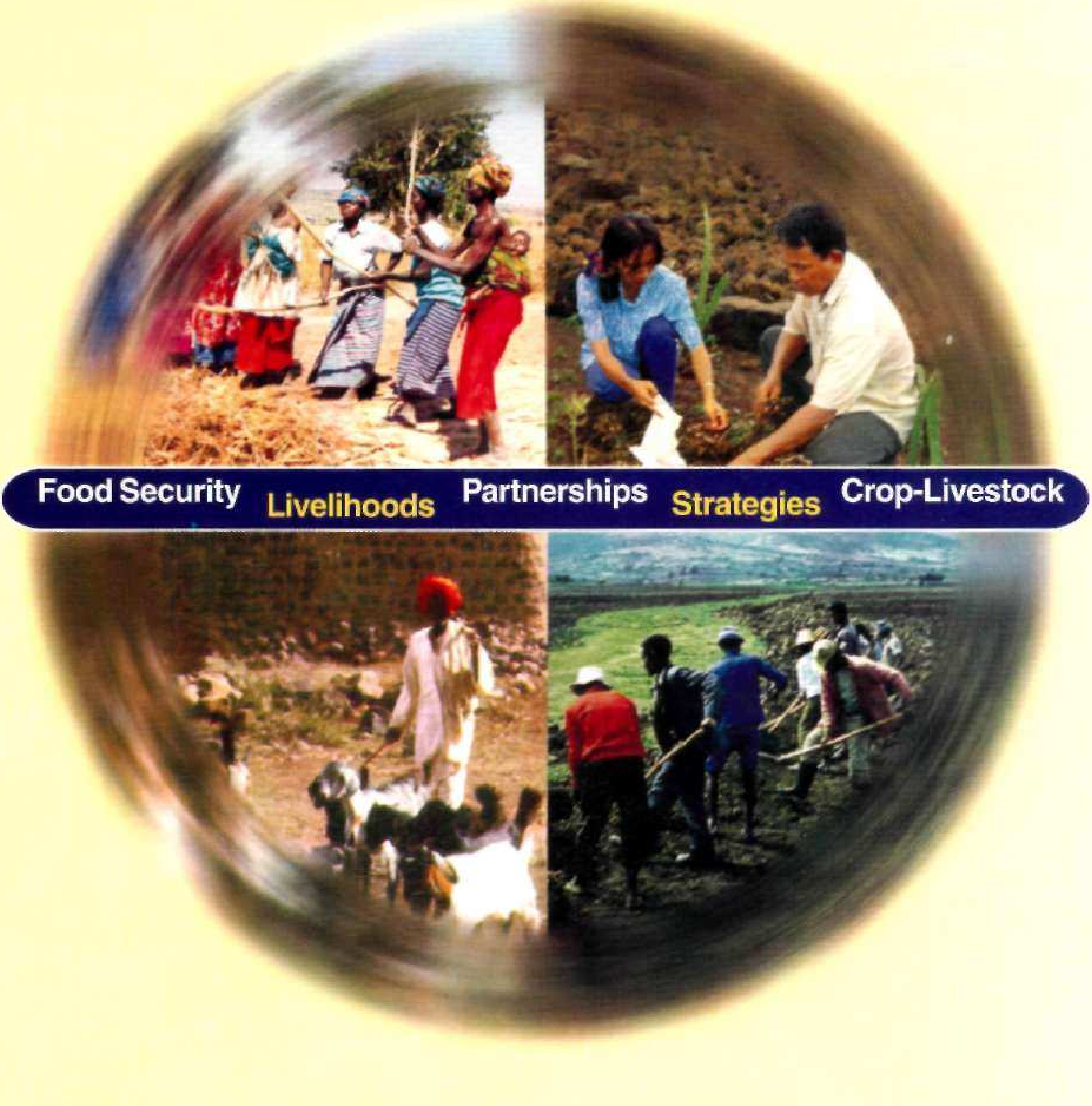
Future of Agriculture in the Semi-Arid Tropics



International Crops Research Institute for the Semi-Arid Tropics

Citation: Bantilan, M.C.S., Parthasarathy Rao, P., and Padmaja, R. (eds.) 2001. Future of agriculture in the semi-arid tropics: proceedings of an International Symposium on Future of Agriculture in Semi-Arid Tropics, 14 Nov 2000, ICRISAT, Patancheru, India. (In En. Abstracts in En, Fr.) Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 98 pp. ISBN 92-9066-441-X. Order code CPE 136.

Abstract

Poverty, food insecurity, rapid population growth, and environmental degradation are problems hounding the semi-arid tropics (SAT) today. A long-term strategy is needed to overcome these intractable problems in the fragile SAT ecosystems. This publication reports on a symposium that was devoted to identifying and prioritizing agricultural R&D strategies relevant to ICRISAT and its stakeholders in the future.

Résumé

L'avenir de l'agriculture dans les zones tropicales semi-arides. A l'heure actuelles, les zones tropicales semi-arides font face à de nombreux problèmes tels que la pauvreté, l'insécurité alimentaire, l'explosion démographique et la dégradation environnementale. Une stratégie à long terme est nécessaire afin de cerner ces problèmes intransigeants dans ces zones à écosystème fragile. Cette publication est le compte rendu d'une conférence sur l'identification des stratégies futures et des domaines prioritaires de recherche et de développement pour l'ICRISAT et ses partenaires.

Future of Agriculture in the Semi-Arid Tropics

Proceedings of an International Symposium on
Future of Agriculture in Semi-Arid Tropics
14 November 2000
ICRISAT, Patancheru, India

Edited by
M C S Bantilan, P Parthasarathy Rao, and R Padmaja

ICRISAT

International Crops Research Institute for the Semi-Arid Tropics

2001

Acknowledgments

The authors are grateful for the constructive comments offered by M C S Bantilan, A Hall, P Parthasarathy Rao, J Rusike, and G L Monaco. They would also like to express their thanks to D D Rohrbach, and K Anand Kumar, who were the rapporteurs during the symposium; members of the Organizing Committee; and SEPP staff, especially N V N Chari, G Sheshi Kala, Padmini Haridas, G V Anupama, E Jagdeesh, M V Rama Lakshmi, and Aditi Deb Roy.

Thanks are due to Language Editor Smitha Sitaraman, and all ICRISAT scientists and other staff.

Contents

Preface

Poverty, food insecurity, rapid population growth, and environmental degradation are problems seriously hounding the developing world today. These are most felt in the Semi-Arid Tropics (SAT), home to one-sixth of the world's population. The SAT, which includes 48 developing countries in Asia and Africa, is characterized by extreme poverty, lingering drought, infertile soils, growing desertification, and environmental degradation.

The challenges in the SAT are indeed formidable. According to a recent report by the Washington-based Worldwatch Institute, the population of Ethiopia (currently 62 million) will balloon three times to 213 million in 2050. Moreover, Pakistan's population too will grow from 148 to 357 million, and that of Nigeria from 122 to 339 million. This means that in 2050, there will be more people in these three countries alone than there were in the whole of Africa in 1950! However, the biggest increase will be in India, ICRISAT's host country. In 2050, India's population will be 1.6 billion, overtaking China as the world's most populous nation.

Adding to this bleak scenario are adverse climatic changes, unemployment, changing food habits, etc. Due to these, the delicate balance between natural resources and agricultural production is precariously threatened. Hence, poverty, food security, and nutrition are still the major challenges the world has to face. These challenges are our lifeline to the future. Although increasing agricultural production in the SAT was a key issue in the past, ICRISAT has broadened its vision to encompass the spectrum of issues to include water, soils, pests, crop-livestock integration, health and nutrition, postharvest technology, and others.

Since its inception, ICRISAT has been helping SAT farmers apply science to increase crop productivity in order to ensure food security, reduce poverty, and protect the environment. However, a long-term strategy is needed to overcome the serious problems in the fragile SAT ecosystems.

Towards this end, ICRISAT is developing a document that will serve as a critical input to the Institute's strategic plan, a 2020 vision for SAT agriculture. This document integrates the results of a symposium on SAT futures organized by the Socioeconomics and Policy Program of ICRISAT. It serves as a foundation for identifying agricultural research and development (R&D) priorities relevant to ICRISAT and its stakeholders. It will also pave the way for identifying the roles of the Institute, other International Agricultural Research Centers (IARCs), the national agricultural research system (NARS), Non-Governmental Organizations (NGOs), and the private sector in implementing research and development programs in the SAT.

The symposium was a culmination of several rounds of consultations and brainstorming held at the regional level across Asia and Africa.

William D Dar

Welcome Address

W D Dar[1]

Let me extend to you all a warm and hearty welcome this morning to this very important international symposium on SAT Futures. We are indeed fortunate to have with us today a panel of internationally renowned scientists, leaders, policy makers, and experts from a wide spectrum of national, regional, and international organizations. I would like to make particular reference to the presence of Dr Kurien, a World Food Prize winner, who, as we all know, has pioneered the White Revolution in this part of the world with a replicable model of development that has become a household word and beacon to the rural farmers in developing countries.

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has the global responsibility for agricultural research in the Semi-Arid Tropics, known as the SAT. Home to one-sixth of the world's population, of which half lack access to even basic health and nutrition, SAT includes parts of 48 developing countries in Africa and Asia and is characterized by stubborn poverty, persistent drought, infertile soils, growing desertification, and overall environmental degradation. Agricultural production struggles to keep pace with alarming population growth. Farming is mostly subsistence-level. It is against this backdrop that ICRISAT began its work 27 years ago.

Since then, ICRISAT's team of highly committed scientists has been tirelessly pursuing the mission of helping the SAT farmers apply science to increase crop productivity and bring about food security, reduce poverty, and protect the environment. Significant strides have been made in enhancing agricultural productivity through genetic enhancement, and preserving crop diversity the world over, particularly in the SAT regions. Over 113 000 germplasm accessions from 130 countries are held in trust by ICRISAT for the international community. We have

Dar, W. D. 2001. Welcome address. Pages 1-3 *in* Future of agriculture in the semi-arid tropics: proceedings of an International Symposium on Future of Agriculture in Semi-Arid Tropics, 14 Nov 2000, ICRISAT. Patancheru, India (Bantilan, M.C.S., Parthasarathy Rao, P., and Padmaja, R., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

1. Director General, International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, Andhra Pradesh, India.

played a very important role in strengthening the national research programs and grassroot-level institutions. Our natural resource management research has achieved a great deal of success in managing scarce water resources, augmenting soil fertility, and attacking growing desertification in the fragile SAT ecosystems.

Much remains to be done to bring about any significant impact on the problems of food insecurity, poverty, and environmental degradation in the SAT. Without a long-term strategy to attack the seemingly intractable problems and challenges ahead, we realize that the journey towards fulfilling our mission is going to be extremely difficult. Studies are underway by our policy research team to develop base documents and framework for analysis for charting the future of agriculture in the SAT, and analyzing critical issues — trends in SAT agriculture, emerging constraints limiting growth, food security, and environmental sustainability over a long term of 20 years.

This initiative is expected to provide a foundation for identifying agricultural research and development priorities relevant to ICRISAT and its stakeholders in the future. The studies will also pave the way for an analysis of the possible roles of ICRISAT, other international centers, NARS, NGOs, and the private sector in implementing R&D activities in the SAT; priorities for institutional development; and the requirements for strengthened partnerships.

ICRISAT commissioned two experts of international repute — D C Spencer from Sierra Leone and J G Ryan from Australia — to develop a white paper on "Challenges and Opportunities Shaping the Future of Agriculture in the Semi-Arid Tropics and their Implications", dwelling on, among others:

- trends, projections, and implications of key agricultural and socioeconomic statistics/ issues in the SAT;
- dimensions of poverty and their implications; and
- key challenges and opportunities in SAT regions.

This extremely important initiative is part of a three-phased action plan.

Several rounds of brainstorming sessions have already been held at the regional level, across Asia and Africa. Today's symposium where we have an assemblage of eminent international panelists signifies an appropriate finale to this highly successful and rewarding consultative phase.

The emerging white paper will be a critical input into the Institute's Long-term Strategic Plan, a '2020' vision of ICRISAT and SAT agriculture, to be developed in the final phase.

Food availability, access, and nutrition are three dimensions of food security which are being increasingly talked about. While the focus of conventional agricultural research has been on agricultural production which has a direct bearing on food availability, I believe that ICRISAT's vision has to extend to encompass the entire gamut of issues — water, soils, pests, crops-livestock integration, carbon sequestration, health and nutrition, postharvest technology, rural livelihoods, and augmenting the income and purchasing power of the poor. It is a formidable list of challenges which can be tackled only with Science with a Human Face.

What is heartening is that this momentous and ambitious initiative has been receiving a great deal of attention all around, including positive notice from the Technical Advisory Committee (TAC) of the Consultative Group on International Agricultural Research (CGIAR). We are fully alive to the gravity of the onerous responsibility that has been cast on ICRISAT, and are constantly reengineering ourselves to handle the challenges. We are committed to strengthen partnerships and work hand in hand with NARS and sister CGIAR centers, advanced research institutes, universities, the private sector, NGOs, extension departments, farmers' organizations, development agencies, policy makers, and regional organizations to realize our dream of a food-secure and environmentally stable SAT.

No one understands the harsh realities of the SAT and SAT agriculture better than the eminent panelists with us today. We cherish the wealth of your experience, wisdom, vision, and innovative ideas. Today's session is going to be a very important learning experience for us. Let us work together and chart the roadmap to the future for the SAT as this blueprint will also spell the future and growth of ICRISAT. 1 hope we will have thought provoking, stimulating, and rewarding deliberations. Thank you all, once again.

Some Challenges, Trends, and Opportunities Shaping the Future of the Semi-Arid Tropics

J G Ryan[1] and D C Spencer[2]

Introduction

The primary purpose of this paper is to provide background information and analysis on possible future trends and scenarios for the Semi-Arid Tropics of the developing world. It is intended these will be factored into the deliberations that are planned for developing a new vision and strategy for ICRISAT.

The four issues addressed in this paper are:

- a review of trends in SAT agriculture between 1960 and 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; and
- a review of possible roles for ICRISAT, NARS, NGOs, and the private sector in implementing these R&D activities in the SAT.

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 to delineate statistics pertaining only to the SAT regions within countries from readily available national data. Particular emphasis has been placed on the SAT of sub-Saharan Africa and South Asia, as these are of primary concern to ICRISAT and to the CGIAR in their current visioning and strategic planning exercises.

The Nature and Extent of Poverty

Going by the TAC/Food and Agriculture Organization (FAO)

Ryan, J. C., and Spencer, D.C. 2001. Some challenges, trends, and opportunities shaping the future of the semi-arid tropics. Pages 4-11 *in* Future of agriculture in the semi-arid tropics: proceedings of an International Symposium on Future of Agriculture in Semi-Arid Tropics, 14 Nov 2000, ICRISAT, Patancheru, India (Bantilan, M.C.S., Parthasarathy Rao, P.. and Padmaja, R. eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

1. Visiting Fellow, Economics Division, Research School of Pacific and Asian Studies, Australian National University, Canberra, Australia.
2. Managing Director, Dunstan Spencer and Associates, Freetown, Sierra Leone.

definition of the Semi-Arid Tropics, there are 55 developing countries that had some area of SAT within their borders. The SAT regions of these countries are estimated to have a total population of more than 1.4 billion people, of which 560 million are classified as poor. Of the total poor, nearly 70% live in rural areas, representing 380 million people.

The SAT of sub-Saharan Africa (SSA) and South Asia (SA) contain more than 80% (442 million) of the total SAT poor. This represents 33% of the total poor in the developing world. In these two regions, 315 million of the poor live in rural areas. South Asia has three times the number of poor of SSA (Table 1).

Evidence on the relationship between the numbers in poverty and the agroecological potential of the environments on which they depend is mixed. Some studies indicate there are more poor in lower potential areas than in higher potential or irrigated areas. Other studies indicate the reverse. Also, evidence on the incidence of poverty, measured as the proportion of the population in a region that is poor, suggests that it does not seem to differ between low- and high-potential areas. Therefore, there may not be a strong case to differentiate regional R&D priorities on the basis of agroecological potential on the grounds of a focus on poverty. Is there a basis to do so on the grounds of the expected productivity gains to be had in low- versus high-potential areas? What is the effect of productivity growth on poverty?

In the Indian SAT, growth in productivity has been higher in the more favorable districts from the early 70s to the early 90s. Also, recent cross-country research indicates that the greater the agricultural and general economic growth, the larger is the reduction in the number of poor. More specifically in India, investments in roads and R&D in low-potential rainfed areas (i.e., with less than 25% irrigation) showed lower productivity gains and reduction in the number of poor than in higher-potential areas. However, all

Table 1. Rural and urban poor (in millions) in the semi-arid tropics.

Regions	Rural rainfed	Rural irrigated	Total rural	Total urban	Total
South Asia	89	147	236	95	331
Sub-Saharan Africa	*7b*	3	79	32	111
Total	165	150	315	127	442

rainfed areas showed better productivity dividends and poverty reduction to investments in roads and R&D than did irrigated areas. Hence, investments in rainfed agriculture in India have a higher payoff than in irrigated agriculture but within this sector, the higher potential areas seem to offer better dividends than the lower potential ones.

The extent of urbanization in developing countries will increase rapidly in the next 25 years. Around 90% of the 1.9 billion increase in the population of developing countries by 2025 will be in urban areas, mostly in the tropics. Interestingly, projections are that more than 50% of the populations of Asia and Africa will live in urban areas by 2025. This implies that a much higher proportion of food supplies will be purchased than is the case today. Though it is also projected that urban poverty will grow faster than rural poverty, poverty will continue to remain a rural phenomenon for the next 25 years.

A decline is projected in the population growth rate in developing countries in the coming decades. During 1987-97, the growth was 1.8% per annum. From 1995/97 to 2015, it is projected to decline to 1.4%. The decline will be rapid in SA but more modest in SSA(Table 2).

Food and Nutrition Security

There has been an overall decline in both the number and proportion of undernourished people in developing countries in recent decades. In 1969/71, there were 960 million undernourished who comprised 37% of the total population of developing countries. Currently, it is estimated that their number has fallen to 800 million, which though still unacceptably large, is only 18% of the total population. The important feature of the current picture is that 17 of the 36 countries with an average per capita consumption of less than 2200 kilocalories per day are in the SAT.

Although the per capita food consumption in developing countries is projected to continue to rise towards 2030, 12 of the 17 countries still projected to consume

Table 2. Population growth rates (% per year).

Region	1987-97	1995/97-2015
South Asia	1.3	0.9
Sub-Saharan Africa	2.7	2.4
Developing countries	1.8	1.4

less than an average of 2200 kilocalories per capita per day will be in SSA. In 2020, SSA and SA will still have about 80% (104 million) of the world's undernourished children. The total number of food insecure people will be greater in SSA than in SA towards 2020. However, child malnutrition will be greater in the latter region than the former, both in terms of incidence (37 versus 29%) and numbers (65 versus 48 million). Thus SSA and SA will remain the food insecurity and child malnutrition hot spots over the next two decades. Of special significance is the fact that apparently the incidence and number of malnourished children is greatest in the SAT compared to other agroecologies, and especially so in the higher altitude SAT regions.

Energy, iron, and vitamin A remain the major nutrient deficiencies in the SAT. The ICRISAT mandate crops are not micronutrient dense and their consumption by the poor seems less responsive to income growth in South Asia than other commodities. Hence it would seem doubtful if breeding for improved micronutrient content would be an effective strategy to reduce micronutrient deficiencies in the diets of the poor in the SAT. On the other hand, the consumption of animal products (milk, meat, and eggs) is growing in importance in diets, even of the poor, and this will lead to a rapid increase in the demand for coarse grains as feed grain, as opposed to their use as foodgrains. However, sorghum and millets will remain staple foodgrains of the poor in SSA and in pockets like Rajasthan and Maharashtra in India, where there are few cropping system alternatives in their SAT regions.

Consumption Patterns of the Poor

In India, the shares of sorghum and millet in the household expenditure budgets of the poor fell by 68% in rural areas and by 51 % in urban areas between the early 70s and the early 90s. The share of the pulses, although small, remained stable. However, the share of oilseeds rose. This shows that the ability of agricultural R&D in relation to these crops to impact on poor consumers through the effects of productivity gains in lowering their relative prices has declined markedly. The prospects for oilseeds to impact on the poor have on the other hand improved.

The expenditure elasticities of demand for all the ICRISAT mandate crops except chickpea by the poor in India, are less than unity and lower than that for other foods. This means that a future increase in demand for these (as foodgrains) derived from income growth by the poor will be relatively subdued. On the contrary, the expenditure elasticities of demand for meat, milk, and eggs are high for the poor; this translates into a rapidly growing derived demand for these crops as feed grains. This raises the issue of the value and desirability of a shift in breeding emphasis to feed grain versus foodgrain traits of sorghum and millet. This issue deserves a bioeconomic study of the relative benefits of such a shift in emphasis to poor consumers and producers of these two crops.

Income Sources of the Poor

Significant changes are occurring in the income patterns of the poor in the SAT, just as is the case with consumption patterns. Documenting and understanding these will help in redesigning R&D strategies and priorities.

In South Asia, the poor have less land; rely heavily on labor income on and off the farm; are less educated; belong to the lower caste; have larger families and more children; and have higher dependency ratios.

In this region, labor-using technological change and increased demand for nonfarm 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 SA.

In sub-Saharan Africa on the other hand, income from crops is a more significant source of income for the poor than the more affluent, as is income from livestock and remittances from emigrants. Crop production is viewed primarily as a subsistence activity and not a source of cash income. Commercial crops and livestock are seen as keys to income growth and investment strategies of SSA farmers.

Nonfarm income seems to be more important to the nonpoor in SSA. Increased opportunities to earn nonfarm income and labor-saving technological change may be more conducive to the poor in SSA. This will become even more apparent as the HIV/AIDS epidemic increasingly reaps its harvest of the young and middle-aged. This will be exacerbated by the increasing feminization of agriculture, especially in SSA, as a result of the migration of men to urban areas. This will imply that particular attention is given to the needs of women in agricultural R&D strategies and the added opportunities provided by their extra cash incomes from remittances.

Dynamics of SAT Agriculture

The share of agriculture in merchandise exports and imports has declined in all SAT regions, except in southern and eastern Africa, where it has been relatively steady. It would appear from these trends that agriculture in the SAT would largely be an import substituting rather than an export-led industry. This is rellected in the decline in the share of ICRISATs mandate crops in the agricultural Gross Domestic Product (GDP) in all SAT regions except West and Central Africa. On the other hand, commodities like commercial crops, livestock, and fish have increasing GDP shares.

The Indian SAT has seen a marked shift away from coarse grains in cropping patterns, in favor of wheat, paddy, and oilseeds from 1970 to 1994. The share of pulses in the gross cropped area has been steady during the same period, whereas the share of oilseeds has been rising. Vegetables, fruits, and spices have also been growing rapidly in relative importance. All these reflect changes in consumption patterns.

Some 76% of the projected growth in cereal production in developing countries is estimated to come from yield growth in the next 20 years (Table 3). Yield growth will be a far more significant contributor in SA than in SSA. These projected rates of growth are far less than historical rates; almost half in the case of yield growth, and are comparable to cereal demand growth projections of 1.8% per annum.

The demand for meat in developing countries is projected to rise by 2.8% per annum by 2020, which is about half the rate in demand growth between 1982 and 1994. The demand for milk will grow at 3.3% per annum, which is slightly lower than in the recent past (3.7% between 1982 and 1994). Feed grain demand will grow at a rate of 2.4% per annum. The predominance of smallholder crop-livestock systems in the SAT and the environmental difficulties of sourcing the required increase in meat production from intensive peri-urban livestock systems, provide good scope for the former to capitalize on the projected dynamic growth in the demand for animal products in developing countries in the coming decades.

A further liberalization of international trade and the rationalization of subsidies in

Table 3. Sources of growth in cereal production (% per year).

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

agriculture will potentially change SAT's comparative advantage. Studies in India, for example, suggest that such trends may favor rice, wheat, and cotton but not pulses and oilseeds. If fertilizer and power subsidies are removed in the process, ICRISAT's mandate crops could gain an advantage as they use little fertilizer and irrigation water at present, relative to rice and wheat. The implications for agricultural R&D priorities are however unclear.

In SSA and SA, the number of agricultural scientists has grown substantially in the last 20 years. Expenditure per scientist, on the other hand, has fallen in SSA and marginally risen in SA. This highlights the need to enhance partnerships among the NARSs and the IARCS to better exploit synergies and improve cost effectiveness.

The role of the private sector in agricultural research in SA is small but growing, There is little involvement in SSA. Biotechnology and genetic improvement seem to be the private sector growth areas. It seems that Intellectual Property Rights (IPR), not only on genes but also on transformation processes and the like, is and will continue to constrain access by the IARCs and NARSs to proprietary technology. While there are opportunities for public-private partnerships, the commercial, biosafety, and associated public liabilities may prevent these from being fully consummated, even where the so-called orphan crops of the CGIAR are involved.

Natural Resources

In SA, the rates of growth of irrigation have been declining from 2.1% per annum from 1961-1971 to 1.24% from 1981-1990. The projections from 1995/97 up to 2030 arc for a growth rate of only 0.6%' per annum. Projections are that SAT countries will be among the worst in terms of water scarcity in the coming decades. There will be increasing competition for water for nonagricultural uses and this will ensure that the real economic value of water rises relative to other agricultural inputs, regardless of whether governments choose to price water at its real value. This will create an imperative to improve water use efficiencies (WUE) in the SAT at all levels. This has clear implications for agricultural R&D strategies. It will open up new opportunities in genetic engineering of drought tolerance and water use efficiency genes, including the possibility of transgenic approaches involving both ICRISAT's mandate and nonmandate crops. In this context, it is relevant to ask whether a species mandate is too constraining in the age of functional genomics, transgenics, and marker-assisted breeding? Indeed, with the growing IPR imperatives on both public and private sectors, the scope for the former may be further circumscribed anyway.

Nutrient depletion in the SAT of SSA exceeds replenishment by a factor of more than three times. Combined with the substantial decline in the growth of fertilizer use in the 90s in all SAT regions, this implies added priority for R&D aimed at improving nutrient use efficiency, especially in SSA. This should involve an integrated soil, water, and nutrient management approach. As it appears that most natural resource management research can be location-specific, it is important to clearly specify an agenda which justifies international R&D.

Conclusion

There are inherent differences in the characteristics of the SAT countries of SSA and SA. In SSA, nonfarm income seems to be more important to the nonpoor. There are greater opportunities to earn such income. Also, labor-saving technological change may be more conducive to the poor. This is an area that can be explored while devising R&D strategies for the region. Attention also needs to be paid to the needs of women given the added opportunities provided by their extra cash incomes. Another vital area is that of expenditure on scientists. While the number of agricultural scientist in this region has grown, expenditure on them has fallen. There is a need to enhance partnerships among NARS and IARCs to better exploit synergies and improve cost effectiveness. Nutrient depletion combined with a decline in the growth of fertilizer use implies added R&D priority aimed at improving nutrient use efficiency in this region.

South Asia, on the other hand, is plagued by water scarcity. The rate of growth of irrigation has declined. R&D stategies for this region must focus on improving water use efficiencies, which will in turn open up new opportunities in genetic engineering of drought tolerance and WUE genes. These suggest the need for separate agricultural R&D strategies for these two major SAT regions.

Risk, Resources, and Research in the Semi-Arid Tropics

J R Anderson[1]

Introduction

During a visit to Patancheru in October, when the proposal to share a few thoughts with you was put to me, I had just learned of the recent work of Ryan and Spencer, on which I will express a few thoughts. I thought back to some work on future sub-Saharan African (SSA) agricultural prospects that I had done a few years back with Pierre Crosson which had never really seen the light of day, and it occurred to me that this could be an occasion to give it some exposure and get the feedback on it that we had never had. I will draw some comments on the land resource later.

Risk

One small four-letter word in a title, one giant concept for research strategists. Risk gets only peripheral treatment by Ryan and Spencer. In fact, the only three substantive mentions of risk that they make are as, and to give full context and recognition, let me quote:

(a) "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 commodity demand patterns away from cereals towards animal products, fruits and vegetables;
- a means of arresting resource degradation by creative changes in livestock-horticulture-crop

Anderson, J.R. 2001. Risk, resources, and research in the semi-arid tropics. Pages 12-50 *in* Future of agriculture in the semi-arid tropics: proceedings of an International Symposium on Future of Agriculture in Semi-Arid Tropics, 14 Nov 2(XX), ICRISAT, Patancheru, India (Bantilan. M.C.S., Parthasarathy Rao, P., and Padmaja, R., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

1. Advisor, Rural Development Department, World Bank, Washington DC, USA.

systems to exploit synergism and economize on increasingly scarce water;
- reduction of the incidence and damage caused by pests and diseases."

(b) "...the absolute increases in population are such as to place ever increasing demands on land and water resources. Increasing urbanization will serve to exacerbate this. Off-farm income sources will grow as a consequence, which offers new opportunities for the poor in terms of risk diffusion and income enhancement, along with investment funds for agriculture."

(c) "Water-use efficiency could also be the primary focus of the 1CRISAT natural resource management research. This would include crop and simulation modeling, and watershed management in 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 crop and systems simulation models particularly relevant as a complement to other R&D approaches. Models offer three cost-effective advantages:
- a means of extrapolation of location-specific research to achieve technological spillovers;
- an ability to assess the risks of alternative technology options;
- ability to assess the likely sustainability of alternative technology options that are beyond the experience of farmers."

In brief, (a) points to the risk-spreading advantages of on-farm diversification, (b) to the same important notion relative to the vitally significant phenomenon of rural dwellers diversifying into the nonfarm economy, and only (c) directly raises issues of research method (modeling) and research strategy (technological risk assessment). While agreeing that all these three are important, I am forced to conclude that, with such minimal mention and in contrast to Walker and Ryan (1990), Ryan and Spencer have possibly seriously underplayed the significance of risk in SAT research needs and opportunities. In making such an allegation, I think I am demonstrating that leopards do not easily change their spots (Anderson 1980).

Risk is such a pervasive feature of life in the SAT that it is my contention that it has to receive primary recognition as the phenomenon that most sets both the possibilities and priorities for SAT research. I am using the term "risk" to describe compactly those uncertain and unpredictable events and outcomes that have consequences for the concerned economic agents, and as such include events as different in temporal and spatial scales as droughts and short intense storms, and as diverse in origin as the climate, the biota, the bureaucrats, and the commodity markets. I am not alone in adducing such an overarching if not overwhelming role for risk. Of recent works cogent to the SAT, Mortimore and Adams (1999), generalizing from study sites in northern Nigeria, make the case for risk centricity most persuasively, and strategically too in terms of comprehending phenomena such as the "Sahel crisis".

For broaching questions of research strategy, I quote some of their lines: "For farmers, risk taking is a way of life. .. .Poor families have to manage their constraints—of labour, time and energy, of soil fertility, of livestock, of biodiversity, of livelihood options, and above all, of rainfall—if they are to survive." Mortimore and Adams go on to develop a model *of* constraints and responses in which diversity, flexibility, and adaptability are charted as the key elements of successful Sahelian systems of resource management. It is these elements that I feel must be constantly revisited in contemplating ICRISAT's strategy. Not that ICRISAT is a stranger to any of these, but it is my impression that it is only in recent years that diversity climbed higher in the research strategy. I know that aspects of adaptability are being addressed in past and present work on response farming approaches, but perhaps these deserve greater attention. More generally, I suspect that flexibility has yet to be sufficiently mainstreamed into the research portfolio of ICRISAT, but I see encouraging signs that things are moving in the right direction, at least in Natural Resource Management Program (NRMP), although it is surely intrinsically difficult to structure a research program around farmers' overtly opportunistic farming and their shifts to possibly distant off-farm activities. Dealing more comprehensively with livestock in SAT farming systems cuts across these elements, and will surely be important in progress; so it is pleasing to note that it is one of the themes in today's program as well as being appropriately highlighted by Ryan and Spencer.

Mortimore and Adams conclude, and I concur, that more work is needed on integrating risk and variability into development planning for poor households; so perhaps a Center Project may be warranted, probably led by the Socioeconomic and Policy Program (SEPP), but involving all the Center Programs.

Constraining Resources

The literature pertaining to SAT development abounds with claims about the constraining nature of the various resources on which agriculture depends. Surely most common is the rainfall regime, which is usually of limited abundance. Ryan and Spencer refer to this as a water scarcity problem, which is probably a better term, given the use of irrigation in many SAT niches, aided and abetted by catchment storages of various dimension. But even just rainfall, three-quarters of a meter or so of it is not to be sneered at, agriculturally speaking, if it can be harnessed to good effect. Where 1 come from, it looks promising indeed. But as we all know so well, it is not just the annual average rainfall that counts. Distribution over time is the key, as is inter-year variation in amount. But even micro-time-scale aspects are important, as intensive falls over short periods can have major effects on erosion impacts and loss of water that may have been used agriculturally (Anderson and Thampapillai 1990).

In the frequency of claimed major constraints stakes, the second place probably goes to soil phosphorus (P). Aspects of this soil research feature, along with others, are taken up later. In the many severely weathered soils of the SAT, especially those with low pH and high Al, Fe, and fixing potential, available P is surely in short supply, and crops in their early stages of growth most definitely need some significant P to prosper. Herewith are surely many continuing research opportunities, including those long under review by ICRISAT. As Ryan and Spencer note in their statements about the use of simulation models, there are definitely good uses of carefully crafted models for exploring a range of tactical options for use of P in the face of rainfall uncertainty.

Other soil characteristics also get regular mention by SAT commentators and research strategists. Low soil organic matter is a popular contender for major constraint status, implicated so strongly as it is in aspects such as infiltration rates, soil evaporation, and fixing potential. Similarly, soil nitrogen gets much attention, ranging from concerns to incorporate legumes more productively into cropping systems, to improving the efficiency of rhizobial fixation, to enhancing the efficiency of use of whatever nitrogen is in the soil at a given time, and so on.

The "fertile" imagination of our soil-science colleagues leads to a long list of additional soil chemical (other macro and many micro-nutrients and their availability for plant growth), and physical candidate problems, and they are surely correct in many instances, depending on parent material, weathering history, past exploitation, and so on, but local specificity is surely critical in such work, and one has to ask, as do Ryan and

Spencer, about the international public good nature of such investigations.

However, we need to move to the issue of economic advance in the SAT, if indeed we want to address the broader issue of poverty alleviation in this challenging zone. There are other forms of capital to consider: financial, manufactured, and human and social, which are probably even more important in the rural nonfarm economy than they are in the farming domain.

Then, we come to aspects of labor, which in many instances are highly constraining to growth opportunities, especially in SSA. The critical timing of field operations in the SAT following rainfall events means that the capacity to achieve timely agricultural activities is crucial to success. When mechanized operations are possible, through ownership or rental, labor per se may be less *of* a constraint, and this is certainly a major differentiating feature of the SATs around the world. Exploitation of niche opportunities in all of them is critical to survival (Anderson and Jodha 1994). For example, in many parts of the machinery-scarce SSA SAT, male labor is decreasingly available for farm tasks when males are absent at jobs in geographically distant points, such as in mines or in commercial activities in countries with more vigorous employment opportunities.

Other Ryan and Spencer Conclusions and Implications

Ryan and Spencer conclude that it is in the SAT that the challenges of poverty, food, and nutrition security will remain in spite of the generally optimistic outlook for the developing world as a whole. They argue that the particularities of the SAT require a special focus if these scourges are to be eradicated. These special focus themes 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.

They go on to argue that water will "likely be the primary limiting resource in the SAT in the millennium", which may be overstating things a little, but by the nature of SAT life this is bound to be true most of the time. They then raise important questions about the priorities that should be accorded to the mandate crops—sorghum and pearl millet—by ICRISAT in the future, if the primary aim is to benefit the poor rather than possibly improve livestock feeders.

The authors' predictions and concerns about agricultural biotechnology and Intellectual Property Rights closely match my own (Anderson 2000), so I will not belabor the points, beyond noting their criticality for the IARCs and even more so for the public NARIs with which they work. They also make a strong call for "integrated crop-livestock (and a little later silviculture-horticulture) management systems research", which sounds remarkably like a plea for broad Farming Systems Research (FSR), which has a happy nostalgic ring, even if this twist to it may stretch research planning in ICRISAT beyond traditional boundaries, such as is indeed being done in collaborative work underway between NRMP and the International Livestock Research Institute (ILRI). The use of the term "integrated" by them is surely not accidental, being forcefully in vogue in NRMP, the CGIAR, and interestingly, also Mortimore and Adams 1999.

Further on in their futuristic summary, Ryan and Spencer mention that "... previous watershed management R&D has not realised its promise. Widespread and demonstrable impact has not been evident." They save the day for IARC engagement by finessing an increasing-water-scarcity, growing-modeling-capability, poverty-oriented-marginal areas argument, but many readers will interpret this as a warning bell.

They pose an interesting question about the nature of international public goods (IPGs) in much NRM work, concluding (somewhat tentatively) that IARCs probably have a comparative advantage in such work to the extent that it involves "new science", such as stochastic simulation models,[2] GIS, GPS; and multilevel analysis. The issue is an important one for ICRISAT NRMP, and accordingly it would be great if we were all comfortable with this conclusion. But I think it is still a good question, which I do not regard as having yet been convincingly put to bed. Certainly, there is no reason why many NARSs, including all the big, strong ones, and an increasing number of medium-sized NARIs cannot make good use of these same tools, and beyond their own borders.

Conclusion

I have no particular difference with most of the other Ryan and Spencer conclusions, such as calling for stronger commitment of governments to their under-resourced NARIs (also taken up in Anderson 2000), and better connectivity/complementarity of NARSs through stronger regional collaborative arrangements; for diverse ICRISAT strategies for NRM research around the global SAT; for a deeper understanding of

2. My skepticism at the use of the term "new science" comes from a feeling that some of the methods implied are not all that new, such as crop models (Dent and Anderson 1971).

poverty on and off farms in the SAT, including through a renewal of Village-level-Studies (VLS) and through a renewed focus on land policy issues; and, last but not least, for more research on the nature, extent, consequences, and trends in land degradation in the SAT, with which I agree (Anderson 1999, in concert with others such as Leach and Mearns 1996 and Mortimore and Adams 1999). But this is a large agenda for a time of slender resources; so I do wish ICRISAT succeeds in assembling the needful to address it in an effective prioritized manner.

The Land Resource in SSA: Earlier Reflections with Pierre Crosson

I return to extracts of some work done but not formally published as Crosson and Anderson. Use of the plural "we" here refers to our joint effort, which was part of the World Bank's Africa Region response to UNCED. This modified extract refers primarily to the land resource in SSA. Pierre is with RFF, Washington, DC.

Some notion of the scale of the future demands on SSA's agricultural system is needed to understand the threat to the sustainability of the SSA agricultural system (Boserup 1981; Binswanger and Pingali 1988; Lele and Stone 1989) and the conditions for avoiding the threat. Crosson and Anderson considered 3.3% the minimum acceptable rate in annual production increase because it implies no decline in the share of imports, and a substantial increase in their absolute amount, in satisfying SSA's food demand. If one believes that agricultural policy in SSA over the next several decades will seek at least to reduce the share of food imports in domestic demand, then a 3.3% increase would be judged unacceptably low. Compared to likely aspirations for future agricultural production in SSA, these demand and related production scenarios should be regarded as presenting a relatively weak challenge to the sustainability of the region's agricultural production system. Compared to production performance over the past couple of decades, however, the challenge looks more formidable (Rosegrant and Agcaoili 1994). All production increases naturally reflect increases in the quantity of resources employed, or increases in the productivity of the resources employed, or some combination of both.

Increasing the supply of land. The supplies of land and water have both quantitative and qualitative dimensions. With respect to land, the quantitative dimension refers to the area of land of given quality with respect to the soil characteristics bearing on its productivity. The principal characteristics are naturally-occurring plant-available nutrients, topsoil depth and soil water-holding capacity, acidity, and density. The supply of land can be increased along the quantitative dimension by increasing the number of hectares of a given quality. Supply along the qualitative dimension can be increased by enhancing the productivity-relevant characteristics of the soil, e.g., building soil organic matter to improve soil structure, nutrient supply, and water-holding capacity. In the agriculturally important cases of many inland valleys (*fadamas, bas fonds,* etc.), the agronomically favorable soil characteristics have come at the expense of erosion from the surrounding uplands.

Of course, the supply of cropland is not solely a function of the soil, terrain, and climatic characteristics of the land. The economic costs of transportation linking the farm with both input and output markets are of major importance in determining which land can be brought into production economically.

Much of the discussion on the pest-and-disease constraints focuses on the tsetse fly, the major carrier of trypanosomiasis, a serious disease affecting both animals and people. In 1963, the FAO published a study of tsetse fly infestation in Africa in which it was estimated that some 1 billion ha of land in the central part of the continent were affected (Crosson and Anderson 1992). Subsequent work suggests a figure closer to 0.7 billion ha (Jahnke 1982). Although the threat of the tsetse fly is primarily to cattle, it nonetheless could inhibit conversion of land to crop production because much of African agriculture is built on an intimate relationship of animals to crops (McIntire et al. 1992), with animals in some situations providing the mode of tilling the land, in others providing meat and milk, and in still others providing manure for soil enrichment. Consequently, where cattle raising is inhibited by the threat of the tsetse fly, crop production is also likely to be inhibited (Ruthenberg 1980).

Although the view is widely held that tsetse fly infestation effectively puts large areas of SSA off limits for crop and animal production, increasing evidence suggests that this view needs modification. First, increasing population pressure leads to the destruction of the savannah-shrub vegetation, the habitat of the most widespread tsetse subgroup (*Glossina morsitans).* Experience suggests that flies of this subgroup virtually disappear when population exceeds 40 inhabitants per km^2 (Jordan 1988). Second, simple nonpolluting technologies are becoming available to control the fly. Fly traps and screens impregnated with nonpolluting insecticides, and fly repellents applied directly to the animals have been shown to protect herds in high tsetse-challenged environments (Cuissance 1991). Third, the combination of increased availability of trypanocidal pharmaceuticals and acquired resistance allows animals of trypano-sensitive breeds to survive in a tsetse environment. At least 40 million cattle of such breeds can now be found in tsetse-infested zones (Winrock International 1992). Fourth, increased attention to the development of trypano-tolerant breeds has increased the availability of genetically-resistant animals for the highly infected areas. Thus population growth and the spread of the new tsetse control technologies may make the fly less of an obstacle to developing potentially cultivable land for crop and animal production in SSA than has been commonly believed.

Urban growth was rapid in SSA over the past several decades, and by 1988/90 urban areas occupied roughly 3% (24 million ha) of the 797 million ha in the region with potential for crop production (FAO 1994). FAO (1994) anticipates that by 2010, continued urban growth will take another 12 million ha of SSA's stock of potential cropland. A continuation of that rate of encroachment to 2025 would take about another 9 million ha of the stock. Over the period from 1988/90 to 2025, therefore, urban growth would take 21 million ha (less than 3%) of SSA's current stock of land with potential for crop production. Even if the FAO's expectations about future urban growth in SSA, and our extrapolation of those expectations are wildly off target, it appears most unlikely that urbanization would significantly limit the supply of cropland in the region over the next several decades.

FAO (1993) notes that throughout the Less Developed Countries (LDCs), considerable amounts of land are set aside as protected areas in which agriculture and other economic activities are prohibited by law. Typically these areas are national parks, conservation forests, and wildlife preserves. According to FAO, about half of the protected land in the LDCs is land that has potential for crop production. In SSA, this is the case with 78 million ha, about 10% of the area's stock of potential cropland (FAO 1994). FAO (1993) estimates that by 2010 the percentage of protected land will have risen to 10.5, or another 6 million ha.

In 1988/90, some 200 million ha (25%) of SSA's 797 million ha of potential cropland was in forests (FAO 1994). Some unknown but probably significant part of the 78 million ha of protected land is forested and, therefore, is included in the 200 million ha figure. FAO (1993) expects that by 2010 an additional 9 million ha of potential cropland will be in forests.

Continuation of this trend to 2025 would shift another 6 million ha from the present stock of potential cropland to the stock of forested land. By 2025, therefore, the amount of potential cropland in forests would have risen from the present 200 million ha to 215 million ha, 27% of the present land with crop potential.

FAO (1993) does not indicate the grounds for believing that some of the land with crop potential would be shifted to forests. We think it likely, however, that this could occur in an effort to augment the supply of wildlife and other environmental values of the land by increasing the amount of forest land protected against agricultural and other economic activities. Conversion of forested land to crop production arouses much concern in tropical Africa (as it does elsewhere) because of potential loses of valuable wildlife habitat and biodiversity, and disruption of hydrological cycles, with consequent increases in erosion and downstream deliveries of sediment that damages irrigation systems, accelerates the sedimentation of reservoirs, increases the risk of flooding, and imposes higher costs of cleaning up water for municipal and industrial uses (National Research Council 1993).

We believe it likely that the marginal costs of these various environmental and economic consequences of deforestation in SSA will rise, both because demand for the environmental and economic services of forests is rising and because deforestation diminishes the supply of the services. With respect to environmental consequences, it will be difficult, and in most cases probably impossible, to quantify the cost increases. The experience of the past several decades indicates, however, that quantification of environmental costs is not necessary for societies to develop and implement policies designed to control the costs. Societies in SSA have not been and will not be exempt from this experience. We think it likely, therefore, that over the next several decades, these societies will not only strengthen measures to curb encroachments by farmers on the 78 million ha of protected land but will also make efforts to increase the amount of such land. Some of the newly protected land would surely be land with potential for crop production. (That is one reason why it would need protection.) Though we have no way of estimating how much potential cropland might be added to the stock of protected land, an increase in the region of 100 million ha seems plausible. In this case the effective amount of potential SSA cropland would be not 797 million ha but about 700 million ha.

Even if FAO should prove to be very conservative in estimating the future supply of cropland in SSA —supposing that the effective supply could be increased by two-thirds instead of FAO's 37%—the expansion of land along the quantitative dimension would still leave the increase in production far behind the 3.1 times increase required by the demand scenario. Other sources of increased production would have to be found.

Supply of land: the qualitative dimension. The qualitative dimension of land supply refers to soil characteristics such as organic matter content, nutrient content, topsoil depth, water-holding capacity, acidity, and bulk density. The more favorable these characteristics are for plant growth, the greater the effective supply of agricultural land. It follows that the supply of land can be increased along the qualitative dimension in two ways: (a) by reducing present rates of land degradation, thus avoiding future losses of productivity; and (b) by improving the soil characteristics of land, including presently degraded land, thus increasing present and future productivity.

There are varying definitions of land degradation (briefly reviewed in Crosson and Anderson 1992), but they all have in common the notion of changes in characteristics of the soil that reduce its per hectare productivity in plant production, whether for crops or forage for animals. That is the meaning of the term as used here. The present and prospective data situation on land degradation for SSA is rather bleak (Stocking 1992). Estimates presented by Sombroek (1993) indicate that erosion by water and wind account for almost 85% of the 494 million ha of degraded land in Africa (not just SSA). This is consistent with the literature on land degradation, which focuses mainly on these two forms of erosion. The Sombroek estimates also indicate that nutrient depletion under agricultural uses of the land account for about 10% of the degraded land area of Africa.

References to nutrient depletion as a factor limiting achievement of sustainable agriculture in SSA are scattered throughout the literature dealing with agricultural uses of the land in the region (World Bank 1992a). Most African soils are derived from rocks that from the beginning had low nutrient content. Moreover, most of these soils are very old, so they have been subject to leaching of nutrients for a long time. Typically, therefore, they are nutrient poor, even in an undisturbed state. Most of them are seriously deficient in phosphorus in particular (Yates and Kiss 1992).

Traditionally, SSA farmers dealt with the problem of soil nutrient depletion through the practice of shifting cultivation, which left nutrient-depleted land in fallow long enough to restore nutrients for subsequent use in cropping. Serviceable though this system might have been, Yates and Kiss

(1992) assert that "... most African soils have suffered nutrient mining for centuries." Whatever the historical experience might have been, a survey by Stoorvogel and Smaling (1990) cited by Yates and Kiss indicates that in 1983, agricultural uses of the land in 38 SSA countries resulted in mean net nutrient removals from the soil of 22 kg nitrogen, 6 kg phosphorus, and 23 kg potassium ha^{-1} $year^{-1}$. Yates and Kiss do not indicate how much of this nutrient mining is attributable to erosion and how much is carried away in crops. However, the National Research Council (NRC 1993) asserts that about 40% of soil carbon, 60% of the nitrogen, and two-thirds of the phosphorus is removed with the crop. Most of the potassium, calcium, and magnesium remain in the crop residues, according to the NRC. Neither Yates and Kiss (1992) nor the NRC (1993) give estimates of the effects of nutrient mining on crop yields or the productivity of pasture; but that the effects are negative is a common theme in the literature (e.g., FAO 1986; Carr 1989; Miller and Larson 1990; Winrock International 1992).

The literature on agricultural development in SSA is replete with assertions that land degradation, especially from wind and water erosion, is a major threat to present and future agricultural production in the region. FAO (1986), for example, states that accelerated land degradation has been a major factor contributing to the poor performance of African agriculture over the past couple of decades, and that "urgent action" is needed to halt further degradation. Brown and Thomas (1990) assert that tropical Africa has one of the worst erosion problems on arable land in the world, often ". . . attended by irreversible reductions in crop yield."

Brown and Thomas (1990) present no evidence in support of their assertion, and FAO (1986) notes that "little reliable data is available on the extent of land degradation in Africa." This theme of little information about land degradation in Africa (and elsewhere) is found side by side in the literature with assertions such as those above about the severity of the problem. Nelson (1988) systematically reviewed this literature (not limited to but prominently including that related to SSA) and concluded that little reliable information is available about either present rates of land degradation or its consequences on productivity. Other students of the subject agree (El-Swaify et al. 1982; Dregne 1988).

This thinness of evidence reflects the fact that few empirical studies of the problem have been done. In 1995, we were aware of only two for SSA that purported to deal with areas as large as countries. One is by Stocking (1986) which concludes that the annual cost of soil erosion in Zimbabwe, just in terms of the value of losses of soil nitrogen, phosphorus, and potassium, is $1.5 billion (presumably in prices of the early 1980s when the study was done). Crosson (1994), although disclaiming detailed analysis of the Stocking study, found the $ 1.5 billion cost estimate to be implausible. Using World Bank figures for Zimbabwe, Crosson notes that the $1.5 billion would be 28% of the country's GDP and 2.2 times its Gross Agricultural Product (GAP). While acknowledging that such high figures are possible, Crosson considers them unlikely, and concludes that Stocking's estimate must be substantially too high.

The other study is by Bishop and Allen (1989), and deals with erosion-induced losses of soil productivity in Mali. These authors used the Universal Soil Loss Equation (developed in the United States but modified by Bishop and Allen to represent West African conditions) to estimate cropland erosion in an area of Mali comprising about one-third of the nation's most productive cultivated land. They then used regression models of erosion-yield loss relationships to estimate the cumulative costs of erosion in terms of lost production over a 10-year period. They extrapolated this result to the country as a whole and concluded that the cumulative 10-year cost was about 1.5% of Mali's GDP and about 4% of its GAP. According to the World Bank (1992b), Mali's GDP in 1990 was $2.45 billion. The Bishop and Allen estimate, therefore, implies that the cumulative 10-year erosion-induced loss of productivity in Mali was about $37 million.

Since present rates of land degradation in SSA, and the corresponding effects on agricultural productivity are unknown, it is impossible to estimate how much halting present degradation would contribute to the region's supply of agricultural land. However, whatever the current rates of degradation may be, we suspect that their productivity effects are much closer to the 4% of GAP found by Bishop and Allen (1989) for Mali than to the 2.2 times GAP found by Stocking (1986) for Zimbabwe. If we are right about this, then the contribution to future land supply in SSA of reducing land degradation would be small relative to the minimum 3.3% annual production growth rate we take here as a target.

The other way in which land supply may be increased along the qualitative dimension is by restoring the productivity of presently degraded land. At the time that Nelson (1988) wrote, as little was known about the extent and productivity effects of presently degraded land as was known about current rates of degradation. Post-Nelson, two studies have been done that add considerable information about presently degraded land, globally and by region, including SSA. One of the studies is by Dregne and Chou (1992), who estimated the amount of degraded land in the "dry" areas of the world, by which they meant arid, semi-arid, and dry subhumid climatic zones. They used a map prepared by UNESCO to identify these areas. Within these areas they estimated the amount of land under irrigation, in rainfed crop production, in range, and hyper-arid land. They then estimated the degree of degradation of land under irrigation, in rainfed crop production, and in range. (Hyper-arid land was assumed to have no economic agricultural value except under irrigation. Degradation of such land, therefore, is captured in the estimate for irrigated land.) All of the land in each use was assumed to suffer some degree of degradation from slight to moderate to severe to very severe. For irrigated and rainfed cropland, slightly degraded land has lost 0-10% of its potential productivity, given currently used technologies and management practices on the land. Moderately degraded land has lost 10-25%, of its potential productivity, severely degraded land has lost 25-50%, and very severely degraded land has lost more than 50%. For rangeland, the percentage productivity losses in the four categories are slight 0-25; moderate 25-50; severe 50-75; and very severe more than 75. The rangeland percentages are higher because range scientists usually judge rangeland to be in good to excellent condition if it has lost no more than 25% of its potential productivity.

For each land-use category, Crosson and Anderson took the midpoint of productivity loss for each degree of degradation severity and weighted those numbers by the percentage of land in each degradation class, in order to derive a weighted average estimate of the percentages of productivity loss for each land use. For example, slightly degraded irrigated and rainfed cropland was assumed to have lost 5% of its potential productivity, (midpoint between 0 and 10% loss), moderately degraded land was assumed to have lost 18%, severely degraded land 38%, and very severely degraded land 75%. The procedure for rangeland was comparable. The average productivity losses for each land use are irrigated land 6.8%; rainfed cropland 14.1%; and rangeland 44.5%. The interpretation of these percentages is straightforward: if degradation of irrigated land were eliminated, the productivity of the land would increase by 6.8%. Similarly, the productivity of rainfed cropland would increase by 14.1% and that of rangeland by 44.5%.

For what they are worth [and Dregne and Chou (1992) stress the poor quality of the data they had to work with], the results suggest that complete restoration of degraded irrigated and rainfed dry land in SSA would add little toward achievement of the target 3.3% annual production increase for the region. Restoration of degraded rangeland, however, seems to have more promise; but this may be more apparent than real. The question is whether dry rangeland in SSA is, in fact, as degraded as the Dregne and Chou estimates indicate. We raise it because there is an increasing literature that questions whether rangeland degradation in Africa is as severe as is commonly believed. Biot et al. (1994) assert that the scientific community now questions whether serious rangeland degradation is occurring at all on a global scale, if so at what rate, and what the economic significance of such degradation might be. With respect to grazing land in Africa, Winrock International (1992) states that although overgrazing has been accused of leading to desertification of much of this land, "The preponderance of scientific evidence has failed to show that widespread desertification has occurred, although areas around human habitations and water points have been severely damaged. Heavy grazing has changed vegetative cover, but has not seriously decreased the productivity of the rangelands. . ." As part of a wide-ranging research program at the Overseas Development Institute (London) on the use of natural resources and agricultural development in the Machakos region of Kenya, Farah (1991) concluded that, on grazing land in the region, ". . . There was no evidence of irreversible grazing-induced degradation." The difference between these assertions and the Dregne and Chou estimates and suggests the need for more research to determine what the facts are on this issue (Kangasniemi and Reardon 1994).

The other post-Nelson study on land degradation around the world was done by Oldeman et al. (1991). They (with the help of numerous collaborators) prepared a map, and an accompanying explanatory test, showing the state of human-induced degradation of the world's soils. Sombroek (1993) presents the results for Africa (not just SSA) in terms of area of degraded land (million ha) as: light 174; moderate 192; strong 124; and extreme 5. We have used Sombroek's data to get at the loss of productivity on Africa's potentially cultivable land attributable to degradation. First, we assumed that the losses of productivity in Sombroek's degradation categories are the same as in the corresponding categories of Dregne and Chou, that is, lightly degraded land has lost 0-10% of its potential productivity, moderately degraded land has lost 10-25%, and so on. As with our calculations with the Dregne and Chou data, we assumed that the actual percentage of productivity loss can be represented by the mid-points in each degradation category. Second, we subtracted the sum of the degraded land, 495 million ha, from the 820 million ha of potentially cultivable land in Africa (FAO 1986), giving 325 million ha of undegraded land. We assumed that the productivity loss on this land is zero. Third, we weighted the percentage of productivity loss in each degradation category by the amount of land in the category to calculate the weighted average loss. The result is a loss of 11.5%. Note that this estimate is for all potentially cultivable land in Africa, not just "dry" land, as in the Dregne and Chou study.

This estimate is, of course, no better than the data and assumptions on which it is based. As far as it goes, it is consistent with the results using the Dregne and Chou data for irrigated and rainfed cropland in Africa in suggesting that restoring the continent's presently degraded land to its full productivity would add little to the production that will be needed in the scenario to 2025.

The estimates of the percentage losses of potential productivity on degraded land set upper limits to the increases in production that could be achieved by restoring the degraded land. This is because the restoration of degraded land costs something, a point made by Bishop and Allen (1989). Indeed, work done on the costs of controlling erosion in the United States suggests that as restoration of productivity proceeds, the marginal costs of achieving it rise (Strohbehn 1986). One implication is that, whatever the degradation-induced loss of potential productivity may be, it most likely would not be economical to restore all of it.

Note that the upper limits of the contribution of land restoration to increased land supply would hold even if significant advances were made in knowledge of ways to accomplish restoration within acceptable economic and environmental costs. The upper limits are set by the amount of current productivity loss on account of land degradation. Advances in knowledge of lower cost techniques for restoration would reduce the difference between the upper limit and actually achievable restoration, but it would not raise the limit.

As noted earlier, estimates of the losses of soil productivity because of nutrient mining are not available for SSA. Whatever these losses may be, the literature suggests that traditional ways of dealing with the problem will not suffice under current conditions in SSA to halt the mining or restore soil nutrients

to levels needed to achieve steady increases in crop and animal production (Larson 1993). In shifting cultivation systems, population growth and resulting pressure on land are making it increasingly difficult to leave land in fallow long enough to adequately restore soil nutrient supplies. And the productivity of so-called "low-input" or "organic" systems, involving mixed crop rotations and livestock to return nutrients to the soil, also falls short. In describing the shortcomings of these systems Yates and Kiss (1992) assert that "In most soils of Africa, current levels of nutrients provided by 'low external input sustainable agriculture' can support no more than low-productivity subsistence type agriculture; doing no more than recycling existing levels of nutrients by biological means can only condemn most of Africa to continuing poverty levels of productivity."

If Yates and Kiss are right about this (and their view reflects not only our own but also a consensus among participants in a World Bank seminar devoted to a discussion of the soil-nutrient problem in SSA), efforts to extend the supply of agricultural land in SSA through low-input techniques to restore soil nutrients are not likely to contribute much toward meeting our target 3.3% annual increase in agricultural production.

Increasing the supply of land along the quantitative dimension by some 0.9% per year from 1990 to 2025 would increase production in SSA over that period by roughly 37%. Expansion along the qualitative dimension by restoring presently degraded land might add another 15%—but maybe more if the extent of degraded rangeland is as great as Dregne and Chou suggest. How much land supply might be increased by controlling erosion to avoid future losses of productivity is highly uncertain. Our guess, however, is that it would be on the order of the increase that might be achieved by restoring presently degraded land. Putting the potential quantitative and qualitative increases together suggests that the supply of land in SSA might be increased some 60-70% between 1990 and 2025 at what are here deemed to be acceptable economic and environmental costs. In our demand scenario, the minimum acceptable increase in food production over that period is a little over 200% (3.3% annually for 35 years). The increase in land supply would contribute significantly to achieving this, but other sources of production increase would have to be found. Needless to say, our broad-canvas approach tells nothing of the local pressures on land that may have severe resettlement consequences for affected peoples (Russell et al. 1990; Cook 1994).

Water-land substitution issues. Postel (1992) asserts that the high start-up cost of large surface irrigation systems is stimulating interest in smaller scale alternatives in SSA. One such system is called "garden irrigation" in *"dambos." Dambos* are production undertakings in wet lands or swampy areas that dry out enough in the dry season to permit the taking of a crop drawing on the residual soil moisture. Individually, the *dambos* are quite small, but in the aggregate they can be significant, e.g., in Zimbabwe *dambos* account for some 20 000 ha, almost 10% of the country's irrigated area. Much of the appeal of *dambos* is that the capital cost of installing them is $100-$2500 per ha, much less than the cost of large, traditional systems (Postel 1992).

Postel (1992) argues that simple, low-cost wells and pumps to tap shallow aquifers as well as rivers and streams offer considerable potential for increasing irrigated food production and income for farm families in SSA, and are stimulating increasing interest there as a consequence. More than 100 000 ha in Niger as well as smaller areas in Chad, Mali, northern Nigeria, and several other Sahelian countries are underlain by these shallow aquifers. According to Postel, more than 100 million people in Africa could benefit from greater use of these small-scale irrigation projects. In fact, farmers in northern Nigeria are already doing this. More than 8600 wells had been established in that region by the late 1980s, each capable of irrigating up to 2 ha. The cost to these farmers was $1000-$2000 per ha. Yields on these plots rose by 25-40% in the wet season relative to preirrigation yields, and these farmers have also added a dry-season crop. In the Kanem area of Chad, a combination of shallow wells and portable pumps has permitted an expansion of the irrigated area and led to a 130% increase in farmers' cash income (Postel 1992).

This productive exploitation of shallow aquifers would be indefinitely sustainable only if the annual drawdown of the aquifers is not greater than annual replenishment. The relationship of drawdown to replenishment has been little researched (Sandra Postel, personal communication). Judgments about the long-term potential of the aquifers must wait for information about the relationship. It does not necessarily follow, however, that current use of the aquifers should be curtailed until then. Even if the aquifers were ultimately exhausted, the income they would yield might be better used to provide for the sustenance of the people involved, with perhaps a surplus that could be invested in new opportunities that would substitute for the aquifers when they were depleted.

Brown and Thomas (1990) evidently agree with Postel that the greatest economic potential for expanded irrigation in Africa is through small-scale projects. In the same vein, Okigbo (1990) writes that small-scale irrigation in subhumid and savanna areas of SSA has been sustainable "when good soil management and adequate drainage have prevailed". Lal (1987) shares some of this enthusiasm for small-scale irrigation in Africa, but notes that its potential "awaits realization".

The argument that the irrigation potential of SSA could most economically be realized by way of small-scale projects seems to have considerable support from knowledgeable people in that field. The evidence supporting this position seems to be mostly anecdotal, but where it exists, the evidence seems reasonably firm. By our definition, costs of salinization and waterlogging associated with irrigation are not environmental because they are reflected in prices of marketed farm output. But in the literature, these costs are treated as environmental consequences of irrigation, and to avoid confusion, we treat them here so. In the work of Dregne and Chou (1992), salinization and waterlogging are the principal causes of degradation of irrigated land. Our calculations using the Dregne and Chou data showed that salinization and waterlogging have reduced potential productivity on SSA's irrigated land by about 7%. A question not addressed here is the extent to which these forms of degradation might constrain the realization of SSAs potential irrigation.

Water harvesting is not, strictly speaking, an alternative to irrigation, at least not to large-scale irrigation, because such irrigation is not generally feasible where water harvesting is. Water harvesting is the taking of measures to slow runoff of precipitation from fanners' fields, thus increasing infiltration of water to the crop root zone where it is available to support more robust plant growth as well as reduce soil erosion. A frequently used physical framework of water harvesting systems is a set of ridges and bunds on farmers' fields designed to channel and hold runoff in places where it can contribute most to crop growth (Critchley et al. 1992). The advantages of water harvesting as a technique for increasing water supply in dry areas are widely noted (Brown and Thomas 1990; Seckler et al. 1991; Tiffin and Mortimore 1992; English et al. 1994). The most fully developed discussion, however, is in Critchley et al. (1992), where the authors caution that, although the productivity advantages of water harvesting in dry areas have been widely recorded, the technique is no panacea for crop production in drought-prone areas. Nor, according to them should water harvesting he regarded as a freestanding technique but rather "... as one element of village land use management". They also emphasize that water-harvesting development should always be accompanied by improvements in plant husbandry to capture the benefits of the increased moisture. These improvements include weed control, fertility management, and "opportunism" with respect to the timing of planting. Fertility management is most important because fertility is often the most limiting factor to crop growth after moisture. With respect to fertility management, the authors mention use of manure and composting.

As a technique for increasing water supply, water harvesting would seem to have special relevance to SSA because so much of the region is arid, semi-arid or subhumid. Critchley et al. (1992) claim, however, that little is known about traditional water harvesting practices in the region. Experience in the Machakos district of Kenya over the past two or three decades may be an exception. Tiffin and Mortimore (1992) report in detail how the district underwent a transformation of its agricultural sector in that period, based in good measure on substantial improvements in management of the region's land and water resources. An important component of the improvement was the building of terraces to control soil erosion and to slow runoff, thus increasing the supply of water in the crop root zone. Perhaps the most significant feature of this achievement was that it resulted almost entirely from farmers' decisions to invest their own resources in improvement of the natural resource base and other aspects of the farm enterprise. The government contribution—by no means trivial—was to improve farm-to-market roads, both within the region and between the region and Nairobi.

There seems to be little doubt that water harvesting has potential for increasing the water supply to agriculture in SSA. And the small scale of water harvesting is consistent with the view that the economics of future growth in irrigation is likely to favor small-scale projects. Moreover, the Machakos experience suggests that the small-scale of water harvesting puts the practice within the resource capacity of small-scale farmers, and that they will adopt it if market and other economic conditions are favorable. How much all this may induce the spread of water harvesting in SSA over the next several decades, however, we are quite unable to say with any precision. Our guess is that water harvesting has the potential to make a significant but still small contribution to the increased supply of water to SSA crops.

We concluded earlier that the supply of land in SSA might be increased by 60-70% over the period to 2025 at socially acceptable economic and environmental costs. Given the present productivity of the land, the increase in supply, of course, would increase production too by 60-70%. How much the increase in water supply from better catchment management, the spread of irrigation, and water harvesting might add to production is difficult to say. However, we think that the combination of economic and environmental costs will keep irrigation expansion well short of the potential increase estimated by the World Bank/UNDP, and that the potential of water harvesting is too little to make a major contribution to increased production through increased water supply. If the minimum acceptable increase in food production for SSA depicted in our demand scenario is to be achieved, sources of production growth other than increased supplies of land and water will have to carry the major burden.

One finds in the literature the argument that absent improvements in soil management, and even large increases in fertilizer will not sustain continuous high-yield crop production on low natural fertility tropical soils (Pieri 1992). Indeed, Seckler et al. (1991) cite experts who assert that to get the high-yield payoff promised by increased use of inorganic fertilizers on these soils, it may be necessary in many situations to combine the fertilizers with increased use of composts, animal manures, and green manures. Lal (1987) describes a study in Burkina Faso showing that, relative to the traditional system of ridge-furrow cultivation, a system of tied ridges greatly increased the yield payoff to fertilizer because tied ridges slow runoff and increase infiltration of water to the crop root zone. FAO (1993) notes that some LDCs (not just in SSA) are having increasing difficulty getting satisfactory yield responses to increases in fertilizer, and refers to evidence suggesting that "...fertilizer alone may be insufficient in the long term and that measures to enhance organic matter in the soil are essential." Work in Burkina Faso (Barbier 1993) highlights the difficulty of maintaining productivity under growing population pressure even in the relatively high-potential areas. A more positive experience in Benin involving use of the green manure crop *Mucuna* is documented by Versteeg and Koudokpon (1993).

The essence of these arguments is that, on many of the SSA soils, inorganic fertilizer and other soil amendments, such as lime, and improvements in soil management are to some extent complements, meaning that the yield payoff to increased use of one is small unless the other too is increased. But the fertilizer-soil-management relationship is not likely to be solely one of complementarity. At the margin, it must often be the case that more of one can be substituted in production for less of the other. In this case, the price of fertilizer and the costs of soil-management improvements come into play in determining the optimal combination of the two inputs. Thus in dealing with the nutrient problem, SSA farmers—and those who would advise them—confront a complex management problem. Not only must the farmers have a satisfactory understanding of the technical relationships of complementarity and substitutability between additional fertilizer and improved soil management, but they must also know how to manipulate these relationships in accordance with the economic conditions of supply of the two inputs. It is well established that farmers in SSA (as elsewhere) are very knowledgeable about the natural conditions under which they operate. Most of them, however, have little if any experience with the use of fertilizers. To learn how to optimally combine large increases in these materials with improvements in soil management is likely to present a difficult learning experience to these farmers (Izac 1994). In view of all this, it appears safe to say that, over much if not most of SSA, simply increasing applications of inorganic fertilizer will not be enough to solve the soil-nutrient supply problem.

The literature describing the production potential of presently known but not widely adopted technologies and management practices is vague about their environmental consequences—positive and negative. That they are not widely adopted is sufficient evidence that, under existing conditions for most SSA farmers they are not economically competitive with prevailing techniques (Anderson 1991). The references in FAO (1986) and in Seckler et al. (1991) to increased use of agricultural chemicals suggests that wide adoption of the presently known, more productive technologies and practices (henceforth MPTP) could impose significantly higher environmental costs in terms of damage to ecosystems and water quality. However, because MPTP increase yields of crops and animals per unit of land relative to prevailing practices, their wide adoption should reduce farmer incentives to bring more erodible land into production (Jha and Hojjati 1993 describe some conflicting effects) and to clear forests and drain wetlands. But it would also reduce incentives for migration and thus may increase local population-pressure effects (Hoddinott 1994). Relative to current practices, it seems on balance, wide adoption of

MPTP may reduce downstream damage of sediment from eroded land, strengthen protection of the biological diversity and other environmental services provided by forests, and enhance the value of wildlife habitat and other services of wetlands. What the net effect of these varying tendencies in environmental costs of MPTP might be we (along with others) are quite unable to say. A judgment about the social acceptability of the environmental costs of wide adoption of MPTP thus must be withheld.

With this caveat about environmental costs and notwithstanding the needs for and difficulties in local "tuning" in what are often highly heterogeneous systems (Smith and Weber 1994), the evidence is strong that known technologies and management practices suitable to the climate and soil conditions of much of SSA have the potential to substantially raise crop and animal output per hectare of agricultural land in the region (Wallis 1994). Indeed, they have already done so in the 1980s, as work by Block (1994); Craig et al. (1994); Thirtle et al. (1994) has recently demonstrated.

Though the potential of MPTP may be substantial, we are satisfied that even if the potential is realized, the resulting increase in food production would fall short of our stipulated 3.3% annual increase in demand. That is, after allowing for the potential increases in supplies of land and water discussed earlier, and full realization of the potential of MPTP, the resulting increase in food production from the early 1990s to 2025 almost surely would be less than 3 times (3.3% annually). Thus we are led to address the question: what kinds and volume of new knowledge would be required to close the likely demand-supply gap at acceptable economic and environmental costs?

Need for new knowledge. The distinction between "new" knowledge and "existing knowledge" is somewhat ambiguous. For instance, modern agronomists "know" how to grow soybeans, and how the crop can be used to provide a worthy agricultural harvest, as well as make a valuable contribution of fixed nitrogen to the soil that can be exploited by subsequent crops (Mulongoy et al. 1992). It is quite a different thing, however, to get soybeans to effectively provide these functions in the cropping systems of eastern Africa, for instance. The knowledge in such a case then turns on a variety of specialized aspects of the agricultural knowledge system, such as having cultivars of soybeans that can deal with the competition for light and nutrients in such farming systems, particularly if intercropped; the microbiology of having rhizobia in place that can effectively inoculate the crop, whether these be "promiscuous" or more selectively identified materials to associate with designated cultivars in particular circumstances, and then to get to farmers all the materials and information they will need to use such a technique. Growing soybeans on this scale and under these conditions requires "new" knowledge beyond what local agronomists typically now "know".

Kinds of new knowledge. Some of the technological issues are also rather generic in nature (Morris and Byerlee 1992; Greenland et al. 1994). The issue of soil plant-nutrient management is one that can be tackled at a rather general level, although surely much local specificity is involved, especially when it comes to dealing with the particularities of micronutrient deficiencies and the subtleties of climatic uncertainties (McGowan and Jones 1992). For the macro-nutrients, however, the problems of inadequate supply of N and P are widespread and similar (Tshibaka and Baanante 1990). The landed costs of such nutrients in SSA, if supplied in conventional inorganic forms (that increase in price relative to organic forms under structural adjustment), is high by any standards—by international comparisons (Larson 1993) or relative to the returns from crops to which such nutrients may be applied (Carr 1989; 1993).

In the near-to-medium term, the additional nutrient supplies for high productivity agriculture in SSA will have to be provided by inorganic fertilizers (Larson 1993) probably, as noted above, in combination with improved management of soil nutrients and water. Over the longer term stretching to 2025, however, a more vigorous exploitation of the potential for biological N fixation has promise as an answer to the problem of N deficiency. Within a decade or so, advances in genetic engineering may provide part of the answer. But in the meanwhile, progress in biological nitrogen fixation can be achieved fairly cheaply and reasonably effectively through symbiotic associations with a variety of legume species, including some trees (notably *Faidherbia albida)* and many leguminous crops. There is much unexploited opportunity for traditional and nontraditional leguminous crops to be used within African cropping systems, including *Phaseolus, Stylosanthes, Vigna* and *Vicia* species, that can be grown as crops, and a variety of species more suitable for grazing and that could be used in noncultivated lands as well (Tarawali 1991; Kaufmann 1992). A difficult problem with the exploitation of such leguminous species is that to be productive and effective, they need greater supplies of P than are usually found in SSA soils.

This takes us to the second major nutrient that is in chronic short supply in many African soil associations, namely, P. (Fortunately, potassium is less of a "problem" nutrient in many African farming systems—Carr 1989.) The anomaly of soils deficient in P, and the prevalence of high-grade supplies of rock phosphate in Africa, has been noted by many people, but the reality of exploiting such P resources within the agricultural sector seems as far away as ever. Clearly, many technical difficulties have to be overcome before socially profitable use of these resources can be made. Some of the technical matters relate to processing techniques to improve the handling and effectiveness of the applied material. Others relate to handling costs which, in turn, depend directly on the state of infrastructural development, particularly rail and road networks, and to retailers' selling margins (Larson 1993).

Crop improvement—using new methods (Thottappilly et al. 1992) and old ones—is a traditional field of agricultural research that must be pursued in a sustained and vigorous way in the many agroecologies of SSA in order to generate the gains needed to close the demand-supply gap likely to emerge over the next several decades. All of the major foodcrops are in need of further improvements that can be exploited in local circumstances, including those that contribute to the value of crop residues as livestock feed. This means that crop improvement programs must be spread over the range of ecologies, but it is in some such activities that there is considerable scope for effective cooperation among neighboring countries. The economies of size associated with individual crop improvement programs are such that the target area must be sufficiently large to justify the expenditure (Brennan 1992; Bohn and Byerlee 1993). The breeding objectives must also be appropriate and, while the problems are many, and the potential list of objectives long, attention must be focused on relatively few specific priorities to give programs focus and cost efficiency. In many areas, the emphasis will be on abiotic stresses, such as drought and climatic variation (Hassan et al. 1993), and deal with problem soils, including those with high aluminium levels. In many more instances, the emphasis will continue to be on dealing with biotic stresses and, because of the evolution of the pests and pathogens involved, such work needs to be on a continuing basis.

Experience (Oemke 1992; USAID 1993; Sanders 1995) suggests that several plant breeding initiatives of the past few decades have, indeed, been quite successful.

Researchers concerned with sustainable agriculture in SSA have probably paid more attention to land tenure systems and their effects on incentives of SSA farmers to invest in MPTP than on any other institution or set of institutions. The literature concerning land tenure in SSA is now vast, and no attempt is made here to review it in detail.

The literature on land tenure systems in SSA (especially Migot-Adholla et al. 1991; Place and Hazell 1993; Bruce et al. 1994) does suggest that local people in the region are finding ways to modify existing land tenure systems to increase the security of property rights where the existing systems impede seizure of profitable opportunities to invest in MPTP. This is happening even in areas where laws and public policies forbid it. Without denying that existing tenure systems may still impede innovation in some parts of SSA (Clay and Reardon 1994), the capacity of people to change the systems in a direction favorable to innovation now seems to be an established fact. An important policy implication follows: where these processes of change are underway, the best policy may be for governments to back off, not abandoning the field, but adopting a posture of surveillance rather than one of heavy-handed regulation. Where private initiative appears to be taking agricultural development in the right direction, let the process work its way out.

Incentives to adopt MPTP. Despite the considerable potential of MPTP its realization its will not be easy. The declining trend of world agricultural commodity prices, should it continue, would tend to weaken farmer incentives to invest in MPTP, despite the potential. Even if commodity prices do not decline, a wider adoption of MPTP will require changes in government price, taxation, and foreign exchange policies that discriminate against agriculture, and large additional investments in the transport and communication infrastructure and in other services provided to farmers. Although spontaneous processes of change seem to be moving land tenure systems in the direction of strengthening property rights in land, with favorable effects on farmer investment incentives, needed increases in education of farmers lagged badly after the early 1980s.

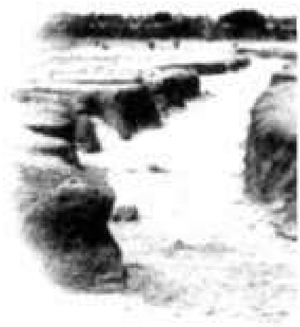
Whether SSA governments will make the changes in policies and institutions required to provide farmers incentives to tap the substantial potential of MPTP is difficult to say. But, even if the changes were made and widespread adoption of MPTP were to occur, new technologies and practices will be needed to sustainably satisfy the stipulated 3.3% annual increase in demand. Providing governments the capacity and incentives to develop these new technologies and practices will be critically important.

Incentives and Capacity to Develop New Technologies

Importance of human capital. At the most generic level, the key need for the agricultural knowledge system that will underpin the next several decades of African agriculture is that part embodied in the human capital servicing the sector. This takes us immediately into the issue of: (a) the agricultural higher education subsector and, to some extent, the more general education sector on which it depends (Zymelman 1990); (b) the agricultural research subsector, whether this be the public structures of the national agricultural research program, or those elements of the private sector that have an important role to play, such as through the seed industry, fertilizer industry etc.; and (c) the third subsectoral component, namely, the extension system, again including both the public extension service and those private initiatives that can substitute for, or complement (in some instances) such public-good provision. In spite of strong investment in the early 1980s (Pardeyetal. 1991; Anderson et al. 1994), SSA is demonstrably short of the key human resources—not to mention financial resources for supporting field and laboratory research—that make these interrelated subsectors work productively and efficiently. In spite of many attempts to invest appropriately, either from national sources or from the donor community and international lending agencies, there have been sufficient frustrations experienced to sound alarm for the continued successful evolution of such systems over the next several decades. The problems range from resource scarcity, particularly in an era of structural adjustment (Bonte-Friedheim et al. 1993), to the management of public-sector enterprises in ways that are genuinely sustainable. The sustainability issue, in turn, hinges on several key factors, such as the competitiveness of the terms and conditions of public-sector employment, as well as other social and environmental factors, including even the HIV epidemic as it impacts upon subpopulations critical to these subsectors.

There is no substitute for sustained social investment in these educational, research, and extension structures that will be absolutely critical to the expansion and even the preservation of the knowledge base servicing agriculture (Lynam and Blackie 1994). The payoff period to some of these investments is measured in decades, and thus commitments of funds must not only be significant, but must be done on an enduring basis so that the returns can be duly harvested. The experience with institution building in SSA has not always engendered much confidence that such outlays of scarce public resources will indeed always be worthy and will prove sustainable (Tshibaka 1993).

Fortunately, there are many initiatives presently in train that provide the preconditions for a more successful experience in the future in these subsectors. Donors have especially come to the rescue of strapped national governments in trying to revive and refurbish agricultural education systems that, in many cases, had essentially vanished. This work will require many more resources and certainly resource commitments over long periods to achieve the needed gains. In SSA, educational systems are severely overstretched by large student numbers relative to a teaching staff that is in short supply because of national human-capital scarcities. There have been analogous positive developments in the field of national agricultural research system planning, and several initiatives underway should see considerable advantage being achieved through more successful cross-country collaboration and more efficient use of scarce national research resources (Weijenberg et al. 1993). Extension too has been the subject of ongoing attention, with regrettable proliferation of variants of the Training and Visit system (Bindlish and Evenson 1993;Bindlish et al. 1993), and while there may have been some worthy accomplishments in managerial control, they do not make it good enough (Gautam and Anderson 1998; Gautam 2000). The sustainability of such extension systems in the absence of donor resources is, however, a matter of grave concern (Picciotto and Anderson 1997; Purcell and Anderson 1997), as is the rather stifled development of the private sector in this area, notwithstanding the valuable NGO engagements in many places in SSA.



A broad area that may be subject to analysis (by policy analysts dealing with agriculture and the environment) is that concerning policies related to the natural resources of a nation, their exploitation, the environmental consequences of different policies on their sustenance, and so on (Anderson 1992). There are many technological aspects of these issues that will naturally be the subject of concern within national research systems, such as interactions between forest areas and arable areas, between commercial livestock and wildlife, management of soil resources and water harvesting technologies under diverse land tenurial arrangements and property rights, emphasis on marginal relative to more favored environments (Byerlee and Morris 1993) or, as

Kesseba (1993) mentions, high- versus low-potential areas, with their intrinsic links to international SSA migration, and so on. Most of these areas have been subject to little formal analysis in most of SSA.

In all these initiatives, it should not be necessary for several dozen SSA countries to "rediscover the same wheels" in what are often complex and delicate policy matters. Clearly, there is scope for regional and other collaboration through African institutional networks, and there will also be a role for reliable sources of external assistance, both in the donor community (Carter 1993), and in international organizations ranging from international agricultural research centers for much of the technological work across at least the major foodcrops, and to other international organizations, such as development banks, for more wide-ranging institutional assistance. Institutional collaboration in developing and effectively using knowledge of how to manage the natural resource and environmental consequences of emerging new technologies could have high payoffs (Crosson and Anderson 1993).

Conclusion

Many conceptual and empirical issues arise while addressing the sustainability of the agricultural system of SSA and a clear discussion of these is bedeviled by data situations that are seldom satisfactory, often virtually nonexistent, and at best perhaps describable as fragile. Notwithstanding the leaps and bounds being made in GIS capabilities, the quantification of each element we have addressed will require much investment of intellectual resources, whether it be population, income generation, soil-water-vegetation-fauna resources, infrastructure, or knowledge generation and custody itself. Uncertainty abounds. A proper "monitoring and evaluation" of the situation is an important imperative for moving forward. There is no doubt that a sustainable agricultural system in SSA—diverse over space and variable over time as it is—can be achieved. Only the timing is uncertain; but the timing is critical, given the rapidly rising pressure on and increasing intensification of the agricultural system. The challenges are great, indeed, because of the population-driven demand scenario that is in prospect, and because of the unsatisfactory state of agricultural and resource management—including agricultural research itself—that presently prevails in many pockets of the continent.

While we do not wish to underplay the great challenge faced in seeking to achieve such a sustainable agriculture, we believe that the challenge can be met. Where the physical and institutional infrastructure and policy conditions necessary for wider adoption of MPTP have been met, as they appear to have been in the Machakos and other regions of Kenya (Wallis 1994), farmers have responded and achieved significant increases in production and income. Such examples are all too rare in SSA, but they support the argument that human ingenuity, accompanied by political will, can move agricultural systems in the region to sustainable paths (Kesseba 1993). This is not to say, however, that we should stand back from SSA situations that are not yet at a crisis point in unsustainable practice. Indeed, attention to many of these systems must also be urgent before the social costs associated with resource damage reach levels that prove even more difficult, and costly for any subsequent recovery and restoration.

Among a diversity of capital investment possibilities, we have argued strongly for human-capital enhancement, so that African problems can be solved by African analysts and African interventions. This process of human-capital formation is a long and uncertain one, and one that thus requires patience, understanding, and some tolerance of misadventure. Given the urgency of the need for intervention, resources must be quickly forthcoming—mostly from the more-developed world—to make the long-run investments that are needed to undergird a system that is indeed sustainable.

References

Anderson, J.R. 1980. Nature and significance of risk in the exploitation of new technology. Pages 297-302 *in* Socioeconomic constraints to development of Semi-Arid Tropical agriculture (Ryan, J.G., and Thomson, H.L., eds.). ICRISAT, Hyderabad, India.

Anderson, J.R. 1991. A framework for understanding the mixed impact of 'improved' agricultural technologies in Africa. Pages 105-142 *in* Agricultural technology in Sub-Saharan Africa: A workshop on research issues (Gnaegy, S., and Anderson, J. R., eds.). World Bank Discussion Paper No. 26. Washington, D.C.: World Bank.

Anderson, J.R. 1992. Difficulties in African agricultural systems enhancement: Ten hypotheses. Agricultural Systems 38(4): 387-409.

Anderson, J.R. 1999. Poverty, land degradation, and rural research. Paper prepared at the CIAT International Workshop on Assessing the Impact of Agricultural Research on Poverty Alleviation, 14-16 Sep 1999, Costa Rica.

Anderson, J.R. 2000. Technological modernity, environmental correctitude, rural

R&D policy, and imperative Asian rural development paths. Keynote paper at the Third Asian Conference of Agricultural Economists, 18-20 Oct.

Anderson, J.R., and Jodha, N.S. 1994. Agricultural research strategy for more enduring productivity in fragile areas. Pages 432-544 *in* Agricultural technology: Policy issues for the international community (Anderson, J.R., ed.). Wallingford, UK: CAB International.

Anderson, J.R., Pardey, P.G., and Roseboom, J. 1994. Sustaining growth in agriculture: A quantitative review of national and international agricultural research investments. Agricultural Economics 10(2): 107-23.

Anderson, J.R., and Thampapillai, J. 1990. Soil conservation in developing countries: Project and policy intervention. PRS No. 8, World Bank, Washington DC.

Barbier, B. 1993. Modelisation agronomique et economique d'un systeme agraire: Le cos de Bala au Burkina Faso. Ph.D thesis, ENSAM, Montpellier.

Bindlish, V., and Evenson, R. 1993. Evaluation of the performance of T&V extension in Kenya. Agriculture and Rural Development Series No. 7. Technical Department, Africa Region. Washington, D.C.: World Bank.

Bindlish, V., Evenson, R., and Ghetibouo, M. 1993. Evaluation of T&V-based extension in Burkina Faso. World Bank Technical Paper No. 226. Washington, D.C.: World Bank.

Binswanger, II., and Pingali, P. 1988. Technological priorities for farming in Sub-Saharan Africa. World Bank Research Observer 3(l):81-98.

Biot, Y., Blaikie, P.M., Jackson, C, and Palmer-Jones, R. 1994. Rethinking research on land degradation in developing countries. World Bank Discussion Paper No. 289. Washington, D.C.: World Bank.

Bishop, J., and Allen, J. 1989 The on-site costs of soil erosion in Mali. Environment Working Paper No. 21. Washington, D.C.: World Bank.

Block, S. A. 1994. A new view of agricultural productivity in Sub-Saharan Africa. American Journal of Agricultural Economics 76 (3).

Bohn, A., and Byerlee, D. 1993. The wheat breeding industry in developing countries: An analysis of investments and impacts. Pages 1-25 *in* CIMMYT, 1992/93 CIMMYT World Wheat Facts and Trends. Mexico, D.F.: CIMMYT.

Bonte-Friedham, C., Brush, E.G., and Tabor, S. 1993. Human resources in African national agricultural research systems: Management issues for the 1990s.

Pages 31-39 *in* Sustainable food production in Sub-Saharan Africa: constraints and opportunities. Ibadan: IITA.

Boserup, E. 1981. Population and technological change. Chicago, USA : University of Chicago Press.

Brennan, J. P. 1992. Economic criteria for establishing plant breeding programs. Economics Working paper No. 92-01. Mexico, D.F.: CIMMYT.

Brown, H., and Thomas, V. 1990. Ecological considerations for the future of food security in Africa. Pages 353-377 *in* Sustainable agricultural systems (Edwards, C, Lal, R., Madden, P., Miller, R., and House, G, eds.). Ankeny, Iowa : Soil and Water Conservation Society.

Bruce, J.W., Migot-Adholla, S., and Atherton, J. 1994. The findings and their policy implications: Institutional adaptation or replacement? *In* Searching for land tenure security in Africa (Bruce, J.W., and Migot-Adholla, S., eds.). AGRAP, World Bank.

Byerlee, D., and Morris, M.L. 1993. Research for marginal environments: Are we under-invested? Food Policy 18(5):381-393.

Carr, S.J. 1989. Technology for small-scale farmers in Sub-Saharan Africa. World Bank Technical Paper No. 109. Washington, D.C.: World Bank.

Carr, S.J. 1993. Improving cash crops in Africa: Factors influencing the productivity of cotton, coffee, and tea grown by smallholders. World Bank Technical Paper No. 216. Washington, D.C.: World Bank.

Carter, M. 1993. How does Africa get there and how does AID help? Pages 177-187 *in* Agricultural transformation in Africa (Seckler, D., ed.). Arlington, V.A.: Winrock International Institute for Agricultural Development.

Clay, D.C., and Reardon, T. 1994. Determinants of farm-level conservation investments in Rwanda. Harare Conference Proceedings, IAAE Occasional Paper No. 7, Gower, Aldershot.

Cook, C.C. 1994. Involuntary resettlement in Africa: Selected papers from a conference on Environment and settlement issues in Africa. World Bank Technical Paper No. 227, Africa Technical Department Series. Washington, D.C.: World Bank.

Craig, B.J., Pardey, P.G., and Roseboom, J. 1994. International agricultural productivity patterns. Discussion Paper No. 94-03. Netherlands, The Hague: ISNAR.

Critchley, W., Reij, C., and Seznec, A. 1992. Water harvesting for plant production: Vol. II, Case studies and conclusions for Sub-Saharan Africa.

Technical Paper No. 157, Africa Technical Department Series. Washington, D.C.: World Bank.

Crosson, P. 1994. Future supplies of land and water for agriculture. Paper prepared for the International Food Policy Research Institute Roundtable on Population and Food in the Early 21st Century: Meeting Future Food Needs of an Increasing World Population, 14-16 Feb, Washington, D.C.

Crosson, P., and Anderson, J.R. 1992. Resources and global food prospects: Supply and demand for cereals to 2030. World Bank Technical Paper. No. 184. Washington, D.C: World Bank.

Crosson, P,, and Anderson, J.R. 1993. Concerns forsustainability: Integration of natural resource and environmental issues for the research agendas of NARS. Research Report 4. Netherlands, The Hague: ISNAR.

Cuissance, D. 1991. Le piegeage des tetse: Etudes et syntheses de LMEMVT 32. Maison Alfort : France.

Dent, J.B., and Anderson, J.R. 1971. Systems analysis in agricultural management (Dent, J.B., and Anderson, J.R., eds.). Wiley: Sydney.

Dregne, H. 1988. Desertification of drylands", Pages 610-612 in Challenges in Dryland Agriculture: Proceedings of the International Conference on Dryland Farming, Texas Agricultural Experiment Station Amarillo/Bushland, (linger, P., Sneed, T, Jordan, W., and Jensen, R., eds.). Texas, 610-12.

Dregne, H., and Chou, Nan Ting 1992. Global desertificaton dimensions and costs. Pages 249-282 *in* Degradation and restoration of arid lands. Lubbock, Texas : TexasTech University.

El-Swaify, S., Dangler, E., and Armstrong, C. 1982. Soil erosion by water in the tropics. Honolulu : University of Hawaii.

English, J., Tiffen, M., and Mortimore, M. 1994. Land resource management in Machakos District, Kenya 1930-1990. World Bank Environment Paper No. 5. Washington, D.C: World Bank.

FAO (Food and Agriculture Organization of the United Nations). 1986. African agriculture: The next 25 Years. ARC/8613. Rome: FAO.

FAO (Food and Agriculture Organization of the United Nations). 1993. Agriculture: Towards 2010. Rome: FAO.

FAO (Food and Agriculture Organization of the United Nations). 1994. Agriculture: Towards 2010. Rome: FAO.

Farah, K. 1991. Natural vegetation. *In* Environmental change and dryland management in Machakos District, Kenya 1930-1990:

Environmental profile (Mortimore, M, ed.). ODI Working Paper 53. London: Overseas Development Institute.

Gautam, M. 2000. Agricultural extension: The Kenya experience—An impact evaluation. OED. Washington, D C : World Bank.

Gautam, ML and Anderson, J.R. 1998. Reconsidering the evidence on the returns to T&V extension in Kenya. Working Paper Series 2098. Washington, D.C.: World Bank.

Greenland, D., Bowen, G, Eswaran, H., Rhoades, R., and Valentin, C. 1994. Soil, water and nutrient management research—A new agenda. IBSRAM Position Paper. Bangkok: IBSRAM.

Hassan, R.M., Mwangi, W., and Karanja, D. 1993. Wheat supply in Kenya: Production technologies, sources of inefficiency, and potential for productivity growth. Economics Working Paper 93-02. Mexico, D.F.: CIMMYT.

Hoddinott, J. 1994.A model of migration and remittances applied to Western Kenya. Oxford Economic Papers 46(3):459-76.

Izac, A.M.N. 1994. Ecological-economic assessment of soil management practices for sustainable land use in tropical countries. Pages 77-96 *in* Soil resilience and sustainable land use (Greenland, D.J., and Szabolcs, I., eds.). Wallingford, UK: CAB International.

Jahnke, H.E. 1982. Livestock production systems and livestock development in tropical Africa. Kieler Wissenschaftsvertag Vauk, Kiel.

Jha, D., and Hojjati, B. 1993. Fertilizer use on smallholder farms in Eastern Province, Zambia. Research Report No. 94. Washington, D.C.: IFPRI.

Jordan, A. 1988. Trypanosomiasis control and African rural development. London, UK : Longman.

Kangasniemi, J., and Reardon, T. 1994. Demographic pressure and the sustainability of land use in Rwanda. *In* the Harare Conference Proceedings, IAAE Occasional Paper No. 7, Gower, Aldershot.

Kaufmann, R. R. von. 1992. African feed resources and ruminant production from the ecological and socio-economic viewpoint. Pages 109-117 *in* Proceedings of the 25th International Symposium on Tropical Agriculture Research. Tropical Agriculture Research Series No. 25, Tsukuba.

Kesseba, A.M. 1993. Strategies for developing a viable and sustainable agricultural sector in sub-Saharan Africa: Some issues and options. Pages 211 -243 *in* Technologies for sustainable agriculture in the tropics. Madison: American Society of Agronomy.

Lal, R. 1987. Managing the soils of sub-Saharan Africa. Science 236: 1069-76.

Larson, B.A. 1993. Fertilizers to support agricultural development in sub-Saharan Africa: What is needed and why? Center for Economic Policy Studies Discussion Paper No. 13. Arlington, V.A.: Winrock International Institute for Agricultural Development.

Leach, M., and Mearns, R. 1996. Challenging received wisdom in Africa. Pages 1-33 *in* The lie of the land: Challenging received wisdom on the African environment (Leach, M., and Mearns R., eds.). International African Institute and James Currey: Oxford.

Lele, U., and Stone, S.W. 1989. Population pressure, the environment and agricultural intensification: Variations on the Boserup hypothesis. MADIA Discussion Paper 4. Washington, D.C.: World Bank.

Lynam, J.K., and Blackie, M.J. 1994. Building effective agricultural research capacity: The African challenge. Pages 106-134 *in* Agricultural technology: Policy issues for the international community (Anderson, J.R., ed.). Wallingford, UK: CAB International.

McGowan, R.L., and Jones, R.K. 1992. Agriculture of semi-arid eastern Kenya: Problems and possibilities. Pages 8-15 *in* A search for a strategy for sustainable dryland cropping in semi-arid Eastern Kenya (Probert, M., ed.). Canberra, Australia: ACIAR.

McIntire, J., Bourzat, D., and Pingali, P. 1992. Crop-livestock interaction in sub-Saharan Africa. Washington, D.C.: World Bank.

Migot-Adholla, S., Hazell, P., Blarel, B., and Place, F. 1991. Indigenous land rights systems in sub-Saharan Africa: A constraint on productivity? World Bank Economic Review 1(1): 155-75.

Miller, E, and Larson, W. 1990. Lower input effects on soil productivity and nutrient cycling. Pages 549-568 *in* Sustainable agricultural systems (Edwards, C, Lai, R., Madden, P., Miller, R., and House, G, eds.). Ankeny, Iowa : Soil and Water Conservation Society.

Morris, M.L., and Byerlee, D. 1992. Narrowing the wheat gap in sub-Saharan Africa: A review of consumption and production issues. Economic Development and Cultural Change 41(4):737-61.

Mortimore, M. and Adams, W.M. 1999. Working the Sahel: Environment and society in Northern Nigeria. Routledge, London.

Mulongoy, K., Gueye, M., and Spencer, D.S.C. 1992. Biological nitrogen fixation and sustainability of tropical agriculture : proceedings of the Fourth International Conference of the African

Association for Biological Nitrogen Fixation, 24-28 Sep 1990, IITA, Ibadan, Nigeria (Mulongoy, K., Gueye, M, and Spencer, D.S.C., eds.). Chichester: Wiley.

NRC (National Research Council). 1993. Sustainable agriculture and the environment in the humid tropics. Washington, D.C.: National Academy Press.

Nelson, R. 1988. Dryland management: The land degradation problem. Environment Department Working Paper No. 8. Washington, D.C.: World Bank.

Oemke, J. 1992. The impact of agricultural technology in sub-Saharan Africa. Office of Analysis, Research, and Technical Support Technical Paper No. 3, Bureau for Africa. Washington, D.C.: USAID.

Okigbo, B. 1990. Sustainable agricultural systems in tropical Africa. Pages 323-352 *in* Sustainable agricultural systems (Edwards, C, Lal, R., Madden, P., Miller, R., and House, G, eds.). Ankeny, Iowa: Soil and Water Conservation Society.

Oldeman, L., Hakkeling, R., and Sombroek, W. 1991. World map of the status of human-induced soil degradation: An explanatory note, 2nd edn. International Soil Reference and Information Center, Wageningen and United Nations Environment Programme, Nairobi.

Pardey, P. G., Roseboom, J., and Anderson, J. R. 1991. Regional perspectives on national agricultural research. Pages 197-264 *in* Agricultural research policy: International quantitative perspectives (Pardey, P.G, Roseboom, J., and Anderson, J.R., eds.). Cambridge: Cambridge University Press.

Pieri, C. 1992. Fertility of soils: A future for farming in the West Africa Savanna. Berlin: Springer Verlag.

Picciotto, R., and Anderson, J.R. 1997. Reconsidering agricultural extension. World Bank Research Observer 12(2): 249-59.

Place, F., and Hazell. P. 1993. Productivity effects of indigenous land tenure systems in sub-Saharan Africa. American Journal of Agricultural Economics 75(1): 10-19.

Postel, S. 1992. Last oasis: Facing water scarcity. Worldwatch Environmental Alert Series. New York: Norton.

Purcell, D.L., and Anderson, J.R. 1997. Agricultural extension and research: Achievements and problems in national systems. A World Bank Operations Evaluation Study. Washington, D.C.: World Bank.

Rosegrant, M., and Agcaoili, M. 1994. Global and regional food demand, supply and trade prospects to 2010. Paper presented at the

International Food Policy Research Institute Round Table on Population and Food in the Early 21st Century: Meeting Future Food Needs of an Increasing World Population, 14-16 Feb, Washington, D.C.

Russell, S.S., Jacobsen, K., and Stanley, W.D. 1990. International migration and development in sub-Saharan Africa, Vol. I. World Bank Discussion Paper No. 101, Africa Technical Department Series. Washington, D.C: World Bank.

Ruthenberg, H. 1980. Farming systems in the tropics.Oxford : Clarendon Press.

Ryan, J.G., and Spencer, D. 2000. Challenges and opportunities shaping the future of the Semi-Arid Tropics and their implications. Draft of the paper presented at the International symposium on Future of agriculture in the Semi-Arid Tropics, 14 Nov 2000, ICRISAT, Patancheru.

Sanders, J.H. 1995. Success stories: New crop and input technologies in the Sudano-Guinean Zones of Burkina Faso and Mali. *In* The economics of agricultural technology in semi-arid sub-Saharan Africa (Sanders, J.H., Ramaswamy, S., and Shapiro, B. I., eds.). Baltimore: Johns Hopkins University Press.

Seckler, D., Gollin, D., and Antoine, P. 1991. Agricultural potential of Mid-Africa: A technological assessment. Pages 61-103 *in* Agricultural technology in sub-Saharan Africa: A workshop on research issues (Gnaegy, S., and Anderson, J.R., eds.). World Bank Discussion Paper No. 126. Washington, D.C: World Bank.

Smith, J., and Weber, GK. 1994. Strategic research in heterogeneous mandate areas: An example from the West African Savanna. Pages 545-564 *in* Agricultural technology: Policy issues for the international community (Anderson, J. R., ed.). Wallingford, UK: CAB International.

Sombroek, W. 1993. Agricultural use of the physical resources of Africa: Achievements, constraints and future needs. Pages 12-30 *in* Sustainable food production in sub-Saharan Africa 2. Constraints and Opportunities. Ibadan: IITA.

Stocking, M. 1986. The cost of soil erosion in Zimbabwe in terms of the loss of three major nutrients. Consultant's Working Paper No. 3, Soil Conservation Program, Land and Water Division. Rome: FAO.

Stocking, M. 1992. Land degradation and rehabilitation: Research in Africa 1980-1990: Retrospect and Prospect. Dryland Networks Programme Paper No. 34. London: IIED.

Stoorvogel, J.J., and Smaling, E.M.A. 1990. Assessment of soil nutrient depletion in sub-Saharan Africa: 1983-2000 Report 28,

Winand Staring Centre for Integrated Land, Soil and Water Research, Wageningen.

Strohbehn, R. 1986. An economic analysis of USDA erosion control programs: A new perspective. Agricultural Economics Report No. 560, Economic Research Service. Washington, D.C.: United States Department of Agriculture.

Tarawali, G. 1991. The residual effect of *Stylosanthes* fodder banks on maize yield at several locations in Nigeria. Tropical Grasslands 25(1):26-31.

Thirtle, C, Craviollati, P., Hadley, D., and Townsend, R. 1994. A multilateral Malmquist total factor productivity index approach to explaining agricultural growth in Sub-Saharan Africa. Paper for the ESRC Development Economics Study Group Annual Conference, University of Leicester, Mar 1994, Mimeo, University of Reading.

Tiffin, M., and Mortimore, M. 1992. Environment, population growth and productivity in Kenya: a case study of Machakos District. Development Policy Review 10: 359-87.

Thottappilly, G., Monti, L.M., Mohan, D.R., and Moore, A.W. 1992. Biotechnology: Enhancing research on tropical crops in Africa (Thottappilly, G, Monti, L.M., Mohan, D.R., and Moore, A.W., eds.). Ibadan: CTA/IITA.

Tshibaka, T.B. 1993. Policy imperatives for agricultural development in Africa. Pages 65-76 *in* Sustainable food production in sub-Saharan Africa 2. Constraints and opportunities. Ibadan: IITA.

Tshibaka, T.B., and Baanante, C.A. 1990. Fertilizer policy in tropical Africa. Workshop proceedings, Lome, Togo, Apr 1988. IFDC and IFPRI, Muscle Shoals.

USAID (United States Agency for International Development). 1993. Africa: Growth renewed, hope rekindled: A report on the performance of the Development Fund for Africa 1988-1992. Washington, D.C.: USAID.

Versteeg, M., and Koudokpon, V. 1993. Participative farmer testing of four low external input technologies to address soil fertility decline in Mono Province (Benin). Agricultural Systems 42(3): 265-76.

Walker, T.S., and Ryan, J.G. 1990. Village and household economies in India's Semi-Arid Tropics. Baltimore, USA: Johns Hopkins University Press.

Wallis, J.A. 1994. Some intensified systems of farming in the tropics and sub-tropics. World Bank Technical Paper. Washington, D.C.: World Bank.

Weijenberg, J., Dione, J., Fuchs-Carsch, M., Kere, A., and Lefort, J.

1993. Revitalizing agricultural research in the Sahel. World Bank Discussion Paper No. 211, Africa Technical Department Series. Washington, D.C: World Bank.

Winrock International. 1992. Animal agriculture in sub-Saharan Africa. Morrilton, Arkansas: Winrock International Institute for Agricultural Development.

World Bank. 1992a. World development report 1992: Development and the environment. New York : Oxford University Press.

World Bank. 1992b. Environmental status report of Sub-Saharan Africa. Environment Division, Technical Department, Africa region. Washington, D.C: World Bank.

Yates, R.A., and Kiss, A. 1992. Using and sustaining Africa's soils. Agriculture and Rural Development Series No. 6, Technical Department, Africa region. Washington, D.C: World Bank.

Poverty Reduction and Food Security in Sub-Saharan Africa: A Challenge to World Agriculture

V Sekitoleko[1]

Agriculture in Africa

Africa is the only region in the developing world where the regional average of food production per person has been declining over the last 40 years, putting large segments of the population at risk in terms of food insecurity and malnutrition. While the percentage of undernourished in Sub-Saharan Africa (SSA) has declined since the early 1980s, the FAO's estimates for 1995-97 indicate that 33% remain chronically food insecure.

Importance of agriculture. Agriculture continues to dominate the economies and produces the bulk of food consumed in SSA, and accounts for about 70% of total employment, 40% of total merchandise exports, and 34% of African GDP. The sector is the main source of raw material for industry. In fact, as much as two-thirds of manufacturing value-addition in most African countries is based on agricultural raw materials. In addition, the sector is the main buyer of farm implements and services such as transport, and farmers are the main consumers of both imported and locally produced consumer goods.

Agricultural commodities. Most countries in the region continue to rely on one or two traditional commodities for the bulk of export earnings, although the production and market shares of these commodities have been falling since the 1960s. The declining performance and contribution of the agricultural sector in most African countries is symptomatic of inadequate capital formation and heavy decapitalization, which raise costs and lower productivity. This compels most farmers and other economic agents to engage in practices that degrade land

Sekitoleko, V. 2001. Poverty reduction and food security in sub-Saharan Africa: A challenge to world agriculture. Pages 51-62 in Future of agriculture in the semi-arid tropics: proceedings of an International Symposium on Future of Agriculture in Semi-Arid Tropics, 14 Nov 2000, ICRISAT, Patancheru, India (Bantilan, M.C.S., Parthasarathy Rao, P., and Padmaja, R., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

1. Subregional representative for southern and eastern Africa, Food and Agriculture Organization of the United Nations, P O Box 3730, Harare, Zimbabwe.

resources, deplete forest and other natural vegetation, and harm marine and other aquatic resources, including water. Nevertheless, agriculture will remain, in the future, the most important sector for addressing food security and poverty in Africa. In view of agriculture's central roles in the supply of food as well as in generating employment and income, policies aimed at increasing agricultural production and productivity are essential in order to improve household food security as well as to reverse the current economic situation in Africa.

Supply Issues

Rate of agricultural production. Agricultural production in Africa has declined in per capita terms and as a share of global production through most of the period since the 1960s. Recent data indicate a slowing and perhaps a modest reversal of this downward trend for a few commodities. A comparison of the data for the first three years of the last decade with that of the last three years shows that Africa's share of global cereals production increased from 4.9% to just over 5.6%, and per capita production grew from 152 kg to 160 kg. However, this remains far below the global average per capita production of 358 kg, and far too little to make up the ground lost during the previous three decades. In the case of cocoa, one of the main export commodities, Africa's share of global production fell from 72% in the 1960s to 55% in the early 1990s, before recovering to 64% in the late 1990s. For many other commodities, however, the 1990s have brought no reversal of the long-term decline.

Success of agriculture industry. Africa being a diverse continent, reference to all countries in it in aggregate terms is not fair as some have achieved notable agricultural success in some areas. The five African subregions have experienced sharply divergent production trends in the 1990s. West Africa and North Africa have seen a fairly solid growth in annual output (about 3 to 5%) for most of the basic agricultural commodities, while production in Southern Africa has declined or stagnated for most commodities. In east Africa, production figures are more vague because of the horn of Africa. Central Africa has also seen solid growth in some commodities (cereals 4.9% and cocoa 2.6%) and declining or flat output in others (coffee 5.4% and oilcrops 0.8%).

Levels of production. Variation in production is a major issue in many African countries, as most crops are rainfed and thus highly vulnerable to weather-related shocks. The annual per capita production of cereals, for example, fluctuated between 140 kg and 175 kg for the continent as a whole during the 1990s. Regional and national production figures reveal an even higher degree of variation.

Underdeveloped agriculture. A variety of factors contribute to the underdevelopment of the agricultural sector in Africa like perpetual conflicts. The small fragmented markets do not help matters.

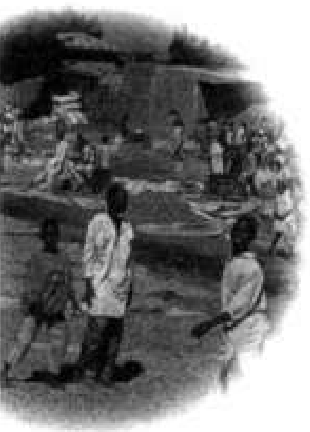
Use of inputs and services. Agriculture in Africa remains least productive and is one of the lowest users of modern inputs in the world, partly because of lack of a policy environment that would encourage farmers to increase production through the adoption of modern technologies and achieve higher yields. Indigenous customary land tenure systems are still prevalent in countries south of the Sahara. Although they are generally based on various forms of group control, which may allow a balanced management of communal property, they represent in many cases an obstacle to the adoption of more advanced techniques, requiring long-term investments.

Agricultural land. Most of the increase in agricultural production in Africa over the past several decades has been achieved by bringing more land under cultivation. Today, only 7% of Africa's total land area (about 150 million hectares) is devoted to crop production. But given the difficult climatic conditions, poor soils, and very uneven distribution of water resources, only another 30 million hectares of unused land can be brought under cultivation without further jeopardizing the environment.

Increasing output. Therefore, any significant increase in Africa's output of food and other crops will have to come from intensified production. This will require much greater use of irrigation, fertilizer, and other inputs as well as the development and application of new and appropriate technologies. However, accelerated degradation of the natural resources upon which agriculture depends remains a significant constraint to production. Human-induced land degradation—linked to rapid population growth and slow introduction of adequate technologies—is a significant problem in most countries. Overexploitation of crop land , overgrazing of grasslands, deforestation, and poor water management have led to serious environmental degradation. Annual deforestation in Africa increased because of population growth, overgrazing, inappropriate cropping practices, fuel wood collection, and armed conflicts with their trail of refugees.

These factors, either individually or in combination, are leading to encroachment on the desert fringes and degradation of moisture areas well away from the deserts. Increasing drought may also be partly due to environmental degradation.

Land development. Currently, only about 2% of sub-Saharan Africa's arable land is under irrigation compared to a third in South Asia. Unlike other regions of the world, fertilizer use is very low in Africa. With fallow periods getting shorter in many African countries, the absence of fertilizer means that soils are being leached of essential minerals. Few farmers can afford fertilizers, especially after the removal (partially in some cases) of subsidies that promoted fertilizer use in the 1960s and 1970s. Efforts to increase producer prices have brought about mixed results. In cases where producers have gained, the effects have been felt unequally. Poor farmers, who are usually subsistence farmers with a small marketed surplus, have tended to benefit much less than large-scale producers, while at the same time facing prohibitively high prices for fertilizer and other inputs. Women farmers, who account for a majority of food producers and usually farm on a very small scale, are at a particular disadvantage.



Education. In agriculture, human capital is the best investment anybody in leadership can make. Education enables farmers to learn new skills, and make more efficient use of available resources including labor. For finally, when the economy starts to experience changes like acquiring new technology, the farmer is able to decode it, or if there is disequilibria in an economy, an educated farmer will find it much easier to adjust and even take advantage of the changes. While education makes farmers better entrepreneurs, it also prepares members of the rural population for off farm employment. This normally leads to modernization in agriculture, thereby requiring less labor force. This in turn results in the surplus labor seeking employment elsewhere where income is better. Finally, it contributes to alleviating rural poverty. Unfortunately, the majority of people here are barely literate.

Lack of information. The lack of timely and accurate information is also a significant constraint to increased production. The need to supply information to both private and government sectors in the subregion needs to be improved. Not all countries have functioning domestic market information services. It is a well known fact that you are what you know. Secondly, this is the information age operating in a global village—so where does sub-Saharan Africa figure?

Agricultural policies. There is also the need for enhanced public policies and development plans. In fact, many countries have neither. As we make progress on the policy and planning fronts, it is certainly reasonable to think that trainee trainers could be trained in a few countries and their expertise be made available to the entire region. Sub-Saharan Africa needs to have its own experts, starting from the household level.

Research. Growth in production requires significant research and improved dissemination techniques. However, many countries in the region suffer from a bias dating back to the colonial era, when resources for agricultural research laid stress on export crops at the cost of indigenous food crops. Efforts to reverse this orientation have been painfully slow. At the same time, most African staples (millet, sorghum, cassava, yam, cowpea, bananas and plantains, and traditional vegetables) have received little attention from advanced research institutions elsewhere. As a result, Africa has lagged behind most other developing regions in generating improved varieties and technologies that are locally adaptable.

Infrastructure. Another important constraint to increased production is the lack of infrastructure and high transport and storage costs. Farmers in close proximity to markets and roads can transport inexpensively, and those who can store their produce can sell later when prices are more favorable. Moreover, the void left by the elimination of state marketing boards has not been filled by efficient private marketing operators. Farmers have also been deprived of other services such as extension, research, and inputs.

Emergencies. The number, scale, and intensity of emergencies in Africa have all been increasing due to both natural disasters, especially drought and human-caused calamities and civil strife and conflict. Wars and related factors have become the most serious cause of food insecurity in much of the region. In 1994, out of the world's total of 32 million disaster victims receiving relief assistance from the World Food Programme (WFP), 21.5 million were living in Africa. Of these, nearly two-thirds were victims of human-caused disasters, distributed among West and Central Africa (4.6 million), the Horn and East Africa (3.9 million), and southern Africa (5.6 million).

Effects on population. In the rural areas of the region, those most vulnerable to food insecurity are smallholder farmers (73% of the rural population in the countries studied), nomadic pastoralists (13%), and cross-cutting these two groups, households headed by women (3.1% of all rural households).

Demand Issues

The most recent FAO statistics indicate that 33% of the population of sub-Saharan Africa is chronically undernourished, compared with 37% two decades ago. A detailed look at the continent reveals significant progress in some subregions and deterioration in others. With Ghana leading the way, eight countries in West Africa reduced hunger significantly between 1980 and 1996. However, the picture is very different in Central, east, and southern Africa, where the proportion and number of the undernourished generally increased. Burundi suffered the largest increase, with the proportion of undernourished people rising from 38 to 63%. Thirteen other countries in Central, east, and southern Africa also showed large increases.

Food consumption. The consumption of individual commodities over the past decade has shown little change in per capita terms at the continent level. The per capita consumption of most commodities (pulses, meat, eggs, milk, fruits, and vegetables) has virtually remained unchanged since the early 1990s, while there have been slight increases in that of cereals (140 to 145 kg) and oilcrops (4.3 to 5 kg). The per capita consumption of cereals in Africa as compared to the world average is about 90% while it is about 66% for oilcrops, 60% for eggs, 50% for milk, and 40% for meat. In contrast, consumption of pulses and starchy roots are about 150% and 200% respectively of the global average.

Food demand. The main constraint to demand in Africa is the lack of purchasing power. Average income growth in Africa has lagged behind other regions in the world. On the other hand, rapid population growth is increasing food demand and creating pressures to increase food supplies. Average GDP growth in agriculture was 2.3% in 1990-97, less than the rate of population increase (2.4). During the same period, overall GNP grew at 2.9%. Currently, protected markets impose high costs on consumers who would be expected to benefit under more liberalized markets.

With market integration, consumers will have the opportunity to buy from the cheapest producers in the region, hence increasing their purchasing power.

Trade Patterns

Agricultural exports. Current export patterns in Africa are characterized by a small number of primary (often plantation-based) commodities and a dependency on preferential access to a few markets in developed countries. The main export crops are cocoa, coffee, and cotton. However, some countries also export substantial quantities of sugar and beef to the European Union (EU) under the ACP Protocols.

Food imports. Most African countries are net importers of staple foods (e.g., rice, wheat, and vegetable oils), and as per capita food production has fallen over the last two decades, their import dependency has increased. For example, imports now account for about 25% of the total supply of cereals in Africa. African food imports originate outside the region, primarily from developed countries and often on concessional terms and/or under export subsidies.

Intra-African agricultural trade. According to official trade statistics, intra-African trade in agricultural products is less than 3% of total agricultural trade. (Intra-African trade accounts for about 10% of total merchandise trade.) Evidence suggests, however, that actual cross-border agricultural trade has a long history and is much more substantial than what official statistics indicate. Artificial colonial boundaries cut through some established trading patterns but did not really interfere with them. After the colonial powers left, the new governments attempted to control cross-border trade, usually with little success. Creating a common market for agriculture would legitimize this trade, enabling governments to quantify it and to take account of it in planning and policy decisions. It would also permit farmers to produce more in accordance with their comparative advantage and market conditions.

Most of the constraints to intra-regional trade in Africa are policy induced and/or are amenable to policy reform. The constraints include, inadequate physical infrastructure. Much of the transportation network in Africa is geared towards trade with the former colonial powers than with neighboring countries. In West Africa, for example, most roads head north from the ports into the cash crop producing areas. There are few roads heading east-west to connect neighboring countries. In eastern and southern Africa, the transportation network is largely geared towards connecting producers of cash crops and areas with natural resources such as copper, to capital cities and the sea. Thus food producers in remote areas may well have potential markets in neighboring countries but have few roads to help them supply those markets. Moreover, much of the infrastructure is in poor condition, slowing down

transportation and increasing freight charges. Many railways are operating below capacity due to a lack of rolling stock and the poor state of tracks. A further constraint, which applies to several countries, is the so-called "third-party ruling" which limits transportation between two countries, to trucks which come from one or the other of those countries.

Unstable market opportunities. Since traders never know when an area is going to be in surplus or in deficit, they cannot establish ongoing and reliable trading partners. Mozambique may be a good market for Tanzanian maize next year, but it may be another five years before such a market opportunity arises again. Therefore, involving in maize trading is much more complex than exporting a cash crop to a European market, where the demand is more or less constant and where trading firms have been in business for 200 years.

Small markets. Most maize production, for example, is by smallholders who are widely dispersed, thereby making economies of scale difficult to achieve. While domestic traders can function in this situation, exporting generally requires larger quantities. Traders face major problems in financing larger transactions because banks are unwilling to lend to them and interest rates are high.

Lack of current market information and trading skills. Most small, local traders have only been importing and exporting for the last two or three years, and have little knowledge about standard contracts, and banking arrangements such as letters of credit, etc. Few have reliable information about potential buyers in other countries and about their requirements in terms of quantity, quality, delivery arrangements, payment, etc. There is a need for a reliable subregional market price information service.

Uncertain policy environment Variable/seasonal tariffs are common and export/import bans occur frequently, disrupting private transactions and inhibiting the development of reliable markets. Documentation procedures in trade are unnecessarily cumbersome. Many rules, licenses, taxes, and duties are applied in an arbitrary fashion according to official whims. Confusion and corruption prevail due to the repeated failure of governments to make all the rules and regulations as transparent as possible and to ensure that everyone knows about them.

Wars and civil strife. At any one time, about one-third of the region is either at war, civil strife, or both.

Macroeconomic Policy Environment

Differing monetary and economic policies will give rise to trade impediments due to nonconvertibility of exchange rates and gaps between official exchange rates and market rates, financial risk, and other factors.

Monetary reform. ECOWAS plans a common currency by 2004, with assistance from IMF, in formulating accession requirements pertaining to monetary and fiscal conditions; convergence among Anglophone countries and then with the Francophone zone.)

Fiscal policy reform. There is an increasing need to address fiscal policies, especially taxation. As countries lose important revenues through increased liberalization of trade, new, efficient, and equitable sources of public revenue need to be generated. This also brings into focus the issue of a more equitable redistribution of public revenues to compensate losers (both within the national economies and within the region) in the process of policy transition. SACU has devised a new formula for revenue sharing from its common external tariff. The new formula was developed in a democratic way and favors the weaker members.

Privatization and the role of the state. The balance between public and private sectors is crucial. While **privatization** of some activities is essential to ensure competitiveness, the public sector still has an important role in providing transportation, power, water, communications, education, and health.

Funding for Agriculture

Why does ODA for agriculture and rural development continue to drop year after year in spite of the emphasis all major donors and international banks lay on poverty reduction and the recognition that poverty is highest in rural areas?

The Joint Forum on Development Progress, convened by the UN, OECD, World Bank, and the IMF, at its meeting recently, deplored the fact that "aid has since 1992 fallen from one-third to one-quarter of one per cent of donors' GNP", and argued that "the present level needs to be increased, to fund many worthwhile projects" which would contribute to the ability of developing countries to meet their poverty alleviation goals.

The drop in ODA for agriculture and rural development has been particularly marked, falling from around 25 to 30% of total ODA in the 1980s, to less than 15% in the 90s. And as with much of the aid, it is not necessarily targeted at those countries which most need it.

OECD transfers. OECD transfers to the rural people living in developing countries amounts to around US$ 10 billion per annum, compared to over US$ 350 billion to farmers in member countries.

OECD transfers to Africa. The situation in Africa is particularly dismaying. For instance, over the past three years, total World Bank/IDA funding for agricultural and rural development for sub-Saharan Africa has amounted to less than US$ 250 million per year, or less than US$ 1.40 per malnourished person in the region — a mere drop in the ocean of needs.

What is at the heart of this? Is it a lack of viable investment opportunities; the poor track record of agricultural projects in the past, or a lack of confidence in institutional capacities and national policies for rural development? Or maybe an urban bias in resource allocations or perhaps it is much easier to invest in other sectors, where the results do not depend on the decisions of a vast number of widely dispersed small farmers exposed to the vagaries of nature?

If we accept that many of the poorest countries — such as those in the Horn of Africa — will continue to be heavily dependent on external financing if they are to make progress in reducing poverty and improving food security, what can be done to reverse recent trends and thereby ensure that adequate funding is available for well designed programs for achieving the goals to which both developing and developed countries have subscribed?

What steps can we take to raise the level of the world's scarce productive resources and enhance their productive potential for future generations? Can the rural people have a greater say in their destiny? Can the Africans have a greater say in their own affairs? Most of these are African problems; maybe it is time we found African solutions.

Free Trade Zones

Recently, while at the launch of the free trade area of COMESA, I kept wondering how certain we could be that trading policies, as now applied, would contribute positively to poverty reduction and improved food security, especially in the LIFDCS?

Agriculture Trade Liberalization

Few people doubt the long-term benefits of more open and competitive markets, but is there not a serious danger that, at least during a transition period, many poor people — especially in rural areas — may become worse off and by implication, more food insecure? The supply response of a agrarian societies in developing country to changing market opportunities can only be slow, given many small farmers' limited access to capital, technologies, market knowledge, and extra land, and the general weaknesses of supporting institutions.

In the meantime, vast numbers of such farmers find themselves pitted in increasingly direct competition with larger farmers in the developed world, whose more ready access to modern technology, various forms of persistent protection, and a progressive growth in farm scale have enabled them to withstand a secular decline in world cereal prices. Under small farm conditions in developing countries, failing cereal prices equate with a spiraling drop in rural incomes, reduced capacity to buy inputs, and ultimately to a fall in production incentives, precisely the scenario that we all wish to avoid.

Any options? We must ask ourselves what options exist for managing global and national liberalization processes, nationally and internationally, in ways which we are confident will contribute to improved food security for both the urban and the rural poor in the long and short term.

Can agricultural development alone help? It is very clear that though there are opportunities to improve the performance of both crop- and livestock- based farming systems, agriculture alone cannot provide the basis for a significant improvement in the livelihoods of the people in Africa. And yet, the opportunities for diversification of employment are severely constrained by the natural resources with which the region is endowed. Better nutrition, health, and education minus conflict and wars in an environment of democratic leadership and awareness, will lead to greater equilibrium between the people and their environment. Urgent though the needs are, such processes must be locally driven and managed if they are to take hold. Therefore, the challenge for the international community will be to provide assistance on an ample scale in ways which successfully encourage local initiative.

Debt relief. Given the progress being made in debt reduction through the HIPC initiative, can't we focus national Poverty Reduction Programmes on food security projects as well as on health and education activities?

Leadership. The time has come to take a serious look at developing a leadership right from the household and village levels, to the head of state, especially since the major financiers of government, led by the World Bank, put democracy and decentralization as prerequisites for funding. I believe this would generate sufficient human capital to tackle poverty reduction and improve food security in the world's poorest countries. Can't the amazing coalition of public support which has contributed to bolstering international resolve to reduce debt also not mobilize political support for an end to the further incapacitation of African governments and its peoples?

The potential. The achievement of the abundant African potential requires the following conditions:

- more certain tenure to farm land;
- markets with adequate supplies of fertilizer and improved seeds;
- tools and technical options as well as a coordinated and clearly-focused program towards achievement of peace;
- research, access to credit and extension, and other social and health services;
- land and irrigation development;
- increasing land and labor productivity;
- improved infrastructure services;
- developing additional technologies to overcome production constraints that currently have no technical solutions;
- prevention of animal disease for increased livestock production and trade;
- mitigation of natural disasters such as drought; and
- better information services and setting up of commodity exchanges.

The resulting configuration of the agricultural sector is one that will be more diversified, productive, private-sector led, and internationally competitive. In time, the goals of higher and more evenly distributed farm incomes and food security will be attained. Both are essential to improve the quality of life and attain human development.

Finally, I believe that until we have stable, responsible, and respected governments in the countries covering the region, all the above, including the title, will come to naught.

Breaking the Unholy Alliance of Food Insecurity, Poverty, and Environmental Degradation in the Asia-Pacific Region

R B Singh[1]

The Current Scenario

We have entered a millennium full of challenges and opportunities. Living standards in much of the developing world continue to improve, but in many of the least developed, low-income, food-deficit countries, livelihood security has deteriorated further while per capita economic assistance from the developed world has greatly declined.

Though mankind has made unprecedented progress—from mapping the human and rice genomes, the possibility of the transfer of any gene from one organism into another, to cyber-space, and instant global communi-cation— today, nearly 800 million people are denied the most basic right: the right to food. Some 1.2 billion subsist on less than US$ I a day. Half of the world's population still survives on less than US$ 2 a day. In a world of unprecedented wealth, these levels of deprivation are disgraceful.

Drawing from technological breakthroughs and the progress in production and productivity of agriculture and food in the Green Revolution era and beyond, I am optimistic of our success in the fight against hunger and poverty. The FAO report on the State of Food Insecurity in the World revealed that between 1990-1992 and 1995-1997, the total number of malnourished people decreased by 40 million. This average annual reduction of 8 million people though encouraging, is not enough.

The Asia and Pacific regions saw the number of undernourished fall from 32% of the population to 21% in the eighties; and further down to 17% by the triennium 1996/98. However, the number of

Singh, R. B. 2001. Breaking the unholy alliance of food insecurity, poverty, and environmental degradation in the Asia-Pacific region. Pages 63-72 *in* Future of agriculture in the semi-arid tropics: proceedings of an International Symposium on Future of Agriculture in Semi-Arid Tropics, 14 Nov 2000,1CRISAT, Patancheru, India (Bantilan, M.C.S., Parthasarathy Rao, P., and Padmaja, R., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

1. Assistant Director General and Regional Representative, Food and Agriculture Organization of the United Nations, Regional Office for Asia and the Pacific, Bangkok, Thailand.

hungry people in this region actually increased by three million in the last six years to 515 million (i.e., 64 % of the world's under-nourished people). The extent of hunger is particularly serious in Bangladesh, Democratic People's Republic of Korea, and Mongolia (Table 1).

Are we wavering in the commitment and promise of reducing by half the number of undernourished people by the year 2015 made at the World Food Summit in 1996? To meet our pledge, the ranks of the region's hungry must be reduced by at least 14 million per year instead of the 13 million set at that time.

The hungry child can't wait. It is today that his bones and sinews are being formed. "You cannot tell him tomorrow", a famous novelist has written. "His name is today".

Experience has taught us to hedge our bets. The multiple causes of food insecurity continue to increase the number of vulnerable households. Land degradation and water scarcity, natural and man-made disasters, economic mismanagement, limited import

Table 1. Prevalence and extent of undernourishment, 1996-1998.

Region and countries	Number of undernourished (million)	Proportion of undernourished population (%)	Food deficit of the undernourished (kcal person^{-1} day^{-1})
Developing world	792	18	
Asia and Pacific	515	17	
East Asia	155	12	
China	140	11	250
Korea DPR	13	57	340
Mongolia	1.1	45	310
Oceania (PNG)	1.3	29	260
Southeast Asia	65	13	
Cambodia	3.4	33	270
Indonesia	12.3	6	200
Lao PDR	1.5	29	2S0
Myanmar	3.1	7	200
Philippines	15	21	270
Thailand	12	21	260
Vietnam	17	22	280
South Asia	294	23	
Bangladesh	47	38	340
India	208	21	290
Nepal	6.2	28	260
Pakistan	29	20	270
Sri Lanka	4.5	25	260

capacity, inefficient marketing systems, poverty, and sanitation and health-related problems are often interrelated and have worsened in many developing countries, more so in the last decade.

Food insecurity and poverty are closely related for poor, small, and marginal farmers. Lack of sufficient and reliable income lies at the core of food insecurity and the inability to achieve sustainable livelihood. Inadequate or inaccessible health services and sanitation, food supply, and modern energy sources render the poor susceptible to malnourishment and illnesses, thereby hindering their productivity. Disasters have also caused food insecurity among vulnerable population groups in the region.

Rising population density, migration to vulnerable areas, and associated environmental degradation magnify the effects of such disasters. Large and devastating impact in terms of price upswings and instability of food access often push people from transitory poverty into poverty traps. Global environmental changes as well as climate variability triggered by El Nino, will constitute additional stresses, and may contribute to further weakening the resilience of traditional food production systems.

Disaggregations reveal that the different subregions of the Asia-Pacific region have specific concerns and opportunities. For instance, South Asia is home to one-third of the world's undernourished and two-fifths of the world's poor. The subregion accounted for 51% of the world's malnourished children in 1995, which is projected to decline to 41% in 2020. With such a high concentration of hungry children, the future of these nations is already gloomy. Should these disaggregations and stark realities not be kept in mind while setting our research and support priorities?

Poverty remains mainly a rural phenomenon in the region. About three-fourths of the poor live in rural areas. Even urban poverty is partly an indirect effect of rural poverty. Agrarian and landless rural households have the highest concentration of poor. With over 3.44 billion people, the region includes several of the most populous countries of the world. Although the region's population growth rate decelerated from 2.36% per year in the 1960s to 1.43% during the 1990s, some countries have population growth rates of over 2% per year and high population densities. Thus, in some cases the absolute number of poor people increased although the proportion of population under the poverty line declined.

While fast growing economies need to enhance rural incomes to reduce intersectoral disparities and achieve balanced human development, low-income countries have to contend with problems like poverty, food insecurity, low levels of human resources, institutional and infrastructure bottlenecks impeding productivity, limited access to capital and modern technology, and marketing constraints.

The Strategic Concerns

Population pressure and demographic transition. By 2020, another 750 million, i.e., 22% more people will be added to the region, which is also expected to witness a rapid rural-urban transformation with the ratio of urban population increasing from 36 to 48% in two decades. As people's incomes increase and they move from rural to urban areas, their dietary patterns diversify. Their demand for cereals changes from coarse to fine grains, and they tend to consume more livestock products, fruits, vegetables, and processed food. If incomes also grow at rates resembling recent trends, countries in the Asia-Pacific region would account for more than half the increase in the global demand for cereals and an even larger share (57%) for meat products. While the demand for cereals for direct consumption (rice) is beginning to level off, the derived demand for cereals (maize for animal feed) is growing substantially, mainly driven by the rapidly growing demand for meat.

In addition to an increase in demand for food and agricultural raw materials, there will be a substantial change in the composition of demand with growing incomes, urbanization, and nutritional awareness. Can the region meet these demands? The case for optimism is not lost. Past decades have witnessed a more daunting demand-supply situation for food and agricultural products than prevailing now. Populous Asia-Pacific countries have demonstrated a remarkable capacity to respond to the challenges of rising demand despite severe resource constraints. However, these projections have profound implications for the availability and adequacy of land, water, and labor for agricultural purposes, as well as for the environment and technologies as the agricultural sector gradually adapts to the market forces.

Population pressure has an adverse influence on poverty and food security. But poverty and food security also affect demographic transition to lower fertility rates in developing countries. Given such an inter-relationship with health and fertility, poverty and food security should form an important element in strategies aimed at reducing population growth, minimizing environmental degradation, and promoting socioeconomic development.

Resource base degradation and water scarcity. Population pressure as well as inappropriate policies and institutional framework are taking a heavy toll on the natural resource base. A good part of the cropped land in the region is in fragile, rainfed, and semi-arid areas, with steep slopes or poor soils or both. Low and declining soil fertility is a growing problem. The situation calls for continuing efforts to improve land tenure administration and institution building for better access by the poor, on the one hand, and to protect and work with indigenous rights in natural resources on the other. Dwindling per capita resources and the slow growth of productive nonfarm employment opportunities in many parts of the region have intensified the pressure exerted by the poor on natural resources through nonsustainable farming practices. Indeed, there exist discernible links between the natural resource base, agricultural productivity, health and nutritional status of the population, and poverty.

Globalization, inequality, and poverty. Globalization has aroused the fear that it exacerbates inequality, helps perpetuate poverty in some segments of society, and contributes to the inability of developing countries to defend themselves from external shocks. Indeed, calls for a slowdown to embrace it intensified as economies that openly welcomed globalization began to tumble in the wake of the Asian crisis. Such calls are akin to the regime of inappropriate controls that was quite popular in the 1950s and early 1960s but failed in delivering growth and poverty alleviation. In contrast, cross-country evidence indicates that opening up of the goods markets and pursuing comparative advantage in line with factor endowments is advantageous for growth and equality in developing countries where low-skill labor is abundant and capital is scarce. However, subtle timing and sequencing of liberalization are important. Appropriate compensatory and targeted policies may be needed. Moreover, institutional mechanisms to enhance the transparency and efficiency of international trade and financial transactions and to monitor and signal impending distress situations need to be promoted.

In recent years, there has been a general feeling of acceptance of, if not resignation to, the globalization of agriculture. The growing linkages of small farms through trade may not be obvious in a small farming village, but their importance is increasingly evident. Between 1970 and 1996, agricultural trade in the Asia-Pacific region (in nominal terms) expanded by about a factor of eight, almost at the same rate as the growth of world agricultural trade. In 1997, the total share of Asia's agricultural trade (exports plus imports) constituted 18% of world agricultural trade.

Many developing countries still lack the minimum technical and legal specialists to be able to take advantage of the special and differential treatment available to them and to participate effectively in the coming negotiations to ensure that their interests are taken into account. Countries in the region may therefore wish to develop national expertise on various agriculture-related agreements.

The Way Ahead

Global call to break the unholy alliance. The unholy alliance between food insecurity, poverty, and environmental degradation must be broken. Freeing humanity from hunger and malnutrition is a moral obligation. During the past decade, three major world summits were held to address these issues: the Earth Summit on environmental protection and sustainable development (1992), the World Summit for Social Development on alleviation of poverty and social ills (1995), and the World Food Summit on food security (1996).

To top these, the United Nations Millennium Summit 2000, in its Declaration, highlighted the importance of values and principles, peace and security, development and poverty eradication, protecting our common environment, human rights, democracy and good governance; and protecting the vulnerable.

In addition, there are several regional and global fora, including the CGIAR Centers' Weeks and the Global Forum on Agricultural Research (GFAR) which continuously review the situation and evolve dynamic and responsive priorities, strategies, and action plans. We must keep track of these developments and internalize them in our visions, strategies, and programs. In this context, we greatly appreciate ICRISAT's philosophy of 'Science with a human face', which is akin to our longstanding approach.

ICRISAT faces the greatest challenge of addressing the highly complex problems of the harshest agroecosystems. The Semi-Arid Tropics is characterized by persistent drought, infertile soils, huge loss of top soil, and high uncertainties of climate change and scant rainfall. It has the formidable task of breaking this unholy alliance. The promising developments in technologies and their diffusion in the past and the present, and the holistic plans for productivity and sustainability gains undertaken by the Institute give us hope.

Technology with a human face. Technologies cannot operate in a vacuum; they must have a human face. During the past three decades, excellent progress has been made in reducing hunger and poverty. This was mostly science- and technology-led. But much still needs to be accomplished before hunger is finally wiped out. Someone has said, "It is humankind that is responsible for having imposed hunger on itself for so long, but humankind is also capable of eliminating this burden. There can be no greater challenge than this".

We must look ahead to what is new in the century. We must traverse through the old revolution of rising human expectations overlapping those stemming from cyberspace, globalization, and new technology, especially biotechnology.

As we harness new opportunities, we must be mindful of the interests of billions of small and subsistence farmers, fisherfolk, and forest dwellers. We cannot afford to neglect social aspirations for a more just, equitable, and sustainable way of life. We must always keep in sight the hungriest, the poorest, and the water-hungry, sun-drenched vast SAT lands as we decide our priorities, policies, and strategies.

Enhanced and sustained food and agricultural production. There is ample scope to improve our average yields. Generation and effective assessment and diffusion of packages of appropriate technologies involving a system- and program-based approach, participatory mechanisms, greater congruency between productivity and sustainability through integrated pest management and integrated soil-, water-, irrigation-, and nutrient-management should be aggressively promoted. The food and other agricultural products thus produced in pockets where needed the most, improve the entitlements of the inhabitants. In predominantly agrarian economies, there is no mechanism for distributing entitlements to peasants other than that of enabling them to develop their food and agricultural produce. Rainfed and other noncongenial areas, where the entitlements are low, must receive high priority.

Raising agricultural productivity requires continuing investment in human resource development, agricultural R&D, improved information and extension, farm-to-market roads and related infrastructure, and efficient small-scale, farmer-controlled irrigation technologies. Such investments would give small farmers the option and flexibility to adjust to market conditions.

Entitlement **to** food. Hunger often results from people's lack of access to the plentiful food in the market. Nobel laureate Amartya Sen has the following to say, which eloquently summarizes the path policy makers must follow:

> " The mere presence of food in the economy, or in the market, does not entitle a person to consume it. A person's entitlements depend on what she owns initially and what she can acquire through exchange."

Building technological and human resource capital. Research is the engine of growth. Directed research policies and desired support are fundamental to the growth and development process, which must increasingly become science-based. Blending new, conventional, and indigenous technologies, called "ecotechnology", is the desired path. In India, the 1CAR, its institutes, and agricultural universities have prepared their Perspective Plan - Vision 2020, an exercise which has provided the necessary roadmap. The NATP, AHRD, and other initiatives have provided targeted research and human resource development support. These initiatives must be judiciously harnessed and effectively monitored for their impacts.

I wish to particularly highlight the prospects of biotechnology. It is fortuitous that as we have entered the new millennium and were seeking a technological breakthrough which may spearhead agricultural production in the next 30 years, modern biotechnology with its multiple and far-reaching potential has appeared on the horizon. It has the potential to enhance yield levels, increase input-use efficiency, reduce risk and depress the effects of biotic and abiotic stresses, and enhance nutritional quality leading to increased food security, nutritional adequacy, poverty alleviation, environmental protection, and sustainable agriculture. Often referred to as the 'Gene Revolution' or 'Bio-Revolution', biotechnology, if judiciously harnessed, and blended with traditional and conventional technologies and supported by appropriate policies, can lead to an Evergreen Revolution - synergizing the accelerated pace of growth and sustainable development.

Future efforts must concentrate on reaping the benefits as well as minimizing the negative effects of biotechnology on a case by case basis. Biotechnology should be kept in a balanced perspective by integrating it within the national research and technology development framework. It should be used as an adjunct to rather than a substitute for conventional technologies in solving problems identified through national priority setting mechanisms. Priority setting should also take into account national development policies, private sector interests, market possibilities, public perception, and consumers' views. Accordingly, various stakeholders, the public and private sector, industries, NGOs, and civil societies should be involved in the formulation and implementation of national biotechnology policies, strategies, plans, and programs.

The technology risks must be critically and scientifically assessed in a transparent manner. Capacities and measures should be in place to manage the risks, minimize the negative effects, and promote the positive impacts. Each country must have the necessary infrastructure, human resource, financial support, and policy to meet the challenges and capture the novel opportunities. Competence will particularly be required in formulating country-specific rules on biosafety and Intellectual Property Rights management regimes, along with commensurate financial, institutional, information, and human resources for their effective implementation.

Keeping pace with globalization. The globalization of agricultural trade will result in access to markets, new opportunities for employment and income generation, productivity gains, and increased flow of investments into sustainable agriculture and rural development. If managed well, the liberalization of agricultural markets will be beneficial in developing countries in the long run. It will force the adoption of new technologies, shift production functions upwards, and attract new capital into the deprived sector. Trade agreements must be accompanied by operationally effective measures to ease the adjustment process for small farmers in developing countries.

Exploiting cyberspace. The power of Information and Communication Technology (ICT) must be harnessed to empower the poor. It should touch the untouched. Effort must be made to strengthen informatics in agriculture by developing new databases, linking the databases to international databases, and adding value to information in order to facilitate decision-making at various levels. Developing production models for various agroecological regimes in order to forecast production potential should assume greater importance. Using remote sensing and GIS, natural and other agricultural resources should be mapped at micro and macro levels. The data can be effectively used for land- and water-use planning, agricultural forecasting, market intelligence, e-commerce, contingency planning, and prediction of disease and pest incidences. This is particularly important for SAT countries where uncertainties rule the regime.

Epilogue

Ways of improving productivity and diversifying agriculture and the rural economy in order to create employment and income opportunities which will ultimately alleviate poverty and deprivation, will continue to occupy the minds of policy makers in the region. Broadbased sustained growth in agriculture and the rural sector is the key strategy for addressing rural poverty. However, it must be remembered that the sector faces a vastly changing landscape in a globally competitive environment and is caught in a bind with increasing costs of capital and labor relative to output prices. Industrialization draws the younger, better-educated, and more productive labor force out of agriculture, while globalization and trade liberalization call for higher efficiencies through the application of modern science and technology in agriculture. Finding the right formula to sustain agricultural growth in a setting of rapid and dynamic change requires vision, forward-looking policy measures, and innovative approaches.

Major paradigm shifts are needed to break the unholy alliance. The problems and solutions must be disaggregated. For instance, the South Asian subregion should have the highest regional and global priority while addressing the issues. Likewise, fragile agroecosystems such as the SAT must receive highest support from all stakeholders, NARS, the CG system, the United Nations, NGOs, and the private sector. The subregional and regional peculiarities must underpin global agenda setting. Major shifts will be needed in the structure, function, governance, and policies of these bodies to realize the goal of a hunger-free Asia and world. The name of the game is partnership. Appropriate mechanisms must be in place and effectively managed for ensuring partnership through forging vertical and horizontal linkages.

The FAO as a cosponsor of the CGIAR and the provider of the TAC and GFAR Secretariats, is one of the most formidable partners of the CGIAR system. In particular with ICRISAT, the Organization has had excellent cooperation in program formulation and execution, networking, and human resource development. We must further strengthen our cooperation in the field of policy advocacy, information sharing, and management of agrobiodiversity, and technologies. The FAO Regional Office for Asia and the Pacific Region, as the initiator of APAARI, would further be strengthening this vibrant regional association for priority setting and information sharing in close partnership with NARS, ICRISAT, other CG centers, GFAR, and other regional and international organizations and initiatives. We shall welcome ICRISAT's collaboration, particularly in our Special Programme on Food Security (SPFS) in the SAT region.

Value-based Crop-livestock Production Systems for the Future in the Semi-Arid Tropics

V Kurien[1]

Introduction

The history of civilization is closely associated with domestic animals. In the early days of human communities, a few large animals were domesticated, enabling humanity to steadily rise from primitive conditions to a life of higher quality. Large domestic animals made the transition from hunting, gathering, and shifting cultivation to more settled lifestyles possible. Domestic animals have played a key role in the development of the human community and contributed to its well being by releasing people from the hard labor of field work; enabling the transportation of natural resources and farm products to other communities for barter or sale; providing fat and protein for improved nutrition and milk; providing leather, wool, and horn for clothing and shelter; fat for lighting; dried manure for cooking and heating; power to draw water for domestic use and irrigation; and improved and integrated farming systems on cropped land. The domestication of animals was the first step towards improving the quality of life through science and technology.

The major advances in civilization leading to trade, industrialization, the application of science, and the development of market economy capitalism were made possible mainly because animals had first freed a proportion of the population from the daily routine of food production.

Traditions and Values[2]

For thousands of years, everyone has been in touch with domestic animals on a day-to-day basis.

Kurien, V. 2001. Value-based crop-livestock production systems for the future in the semi-arid tropics. Pages 73-82 *in* Future of agriculture in the semi-arid tropics: proceedings of an International Symposium on Future of Agriculture in Semi-Arid Tropics, 14 Nov 2000, ICRISAT, Patancheru, India (Bantilan, M.C.S., Parthasarathy Rao, P., and Padmaja, R., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

1. Chairman, Institute of Rural Management, Anand, India.

2. This section is based on John Hodges's article, "Animals and Values in Society", Research for Rural Development (11) 3, 1999.

People have held them in high esteem and even regarded them as sacred. Animals are wealth and are used both for savings and as currency. In some parts of the world, the status of a family is often recorded by the number of livestock owned. In parts of Africa, a bride is given away in return for livestock. In India, Hinduism holds the cow in high esteem and sees a link between the life of domestic cattle and that of humans. In Moslem society, sheep and goats are vital to fulfill religious obligations. In brief, domestic animals have greatly influenced community rituals and values in most early societies.

While traditions and rituals are often beautiful and mark for us the pattern of life, they are rarely essential. In contrast, community and public values enable a society to survive and advance — or they cause its decline. Values direct activities; they allocate resources in a society and thereby shape its nature.

The values our society holds today are focused upon material prosperity, economic growth, Gross National Product (GNP), and the rights of the individual to do what he or she prefers with the rewards of labor and investment. In a democracy like ours, society's values shape government policy and legislation. People today are deeply concerned that our current, narrowly focused values do not provide sufficient care for the environment and for animals and further, that they define quality of life solely in material terms for immediate consumption.

The new values have come about partly because of the lack of day-to-day contact with animals and the natural environment. The fact that a person owns animals leads to a personal commitment to care for them. When people accompany cattle, sheep or goats into the natural environment, they realize that animals and human communities are parts of the whole natural order. Domestic animals need society for protection. Neither can live in isolation.

Thus, the values of simpler societies were for thousands of years based upon a holistic view of life, which has been lost. We discovered that by focusing upon a single component, like crop production, we can make it more productive, but in our enthusiasm we forget the balance of the whole. This is the danger of reductionism. We need to ponder the deeper implications of the lost relationship of our civilization with the environment, with domestic animals, and with each other.

Rural Livelihood Systems

Indian farmers have traditionally preferred crop farming, and great success has been achieved in foodgrain production through the adoption of high-yielding varieties and associated packages of improved technology. But crop production alone is subject to a high degree of risk and uncertainty and provides seasonal, irregular, and uncertain farm income and employment to farmers.

The problems are more acute in semi-arid regions than in others. Added to this is the decreasing farm size and increasing number of operational holdings. On an average, the size of land holdings in India is declining. Between 1985-86 and 1990-91 alone, operational holdings increased from 97 million to 106 million while the average size of operational holdings decreased from 1.69 ha to 1.55 ha. The small and marginal farms that accounted for 76.2% of the total farms increased to 78.4% during the same period. Similarly, the large- and medium-sized farms decreased from 10.2 to 8.7%. Succession laws pertaining to land division and fragmentation are leading to uneconomic farm sizes in India. This trend is unlikely to change in the near future.

The SAT is the largest region in India with 70% of the country's total cropped area. This region supports 40% of the population and contributes about 45% to total food supplies. The farmers of the region are generally poor and have a low risk-bearing ability. The persistence of mass poverty in these areas shows that interventions have failed. One of the major problems is the suitability of Green Revolution technologies to the diverse and risk-prone conditions of semi-arid areas for widespread adoption. As a result, agriculture in a large part of the semi-arid areas still remains under low-productivity; and low output conditions aggravate poverty.

The semi-arid areas have also been prone to large-scale degradation of natural resources caused by depletion of forests, soil erosion, declining common pool resources, etc. The consequence is a further erosion of the livelihood support system of the poor who depend on them. People have voluntarily adopted many strategies — ranging from a tendency to overexploit the already degraded resources to diversifying the sources of livelihood like migrating out to better off areas — to overcome their vulnerability. Evidence suggests that such diversification seems to have become a major survival strategy of the poor. It assumes added importance in the semi-arid areas in terms of addressing the question of poverty and issues related to sustainability of rural livelihood systems.

Deteriorating Livelihood Systems and Security

From time immemorial, Indian farmers had been practising mixed farming with crop and livestock enterprises supplementing or complementing each other. With increasing population and decreasing farm size, there has been increasing pressure on land, resulting in crop cultivation being extended to the less fertile and marginal lands. In the semi-arid areas, land under cultivation has not been able to feed the population resulting in both malnutrition and undernutrition, more so among the small and marginal landholders and the landless. The rural livelihood systems are increasingly becoming unsustainable. To reduce such problems, there is a need to rear milch animals along with crop production, ensuring regular income and employment throughout the year.

The combination of crop and livestock enterprises contributes to livelihood sustainability and also results in environment-friendly management systems. Livelihood sustainability is ensured through quick and regular returns, improved nutrition, and provision of employment to nonutilized family labor (especially women and children). The system is environment-friendly because byproducts of crop and livestock serve as inputs in the production of both enterprises. The exact composition of crops and optimal level of livestock enterprise will vary in different regions based on agroclimatic conditions and resource endowments in different socioeconomic groups.

Ensuring livelihood security—food, nutritional, social, and emotional security—is the prime concern of farmers. Each component has its own threshold that varies with time, space, and individual families. In the semi-arid areas, food security refers to the ability of the farm family to meet the food and fodder needs of the family and the livestock it owns, given the resources under its control. Understanding rural livelihood systems in a holistic manner and ensuring livelihood security to rural families in semi-arid areas is critical at this juncture.

Until now, the issue of food security has been tackled at the national level irrespective of where the food is produced in India. Emphasis was on the resource rich regions of the country. Green revolution technologies helped India achieve food security although they resulted in regional disparities in foodgrain production and inequalities in income distribution among farmers. Green revolution technologies were developed with predominantly technological and economic perspectives. Farmers in resource rich regions readily adopted them since food security was not an issue they had to contend with, whereas the same technologies did not find many adopters in the semi-arid regions. There is growing evidence to show that livelihood security is a key determinant in technology adoption.

To date, we have been evolving and evaluating technologies based purely on our own perspective of success or failure and on economic rationale. The success or failure of technologies are gauged using yardsticks developed by technologists. However, farmers gauge technologies based on considerations important to them and not merely on technical and economic parameters alone. It is often argued that the technologies developed for semi-arid regions are inappropriate based on observations that farmers were not adopting them on a large scale. This is a misplaced fallacy. It appears that the nonadoption of mainstream technologies is not based solely on farmers' technical consideration (inappropriateness) of the technologies but a combination of other parameters including technical. The rationale in developing and disseminating technologies is primarily based on technical considerations and justified by economic analysis by the scientific community wherein nontechnical and noneconomic components are largely ignored. For example, several fanners in Panchamahals (a semi-arid district of Gujarat) grow a combination of rice (short duration) and pigeonpea (long duration)—one crop that requires standing water and the other well-drained soils. While agronomists would argue that such a combination is inappropriate based on technological considerations alone, economists may not be able to justify it based on economic rationality. To agronomists and economists, a maize and pigeonpea combination would be near perfect. Do we then say that farmers are irrational?

Given the erratic rainfall and its distribution, farmers found that if rainfall is heavy and early in the season, the maize crop is destroyed, rice benefits, and the pigeonpea crop may suffer slightly. This is especially true in low-lying areas. But they get both crops. They also believe that the two crops extract nutrients and moisture from the soil at different points in time. Alternatively, wheat could be grown after the harvest of rice if the residual moisture facilitates sowing. However, their experience suggests that both being shallow-rooted crops, the wheat crop will suffer for want of nutrients and moisture during the later stages of its growth when the upper layers of the soil become dry.

What seems inappropriate to agricultural scientists may be perfectly appropriate to farmers. The farmers, for reasons other than the inappropriateness of the technologies, may not adopt what seems appropriate for the developers of technologies. In most cases, adopters of modern agricultural technologies were above the livelihood security threshold and nonadopters were invariably below it.

If significant gains have to be made in the semi-arid regions, future research should be addressed in a transdisciplinary and holistic framework without losing sight of the farmers' perspectives. Agronomists, economists, social scientists, livestock specialists, environmentalists, and others concerned must work together in meeting the needs of a farm family.

Biodiversity in Crop and Livestock Production Systems

Crops. Today, much of crop diversity is being lost. Many unique varieties are disappearing and becoming extinct. The FAO estimates that since the beginning of this century, about 75 % of the genetic diversity of agricultural crops has been lost. "Genetic erosion" refers to the loss of genetic diversity between and within populations of the same species. The primary reason for this loss is that commercial, uniform varieties are replacing traditional varieties. When farmers abandon their community-bred varieties to plant new ones, the old varieties become extinct.

The "Green Revolution" refers to the development of high-yielding grains that were introduced by international crop breeding institutions in the 1950s. The spread of new varieties was dramatic. In the process, new and uniform cultivars from both the public and private sectors replaced community-bred varieties on a massive scale. Erosion of crop genetic diversity threatens the existence and stability of our global food supply.

Crop genetic diversity is the key to food security and sustainable agriculture because it enables farmers to adapt crops suited to their own ecological needs and cultural traditions. Without this diversity, options for long-term sustainability and agricultural self-reliance are lost. The type of seed sown to a large extent determines the farmer's need for fertilizers, pesticides, and irrigation. Communities that lose community-bred varieties and indigenous knowledge about them risk losing control over their farming systems and becoming dependent on external sources of seeds and the inputs needed to grow and protect them. Therefore, self reliance in agriculture is impossible without an agricultural system adapted to a community and its environment.

An estimated 60 % of the world's agricultural land is still farmed by traditional or subsistence farmers, mostly in marginal areas. A majority of the world's resource-poor farmers are women. As Norwegian plant breeder Trygve Berg points out, most of the south's farmers produce food under conditions which are considered marginal, making their problems and needs far from marginal. Though frequently characterized as "resource poor," many marginal fanning areas tend to be extraordinarily rich in plant and animal genetic diversity and traditional knowledge.

In spite of success in raising yields and food production in some high-potential areas, the Green Revolution's universal approach to high-input, high-yielding plant breeding has been largely unsuccessful in less hospitable, site-specific farming environments. For the majority of the world's farmers, therefore, self reliance in food production depends on adapting technologies and germplasm to a wide range of poor production environments.

Ultimately, farming communities hold the key to the conservation and use of agricultural biodiversity, and to food security for millions of the world's poor. They are the innovators best suited to develop new technologies, germplasm, and manage their diverse ecosystems. As plant collector David Wood observes: "There are about 3 billion farming people in the world. They have almost infinite capacity, experience, and application to select and maintain crop germplasm". In the long run, the conservation of plant genetic diversity depends not so much on a small number of institutional plant breeders in the formal sector, but on the vast number of poor farmers who select, improve, and use crop diversity, especially in marginal farming environments. But neither institutional breeders nor farmer breeders can succeed alone. Success depends on integrated approaches that combine the best of traditional knowledge and institutional technologies.

Livestock. Worldwide, the greatest threat to domestic animal diversity comes from the highly specialized nature of commercial livestock production. In the industrialized world, commercial livestock farming is based on very few breeds or strains that have been selected for the intensive production of meat, milk or eggs in highly controlled and regulated conditions. The spread of industrial agriculture in the south places thousands of native breeds at risk from genetic dilution or replacement by imported stocks. Commercial breeds imported from North America and western Europe are usually unable to sustain high production in less hospitable environments. They require intensive management and costly inputs such as high-protein feed, medication, and climate-controlled housing. Introduction of intensive animal production in most areas of the south creates a dependency on imported technologies and germplasm; this is neither affordable nor sustainable for poor farmers.

The common approach of importing exotic animal breeds to boost productivity of livestock in the south is now being rethought in recognition of the fact that native breeds are far more likely to be productive under low-input conditions. Many native breeds have great potential to increase production without loss of local adaptation, which can be realized with appropriate selection programs. According to an FAO expert on animal genetics, "In 80% of the world's rural areas, the locally adapted genetic resources are superior to common modern breeds".

Ironically, it is the unparalleled productivity and success of these industrial stocks that is indirectly responsible for most of the erosion and loss of poultry genetic resources worldwide. Well-meaning foreign aid programs that donate imported animal semen to the developing world, for example, have been cited as agents of extinction for many indigenous breeds, particularly cattle. It is important to note, however, that these same technologies, if properly used, can be valuable tools for genetic resource management and conservation.

The gradual disappearance of indigenous breeds that are able to survive in extreme environments, such as deserts or other noncultivable lands, undermines food and livelihood security for the poor, and the capacity of people to survive in marginal areas. An estimated 12% of the world's population lives in areas where people depend almost entirely on products obtained from ruminant livestock — cattle, sheep, and goats. Farmers and pastoralists in many areas of the world not only contribute significantly to the maintenance of biodiversity in domesticated animals, but also help keep otherwise barren tracts of land available for human habitation. For these farmers, an animal's most essential quality is not its rate of growth or yield of milk, but its basic ability to survive and reproduce, which in turn ensures the family's self reliance and survival.

The challenge for the scientific community is to link conservation and development by enabling farm communities to assume a major role in managing and benefiting from the genetic resources on which their livelihoods depend. To succeed, farmers must have greater control over their genetic resources, access to technologies, research information, and a wider range of genetic resources and enhanced germplasm. This requires the formal sector to build upon the knowledge and experience of farmers, involve farmers in setting the research agenda, enable them to select and assess technologies, and work with them as partners in the maintenance and further development of their own seeds and livestock breeds.

Women and Livestock Management

Livestock management was always perceived as the traditional responsibility of women. For women, livestock are essential as a source of fuel, food, and supplementary income for the family. For most women, high fat in milk is more important than the quantity of milk. Many women prefer keeping goats due to the ease of handling, low input need, inexpensive source of good quality food for the family, and also the manure.

Women possess sound knowledge of livestock production management, particularly of feed resources. They know each animal's production characteristics, temperament, and feeding behavior. Most women are aware of the need for good quality feed in order to achieve better production but feel that feeding a nonproducing animal is not necessary. A proper understanding of traditional methods, which have emerged out of experience, supplemented with newer knowledge could help in developing effective animal feeding strategies for more productive animals. Besides major feed resources like crop residues and cultivated fodder, women have identified locally existing grasses, creepers, weeds, and tree species that could be utilized as supplementary feeds and are beneficial for dairy animals. Most of these are available seasonally and are generally dried and stored for use in the dry season. The availability of good quality feeds and fodder is always a constraint in rainfed and underdeveloped areas.

Feeding accounts for almost 70% of the cost of livestock production. Farmers are usually blamed for keeping an unnecessarily large number of animals because many animals are considered as nonproductive and are fed without any returns. A critical look at the practices adopted by farmers, particularly women, indicates that through experience they have developed effective ways of optimizing utilization of available feed resources. Such efforts are necessary simultaneously with breed improvement for large-scale livestock development programs.

The milch buffalo, the main dairy animal in India till recently, is usually stall fed. Available concentrates and good quality fodder are offered to them. High producing animals, recently calved animals, or those in late pregnancy are offered special supplementary feeds like edible oil, jaggery, grains, and oil cake. Materials like cottonseed, cotton seed cake, copra cake, and rice polishing were historically recognized as beneficial

and have been traditionally used to feed buffaloes or high-producing cows. These practices are clearly indicative of the farmers' wisdom and show that their approaches are exercises in resource optimization. Scientists, based on their specialized training, tend to look at farmers' reality within the rational framework of their disciplines rather than the totality. Farmers, on the other hand, look at reality as it exists before them without being aware of the disciplinary divisions. Therefore, before criticizing them for resistance to change or trying to forcefully introduce systems according to our own thinking, it is essential to critically study the traditional practices. It is possible to find solutions to many constraints from the farmers themselves, particularly from women.

Conclusion

As Checkland points out, "it is not nature, which divides itself up into physics, biology, psychology, economics, sociology, etc., it is we who impose these divisions on nature. And these divisions become so ingrained in our thinking that the power of reductionist science aside, it is not surprising that we find it hard to see the unity that underlies the divisions". It is only when we as scientists look at the world in a holistic manner from a farmers' perspective by removing the blindfold imposed by our narrow disciplinary training and experiences will we be able to make a difference to the lives of farmers living in semi-arid areas.

1 hope that the distinguished audience gathered here today would consider thes following propositions for the prosperity of semi-arid areas:

- incorporate farmers' and societal values based on our traditions into their research agenda;
- look at the reality of farmers' problems, constraints, and opportunities from the farmers' perspective rather than from their own;
- look at crop-livestock (and other) systems in the context of the farmers' livelihood systems to assure livelihood security;
- test, standardize, and promote the traditional (indigenous) knowledge base on the fanners' wisdom and experiences;
- develop technologies that ensure conservation of biodiversity of both plant and animal species; and
- develop technologies that are humane, gender sensitive, sustainable, equitable, and environmentally friendly.

Role of Global and Regional Fora in SAT Agriculture: Future Scenario

R S Paroda[1]

The Semi-Arid Tropics (SAT) comprise 55 countries which together account for a sixth of the world's population. Among the basic issues confronting the region are rural poverty, food and nutritional insecurity, population growth, urbanization, environmental concerns, global climatic changes, concentration and internalization of input supplies, and agricultural sustainability. It has been observed that economies that are predominantly agriculture-based are beset with rural poverty. In the developed and industrialized countries, barely 4-10% of the people are dependent on agriculture; on the contrary, in the SAT, almost 65% of the population is dependent on agriculture and a staggering 800 million people are malnourished.

Rapid urbanization is presenting several problems to the economies of countries in the SAT. With good land being diverted for nonagricultural purposes, these countries are experiencing water and land scarcity. In such a scenario, peri-urban agriculture has a very important role to play in attaining food security. Then there are global climatic changes to contend with which are far more pronounced in the SAT and need to be managed effectively.

This scenario underscores the need for cooperation to achieve food security and for harmonizing intergovernmental conventions and agreements. This will aid the process of capitalizing on complementarities and help harness synergies for the benefit of mankind. This is where global and regional fora can play a very important role. It is essential that there be effective cooperation among the various NARS, and between NARS and the CG, and NARS and regional and global fora. In the coming years we will witness globalization not only of

Paroda, R.S. 2001. Role of global and regional fora in SAT agriculture: Future scenario. Pages 83-86 *in* Future of agriculture in the semi-arid tropics: proceedings of an International Symposium on Future of Agriculture in Semi-Arid Tropics, 14 Nov 2000, ICRISAT, Patancheru. India (Bantilan, M.C.S., Parthasarathy Rao, P., and Padmaja, R., eds.). Patancheru 502 324, Andhra Pradesh. India: International Crops Research Institute for the Semi-Arid Tropics.

1. Director General, Indian Council of Agricultural Research (ICAR), Krishi Bhavan, New Delhi 110 001. The paper was presented by Mangla Rai, Deputy Director General (Crops), ICAR.

markets but also of insects, pests, and diseases. This calls for the harmonization of quarantine and postquarantine regulations as well.

Global agricultural research fora should facilitate the exchange of information, materials, and knowledge, and help in the process of technology transfer. They must foster cost-efficient collaboration among the stakeholders; promote integration of NARS and enhance human resource development capacity to help in technology generation and transfer; facilitate the formulation of a truly global framework for development-oriented agricultural research; and increase awareness among policy-makers and donors for investments in agricultural research. A global forum on agricultural research can be successful only if there is a consensual and efficient mechanism to set up global and regional priorities.

I believe that agriculture is simply the conversion of solar energy by means of a biological system that is portable and marketable into a chemical form of energy — you may call it food, fuel or fodder. This requires us to see agriculture in an ecoregional perspective in which land, labor, resources, and markets have to bring about efficient land-use management. This calls for a new institutional mechanism for reshaping cooperation in agricultural research and development.

Common funding principles and adequate funding mechanisms to support investment in this area have to be worked out.

Coming to the Asia-Pacific Association of Agricultural Research Institutions (APAARI), the road ahead must traverse through devising strategies for regional collaboration/networks on priority programs, development of human resources, policy advocacy, resource generation, and publication enhancement.

Research networks—for information exchange, scientific consultation, and collaborative research—have a crucial role to play in the SAT. Regional priorities are addressed here and there is scope for technology spillover. Technology generated in one country may be useful in another. Take the case of the SAT itself. Be it pearl millet, groundnut, chickpea, pigeonpea or sorghum, varieties released in one country are being cultivated in over a dozen others in the region. One can also capitalize on complementarities in areas like training and human resource development. Researchers can join mainstream global research. Finally, research networks provide cost-efficient coordination for sustainable agricultural research and development.

Coming to the CGIAR-NARS partnership, there are several issues to be tackled. How should the regional fora be strengthened to make this partnership more effective and constructive? And when you mention effectiveness, you have to take into account efficiency, which determines the effectiveness of a partnership. Its effectiveness will determine its relevance and the relevance will in turn determine whether the partnership is strong or weak and whether or not it is capable of delivering the desired results.

Secondly, how can the varied needs of NARS be better addressed through the CGIAR system and on the regional forum? Again, this is where we need to explore the possibility of cooperative effort.

We basically need to shift to a systems approach which calls for convergence. This would include in its ambit all the components in the chain—processing, product development, value addition, marketing, trade, and even the use of the material and its impact. This essentially involves placing the farming system squarely in the ambit of the production-to-consumption systems mode.

For instance, it is inherent in Integrated Pest Management that it must be viewed in a systems perspective. When pearl millet is included in a cropping system, a basic integration is called for. The same principle holds good for natural plant management systems.

I believe that farming systems is an area that needs strengthening. Take the case of India. We started with the Indian Agricultural Research Institutes, then went on to the universities system, then to crop-oriented institutions, and finally to national research centers. However, the very basic systems perspective and integration has been lacking in our national system.

Shifting the focus to natural resource management, agrobiodiversity, and conservation and utilization, it is believed that 70-75% of the agrobiodiversity lies in the developing countries. However, have we been able to evaluate its worth or even sample the existing variability? Or have we been able to effectively classify and catalog it so that it can be used for commercial product development? These are some of the areas where greater effort and partnership could be rewarding.

There is an Indian saying, *'Vasudaiva kutumbakam',* which means that 'the whole world is a family'. In the context of biotechnology, this would mean that there can be no barrier to gene flow. It is estimated that there are 1.7 million species in the universe. And with genomics, sequencing and functional genomics, many possibilities would be open to us. This too is an area where complementarity can be capitalized upon.

Closely related is the issue of biosafety. In the context of research on transgenics, we need to join hands to tackle the basic safety issues, be it carcinogenicity or the herbicide resistance gene which has the potential to get fixed or the sterility genes.

Attaining objectives in priority areas would require South-South cooperation, ties among countries in the region; collaboration with CG institutions; and NARS linkages with institutions in the developed world. I think these fora can play a vital role in setting regional priorities, which can then be effectively fitted into national priorities.

For strengthening partnerships, creating public awareness, and catalyzing policy-makers, interaction among the regional and global fora and NARS would indeed be crucial. It is ultimately technology which will percolate and increase productivity and production, and enhance profitability for farmers. But we need to keep people in the center. We need to address poverty and sustainability. And for doing so, cooperation is essential.

In conclusion, cooperation, competition, and coordination are the key words that will help us achieve a win-win situation.

Closing Remarks

J M Lenne[1]

Distinguished guests, colleagues, friends, ladies and gentlemen, I've got the impossible task of making closing remarks after a day when I think everything has already been said. However, I'll try to highlight areas that are of importance to ICRISAT.

As our Director General William Dar said this morning, today is part of a process that actually began some time ago. We've had many consultations, we've had documents written, including a white paper, and this has culminated in this SAT symposium today. On behalf of ICRISAT, I wish to sincerely thank all our distinguished speakers for their words of wisdom. I'm sure we're going to revisit many of these ideas; we'll be discussing them quite a lot over the next few months. Some of the important things we need to do are to focus and set priorities; only then can we begin to make choices.

The future of agriculture in the SAT is mainstream in ICRISAT's research agenda. We have a Centers project which will increasingly influence the direction of our research strategy.

Agriculture will continue to dominate the economies of much of the SAT, as was mentioned by one of our speakers today. And this will most probably occur for some time to come. Jim Ryan noted that investment in agricultural research and development has a proven record of contributing to poverty reduction. Thus agriculture and its farmers have a future in the SAT. And ICRISAT and its partners, especially through a whole range of different ways of working together, must play a continuing role in ensuring that the future is as bright as possible. Poverty reduction, food security, and improved child nutrition are clearly the target of our motto "Science with a human face".

Lenne, J. M. 2001. Closing remarks. Pages 87-89 *in* Future of agriculture in the semi-arid tropics: proceedings of an International Symposium on Future of Agriculture in Semi-Arid Tropics, 14 Nov 2000,ICRISAT, Patancheru, India (Bantilan, M.C.S.. Parthasarathy Rao, P., and Padmaja, R., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

1. Deputy Director General (Research), International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, Andhra Pradesh, India.

We take note of the skepticism about biotechnological approaches to tackling malnutrition, yet the reality is that some of the donors are investing in this area. We have golden and iron-enriched rice being produced, and in India itself, we have high betacarotene mustard and rapeseed oil being developed. Enhancing vitamin A and iron contents of staple foods is considered to be one of the best ways of tackling malnutrition among the poor. Given the 65 million malnourished children in the SAT, we must look at all the options available. Our sister concerns such as CIMMYT and IRRI are moving ahead on this. They seem to have satisfactorily addressed the issue of working in partnership with the private sector. So perhaps we can learn how to go ahead from them.

Many critical issues came up today that will affect our future research strategy. I think the crucial one was made by Kurien: how we enhance the involvement of farmers in our research decision making is very, very critical. Should we broaden our horizons to include other crops? Then comes the question of choices: should they be cash crops or food crops? Here partnerships are obviously going to be very important. There is another critical question posed by Jim: should we develop different research and development strategies for South Asia and sub-Saharan Africa? Should we get involved in postharvest research? We've done this before, but it appears that now even more than before, future utilization of some of our crops may depend on ICRISAT again becoming active or facilitating postharvest research.

The importance of integrated crop-livestock systems has come up several times. We're already actively involved in work on crop residues but perhaps we need to closely examine quality issues. And finally, to what degree should we address the needs of the commercial sector? There is plenty of demand by the alcohol, starch, and snack food groups. These may be the most important markets for our crops in the future.

I think facts, figures and trends are important in guiding us. However, we should not lose sight of the fact that millions of poor farmers will continue to grow sorghum, millet, groundnut, chickpea, and pigeonpea in the SAT. And whatever ICRISAT and its partners decide to do in the future, we have to deal with this reality. Several of our distinguished speakers have highlighted the importance of considering the whole cropping system in our deliberations. In this context I'd like to conclude with some remarks by one of our scientists at a recent workshop. And although they relate to sorghum, I think they also apply to other ICRISAT crops.

He said, "Sorghum probably represents half of the cereal consumption of 60 million people in key sorghum-producing regions in India. Sorghum, and certainly the rainy-season crop does provide the poor with cheap food." However, its importance as an input in SAT farming systems has not been exploited. The crop's integrated nature in the Indian SAT as well as other SAT systems, is what needs attention. In other words, sorghum underpins the system, and is therefore important in allowing the poor access to employment and food.

Acronyms and Abbreviations

ACP Protocol	African, Caribbean, and Pacific (States) Protocol
AIDS	Acquired Immunodeficiency Syndrome
APAARI	Asia-Pacific Association of Agricultural Research Institutions
CGIAR	Consultative Group on International Agricultural Research
CIMMYT	Centro Internacional de Mejoramiento de Maiz y del Trigo
ECOWAS	Economic Community of West African States
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FSR	Farming Systems Research
GAP	gross agricultural product
GDP	gross domestic product
GFAR	Global Forum on Agricultural Research
GIS	Geographic Information System
GNP	gross national product
GPS	Global Positioning System
IARCs	International Agricultural Research Centers
ICAR	Indian Council of Agricultural Research
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ICT	Information and Communication Technology
IDA	International Development Association
ILRI	International Livestock Research Institute
IMF	International Monetary Fund
IPGs	international public goods
[PR	Intellectual Property Rights
IRRI	International Rice Research Institute
LDCs	less developed countries
LIFDCS	Low Income Food Deficit Countries

MPTP	more productive technologies and practices
NARS	National agricultural research systems
NATP	National Agricultural Technology Project
NGO	Nongovernmental organization
NRC	National Research Council
NRMP	Natural Resources Management Program
ODA	Official Development Asssistance
OECD	Organization de cooperation et de developpement economiques
R&D	research and development
SA	South Asia
SAT	Semi-Arid Tropics
SEPP	Socioeconomics and Policy Program
SPFS	Special Programme on Food Security
SSA	sub-Saharan Africa
TAC	Technical Advisory Committee of the CGIAR
UNCED	United Nations Conference on Environment and Development
UNDP	United Nations Development Programme
UNESCO	United Nations Education, Scientific, and Cultural Organization
USAID	United States Agency for International Development
VLS	Village-level Studies
WFP	World Food Programme
WUE	water-use efficiency

Panelists

J R Anderson
Advisor, Rural Development Strategy and Policy
World Bank
Washington DC 20433
USA
Phone: +202 473 0437
Fax: +202 522 3308
E-mail: janderson@world bank.org

V Kurien
Chairman
Institute of Rural Management
Anand 388001
Gujarat
India
Phone: +61655
Fax: +02692-62422
E-mail: PAJ@FAC.IRM.ERNET.IN

R S Paroda
Director General
Indian Council of Agricultural Research (ICAR)
Krishi Bhavan
New Delhi 110 001

J G Ryan
Visiting Fellow
Economics Division
Research School of Pacific and Asian Studies
Australian National University
Canberra
Australia
E-mail: ryanjirn@cyberonecom.au

V Sekitoleko
Subregional Representative for Southern and Eastern Africa
Food and Agriculture Organization of the United Nations
P O Box 3730
Harare, Zimbabwe
Phone: ++ 263-4-791407
Fax: ++ 263 4 703497
E-mail: victoria.sekitoleko@fao.org

R B Singh
Assistant Director General and Regional Representative for Asia and the Pacific
Food and Agriculture Organization of the United Nations
Maliwan Mansion
38 Phra Atit Road
Bangkok 10200
Thailand
Phone: ++ (622) 281-7844
Fax: ++(622) 280-0445
E-mail: FAO-RAP@FAO.ORG

About ICRISAT

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

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

ICRISAT was established in 1972. It is one of 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.

Science with a Human Face

ICRISAT

International Crops Research Institute for the Semi-Arid Tropics

Patancheru 502 324, Andhra Pradesh, India

http://www.icrisat.org

FUTURE HARVEST

Science for Food, the Environment, and the World's Poor

CGIAR

Consultative Group on International Agricultural Research

ISBN-92-9066-441-X CPE 136 527-2001