ICRISAT in the 21st Century: Towards Sustainable Food Security

Proceedings of an International Workshop to mark ICRISAT's Silver Jubilee

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Abstract

Six eminent agricultural scientists and science-administrators were invited to present their vision of the role of the Institute in the coming century. The one-day workshop - held to mark 25 years of ICRISAT - ranged across the diverse yet deeply interlinked themes of increasing productivity, protecting the environment, saving biodiversity, improving policies, and strengthening national programs. Scientists from the Institute, and distinguished invitees for the Institute's Silver Jubilee celebrations keenly participated in the discussions following the presentations. The summary recommendations of the Workshop are also presented.

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

1998

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Preface

An international workshop on "ICRISAT in the 21st Century: Towards Sustainable Food Security" was organized on 17 November 1997, on the occasion of ICRISAT's Silver Jubilee celebrations (ISJC). A quarter century is long enough for an international agricultural research center (IARC) to reflect on its achievements, and to outline strategies for the future. Established in 1972 as the first IARC under the auspices of the Consultative Group on International Agricultural Research (CGIAR), ICRISAT has had many firsts (the world's first pigeonpea hybrid, for example). Awards and rewards have been showered on the Institute's individual scientists for excellence in their fields of specialization, and on joint NARS-ICRISAT teams for impact of technologies in farmers' fields. Some of these joint NARS-ICRISAT endeavors have resulted in increasing productivity, production, and farmers' incomes. The King Baudouin Award in 1996 for developing high-yielding, downy mildew resistant pearl millet is one such achievement. However, the release of more than 365 improved varieties in 70 countries around the world is a greater indication of ICRISAT's contributions in partnership with NARS.

The challenge for ICRISAT, and the CGIAR, is even greater now than it was 25 years ago. Decreasing funding for international agricultural research in general, and to the CGIAR in particular, is a matter of concern. Coupled with the decreased funding is the scenario of an ever-increasing world population, expected to swell to 7 billion by the year 2010. Most of this population increase will be in Asia, Africa, and to a lesser extent in Latin America, where majority of the world's poor people live.

In the harsh semi-arid tropics (SAT) farmers face many constraints to increasing food production. New technologies are adopted more slowly here than in better-endowed higher rainfall regions. Moreover, SAT suffers from environmental degradation due to soil erosion (both wind and water-induced), desertification, salinity, acidity, etc. Concerted research and development is needed to ensure sustainable development of natural resources.

There have been perceptible changes and developments in the NARS. Many NARS now have improved human resources, research and extension infrastructure. The private sector is becoming increasingly involved in research, especially in crop improvement, biotechnology, and pest and disease management. Also, NGOs are playing a more significant role in agricultural R&D than they did even 5 years ago. Among the CGIAR Centers, there is greater interest in systemwide initiatives and ecoregional research initiatives involving crops, livestock, aquatic resources, and forestry. Hence, ICRISAT, NARS, and other IARCs need to shift research agendas to benefit from, and contribute to, strategic partnerships with all stakeholders.

The theme for ICRISAT's Silver Jubilee workshop was therefore chosen to reflect the emerging needs of the 21st century. We invited six eminent scientists (Drs I Serageldin, M S Swaminathan, R S Paroda, L D Swindale, J G Ryan, and H Fitzhugh) to evaluate our past achievements and provide future directions for ICRISAT. The discussions were moderated by two distinguished research administrators (Drs P V Shenoi and A van der Osten).

My sincere thanks to all invited speakers, moderators, and participants of the workshop for their input. Appreciation is also due to Mr S Parthasarathy (Chairperson of the ISJC Organizing Committee) and the chairperson and members of the workshop subcommittee for the excellent arrangements. Finally, I would like to acknowledge the assistance of Dr O P Rupela in recording the discussions, and that of Drs C L L Gowda and A Giridhar Rao in editing these Proceedings.

Shawki M Barghouti
Director General

ICRISAT's Achievements and Future Challenges

I Serageldin

Excellencies, Distinguished Visitors.

A time for celebration

I am delighted to be here today, as we look back at ICRISAT's quarter century of effort and achievement, and look forward to its continued effectiveness as an instrument of development, a source of hope and comfort to the very poor of the semi-arid tropics (SAT). To my ICRISAT colleagues, past and present, I say: Thank you for the privilege of being able to join in your commemoration.

This is a time to re-live the record of effort that is the hallmark of ICRISAT's first 25 years. This is a time to celebrate the achievements that resulted from those efforts. This is a time to honor the women and men who supported the efforts and created the achievements. Above all, this is a time to pledge redoubled efforts in the future, even more than in the past, on behalf of the poor and the marginalized who call the semi-arid tropics their home.

I salute all of you who have been or are engaged in this task:

- the **founders** of the CGIAR who created ICRISAT
- **India,** the Center's host country, whose support, loyalty, and leadership have been vigorous and undiminished
- the **donors** who have supported ICRISAT's research with close to half a billion dollars since its creation

- the **donor-scientist-government partnerships** responsible for creating a network of research facilities in the Sahel, and in southern and eastern Africa, where the benefits of science were urgently needed
- the **scientists, managers, and all others** who have contributed to ICRISAT's development as a Center of excellence;
- **ICRISAT's partners** in national agricultural research systems (NARS), who have supported the Center's efforts; and, of particular importance,
- the **farm women and men** who have inspired ICRISAT, and transformed laboratory-based knowledge into tangible benefits in their fields and homes.

I salute them all, and I invite you, ladies and gentlemen, to join me in that salute with a round of applause.

Looking back

My friends, let us now look back briefly on some details of what ICRISAT and its partners have achieved.

ICRISAT-based varieties have helped to increase yields, maintain soil fertility, reduce pest damage, raise incomes, and improve the farmers' quality of life. A cycle of cause and effect thus runs from the use of new technologies to the generation of surplus production and increased income through investment in more sustainable management methods to longer-term economic growth and higher living standards. These developments have directly affected the lives of farm women and men.

The reach of new technologies extends far beyond Patancheru. For example: currently, half of India's hybrid sorghum acreage is planted to ICRISAT-derived varieties; early maturing, ICRISAT-derived varieties that avoid late-season drought are helping to stabilize production in sub-Saharan Africa, and improved varieties of groundnut are spreading both in India and southern Africa.

ICRISAT's approach to research is heavily partnership-oriented. An illustrative example is ICRISAT's work on pearl millet which has resulted in the development of cultivars that are resistant to biotic constraints (downy mildew, which reduces yields by over 40%, and the panicle diseases, ergot, and smut) as well as to abiotic constraints (drought, heat, and low soil fertility). Partnership with NARS scientists and with farmers' organizations - particularly on breeding landraces into improved varieties - were at the heart of ICRISAT's efforts. In a further extension of the partnership mode, ICRISAT has been working with the International Livestock Research Institute (ILRI) and the International Fertilizer Development Center (IFDC) on soil nutrient improvement through the use of biomass and animal dung.

Pearl millet was once considered **unimprovable.** Today, the annual returns to pearl millet farmers from ICRISAT's **improved** varieties, grown by poor farmers on some 27 million ha in Africa and Asia, is about US$ 54 million - about double ICRISAT's total funding in 1996. This is in keeping with the consistently high rates of return on investment in ICRISAT's research, from a "low" of 11-15% on sorghum in Zambia to a high of 65% for pigeonpea in India. To that, one has to add nonmonetary benefits in the areas of sustainability and gender equity.

These achievements have not gone unnoticed. The Center as well as individual scientists have received awards for scientific excellence from institutions too numerous to list, in several countries including Australia, Britain, India, Kenya, Nigeria, and the USA. Within the CGIAR, ICRISAT received the King Baudouin Award of the CGIAR in 1996, the Group's Silver Jubilee Year, for its outstanding work on pearl millet That same year, when the Chairman's Excellence in Science Awards were inaugurated, an ICRISAT scientist received the award for an Outstanding Local Professional. The performance was repeated this year, when another ICRISAT scientist was the recipient of the same award. The external review panel which assessed the Center's performance last year drew the attention of the CGIAR to its "enduring and conspicuous successes" in crop improvement, natural resources management, and germplasm conservation and enhancement.

Looking ahead

Improving the human condition, nurturing partnerships, improving crops, natural resource management, high rates of return on investment and international recognition: this is an impressive array of accomplishments.

But the tasks of development are never done. There is always one more river to cross, one more mountain to climb. Although ICRISAT and its partners have made a great difference in the lives of poor farmers, some 380 million people in the semi-arid tropics are today counted among the absolutely poor, unable to meet minimum standards of health and nutrition. Consider how many more would have been encompassed in this accounting but for the impact of ICRISAT's research. Consider, too, how much more ICRISAT and its partners need to achieve, to help the millions who remain devastatingly impoverished.

More than half the population of the semi-arid tropics is engaged in agriculture or activities connected with agriculture. Redoubled efforts to develop sustainable agriculture are vital to the resolution of their problems. The tasks deserve utmost priority. For, as Jawaharlal Nehru once said, in development "everything else can wait but not agriculture."

The challenge of transforming agriculture in these regions is complex, involving not only crop science, and natural resource management, but also policy issues such as price, trade barriers, infrastructure, and the need for institution building. Drought is an overriding concern but cannot be approached as a discrete issue. It requires a package of approaches within the context of farming systems.

ICRISAT has already set out four broad targets for the immediate future:

- Reduce poverty
- Create diversified opportunities
- Protect fragile environments
- Promote inclusiveness.

In approaching these targets, ICRISAT is not alone. It can draw strength from the support of CGIAR members, the wisdom of its scientists, and the experience of many partners now coalescing into a Global Forum for agricultural research. Let me suggest that in addressing the problems of the semi-arid tropics this coalition of the caring should undertake a double shift in the research paradigm.

The first of these shifts requires the integration of crop specific research, which has been so successful in the past into a broader more holistic vision that brings in the concept of natural resource management for sustainability, and looks to achieving results through increasing the productivity and profitability of complex farming systems at the smallholder former level. The task is to intensify complex agricultural production systems while preventing damage to natural resources and biodiversity, and improving the welfare of farmers. Doubling the yields in complex farming systems in an environmentally positive manner is an enormous challenge that is not going to be easy to meet We cannot dodge the challenge. ICRISAT, a Center dedicated to the ecoregional concept of the semi-arid tropics, is well placed to be at the forefront of those tackling this problem.

The second shift is to utilize the most cutting-edge science associated with genetic mapping, and molecular markers to assist and accelerate the breeding process, and achieve the promise of all that science can do for the poor and the environment.

Biotechnology - one of many tools of agricultural research and development - can provide many advantages to institutions such as ICRISAT that pursue the mission of environmental protection, poverty reduction, and food security centered on the smallholder farmer in developing countries. The first fruits of the new technology are already benefiting the commercial crops of the industrialized countries, and there is no reason why the tools of biotechnology cannot be employed to pursue the mission of environmentally and socially sustainable development.

The tools can be used to introduce environmentally friendly disease and pest resistance. They can help develop hardier plants with resistance or tolerance to drought, salt, and herbicides. Plant characteristics can be genetically altered to adjust crop duration, increase transportability, reduce postharvest losses (e.g., shelf-life, etc.) as well as water content, stem size, etc., all aspects of great relevance to poor farmers in low-potential environments.

The biotechnology revolution is here. It is relevant to the problems of the world. But for many of us, it raises important questions relating to ethics, intellectual property rights, and biosafety. How great is the promise, how strong is the peril? There is much that has been said on both sides of these questions. Both sets of issues need to be scrutinized in the light of reason, not of emotion or prejudice. For it is only through such scrutiny that a productive construct can be fashioned out of the diverse aspects - science, agriculture, law, property rights, farmers' rights, the working of civil society, the role of women, and more - that impinge upon a truly complex situation.

Let me now return to genetic mapping and molecular markers and address the changing scientific paradigm; and the need for expanded systemic relationships with advanced research institutes (ARIs).

As you know, important work is currently being done by many scientists on genomics, genetic mapping, and the identification of quantitative trait loci (QTLs). Genetic linkage maps based on molecular markers have made it possible for QTLs to be identified, studied, and applied in crop breeding.

The research paradigm should shift from selecting parents on the basis of phenotype to evaluating their directly for useful genes. The tools that make such an analysis possible are molecular maps, and the integrative power of QTL analysis. If we accept this thinking, then it argues for the expansion of our efforts at genotypic rather than phenotypic screening and characterization of our germplasm, based on the relevance of the traits for particular agronomic characteristics. Again, here, ICRISAT, with its vast genetic resource collections and enormous experience, is well placed to play a powerful role in this evolving paradigm.

The work of this type, it should be noted, will benefit from crossing the traditional commodity-specific lines. Indeed we are discovering that the architecture of the genomes for monocots has much in common across species, an observation that also holds for dicots such as tomatoes and potatoes. Thus, there is some possible benefit of creating a critical mass of scientists from NARS and CGIAR Centers working on the same problems who can beneficially work as a group, to enrich and be enriched by each others' work.

They can be located here, at the hub of an important IARC surrounded by an immense and powerful NARS. They can be located within a particular ARI that has specialized in this or another area of advanced research. In either formulation, ICRISAT has a major role to play as the platform for such interchange, as the catalyst for such intercourse, as the enabler as much as the doer.

Wherever they are located, such constellations would build bridges across the global agricultural research system, strengthen the networking of scientists, and help engage some of the best ARIs more closely with the problems of developing countries.

Such approaches can then begin to more radically transform the reality of the international agricultural research system, redefining the role of the CGIAR as facilitator and enabler of more open access for the South, while remaining involved with the best science everywhere in the world. The will help start building a reality around the rhetoric of partnerships and collaborations as we enter the age of the knowledge-based society. It will be another step in the direction of harnessing science to the cause of the poor and the environment.

Concluding remarks

Thus the future will require a different type of science: a continuing and vast collaboration involving NARS, CGIAR centers, ARIs, the private sector, and others in civil society. This will require adjustments in the work programs and the skill mix. Even more, it will require continuous change, where the pangs of restructuring must be matched by the exhilaration of embracing the future. Beyond the content of their work, the centers of scientific excellence in the CGIAR system must act as dynamic catalysts, as platforms for the exchange of information and the development of true networks of scientists from the South and the North. This will enable them to be even more effective partners of national scientists than before. The NARS will also have to undergo transformation, taking on new responsibilities, and working out effective distributions of tasks among themselves, and all other components of the global agricultural research system. ICRISAT is well positioned to undertake these changes, and make them part of the new science paradigm.

A forward-looking approach and a strong sense of institutional strength have enabled ICRISAT to emerge reinvigorated from a process of adjustment that was undoubtedly painful to many individuals and families. We cannot minimize the dislocations caused in personal terms, and our sympathies go forth to those who suffered in this painful process. But the hard realities of this fin de siecle scientific scene is the need for institutions to adjust and grow vigorous, or whither away and become irrelevant. ICRISAT, rich in its history of achievements, strong in its convictions, dedicated to its mission, firm in its commitment to excellence, has adjusted, is adjusting, and will doubtless grow more vigorous, to work with its partners to address the daunting challenges of the new millennium.

ICRISAT's accumulated experience is great. Its collection of germplasm is a wonderful asset. The excellence of its scientists and the impact of their research is manifest, and internationally acknowledged. ICRISAT's leadership is visionary and dedicated. The Center's supporters and partners have repeatedly demonstrated their confidence in and loyalty to ICRISAT. CGIAR members offered the Center a strong vote of confidence by making special efforts at three successive meetings to provide the Center with additional support. The most recent of these was in Washington in October 1997 when they approved a supplementary $3.5 million in special funding for ICRISAT. To all of you, the entire ICRISAT family, we look to play a major role, a decisive role, in the alliance of partners dedicated to the well-being of the countless millions of the poor in the semi-arid tropics, and their children yet unborn. Together we must face the challenges of the future with determination, confidence, and skill. That is the challenge. That is the promise. That is the hope.

So to all of you at ICRISAT, on this special day when we honor past achievements, I say: great as it was, the past was merely prolog. The future beckons. Let us move forward to meet it. Let us fashion it to the pattern of our dreams, not for ourselves, but for the marginalized millions who have a right to better tomorrows.

ICRISAT in the 21st Century: Towards Sustainable Food Security

M S Swaminathan

Introduction

ICRISAT was the first institution to be established by the Consultative Group on International Agricultural Research (CGIAR). The four earlier institutions - International Rice Research Institute (IRRI), Centro Internacional de Mejoramiento del Maiz y del Trigo (CIMMYT), International Institute of Tropical Agriculture (IITA), and Centro Internacional de Agricultura Tropical (CIAT) - founded by the Rockefeller and Ford Foundations, were largely designed to improve the productivity of staple crops in favorable environments. ICRISAT, on the other hand, was established to mobilize science to solve the problems of complex, risk-prone, and diverse environments characteristic of rainfed semi-arid areas. Since ICRISAT is a member of the CGIAR family, I would like to deal in this lecture with the role of CGIAR institutions as a whole in the 21st century.

CGIAR is a research agenda driven organization. The Lucerne Declaration of 1995 exhorts CGIAR to harness the best in both traditional wisdom and frontier science to achieve the following societal goals:

- Meet the multiple challenges of increasing and protecting agricultural productivity, safe-guarding natural resources, and helping to achieve people-centered policies for environmentally sustainable development
- Help to combat poverty and hunger in the world by mobilizing both indigenous knowledge and modern science.

The instruments to achieve these goals are the 16 international agricultural research centers (IARCs) directly supported by the CGIAR and their national and international partners. The 16 Centers are mandated to address the following components of the global food security challenge:

- Improvement of crop productivity: IRRI, CIMMYT, Centro internacional de la Papa (CIP), West African Rice Development Association (WARDA), International Center for Agricultural Research in the Dry Areas (ICARDA), ICRISAT, CIAT, and IITA
- Improvement of animals: International Livestock Research Institute (ILRI)
- Improvement in fisheries: International Center for Living Aquatic Research Management (ICLARM)
- Improvement in forestry and agroforestry: Center for International Forestry Research (CIFOR), and International Center for Research in Agroforestry (ICRAF)
- Improvement of irrigation water management: International Water Management Institute (IWMI)
- Genetic resources conservation: International Plant Genetic Resources Institute (IPGRI)
- Policy research: International Food Policy Research Institute (IFPRI)
- Building the capacity of National Agricultural Research Systems (NARS): International Service for National Agricultural Research (ISNAR)

Of the 16 IARCs, three are in developed countries (IFPRI, ISNAR, and IPGRI), and the rest are in developing countries. Nearly all the Centers are involved in some way or the other in capacity building and networking activities. Many of the commodity-centered institutions are also engaged in farming systems research. In recent years, multicentric and interdisciplinary ecoregional programs have been initiated.

How can this relatively modest research infrastructure be mobilized for making significant contributions to the task of poverty alleviation, natural resources conservation, and enhanced and sustainable food security? Past experience has shown that a small effort can have a large impact only through careful choice of research areas where IARCs, through their strategic research and partnerships with NARS can play a catalytic role. Whatever may be the strength of individual IARCs, the collective strength of the CGIAR system is considerable, thanks to strategic alliances.

Science for food security

Our first goal in the coming millennium should be to further enhance IARC capability in

- maintenance research aimed at defending the yield gains so far achieved
- strategic research related to food security, poverty alleviation, and natural resources conservation
- participatory research with farm families through NARS to incorporate environmental and social sustainability, and gender equity in technology development and dissemination
- anticipatory research in collaboration with advanced institutions to insulate agricultural productivity from potential damage resulting from changes in temperature, precipitation, sea level, and ultraviolet-B radiation.

We must consolidate and defend the gains already achieved. This will call for a strengthening of both maintenance and participatory research.

The second challenge lies in maintaining the tempo of productivity advance in an ecologically sustainable manner under conditions of diminishing per capita arable land and irrigation water availability, and expanding biotic and abiotic stresses. The term "Green Revolution" represented the achievement of significant advances in agricultural production through an improvement in productivity per units of time and land. However, the heavy dependence of some of the production technologies on capital and chemicals tended to be environmentally destructive and socially disruptive. This is true both in industrialized and developing countries. For example in the United Kingdom, Green Audit procedures have revealed the following facts:

> The single most important factor in leveling the economic playing field surrounds the question of Accounting. When a clear green audit emerges of the environmental, social, health and welfare costs attributable to current agricultural food production, processing, packaging and distribution systems, it will become abundantly clear that cheap food comes at an unacceptably high cost.
>
> Work undertaken by the Soil Association has revealed that the need to extract nitrates and pesticides from drinking water is currently costing the tax payer and industry approximately £ 145 million annually. Prior investment in water treatment equipment and control measures amount to a further £ 1275 million. Annual losses of soil through erosion cost the equivalent of about £ 680 million per year in lost crop production. (Rose 1997).

Since there is no option in population-rich and land-hungry countries but to produce more per units of land, water, time, and labor, there is need for technologies which can promote and sustain an ever-green revolution rooted in the principles of ecology, economics, and social and gender equity. It is obvious that the challenge can be met only by integrating recent advances in molecular genetics and genetic engineering, information and space technologies, renewable energy technologies and management science with traditional technologies and ecological wisdom, resulting in appropriate ecotechnologies. There should be no relaxation of yield-enhancing research, since there is no other way of meeting global food needs. We have to produce more but produce it without long-term ecological harm.

The third major challenge is to contribute to poverty alleviation. The rich-poor divide is widening year after year, and according to the World Bank, over 1.2 billion people are living on a per capita per day income of US dollar one or less. Most of them live in developing countries, and there is an increasing trend towards the feminization of poverty and agriculture. The poor suffer from both under- and malnutrition resulting from inadequate purchasing power and silent hunger caused by micronutrient deficiencies. They can be helped only if the following definition of food security developed at the Science Academies Summit held at Madras, India, in July 1996, is adopted by scientists and public policy makers. According to the Summit definition, national polices for sustainable food and nutrition security should ensure:

- that every individual has the physical, economic, social and environmental access to a balanced diet that includes the necessary macro- and micronutrients, safe drinking water, sanitation, environmental hygiene, primary health care, and education, so as to lead a healthy and productive life
- that food originates from efficient and environmentally benign production technologies that conserve and enhance the natural resource base of crops, animal husbandry, forestry, inland and marine fisheries.

The challenge of poverty: the scientific response

There are numerous definitions of poverty and many methods of calculating the poverty line. The parameters of poverty vary from country to country and even from region to region, within a country. But the poor everywhere have some characteristics in common: they have no productive assets like land, livestock, fish pond, forest trees or a small workshop and have no special technical skills. They consequently tend to work as unskilled labor.

The major assets of the poor are their time and labor. How can IARCs help to add economic value to the labor and time of the poor and thereby help them to build productive assets? In the case of women, who are often overworked because of their multiple roles in daily life, and at the same time are underpaid, the research strategy should aim to add value to each hour of work, and reduce the number of hours of work. All this will call for the technological and skill empowerment of the poor, so as to enhance the economic value of their time and labor. While agrarian reform is important for poverty alleviation, IARCs have no comparative advantage in promoting such reforms which depend upon the political system for their introduction and implementation. They have however the capacity to foster a skill revolution, using modem information technology.

A high priority in the next millennium will have to be

- crop intensification
- farming systems diversification
- value addition to primary farm produce

This will call for an end-to-end approach in science, linking production and postharvest technologies in an integrated manner. This will also call for expertise in micro-level planning using GIS techniques and micro-enterprises supported by micro-credit It is obvious that much of such work will have to be carried out in association with NARS and advanced institutions and private industry.

Ecologically sustainable farming is knowledge intensive. It aims to substitute chemicals and capital with knowledge and farm-grown biological inputs. There is therefore a great opportunity to attack simultaneously the twin challenges of poverty and environmental degradation.

If the poverty alleviation goal is to be integrated into the CGIAR's agenda, there has to be a serious analysis of the additional facilities and expertise that will be needed at each IARC for developing multiple livelihood opportunities for the poor and for skill empowerment It would be useful to recall in this context the following statement of Mohammad Yunus, founder of the Grameen Bank in Bangladesh, in a recent lecture, "Poverty is not created by the poor. It is created by the policies we pursue. We cannot solve the problems of poverty with the same concepts and tools which created it in the first place. To create a poverty-free world, we need new conceptualization and a new analytical and action framework (Yunus 1997). Coalitions of the concerned involving both academic and research institutions and non-governmental and farmers' organizations are needed to foster such an analytical and action network.

A business-as-usual approach will not help to transform the Lucerne vision into reality. We must analyze critically the role IARCs can reasonably play in the human quest for a world without extreme poverty and deprivation.

A matrix approach to the setting of research priorities and to the development of appropriate research strategies

To achieve the multiple objectives of CGIAR, the following considerations need to be integrated into the research agenda of ICRISAT:

- Ecology. Conservation and enhancement of the ecological foundations essential for sustainable advances in biological productivity
- Economics. Economic viability is essential for replicability
- Equity. Social and gender equity is essential for poverty alleviation

- Employment Multiple livelihood opportunities are essential for household food and health security
- Energy. Greater emphasis on renewable energy is essential to avoid national and global environmental problems
- Exchange. The new climate created by TRIPS, IPR, CBD and other international developments in trade and exchange of biological materials necessitates appropriate policies in the areas of material, information and technology transfer and exchange.

CGIAR is also a science-driven organization. At the same time, it should not be forgotten that science is not a magic wand with which poverty, gender inequity, and other social and economic problems can be solved. Public policy plays a pivotal role, including policies and priorities for science. There is need to include the excluded, in terms of crops, farming systems, and agroecological regions. ICRISAT can play a pivotal role in strengthening global food security by helping to include in the food basket a whole series of minor millets and legumes, which are fast becoming "lost crops". It is unfortunate that such nutritious crops are being referred to as "coarse cereals".

CGIAR and ICRISAT thus face formidable challenges as they enter the new millennium. At the same time, new and uncommon opportunities also exist for overcoming the prevailing problems of serious gender and social inequity through an appropriate blend of science and public policy. The first step in this process is to face the problems with integrity and intelligence, and not to drown them in a sea of rhetoric.

ICRISAT and sustainable food security

As explained earlier, sustainable food security involves physical, economic, social, and environmental access to food for every child, woman or man. ICRISAT is in a strategic position to promote the realization of such a concept of food security at the level of the individual, since its mandate involves working in environmentally disadvantaged regions, and with economically underprivileged farming families. As meaningful contributions, I would suggest that the research and out-reach agenda of ICRISAT include the following four areas of concentration:

- help improve the productivity, profitability, stability, and sustainability of the major farming systems of the SAT region by integrating frontier science and traditional knowledge and wisdom
- help preserve and enhance the ecological foundations essential for sustainable advances in crop and farm animal productivity
- help generate improved livelihood opportunities for women and men living in poverty through an integrated approach to on-farm and off-farm employment - this will involve farming systems intensification, and diversification and value addition to primary products and concurrent attention to production and postharvest technologies
- help enlarge the crop-mix in the global food basket, by promoting the cultivation of minor millets, legumes, tubers and vegetable crops, which otherwise may soon join the category of "lost crops". This will involve changing the mindset which has led to such nutritious crops being classified in the market as coarse cereals.

In order to implement the above research agenda effectively, ICRISAT will have to develop new patterns of symbiotic partnership with farm families, NGOs, NARS, private sector industry, and the advanced institutions of industrialized and developing countries.

Any research organization, to achieve sustainable dynamism, will have to adopt a policy of continuity and change in its scientific priorities and strategies. Building on its rich traditions of scientific excellence and social relevance, ICRISAT should strive to remain an affirming flame for SAT farm families.

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Additional remarks by Dr Serageldin

We should recognize the value of biodiversity by engaging people in protecting it: not by trying to protect it as islands but finding ways for interaction and exchange between people and nature. And that is really the heart of sustainability. I will venture to complement the presentation of Dr Swaminathan by addressing the social and economic dimensions that are needed for sustainability, since sustainable food security in the 21st century is not only the relationship between humans and nature, but sustainability really involves three dimensions:

- *Environmental sustainability,* which is the sustainability of the ecosystems which we depend on, and the relationship between man and nature.
- *Economic sustainability,* which means the programs that are nonsustainable can lead to hyperinflation with enormous negative impacts on the poor and the destitute. Countries that were flying high in the world until recently are going through serious financial crises. So economic sustainability is important as a framework for human activity.
- *Social sustainability* is equally important, i.e., the relationships that keep a society together have to be protected by addressing issues of rising inequality in society, and the marginalization and exclusion that occurs. Almost all of the world famines (e.g., Rwanda, Southern Sudan, and Somalia) are due to social strife. There is hardly a famine which is because of shortage of food production alone.

So maintaining all these dimensions together is very important and has to be part of the overall sustainability dimension. I would like to summarize food security concerns in the following axioms which I believe to be absolutely crucial.

- It is just not production and the amount of food that is available, but also access to that food. Despite India's 33 million tonnes of surplus foodgrains right now, there is very severe malnutrition. That is not because of absence of food, but because of lack of access. Let me underline immediately that the converse is not true. In other words, one should not say that production is not important. Shortage in production increases the crisis and further reduces access. So production is a necessary, but not a sufficient condition.
- It is not just the output (food) but manner in which the output is produced: are we dealing with systems with inadequate drainage, high soil salinity, and depleting soil fertility? Or are we destroying forests by slash-and-burn agriculture to produce food?
- It is not just technology but also policy that is extremely important If a policy framework which encourages adaptation and adoption of that technology is not in place, it will not be used.

It is not just global balances, but national and local issues that count in food security. The present global balances and the hike in the price of wheat may be relevant but its effects are limited to a few countries that are large food importers. It is not going to impact on chronic food insecurity of the kind that meets the definition that Dr Swaminathan mentioned earlier. Therefore, we have to look below the national level. Secondly, it is not just the national and the local level, but individual household and personal level. For example, if it was just national level food security, the United States would not have had a single hungry person. But you do know that there are hungry people in the USA, and it is a question of access, and therefore the need to design policies to reflect that. National policies on food self-sufficiency should address both the quality of foodgrains produced, and the distribution within a different regions of the country, and different households. Within households we know that there is severe discrimination against the girl child, and that also has to be re-addressed. And finally that is just not the amount of food that the people have but the nutritional content of that food.

These four axioms really highlight the complex food security equation in the 21st century. Where is food security equation we see it today? Let me add three or four ideas to the scenario of what may happen in the 21st century.

The first of these is globalization. The integration of the world's economy has become a reality. No country, or group of countries, can be tied to national markets alone. The global capital market has shown some volatility recently, but this is part of the reality. Equally true in terms of globalization has been the enormous move towards communications, and interconnectivity. And indeed, the boundaries of the nations have become as permeable to ethereal functioning, as capital zooms around computers around the world.

Along with that globalization is also a rise in assertiveness of local groups and local identities, be it ethnic or religious, or tribal groups. When we put the two together, a third dimension of inequities is emerging. The inequalities in the world as well as between countries are growing, and this is a very serious problem. For example, the top 20% of the world today receive over 83% of the world's income. The other 80% live on 17% of the world's income. The bottom 20% live on less than 1.4% of the world's income. The top 20%, which roughly corresponds to Organisation for Economic Co-operation and Development (OECD) countries, were 30 times as rich as the bottom 20% 30 years ago. They are now over 60 times as rich. And yet what we have is a situation where that top 20% says that they cannot afford to give 0.3 of 1% GNP in terms of official development assistance to poorer countries.

The rise in global inequity is matched by a rising inequity within countries. This is linked to a move towards a knowledge-based society, where the gaps between the "haves" and the "have-nots" are closely tied to gaps between the educated and the uneducated. We need to tackle the combined issues of poverty reduction, food scarcity, and environmental protection in the tropics where the majority of the poor live. One cannot expect and await a handout from the rich to the poor, but find ways of empowering the poor to deal with their own problems. Dr Swaminathan mentioned that we need to emphasize the issue of employment creation, income generation, and microcredit schemes to reach millions of poorest families. These schemes allow the poor people to supplement their income by having access to credit without having a collateral. The amounts are not insignificant (in 1955 we had over 13 million borrowers who had over US$ 7 billion loans oustanding). The average loan size was US$ 50-100. On the other hand, we also have 45 million depositors who deposited US$ 19 billion. That is growing very fast, and this is one way to complement the activity. This is relevant to ICRISAT's role because of integrated perspective of the farming systems. Integrating the perspective of the farming systems includes livestock, crops, soil, rainfall, and so on; but it also integrates the activities of the human beings who make that farming systems work - by access to credit to supplement that role.

I would like to end with two observations on the scientific aspects that ICRISAT should concentrate on in the future. The first is biodiversity, in terms of species, the numbers of species that have been used, and number of varieties being used. But the genetic diversity within species is also equally important We are discovering that complex traits, such as yield for example, are the results of multiple genes, called Quantitative Trait Loci (QTLs). There may be seven or eight of them, for example, which contribute to yield. High-yielding varieties may have four or five of those. But low-yielding varieties, landraces, or wild relatives may have others, but may not have expressed it. In the past we have used a narrow genetic base in traditional plant breeding. We are now beginning to discover that we can reach into these unknown and undiscovered aspects, not just for wild races for resistances (to diseases or to stress) but also for yield. Now we have technologies (such as molecular markers and gene mapping) to help us. The contemporary cutting-edge science comes not as a substitute but as a complement to the traditional plant breeding. It brings a knowledge that we could not perceive earlier, because it was not expressed in the plant. But today, with the best of contemporary science, we doubly enrich the degree of knowledge. If we do this in the manner Dr Swaminathan pointed out, which recognizes the rights of the contributions of poor and indigenous farmers, then we will also be making a contribution towards resolving the issues of the equities, empowering the poor, and evolving the research paradigm towards the double shift that they talked about in the ever-green revolution. In that sense the image of the scientists and farmers united together to forge the future, reaching into the heart of the most advanced universities in the world, and back to the most distant fields, is not an impossible dream - it is a dream that is within our hands to fashion. And it is up to us to rise to that challenge.

Strengthening Agricultural Research for Sustainable Food Security: The Role of National and International Institutions

R S Paroda

Introduction

Looking at the last 50 years, the food security situation in India appears to be improving. The following features of India's robust and resilient foodgrain economy are particularly striking:

- negligible dependence on imports of cereals to meet domestic demand
- improvement in per-capita availability of foodgrains despite the population rising to about 960 million, and a per-capita calorie intake closer to accepted norms
- cereal exports on an average exceeding imports during the nineties
- considerable stability in foodgrain availability from domestic sources
- diversified cereal production increasing physical access to food in different regions
- yield increase in cereal production
- higher growth rate of average per-capita income as compared to increase in prices of rice and wheat
- diversification of the cropping pattern with high value crops replacing low-yielding coarse cereals; thereby increasing availability of other commodities like oilseeds, vegetables and fruits, sugarcane, condiments and spices

Despite these favorable trends in food security, both poverty and malnutrition still remain serious problems. The average figures hide inequalities that prevent the poor from taking advantage of the increased food supplies. These include lack of productive employment for the poor, and particularly in rural areas, lack of access to both food and non-food goods and services because of poor infrastructure development

In South Asia, 58% children are malnourished. Even with the projected increase in food availability and better sanitation and health conditions, 46% children will remain malnourished in 2020. Maternal health and nutrition are crucially linked to the overall health and nutritional security of the population. When health care is generally poor, and women are ill or malnourished, their capacity to care for their children is affected, which in turn affects the nutritional status of the children. Access to clean water and proper sanitation are two of the most important determinants of good nutrition. Education levels are also very low, especially those of women. Unfortunately, most existing food security programs do not address intrahousehold distribution.

Since there is very little scope to increase the area under cultivation, future production increases must come from yield increases. The momentum of the Green Revolution has also generally slowed down. Considering the large projected demand for food, this decline/stagnation in agricultural productivity is a matter of serious concern. Given the complexity of enhancing food production in a sustainable manner in the years to come, future gains will have to be realized through the generation and adoption of new, relevant, and appropriate agricultural technologies.

It is not easy to achieve these objectives, because India's population is still growing at 1.8% a year, though the rate is declining. Besides population increase, improved purchasing power resulting from economic growth will enhance not only the demand for cereal food, but also the demand for non-cereal and non-crop based products. A gradual shift in food habits is also visible in the varieties of food products now available in the market World market demand will further push these trends upward.

Per-capita availability of arable land is declining, while input use efficiency is relatively low despite increased irrigation and fertilizer use. Because of the expanding demand for water for non-agricultural purposes, good quality water will become the scarcest resource of the future. Thus, judicious use of land and water will be the central issues of the growth process. Further, land and water resources are already facing acute degradation stress; supply of non-renewable resources like fossil fuel and phosphates will be further constrained. On the contrary, agrochemical use will have to be increased to ensure vertical gains in productivity. Management of these including common property resources will pose severe economic and political challenges. Also, there is increasing labor scarcity; better education and faster growth in the non-farm sector will induce rapid urban migration and occupational changes over the next few years.

Postharvest losses are also very high, and there is a widespread mismatch between production and postharvest technologies. One of the surest and cheapest ways of increasing the availability of agricultural supply is to minimize these losses by developing appropriate postharvest technologies, and by building the required infrastructure in the country. Postharvest technologies can also add value to the agricultural products besides facilitating growth of a buoyant agribusiness sector. Infrastructure is emerging as a major supply constraint as availability of public resources to invest in infrastructure is declining in both the domestic and export sectors. Private sector investment is also relatively low. The existing institutions need reorientation, particularly following liberalization and globalization. New institutional innovations must take place using new science, and we can no longer take institutions as given. The roles of the state, cooperative sector, private sector, NGOs, and other stakeholders are to be redefined to face challenges in both input and output markets.

Agriculture provides the strongest basis for economic development poverty alleviation, and rural employment through linkages with the non-agricultural sector. More investment both national and international, is essential besides pro-agriculture policies by the Government.

Obviously, therefore, there is no room for complacency. On the contrary, more rigorous efforts are needed now, especially when more opportunities exist now than ever before waiting to be harnessed.

Research priorities for the semi-arid tropics

On the 25th anniversary of ICRISAT, and the 50th year of India's Independence, and as the 20th century draws to a close, it is an opportune moment to take stock of existing strengths and prepare for the future, drawing deeply on the achievements of the past. Both Indian NARS and ICRISAT have grown in strength.

The Indian NARS is one of the largest agricultural R&D agencies in the world, with 30 000 personnel and more than 7000 people engaged in active research and management in ICAR alone. Besides, there are 28 state agricultural universities, 4 deemed universities and 1 central university. The NARS has evolved more than 2300 high-yielding varieties/hybrids of field crops to improve productivity; it has the largest genebank in the world; it is the first NARS in the world to develop hybrid cotton, pearl millet, sorghum, castor, and mango; the second NARS to develop its own hybrid rice; its research contributions in terms of improved varieties, hybrids, production practices, etc., make India the largest producer of fruits, and the second largest producer of vegetables in the world, and has helped to usher in green, yellow, white, and blue revolutions. Similarly, ICRISAT's strengths in developing SAT technologies appropriate to resource-poor smallholders, especially low-cost integrated pest management (IPM) techniques, improving soil organic matter, and low cost tillage implements to improve water management are important. Three important dimensions of ICRISAT's work on poverty alleviation are: increased incomes from more efficient production technology, decreased risk because of technologies which stabilize production, and lower prices to poor consumers resulting from decreased unit costs of production.

In view of flattening of the budget for both national and international agricultural research, it is important to think of strengthening agricultural research through synergies of action by partnership, collaboration, and sharing facilities and human resources. The research agenda of both ICAR and ICRISAT is specifically directed towards facets of agricultural development developing the poorest of the poor. The priorities of ICRISAT include crop improvement, desert margin systems, dry savanna systems, semi-arid watershed systems, diversifying rice-wheat systems, research evaluation, impact assessment and priority setting, markets and policy research, and genetic resources collection, conservation, evaluation, and utilization.

The priorities of NARS include i) conservation, planned enhancement and utilization of agro-biodiversity; ii) enhancing productivity through evolution of high-yielding hybrids and varieties; iii) research on crop diversification, quality improvement, postharvest technology, value addition and export-oriented commodities; iv) sustaining enhanced productivity of irrigated agriculture and judicious development and use of energy, especially renewable sources of energy; v) characterizing and developing sustainable land-use models for rainfed agriculture in high-rainfall areas; vi) developing IPM and integrated nutrient management system approaches and systems for sustainable agriculture; vii) fostering excellence in the relevant basic and strategic research, viii) generating research and technologies geared to promote equity among regions, sectors of society, and gender; ix) strengthening social science, policy planning, agribusiness, research monitoring mechanisms, administration and personnel reforms, and publication and information dissemination system; x) strengthening the Agricultural Research Information System (ARIS); xi) promoting the Agricultural Human Resource Development (AHRD); xi) linking scientists with farmers through Institute Village Linkage Programme (IVLP) as an innovative technology transfer model; xii) institutionalizing and strengthening linkages/partnerships with the CGIAR and other national and international research and development agencies and NGOs, farmers' organizations, private sector, etc.; and xiii) optimizing resources through planning, prioritization, and coordination. As can be seen, natural resource conservation and system management research through the watershed approach, socioeconomic and policy research, and genetic resource conservation are high priority areas for both ICRISAT and NARS.

The great majority of the farmers who live in the SAT and who cultivate sorghum, pearl millet, chickpea, pigeonpea, and groundnut belong to the poorest sectors of the society, and live in South Asia. These crops on which both ICAR and ICRISAT have strong research programs are crucial to the welfare of the poor in the SAT. The legumes are particularly important for diversification, and sustainability of their cropping systems.

Recent advances and future research thrusts

The ICAR research institutes which have explicit mandate for the semi-arid tropics include Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad, Central Arid Zone Research Institute (CAZRI), Jodhpur, and the Central Soil Conservation Research and Training Institute (CSCRTI), Dehradun. Other institutions include Indian Institute of Pulses Research (IIPR), Kanpur, Directorate of Oilseeds Research (DOR), National Research Centre for Sorghum (NRCS), Hyderabad, National Research Centre for Groundnut (NRCG), Junagadh, and the All India Coordinated Projects. These institutions have multidisciplinary programs to provide seed-based technologies, natural resource management, and improved management practices with sustainable system management options most appropriate to resource-poor small farmers. Examples in these categories include improved crop varieties resistant to biotic and abiotic stress, simplified, low-cost IPM techniques, in situ sources of organic matter, low-cost systems to improve water management, and others. Several have had significant impact on increasing incomes because of more efficient production technology, and decreased risk farmers run from technologies which stabilize production, and lower prices to poor consumers because of decreased unit costs of production. The new CGIAR paradigms are partnership, devolution, and governance. The Indian NARS is playing an effective role in contributing to these new paradigms.

The contributions of ICRISAT to these achievements are no less important. However, more concerted efforts are needed to develop collaborative programs so that the limited budget available in the national as well as international agricultural system is optimally utilized. ICRISAT has great comparative advantages in understanding sustainability consequences of technological interventions, "new science" investments in geographic information systems and simulation modeling of soil, water, and nutrient interactions, and expertise to deal with socioeconomic aspects including analysis of gender issues, project prioritization, monitoring, evaluation, and impact assessment. It also has comparative advantages and facilities in biotechnology, information management systems, and participatory research methodologies. Each of these holds promise to increase the probability of success of research in specific areas. These capabilities should be shared with NARS to develop research proposals, and in human resource development and skill upgradation. The research infrastructure built at ICRISAT-Patancheru is a unique facility that NARS can make use of. Similarly, the vast network of ICAR institutions and agricultural universities in the country are useful to ICRISAT to assess and refine its technologies. It is very difficult to build an infrastructure of the kind which ICRISAT has; and similarly it is very difficult for ICRISAT to build an infrastructure of the type the Indian NARS has: wisdom lies in sharing these great strengths to solve the challenging problems in a true partnership mode.

Opportunities and strategies

Physical

- A very large proportion of the area under various food crops in India fall in the low-productivity category. The share of low productivity area varies from 57% in coarse cereals to 92% in oilseeds. Sizable low productivity areas (82%) are in the states of Maharashtra, Karnataka, Madhya Pradesh, and Andhra Pradesh.
- Over 24.5 million ha remain as wasteland and 16.6 million ha as fallow lands. Sizable portions of this unutilized land can be brought under cultivation through soil amendment, introducing suitable crops in the wastelands, moisture conservation measures, developing facilities for life-saving irrigation wherever feasible, and introducing crop species/varieties matching the available soil water in fallow lands.
- About 8-10 million ha of saturated soils remain underexploited in the rainfed lowland areas of eastern India. With the exception of West Bengal, all the eastern states are almost entirely monocropped. After rice cultivation, vast areas in the rainfed lowlands and deep water rice lands remain fallow, in spite of the fact that there is large underutilized ground water potential. Through concerted research and development crop intensification is possible over a sizable area. About 1 million ha can immediately be brought under winter (Boro) rice in the states of Bihar, Assam, and Orissa. Potential for groundnut after rice is very good in Orissa and Bihar. Postrainy season pigeonpea is also a good possibility.
- There is vast potential to intercrop quick-maturing crops with wide-spaced crops. Interrow space and sowing time intervals available in crops like sugarcane, banana, cotton, sorghum, etc., are greatly underutilized. With the introduction of paired-row sowing and drip irrigation, 10-12 million ha can be brought under an intercrop of short-duration pulses or oilseeds.
- There is unlimited scope to conserve and utilize rain water. India is fortunate to receive the highest precipitation among countries of this size in the world. Watershed development in such areas will help greatly and provide protective irrigation to rainfed crops, while helping to recharge the groundwater. The experience of Indian NARS in developing and operating 47 watersheds constructed by ICAR, and ICRISAT's strength in inter-disciplinary research will be very useful in efficient use of rain water. An interdisciplinary approach, with strong social science input will help in promoting this technology which is so critical for the "evergreen revolution" by making these gray areas green.

Technical

Consolidating yield gains. High-yielding dwarf varieties in wheat and rice as well as heterotic hybrids in maize, sorghum and pearl millet brought about a major advance in food production. Yield gap analysis reveals that the sizable potential of these crops is yet to be fully realized. Differences between experimental and farmers' yields are quite wide. Equally wide is the gap between potential and realizable yields. For instance, in rice, about 40% of the potential available in the present day high-yielding varieties is still to be exploited. The same holds true in other crops as well. What is required to achieve such yield targets is diagnosis and correction of factors constraining yield increase. Insulation of all future varieties with desired levels of resistance to key pests and diseases, and tolerance to salinity, drought, temperature extremes, etc. should be the priority research option to consolidate the genetic yield potential. Also, a thrust on IPM, systems research, biotechnology for genetic enhancement and resistance to stress (both biotic and abiotic) are the areas where joint research programs would be of great mutual benefit

Maximization of productivity of rainfed crops. Even if the ultimate irrigation potential of the country is realized, about 50% of the cultivable area may continue to be rainfed. Strategic research on rainfed agriculture may be a priority area, to insulate the farmer from high risk-proneness of dryland farming. The thrust areas of research will be

- a detailed resource (land, climate and water) characterization to optimize land use for rainfed crops and other alternative land-use systems
- understanding of crop-weather-soil relationship to provide better agro-met advisory services
- concerted research and development efforts
- rain water conservation and integrated nutrient management
- watershed development to raise productivity of rainfed crops
- improvement of agricultural credit
- insurance cover for risk prone areas and crops and marketing facilities

Our present national strategy for the second Green Revolution is to convert these gray areas into green.

Over 97 million ha (72%) of the cropped area is rainfed. This accounts for 44% of food crops (55% rice and 91% pulses), 90% groundnut, and 68% of cotton. In spite of wide variation in the level of precipitation, rainfed areas are very low in productivity and predominantly monocropped. The productive potential of rainfed uplands in particular has deteriorated because of poor management rather than over-exploitation. By developing land-capacity based cropping and management strategies alone can their productivity level could be enhanced and sustained. Four decades of experience with hybrid crops suggests that hybrids have greater resilience to critical environments than do varieties. Development and use of short-duration hybrids/composites/varieties of millets, cotton, sunflower, castor, etc., in low rainfall areas is one of the strategies of crop planning based on locational advantages. In some arid and semi-arid environments sowing horticultural crops has been found more profitable than some of the annual food or oilseed crops. For rainfed lowland/semi-deep water ecologies in eastern India, farmers are increasingly adopting higher-yielding varieties in place of low-yielding local varieties like Monoharsali, T 141, Bakol, Mahsuri, etc. To enhance and stabilize productivity in such critical and diverse environments, technology packages must be tailor-made and location-specific. Technologies should also have built-in provision for risk distribution and contingency planning.

In spite of sharp decline in area under sorghum and millets, and the static area under maize, there has been steady advance in production attributable to impressive productivity growth, which in turn is because of wide adoption of high-yielding hybrids.

As for the pulses, the emphasis has been to breed short-duration varieties as in pigeonpea, and disease and pest resistant varieties in pigeonpea, chickpea, and *Vigna* species, which contribute the most to India's pulse production. Increasing adoption of improved varieties has contributed considerably to the impressive production increase of 1 million t, and rise in productivity to 601 kg ha^{-1} from 555 kg ha^{-1} during the last 4 years. Short-duration varieties of pigeonpea have helped to improve the cropping intensity in northern India, and chickpea, blackgram and mungbeans in southern India.

In eastern India rice is grown under varied moisture regimes ranging from rainfed upland to rainfed lowland and deep water situations. Under such fragile conditions, rice production and stability depend on year-to-year crop prospects of rainfed rice. Lack of high-yielding varieties adapted to the diverse growing conditions of rainfed areas has been the major constraint to increasing productivity. Greater research emphasis on improvement of rainfed rice during the last 10 years has led to the development of a wide choice of varieties for uplands and shallow and semi-deep water lowlands. They yield 40-60% higher than the ruling local varieties. The impact of these varieties is seen in increased production and productivity in the eastern states.

Stabilizing and improving crop productivity. Scientists in the Indian NARS have worked tirelessly to consolidate yield levels by insulating developed varieties with high levels of resistant/tolerance to biotic and abiotic stresses which are the major factors for destabilizing yields. The achievements in rice and wheat are exemplary. Breeding efforts of the last several years have resulted in a wide choice of varieties with specific and multiple resistance. The focus of research at ICRISAT is also specifically to reduce the risk associated with intensified, more productive agricultural systems. A prime example is the control of downy mildew disease of pearl millet, for which ICRISAT received the 1996 King Baudouin Award of the CGIAR. This research has revitalized pearl millet economy in the harshest environment. The development of short-duration varieties is particularly effective in reducing the drought risk for all ICRISAT mandate crops. Reduction in duration by almost half without any decline in yield potential of pigeonpea is indeed a spectacular achievement However, there is great scope to introduce stability in production by strengthening research in the areas of integrated plant nutrient management, integrated pest management, bio-technological research, social science research, Geographical Information Systems (GIS) and crop modeling and land-use planning. Collaborative research in these areas will ensure further stability in the production of these important yet scientifically insufficiently addressed crops in the semi-arid tropics.

Ecoregional approach. There are many routes to rapid agricultural growth: by expanding land area with relatively low technology which is rather limited; through yield-increasing technology, and/or by changing the composition of production.

In this scenario, ecoregional planning will aim at enhancing and sustaining agricultural production basis to meet the needs of the growing population. This will imply an upscaling of research activities within ecoregions and dovetailing research and development priorities between and within ecoregions, and will call for an effective collaborative mechanism, i.e., responsibility for a higher level of integration in research and development efforts. Thus, a clear distinction of collaborative mechanism, and between priority setting at the ecoregional level and its effective execution at the local levels will be essential.

In the ecoregional approach to research and management of natural resources, a balance in development and utilization of biodiversity is critical. Research should aim at improving the productivity of scarce resources while protecting the quality of soil and water, and safeguarding biodiversity for posterity. On the issue of management, the following points need attention.

- research on conservation and management of ecosystems that include multi-crop and multi-economic farming systems in a program mode
- accelerated research on the management of production systems

- socioeconomic and public policy research to understand farmer and community decision-making processes regarding the utilization of resources and factors affecting farmers' incentives and adoption of improved technologies
- development of capacity of NARS for more effective understanding of natural resource management research.

The most important end-product of an ecoregional approach may be to provide a framework for sustainability. Incorporating social and economic components would ensure success of the ecoregional approach. It is also recognized that training on the various facets of a multi-disciplinary approach in a program mode will be extremely important for the success of the efforts.

An important starting point is to compile the existing information to identify the driving forces of land-use changes and resource-base degradation. This will address issues of natural resources, innovations and technological options, present use of resources, future land use potentials for agricultural production, policy objectives and short- to long-term goals, research capacity building, population dynamics, farmers' decision-making processes and capabilities, and market evaluation and intervention processes.

Reorienting agricultural research management. With increasing globalization, it is now essential to address the research, financial and administrative aspects of NARS. The high quality of the system needs to be ensured through appropriate institutional arrangements: management reforms, incentives, rewards, training funding mechanisms, interface with all the stakeholders, particularly the private sector, increased communication and information technology, and the need to become not only locally efficient but also globally competitive.

ICAR took many initiatives and reforms towards reorientation of research in extent, content, mode, mechanism, and system; changing the management processes to improve the working environment, and to make the research need-based, effective, efficient, and relevant. These reforms have infused much-needed confidence in the system. However, it is time to see how many of these have been implemented, or if there are impediments and bottlenecks; where new initiatives are needed, what kinds of ripples these changes have brought into the system; whether all the participants have the management skills to understand, appreciate and implement the reforms; and whether ICAR has acquired a mindset which will result in scientific excellence and productivity? These questions should be addressed, if investment in research is to provide optimum results. It is pertinent to note that ICAR has the potential, the ability, and the will to take fresh initiatives and continue to be in the forefront of such an exciting opportunity. It has proven strengths in its skilled manpower and vast infrastructure, and it covers a wide spectrum of knowledge space.

ICAR is launching a demand-driven, need-based, bottom-up, location-specific, multi-disciplinary, program mode, national agricultural technology project (NATP) through World Bank assistance. In the context of reorientation of the agricultural research system, NATP is an opportunity and a challenge, since the vision of NATP is that it is a different way of doing things, and it should be viewed as a vehicle for change.

Building partnership. It will be extremely useful for NARS to build partnership with ICRISAT in crop improvement, enhancement of genetic resources, molecular biology, transgenics (Bt genes for Helicoverpa and stem borer, coat protein genes for legume viruses, apomictic gene in sorghum), basic and strategic work in natural resource conservation (GIS and crop modeling), bridging gaps in systems research and socioeconomic research including gender issues, research prioritization, technology assessment, refinement, transfer and impact assessment Similarly, NARS in India - indeed NARS in the developing countries of Asia and Africa - will benefit from sharing of resources, institutional facilities, testing assessment and refinement of technologies, human resource development and regional and international collaboration.

Epilogue

Till such time as the population stabilizes, the demand for food and other needs will increase, depending upon income-related consumption patterns. To keep pace with the present rate of population growth and consumption patterns, food requirement in India has been estimated to cross the 225 million t mark by 2000 AD. This means an annual agricultural growth of 4%, and an increase in foodgrain by 5 million t per year. Towards the year 2000 AD and beyond, agricultural development in the country will be guided not only by the compulsion of improving food and nutritional security, but also by the concerns for environmental protection, sustainability, and profitability. This is not going to be an easy task considering the non-availability of favorable factors of past growth, fast declining input use efficiency in major cropping systems, and the rapidly shrinking resource base.

Notwithstanding the impressive gains in agricultural production, the vast agricultural potential still remains highly under-realized. Moreover, there are serious gaps both in yield potential and technology transfer as the national average yields of most of the commodities are low.

Fortunately, there have been several technological breakthroughs in recent years, and new cutting-edge technologies are available. These provide new opportunities and augur well for the challenges posed. The growth curves for equity and social and economic justice can only be expected with well thought out and well-planned, and well-executed research and development strategies. The strategy must rally round the conservation of natural resources - soil, water, vegetation, solar energy, etc.

Thus, at the turn of the millennium, the goals of Indian NARS and ICRISAT remain as urgent as ever. They have to contribute to relief of poverty, hunger, and environmental deterioration in the semi-arid tropics. The missions of these two institutions have to be carried out through strategic partnerships with a wide range of other institutions in which each partner contributes according to its special expertise and mandate. ICRISAT as a global center of scientific excellence has clear comparative advantage to contribute broadly applicable "international public goods" particularly in the areas of biotechnology, information management systems, participatory approaches in research and development of human resources of NARS partners. The combined efforts of these two institutions should be to translate public goods into final products that help improve the lives of the rural poor in the SAT; not only of India but also in Africa. The joint research programs, particularly relating to efficient, stable, and low-cost production technology, will have a spin-off for African NARS as well. This partnership must thence be further strengthened to benefit the poorest of the poor most of whom live in the arid and semi-arid tropics.

Future Trends in Resource Management in the Semi-Arid Tropics

L D Swindale

The subject of my remarks today at this symposium marking the 25th Anniversary of ICRISAT is change - actual or potential change in the management of natural resources in the semi-arid tropics (SAT). Change is inevitable in agriculture. Changing economic circumstances, and changing conditions in agricultural trade induce changes in existing agroecosystems, even sustainable ones. The challenge to research is to predict what changes are most likely to occur, and, in today's environmentally conscious world, to predict which will be sustainable. Because research takes time, scientists serve emerging agroecosystems better than they serve existing ones. And I believe that the changes that are occurring in the SAT provide opportunities for ICRISAT to assist national governments and agricultural research organizations stimulate greater investments in semi-arid agriculture.

You will already have heard from me or from others some of what I will say; some of my slides you will have seen before, too, but probably not for a while, and the memory of them may have grown old. At this 25th Anniversary, and particularly at this time of change in management and direction of the Institute, it may be opportune to remind you of some things we have already learned.

West Africa

We all know that much of the agriculture in the West African SAT is primitive, with hand tools much in evidence. But remember that ICRISAT found rapid rates of change in the use of animal traction at

ICRISAT study villages in Burkina Faso. Fairly simple animal-drawn implements, perhaps, but certainly an advance on hand cultivation. ICRISAT scientists, trying to measure determinants of the use of animal traction in West Africa, often were foiled because members of the group "without animal traction" persisted in joining the group "with animal traction" while the studies were in progress.

Further evidence of intensification of agriculture in the West African SAT was provided by two ICRISAT scientists, Helga Vierich and Willem Stoop. They studied five villages in Burkina Faso in which the populations had grown by 14% between 1975 and 1983. The villages all were situated on the gently rolling Mossi Plateau, on toposequences with sandy, infertile top soils, often overlying shallow laterite, on the plateaus and upper slopes; and more fertile soils with higher contents of clay and organic matter in the valley bottoms.

In the southern and wetter parts of the Plateau, where the bottom lands were already intensively cultivated, increasing population led to a marked reduction in fallow periods on the uplands. This led to accelerated erosion, decreased yields and increased incidence of parasitic weeds. Farmers began to change their practices towards greater intensification. Local systems of soil conservation were taken up, much more fertilizer was used, animal traction rapidly increased and investments were made in irrigated gardens of fruits and vegetables. Perhaps most important was the trend away from usufruct tenure towards heritable property. Concomitantly there was an exodus of Fulani pastoralists and emigration of young men from disadvantaged ethnic groups and those not in the main line of lineage succession.

It has been known for many years that increasing population densities in areas of subsistence agriculture in Africa will bring about a gradual intensification of agriculture. Pingali, Bigot and Binswanger, building on the pioneering work of Esther Boserup, have described a population-dependent sequence of intensification in Africa from low-intensity forest fallow to multiple cropping. As population density increased farming systems became more intense. Vierich and Stoop not only confirmed this more general study but illuminated the many consequences and implications of increasing intensification. And the importance of fertilizer in that intensification.

Low soil fertility in West Africa is also well documented. More than 20 years ago, FAO assembled the results of hundreds of fertilizer trials carried out in West Africa by the Freedom from Hunger Fertilizer Program, which I had the privilege of leading for several years. The results showed consistent improvements in yield from the use of fertilizers even with farmers' varieties and the landraces of crops then available. Today the responses with improved cultivars are much greater.

The obvious input is phosphorus. Numerous studies have concluded that phosphorus is needed by West African soils and that it can be used profitably on several crops, in a variety of formulations and in a variety of climatic situations. At ICRISAT-Niamey the response to phosphorus of improved cultivars of pearl millet was spectacular even when raw rock phosphorus was used. And phosphorus is the nutrient most available in the region. Several countries have deposits of rock phosphate. What needs to be determined is the most efficacious method for transferring the phosphorus from the deposits to agricultural land.

Nitrogen is the next most important nutrient. Where it cannot readily be obtained as fertilizer, an agriculture based on legumes is the appropriate response. Legumes in rotation, or intercropped with cereals and root crops, can provide food, fodder, and cash. They also provide nitrogen fixed from the atmosphere to be used by subsequent crops.

In a series of experiments from 1986 to 1996 at ICRISAT-Niamey, combining experiments on pearl millet and cowpea intercrops with research on the duration of the rains - which we can now predict - it was found that in 8 of those 10 years it was possible to harvest a full crop of pearl millet and a crop of cowpea hay and sometimes cowpea grain. With the great shortages of forages in West Africa cowpea hay is more valuable than cowpea grain.

Vierich and Stoop found that production of basic cereals had been displaced by the production of fruits and vegetables. This was directly related to growing market access available to the villagers and the incentives being provided in the country for commercial and particularly export crops. Market access is directly related to crop intensification in the same way as is population. Improving market access - and infrastructure in general - will lead to the intensification of agriculture in West Africa.

In several West African countries there have been significant increases in the production of cotton over the last decade. Mali and Burkina Faso have been particularly successful in promoting cotton. Sorghum and cotton are grown in the same climatic zone - so is groundnut - so that cotton production has probably increased at the expense of sorghum. ICRISAT, in a recent strategic planning exercise, rejected the inclusion of cotton as a mandate crop but did agree to give it more emphasis in resource management research.

If the staple cereals are to occupy less land, they must be higher-yielding and more input-responsive. The late President of Niger, Seyni Kountche, had requested ICRISAT years ago to do research on irrigating pearl millet.

India

Now let me turn to the Indian SAT. Life has improved for many people in India in recent years. More than 100 million Indians now have lifestyles and purchasing power equivalent to that of Western Europe, albeit accompanied by even worse pollution of air and water.

There are still many in India who have yet to benefit from recent economic growth and many of them are in the semi-arid regions. During ICRISAT's decade-long village level study many rural people in the study villages did indeed escape poverty; some, initially not poor, fell into it. The overall trend was clearly downwards, but nearly 50% of the population of the six study villages were poor at the end of the study period. What is the situation today? 1 don't have the data, but I would expect further improvements, particularly in the black soil areas of the central Indian peninsula.

That is because the black soils, or Vertisols, are some of the most productive soils of the SAT for rainfed agriculture. Their high water-holding capacity endows them with the ability to compensate better than most other soils for the low and erratic rainfall. They are widespread in India, particularly in the central peninsula, and generally have potentials far above their use in traditional agriculture.

Improved cropping systems were developed by ICRISAT and CRIDA, the Central Research Institute for Dryland Agriculture, some years ago for the Vertisols in the production zone with more than 750 mm of annual rainfall. The productivity of the soils was increased several-fold, labor requirements increased in the absence of labor-saving technologies, and runoff and erosion were reduced.

In on-farm studies with the improved systems, average gross returns were four to five times those of the traditional systems. Coefficients of variation of gross profits were lower than those for the traditional systems, that is, the stability of production was improved. The on-farm trials testified to the overall viability of the improved systems.

Problems and constraints to adoption of the improved cropping systems, as perceived by farmers, were both technological and institutional. They included: weed, pest, and disease controls, which were not fully integrated into the packages of practices; the need for short-term credit that embraced both rainy and postrainy seasons, particularly for women farmers; and, local marketing and distribution systems that could cope with the increased production that came from the improved technologies.

Working with the National Bureau of Soil Survey and Land Use Planning, ICRISAT developed estimates of the suitabilities of the individual soil series in the region for the improved cropping systems. At the management level used by better farmers in the region, only a few Vertisols, mostly in the vicinity of Bhopal in the central Indian state of Madhya Pradesh, were estimated to be moderately well suited to the intercropping technology. Other soils were marginally suited or unsuited. Farmers' experience supported these conclusions. Sequential cropping was marginally suited or unsuited under rainfed conditions. There would seem to be little prospect of this technology being disseminated through out the region. This is because of the very high frequency of drought as much as one year in four, in the region. But because many farmers in the area have some irrigation water available, a separate estimate of suitabilities using supplemental irrigation was determined. The better farmers generally can give one to two life-saving irrigations to the rainy season crop during dry spells and two to three irrigations (i.e., 50-75 mm of water per irrigation) to postrainy season crops. Even one limited irrigation after maize was found to substantially increase the yields of postrainy season crops.

Even with limited irrigation several Vertisols became well suited to sequential cropping, and most of the others became moderately well suited. The potential to make effective use of the limited water available was clearly demonstrated. Development of irrigation resources and water-harvesting technologies in the area could have high payoff. There is a vast area of soils awaiting investment and much more productive use.

Central India, far more than West Africa, has experience with and opportunities to produce commodities of higher value than the basic cereal crops. Cotton has long been produced on the black soils. So, too, have the famous Nagpur oranges. Soybean production spread rapidly in Madhya Pradesh in the 1980s. ICRISAT legume crops have contributed to the diversity of improved cropping systems in the region. I cannot predict what commodities will prove to be best suited to the region in the future, but I do know that at least 50% of all farmers there have access to some irrigation water, that cheap trickle irrigation systems are now available along with improved seeds, fertilizers and credit facilities. It is fairly easy to predict that increased fertilizer use will accompany the spread of irrigation systems in the region.

The role of ICRISAT

What is the role of ICRISAT in relation to these actual and potential changes in the management of natural resources in the semi-arid tropics? A partner, perhaps, rather than a leader, but that is for others to determine. But developing countries will invest in irrigating dry areas, sometimes regardless of economic and environmental cost, because of its importance in elevating and stabilizing food crop production and rural livelihoods. ICRISAT should be cognizant of these realities.

Improving nutrition and alleviating poverty require increased food supplies, lower prices, and greater purchasing power for the poor. Expanding employment opportunities and income generation must accompany efforts to increase food production. In the semi-arid tropics, livestock products, agroforestry, and horticulture are comparatively labor-intensive and profitable. They provide greater opportunities for employment and improved incomes than increased production of traditional annual cereals, important as these may be to daily food supplies. Dealing with these issues need not alter ICRISAT's attention to its mandate crops, but does argue for expanded and broader horizons in resource management research.

Concluding remarks

I have said little in these remarks about the importance of sustainability and environmental concerns. Other speakers in this Symposium will address these far better than I could do. In my own view, economic viability with all factor costs fully considered is an essential condition for sustainable productivity in agriculture but it is not sufficient Other conditions include:

- Standards and policies that limit the unwise use or degradation of natural resources. Although environmental economics are improving, they have not progressed sufficiently to be a viable alternative to physical standards as a means to arbitrate the trade-offs involved in ensuring sustainable agriculture
- Excessive specialization should be avoided whatever the short-term economic benefits might indicate; excessive crop specialization in the USA is calculated to have cost between $400 and $500 billion in today's dollars in farm income subsidies
- Avoiding dependence upon chemical control of pests and diseases
- Acceptance of the principle that steady decline in productivity, after adjusting for climatic variations, is an indicator that a system will become unsustainable
- Involving the actual land users fully in planning and developing improvements, because although research for farmers and with farmers are both necessary, modern agriculture, to be more sustainable, must be better controlled from within.

In my letter to ICRISAT included in the 25th anniversary souvenir I made some comments about the future which I would like to repeat here, because I don't expect many people will read it in the souvenir. To quote, "The past record of achievement however, leaves no room for complacency. If anything the challenges ahead may be greater than those that have been overcome in the past. The world has become more interdependent barriers to international agricultural trade are being reduced, free market incentives are becoming more important in developing country agriculture, and concerns for the environment constrain agricultural options. But the needs of the poor in the semi-arid tropics, of which there are still many millions, are no less urgent than before. Cost-cutting technologies based on ICRISAT research will accrue to the poorest people, those whom the CGIAR members say they most desire to assist."

Sustainable Food Security and Research Strategies

J G Ryan

I would like to make two general types of observations, which relate to the topic of the Workshop.

First, I will briefly overview the likely food security scenario facing the world in the 21st century, and the options which this provides in the pursuit of sustainable food security strategies. Then, I will allude to a few specific issues that arise as one endeavors to translate strategies into specific research priorities in the rainfed semi-arid tropics.

Food security challenges

One of the compelling statistics that conditions any discussion of sustainable food security is the increasing pressure of population on arable land. The average area of cropland per person worldwide declined from 0.40 ha to 0.81 ha between 1950 and 1975. It is expected to drop to 0.13 ha per person by the year 2000. In Asia the current figure is 0.15 ha per person, and is projected to fall to 0.09 ha by 2025.

Of course these statistics camouflage a lot of dynamics, including the movement of people off the land. The figures refer to the total population, and make no allowance for increases in cropping intensities resulting from agricultural technologies and irrigation which are land-augmenting. However, the pressure on land is real and must be factored explicitly into R&D strategies and priorities. But we should not ignore the fact that when the population is treated in the denominator of a statistic in this way it seem as if people are the problem, a liability which should be addressed. While this provides a rationale for family planning programs it is well to remember that people are also an asset, a resource to be effectively used to help address the problem of sustainable food security. We as agricultural scientists can embrace rural people in our programs to enhance the numerator in the land/people equation.

More than half of the developing world's poor lives in South Asia and Africa, most of them in the semi-arid tropics. Their absolute numbers continue to grow, as well as the proportion of the population which they represent. Current trends indicate that by the year 2025 food gaps could be as much as 255 million tonnes in South Asia, and 214 million tonnes in Africa. Unless the poor in these regions are provided with new income streams to be able to access their food and nutritional requirement in the process of agricultural and general economic development, the projected food gaps will translate into massive human misery and suffering.

A recent study by the World Bank estimates that the demand for staple commodities will continue to rise by about 2.7% yr^{-1} for the next 40 years. Livestock products, fruits, and vegetables will account for a growing share of consumption. The rising demands for livestock products will increase the derived demand for feed grains such as maize, sorghum, and barley, and for forage and pasture legumes. Hence there will be increased competition in consumption of coarse grains for feedgrain versus foodgrain uses, and this will impact especially on the poor. However, as Dr Fitzhugh indicated in his presentation there are strong complementarities between livestock and crop production in rainfed agriculture, and these can be exploited to favor the rural people.

The annual growth in world grain production from 1984 to 1990 was around 1% and world population growth was 2%. During the 1980s Africa's population grew at about 3% annually, while food production grew at only 2%. By the year 2025 the world's food supply will need to both double and diversity. Where will this extra food come from?

During the 1980 one-third of the increase in food production in developing countries was achieved through cultivation of new lands. But opportunities for continued expansion into new lands are rapidly becoming exhausted, and the major share of future food production increases will have to come from higher yields on presently cultivated lands.

Already cropping has extended onto land too dry or too barren to give reliable yields, particularly in sub-Saharan Africa. In Latin America and South East Asia, frontier development involving both crop and livestock production threatens the world's last remaining primary rain forests. Further development of large-scale irrigation is too expensive for most developing countries, and in many areas is severely constrained by water shortages.

In Asia, the pioneering region of the Green Revolution, rice yields increased at an annual rate of about 3% in the 1970s and early 1980s. These increases dropped to less than 2% in the late 1980s, and the concern is that yields may soon plateau.

Research and technological change have been the major sources of productivity growth in agriculture in the past, and their role will become even more important in the future. However, the challenge of world food security is much more complex than it was in the 1960s. Future food security must be attained while at the same time conserving and enhancing the natural resource base on which it depends. Research agendas are increasingly endeavoring to integrate concerns about the environment with the imperatives to improve agricultural productivity. It is not clear to what extent there are "free lunches" to be had in this pursuit; indeed this itself is a worthy topic for concentrated research.

Research priorities

The challenges today are far more complex than the "food first" imperatives of the 1960s and 1970s that gave rise to the Green Revolution. The five related themes of food security, malnutrition, poverty, population growth, and environment are more acute problems than they were when ICRISAT was created 25 years ago.

Coincidentally, it is timely that yesterday I received *Research for Rainfed Farming: Participatory Research - Knowledge to Wisdom* (Katyal, J.C., and Farrington, J., eds.), the proceedings of a workshop held at Central Research Institute for Dryland Agriculture, (CRIDA), which addresses the research challenges facing India's rainfed agricultural sector. I commend this publication to those who are responsible for research policy, conduct and management wherever they may be.

I would like to focus on a few issues of particular relevance to the establishment of research priorities in rainfed areas from an international perspective.

The research continuum. No longer should farmers be regarded only as clients or targets in the research process. Rather, they are partners in what should be an inclusive process. Traditionally, the research continuum included basic, strategic, applied and adaptive components. It is now increasingly accepted that we also must include diagnostic and participatory phases. The latter two especially involve farmers (both men and women) in an interactive and learning process with scientists. The same scientists who are significantly involved in the more basic and strategic ends of the research spectrum should also be involved in interacting with farmers at every stage of the research continuum. Different disciplines should also interact both in laboratories and in farmers' fields. Scientists who traditionally regarded themselves as laboratory oriented need to assume some responsibility for working amongst farmers also. Gone should be the days when they left it to other disciplines, usually social scientists, to work among farmers in a farming systems paradigm. Today scientists of all disciplines should be involved in the paradigm, and this should include working with NGOs and farmers' associations.

Indigenous knowledge. Indigenous knowledge has no doubt been a major factor in sustaining the livelihoods of millions of poor people in the semi-arid tropics. Scientists would be wise to distill this knowledge in defining their research priorities and in their experimental protocols. Some believe that indigenous knowledge and the empowerment of poor people are sufficient conditions to improve their welfare and conserve the environment. This was a theme propounded by many NGOs at the recently negotiated Desertification Convention. While indigenous knowledge and the empowerment of the poor are necessary conditions for sustainable food-secure livelihoods and environmental amenities for the poor, it is difficult to accept that they are sufficient. Indigenous systems have never experienced the extent and speed of population growth and the pressure this exerts on natural resources that has occurred in recent years, and is projected to continue for at least the next 25 years. It is hence optimistic to expect and dangerous to rely solely on indigenous knowledge to provide the innovations that will be required in future. Modern science must be embraced along with indigenous knowledge if we are to succeed. There is no alternative but for scientists, farmers, NGOs development professionals and practitioners, and policymakers to work more closely together to bring out the best in us. The information and communication revolutions can facilitate this inclusiveness.

Marginal versus high-potential environments. This is an issue for both the CGIAR and for Centers within the CG-system. What priority should be accorded to different environments in research portfolios? Is there a greater payoff to research investments in higher-potential environments? Do a greater breadth and depth of poverty in the more marginal environments offset this? If so, what weight should be accorded to efficiency versus equity aspects of the choices to be made? In addition, an experimental dimension must be included in the deliberations. For example, are the hotter and more arid parts of the semi-arid tropics more susceptible to degradation processes such as soil erosion and fertility declines than the cooler and wetter environments? If so, does this mean that more natural resource management research is appropriate in these more marginal environments?

What is the trade-off implied in terms of potential productivity gains? Are there asymmetric research spillovers between the marginal and higher-potential areas which can be exploited to minimize the trade-offs?

Time does not allow me to elaborate on these issues here. I have done so in a paper in the book by Katyal and Farrington mentioned earlier for those who would like to pursue the matter.

Role of modeling. The heterogeneity of the semi-arid tropics and its inherent riskiness makes the use of crop, systems, and simulation modeling imperative in future research agendas. They can complement other R&D approaches and provide a unique tool to integrate indigenous knowledge and modern science. ICRISAT and NARS have more than two decades of concentrated research output that can be effectively utilized to calibrate and validate models. We now have the hardware and software to synthesize these enormous databases of location-specific information into knowledge and wisdom.

Models offer four cost-effective advantages:

- A means to extrapolate location-specific research to achieve technological **spillovers**
- An ability to assess the **risks** of alternative technology options
- An ability to assess the **sustainability** of alternative technology options that are beyond the experience of farmers
- A means to facilitate the **collaboration** among all of the actors in the research continuum described earlier, including advanced research institutions at the forefront of model development.

Breeding versus resource management research. Issues of intellectual property rights, and developments in biotechnology probably influence public R&D agencies like ICRISAT to question the emphasis that ought to be given to the more applied end of plant breeding. On the other hand, natural resource management research opportunities and needs will probably be more in the public good arena. However, the problem with the latter type of research is that it has proven difficult to both measure and demonstrate that investments in it have significant payoffs. Indeed this is itself a researchable issue.

The Convention on Biological Diversity, The World Trade Agreement and other developments following the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, Brazil, in 1992 are leading more and more countries to adopt sui generis legislation to protect their intellectual property in genetic resources. These trends will serve to further distance the IARCs from applied breeding, and focus on more strategic research on germplasm conservation and management.

Indeed this is already reflected in ICRISAT's Medium Term Plan for the period 1998-2000. The share of resources to germplasm enhancement and breeding is projected to decline from 27% currently to 20% by 2000, with production agronomy declining from 17% to 12% during the same period. On the other hand, the share to saving biodiversity will rise from 11% to 18%, and that for protecting the environment will also rise from 17% to 19% of ICRISAT's investment by 2000.

Role of Livestock in Sustaining Agriculture in the Semi-Arid Tropics

H Fitzhugh

The contribution of livestock to the sustainability of production systems is vital, and a strong increase in demand for livestock products is forecast for the next two decades. In addition, such intermediate products as animal traction and manure are important to poor smallholder farmers. (TAC 1996)

On the occasion of the ICRISAT Silver Jubilee, it is fitting to reflect on the importance of livestock in the semi-arid tropics (SAT) and on the opportunities to improve livestock productivity through collaborative research. In the semi-arid tropics of developing regions, livestock account for 30-50% of the value of total agricultural produce. Livestock make direct contributions through food and fiber. Often the sale of livestock and livestock products is the principal source of cash for smallholders in the SAT. In addition, livestock improve crop productivity through traction and animal manures.

The International Livestock Research Institute (ILRI) was established from two predecessor research institutes which, before 1995, had concentrated on livestock systems in sub-Saharan Africa. The decision by the CGIAR to expand the mandate for international livestock research was largely stimulated by the substantial increase in demand for livestock products. Over the next two decades, demand for meat and milk will increase by more than 150%. Almost all this increase will be in developing countries, especially in Asia. This increased demand will be driven by increased incomes and population growth, especially of urban populations. Research will help ensure that smallholder producers benefit from the income-generating opportunities, and consumers benefit from the cost reductions which keep the prices for livestock products relatively low.

The priorities for ILRI expansion out of Africa are first for Asia, then Latin America and the Mediterranean (West Asia-North Africa) regions. The priorities for ILRI's research in Asia have been developed through consultations with livestock specialists in southeast Asia and south Asia in 1995, followed by in-depth studies of regional priorities in 1996 and 97.

In Africa, ILRI scientists based at ICRISAT-Niamey have been collaborating with ICRISAT scientists and national partners since 1989. In 1996, an ILRI ruminant nutritionist moved to ICRISAT-Patancheru to establish new collaborative research to improve feeding values of sorghum and millet crop residues.

ILRI's comparative advantages include access to

- tropical livestock genetic resources
- tropical feed genetic resources
- tropical livestock diseases and parasites
- human resources and infrastructure with special capacity for
  - molecular biology - genetics and health
  - interdisciplinary systems research
- partners
  - national agricultural research systems (NARS)
  - advanced research institutes (ARIs)
  - international agricultural research centers (IARCs) including ICRISAT

Based on these comparative advantages, the areas of research which have priority in the medium-term include

Biological research activities

Ruminant genetics. Focus on characterization, conservation, and use of indigenous animal genetic resources (with primary emphasis on genetic resources from Africa and Asia); and on the genetics of resistance to disease and parasites.

Ruminant health. Focus on the molecular basis of pathogenesis and disease resistance; immu-nology and vaccine development; development of diagnostic tools, and epidemiology and disease control strategy.

Ruminant feed resources. Address the phytochemistry of forages and crops as they affect the palatability and digestibility of feed resources; detoxification of anti-nutritional factors; rumen micro-biology to enhance utilization; and characterization and conservation of forage genetic resources.

Interdisciplinary crop-livestock systems research

This research follows a holistic production-to-market approach, involving partnerships with crop centers and their national partners in ecoregional consortia. ILRI's contributions are interdisciplinary - integrating scientific contributions from economics and ecology with the animal and veterinary sciences. Components include

- livestock policy analysis
- systems analysis and impact assessment
- livestock and the environment
- livestock production under disease risk
- smallholder dairy systems

Systemwide livestock program

As part of ILRI's research on crop-livestock systems, ILRI is the lead Center for the systemwide livestock program (SLP). The SLP is a CGIAR research initiative to improve livestock feed resources and natural resource management in crop-livestock agriculture. The SLP works through crop Centers and their national partners in ecoregional consortia addressing productivity and sustainability research. In Asia, SLP research will be in two priority ecoregions: the semi-arid ecoregion of south Asia led by ICRISAT, and the humid/sub-humid ecoregion in southeast Asia led by IRRI.

With a few exceptions, livestock research capacity is not well-developed in NARS, especially in Asia and Africa. Therefore, ILRI gives priority to strengthening capacity for livestock research through training and information services. ILRI scientists also work in close partnership with national scientists. National capacity is strengthened through these collaborations. Most important, ILRI supports the development of regional livestock research networks to promote South-South exchange of information, lessons learnt, and research-based technologies.

Collaboration and partnerships

The needs of the global agenda for livestock research far exceed ILRI's limited resources, which are approximately 100 scientists and a budget of US$ 30 million in 1998. Therefore, an integral part of our strategy is working through partnerships that leverage our limited resources. These partnerships include scientific networks involved with scientists from advanced research institutes around the world; the ecoregional consortia involving international Centers; national partners; the systemwide programs; and outsourcing research to scientists and institutions which have comparative advantage for certain types of livestock research.

Livestock, soil fertility, and crop yields: An example of collaborative research

In many developed countries, livestock manures are a pollutant and a problem. However, in most developing regions, livestock manures are key to improving nutrient management in resource-scarce cropping systems.

The impact of livestock on the environment, including natural resource management in crop-livestock systems, is a priority for research by ILRI. Most often, this research is done in collaboration with scientists from the crop Centers, such as ICRISAT. The processes of nutrient cycling from soils to plants and, through animals, back to the soils are being studied by ILRI scientists at ICRISAT-Niamey.

Conclusion

Livestock are important to the improvement of productivity and sustainability of agricultural systems in the semi-arid tropics. The substantial increase in demand for livestock products will provide opportunities for income generation from the sale of livestock products, and of crop products for livestock feed. These opportunities Will bring additional stresses on the natural resource base supporting agriculture in the SAT. Therefore, research is needed to provide knowledge and technologies to protect the natural resources as well as improve the productivity of crop-livestock systems in the semi-arid tropics. To be successful, this research must involve close cooperation and collaboration among crop and livestock scientists from both national and international research institutes.

Summary and Recommendations

The forenoon session (speakers: M S Swaminathan and I Serageldin) was moderated by P V Shenoi and the afternoon session (H Fitzhugh, L D Swindale, R S Paroda, and J G Ryan) was moderated by A von der Osten. From the discussion that followed the presentations emerged recommendations for ICRISAT to consider while formulating its research agenda for the 21st century.

Reconsider crop mandate. Farmers today, particularly in Asia, do not depend as strongly on the mandate crops of ICRISAT as they did 25 years ago when ICRISAT was established. They wish to have cash to ensure their families' food and nutritional security. New annual crops (e.g., soybean and sunflower in India) and silvi-pastoral systems are increasingly providing such security. ICRISAT, therefore, needs to reconsider its crop mandate to address the changing needs of SAT farmers. However, the "new" crops mentioned can still be researched as part of natural resources management options.

Expand the scope of sustainability. Economic growth cannot be the sole parameter of sustainability. The notion of sustainability needs to be expanded to include a balance between resource conservation and resource enhancement

Greater involvement in community life. Farmers' representatives have said that ICRISAT has had a significant role in solving farmers' problems in the SAT, and the existence of ICRISAT is still very relevant The new ICRISAT should address issues affecting the lives of farmers. Safe drinking water is as important an issue as that of nutritional security of poor people and is linked to hygiene. Both need to be viewed together. Addressing these at community/village/watershed level is critical to show the impact of agro-technologies. NARS should take the lead in such partnership efforts.

Regulate markets. Market forces crucially influence the production and profitability of crops to farmers. Unless markets are regulated so that farmers get their share of profits, agriculture as an enterprise cannot succeed in the 21st century.

Research to emphasize alternative technologies. Agro-technologies involving high input costs are irrelevant to poor farmers of SAT. For example, farmers in Africa do not apply chemical fertilizers to ICRISAT's mandate crops unless clear benefits can be shown. Other technologies, e.g., pesticides, pose a significant health hazard. Many farmers are unaware of the risks in inappropriate handling of these chemicals. And those who are aware cannot afford the protective clothing. ICRISAT needs to change its research emphasis and work on alternative technologies targeted to poor farmers. These can be labor intensive, and village/community based, and should involve fewer purchased inputs. Available technologies and best-bet alternative technologies should be analyzed for risks associated with them before promoting their on-farm use.

Designate minor millets as "nutritional grains". Minor millets, generally known as "coarse grains", should be called "nutritional grains" since they have high food-value, and yield-potential. In their respective cropping systems these crops have a major role in crop-livestock interactions, human nutrition, and in alleviating protein malnutrition, beyond the SAT mandate of ICRISAT. But the benefits of different nutritive traits in these nutritional grains needs to be vigorously promoted , which is possible if the problem is addressed on a community-wide basis. Therefore, consumption of nutritional grains by the general public should be encouraged. Many of the nutritional grains have tremendous potential in the SAT, and should be exploited to expand the food-basket of the countries for ensuring food security.

Promote groundnut as high-protein crop. Groundnut is now being considered as a high-protein crop to address nutritional security of the poor, rather than as a oilseed crop. This concept should be promoted beyond the SAT. Its value in rice-rice cropping system has been established in some parts of India and needs further strengthening.

More effective teamwork needed. Credit sharing is easier to define in crop improvement research than in the natural resource management (NRM) research. Such poorly defined credit sharing poses difficulties in teamwork amongst NRM scientists. Further, ICRISAT's research also needs greater involvement of national program research and extension staff, policy makers, and nongovernmental organizations.

Increase partnerships. Ecoregional research consortia and systemwide programs will become even more relevant in the SAT, and will need the catalytic leadership role of ICRISAT. Inter-Center linkages for joint research, and sharing overlapping research areas/mandates will be essential.

Meet the needs of the 21st century. All agricultural scientists, not just those at ICRISAT, need to address the research needs of the next century, not just those of yesterday or today. The challenges in the years 2010 and 2020 will be population increase, environmental degradation, and decline in the dependence of farmers on subsistence agriculture. Scientists have a major responsibility in having research outputs ready to meet these challenges.

ICRISAT should explicitly consider the following concepts when it develops a research strategy for the 21 st century:

- integration of commodity research with systems (livestock, agroforestry, etc.) with emphasis on natural resource management
- complementarity of institutions and actors involved in the research process
- team approach in research, especially in NRM
- changed role of national research systems, accompanied by a change in the paradigm of partnership in international Centers, and sharing of resources and research agendas
- use of cutting-edge science, e.g., quantitative trait loci (QTL) to improve yield potential
- resource research strategies, and interaction with partners in an organized fashion.

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Acronyms

AHRD	Agricultural Human Resource Development (India)
ARI	Advanced Research Institutes
ARIS	Agricultural Research Information System (India)
CAZRI	Central Arid Zone Research Institute (India)
CBD	Convention on Biological Diversity (Canada)
CGIAR	Consultative Group on International Agricultural Research (USA)
CIAT	Centra Internacional de Agricultura Tropical (Colombia)
CIFOR	Center for International Forestry Research (Indonesia)
CIP	Centra internacional de la Papa (Peru)
CIMMYT	Centra Internacional de Mejoramiento del Maiz y del Trigo (Mexico)
CRIDA	Central Research Institute for Dryland Agriculture (India),
CSCRTI	Central Soil Conservation Research and Training Institute (India)
DOR	Directorate of Oilseeds Research (India)
GIS	Geographical Information Systems
IARC	International Agricultural Research Center
ICAR	Indian Council of Agricultural Research
ICARDA	International Center for Agricultural Research in the Dry Areas (Syria)
ICLARM	International Center for Living Aquatic Research Management (Philippines)
ICRAF	International Centre for Research in Agroforestry (Kenya)
IFDC	International Fertilizer Development Center (USA)
IFPRI	International Food Policy Research Institute (USA)
IIMI	International Irrigation Management Institute (Sri Lanka)
IIPR	Indian Institute of Pulses Research
IITA	International Institute of Tropical Agriculture (Nigeria)
ILRI	International Livestock Research Institute (Ethiopia and Kenya)
IPGRI	International Plant Genetic Resources Institute (Italy)
IPM	Integrated Pest Management
IPR	Intellectual Property Rights
IRRI	International Rice Research Institute (Philippines)
ISNAR	International Service for National Agricultural Research (Netherlands)
IVLP	Institute Village Linkage Programme (India)
IWMI	International Water Management Institute (Sri Lanka)
NARS	National Agricultural Research Systems
NATP	National Agricultural Technology Project (India)
NGO	Nongovernmental Organization
NRCG	National Research Centre for Groundnut (India)
NRCS	National Research Centre for Sorghum (India)
NRM	Natural Resource Management
OECD	Organisation for Economic Co-operation and Development
QTL	Quantitative Trait Loci
SAT	Semi-Arid Tropics
SLP	Systemwide Livestock Program (ILRI)
TAC	Technical Advisory Committee (CGIAR)
TRIPS	Trade-Related Aspects of Intellectual Property Rights
UNCED	United Nations Conference on Environment and Development
WARDA	West African Rice Development Association (Cote d'lvoire)

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