experience of developed SAT countries for lessons on how the SAT in developing countries might be fashioned. New SAT commodities should be explored.

Is a more diversified SAT agriculture possible in the face of globalization and liberalization? Presumably the latter will tend to lead to more specialization rather than diversification.

Selective mechanization, postharvest technology

With increasing nonfarm employment and migration there is a need to look at selective mechanization of both pre- and postharvest operations, as there is evidence even now of labor scarcity in South Asia. Small tools could be a component of this so that labor displacement is minimized.

It is doubtful whether postharvest research on the current mandate crops would offer significant benefits for the poor. New crops might instead be a preferred option.

Re-engineering ICRISAT

Participants discussed whether ICRISAT has any comparative advantage in the areas identified above, e.g. collaboration with NGOs, or cooperative programs, or even natural resource management research. In the extreme case, if ICRISAT were to shut down, would it make any difference? As indicated earlier, it was agreed that all stakeholders (NGOs, private sector, IARCs, NARS, etc) will have a role to play - but ways must be sought to allow partners to play their roles more effectively.

Several collaborators recommended that ICRISAT revise its programs, with more effort on postharvest issues. The scale of research should be increased from the plot or farm level to watershed or community level. More emphasis should be on "new" methods such as biotechnology, modeling, remote sensing, etc.

While enhancing its regional visibility, ICRISAT should help countries strengthen their own research agendas and keep their research staff (ICRISAT should not be viewed as a competitor and hence destabilizing the NARS through a "biain drain"). This could be looked at as the translation of successful collaboration at the technical level (present state) into promising partnerships at the political level (future state).

Water management policy and water-use efficiency could be the cornerstone of ICRISAT's future strategy. This would include watershed management, which could provide a vehicle for inter-center collaboration (e.g. with IWMI, IRRI, IBSRAM).

A systems approach was viewed as being more relevant than a crop or commodity approach. ICRISAT's current crop mandate was seen as too constraining in this respect and there was support for reviewing this to see if other crops might be more appropriate for the future, in addition to the current ones. Soybean, mungbean, sunflower, finger millet, fonio, barnyard millet, amaranth, cotton, maize, sesame, rapeseed, cowpea, and perennial horticulture species such as date palm, gooseberry, leucaena, and custard apple were mentioned in this respect. This would also allow a crop diversification approach to SAT agriculture. Some concern was expressed that adding crops to the mandate would dilute ICRISAT's crop improvement program and that it would be preferable to partner other IARCs and NARS with strong programs on the crops concerned.

With the growing importance of livestock in future demand patterns and their complementary role to crops in farming systems, ICRISAT should place more emphasis on mixed crop-livestock systems research, in collaboration with ILRI. This should extend beyond improving the quality of cereal stover to forage and pasture research.

With the advance of functional genomics, marker-assisted breeding, and transgenics, the question was raised as to the future relevance of species mandates to ICRISAT. Might it not be more appropriate to focus strategic research not on crop species but on genes of interest? Genes for drought resistance, water-use efficiency, and pest and disease resistance are examples. The genes conferring these and other traits might be more efficiently sought beyond the confines of the current ICRISAT species mandate. ICRISAT could be a resource center for genes, markers, maps, and related information. Most felt ICRISAT should focus primarily on strategic research and NARS at the applied/adaptive levels as partners. In sub-Saharan Africa ICRISAT may still have to play a role at the more applied/adaptive levels.

There was still some ambivalence - especially among the breeders - about putting all the ICRISAT crop improvement eggs in the upstream basket. An appropriate balance between applied/participatory breeding and genomics was urged.

ICRISAT should be prepared to play many different roles depending on needs, priorities, and its comparative and complementary advantages vis-a-vis other R&D actors. These can range from leadership, primary, catalytic, facilitative, convening, custodian, mediator, and advocacy. In this manner the appropriate balance of effort will unfold along the R to D (or discovery to delivery to impact) continuum.

ICRISAT should increase its efforts in human capital improvement, targeting both NARS (research staff) and farmers. IARCs, regional organizations, and NARS should strengthen collaboration (e.g. complementarity in farmer training), with ICRISAT providing guidance and NARS implementing training programs on a wider scale.

ICRISAT might also consider adopting more of an advocacy role on behalf of its clients, partners, and stakeholders than it has done heretofore. This would include promoting the potential of rainfed agriculture to contribute to economic growth and poverty reduction, pointing out development constraints to governments (e.g. seed supply), and sharing cross-country experiences to elicit "best practices".

Due to differences in trends, constraints, and resource endowments, ICRISAT will need different research strategies in sub-Saharan Africa compared to South Asia. But there will be spillovers generated, for example in watershed research, drought-tolerant cultivars etc.

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About ICRISAT

The semi-arid tropics (SAT) encompass 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 16 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 United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP), and the World Bank.

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