THE FOOD AND ENVIRONMENT TIGHTROPE

Record of a seminar conducted by the Crawford Fund for International Agricultural Research, Parliament House, Canberra, 24 November 1999

EDITOR: HILARY CADMAN

Australian Centre for International Agricultural Research
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Contents

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Preface

The Food and Environment Tightrope seminar hosted by the Crawford Fund was the fifth in a series designed to focus attention on the links between food, conflict, nature, wealth, health, poverty, society, development and people.

The seminar had a great deal of cut and thrust, if not spice, as the need for lateral thinking to be applied across the issues canvassed was highlighted. Some of this lateral thinking is reflected in the papers and I commend them for your attention.

One of the world's most celebrated scientists, Professor M.S. Swaminathan, who, with his friend and colleague Norman Borlaug, developed new varieties of wheat that saved much of Asia from starvation and hunger-related disease, delivered the keynote address, 'Walking the Tightrope'.

As a key figure in the 'green revolution' of the 20th century, it would be difficult to think of a better person to discuss the difficult balancing act humanity faces in the new century. Without the increased yields that the green revolution of the 1960s brought about, arable land would have had to double, while forested land would have been halved, in order to feed the world's population up until now.

It is largely because of scientific advances that agricultural yield and population growth have matched each other. The bad news is that 840 million people are still undernourished, and are likely to continue to be chronically short of food unless scientific research is intensified, and political and civil will to help humanity are further stimulated.

In an inspiring address, in which he called for an 'ever-green revolution', Professor Swaminathan pointed out the need for political will and commitment to agriculture in developing countries. In overseas aid he emphasised the need for sustained partnership and not patronage between donor countries and developing countries, and on the home front, he emphasised the need for competence and self-confidence in scientists working in national agricultural research systems.

He was joined by speakers from four of the international agricultural research centres that form the agricultural and scientific network known as the Consultative Group on International Agricultural Research (CGIAR), and by eminent Australian scientists working in agriculture and natural resource management.

We asked them to explain how their work helps those who need it most — the poorest people in the world, many of whom live on less than one dollar a day. How can they feed themselves, create income, and protect the environment? Another speaker, Dr Jeffrey Sayer, recounted that Norman Borlaug once said that you have to have at least one square meal a day if you are going to be an environmentalist!

Our international and Australian speakers had some very interesting views. Can we really farm poor, degraded and saline soils without further damage to the environment? If the poor get richer and then consume more meat and eggs (because they have more money to buy these luxury items), how do we feed the extra livestock on the same amount of land? Do people in the rich nations of the West have the right to demand that poor people in developing countries preserve biodiversity in forests if those people depend on the forests for their medicines, food and fibre?

The well-known Australian agricultural scientist, Dr Lloyd Evans, author of numerous texts on agricultural research, had the difficult task of summing up the proceedings in an address entitled, 'Will we fall of the tightrope?' His opening remarks reminded the audience that population growth "will determine how much additional food is needed, how much forest is logged or converted to arable land, and thereby, the pressure on the world's soil, water, atmospheric and biological resources."

The Crawford Fund urges governments in Australia and around the world to invest wisely in poor people because the future of the planet depends upon it. As Professor Swaminathan said, today's advances in science and technology offer uncommon opportunities for creating a food secure world. "We must **defend** the productivity gains so far made, **extend** the gains to semi-arid and marginal environments, and **work** for new gains using blends of frontier technologies and traditional ecological prudence."

If we ignore these advances today, and defer making policies that give much greater importance to the value of international agricultural research and development, we imperil a safe and healthy global environment for our children and grandchildren tomorrow.

The Hon Tim Fischer MP
Chairman
The Crawford Fund

Abbreviations and acronyms

ACIAR	Australian Centre for International Agricultural Research
ADB	Asian Development Bank
ASB	Alternatives to Slash-and-Burn Consortium
CABI	Centre for Agriculture and Biosciences International
CAZRI	Central Arid Zone Research Institute
CBD	Convention on Biological Diversity
CGIAR	Consultative Group on International Agricultural Research
CIFOR	Center for International Forestry Research
CIMMYT	International Maize and Wheat Improvement Center in Mexico
C&I	criteria and indicators
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EEZ	exclusive economic zone
ET	evapotranspiration
EU	European Union
FAO	Food and Agriculture Organization
GDP	gross domestic product
GIS	geographical information system
GM	genetically modified
GMO	genetically modified organism
GNP	gross national product
GPS	global positioning system
HYVP	high-yielding varieties program
IARI	Indian Agricultural Research Institute
IARC	international agricultural research centre
IBSRAM	International Board for Soil Research and Management

ICAR	Indian Council of Agricultural Research
ICRAF	International Centre for Research in Agroforestry
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFPRI	International Food Policy Research Institute
IPRs	intellectual property rights
IRRI	International Rice Research Institute
ISBRAM	International Board for Soil Research and Management
ISO	International Organization for Standardization
ISRIC	International Soil Reference and Information Centre
ITTO	International Tropical Timber Organization
IUCN	World Conservation Union (formerly International Union for the Conservation of Nature)
IWMI	International Water Management Institute
MSSRF	M.S. Swaminathan Research Foundation
NARS	national agricultural research system
NGO	nongovernment organisation
RMD	resource management domain
TRIPs	trade-related intellectual property rights
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
UPOV	Union for the Protection of New Varieties of Plants
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
WIPO	World Intellectual Property Organization
WTO	World Trade Organization

OPENING ADDRESS

THE HON ALEXANDER DOWNER MP, MINISTER FOR FOREIGN AFFAIRS

Mr Downer was elected Federal Member for Mayo in South Australia in 1984 and has been Minister for Foreign Affairs since 1996. Australia's overseas development assistance program, which includes Australia's contribution to international agricultural research through the Australian Centre for International Agricultural Research, is within Mr Downer's foreign affairs portfolio.

Walking the Tightrope — Australia's Role in Keeping The Balance

THE HON ALEXANDER DOWNER MP, MINISTER FOR FOREIGN AFFAIRS

Introduction

It is a great privilege to be asked to give the opening address at such an accomplished gathering of professionals. Today's program provides an excellent opportunity to explore the challenges facing agricultural researchers, particularly in the light of the experiences of some of our Asian neighbours recovering from the economic crisis.

Australia is in the very fortunate position of having no problem in feeding its people, yet no other country has produced leaders who have more strongly influenced international food security issues. Sir John Crawford is foremost among these leaders. His vision, expertise and persuasive powers can largely be thanked for the foundation of international agricultural research, through the Consultative Group on International Agricultural Research (CGIAR).

Our activities in agricultural research are founded on a solid national interest. For much of Australia's history, technological progress in agriculture fuelled national development, and our research community has actively taken these technological achievements to the world. That is something of which all Australians can be proud.

Today I'd like make a few remarks about Australia's role in keeping the global balance on the food and environment tightrope. But first I want to say something about Australia's approach to achieving international food security, and discuss some of the environmental impacts of East Asia's economic crisis.

The message that I want to leave with you today is one of strong Australian leadership in the area of agricultural research and food security. Australians have been at the forefront of efforts to improve world knowledge in agriculture. And we have demonstrated to the world what applied research of a high order can achieve.

Australians have been at the forefront of efforts to improve world knowledge in agriculture.

Why Food Security Matters

Over 800 million people are chronically undernourished in a world that is able to produce sufficient food for everyone. Two hundred million children under five have protein and energy deficiencies. In developing countries, poverty is far more prevalent in rural areas. The largest numbers of people living in poverty are in South and East Asia. Both regions have over twice as many people living in absolute poverty as subSaharan Africa.

More than most other donors, Australia has a direct interest in poverty alleviation in our region. Within a few hours flight from Australia lie seven developing countries with a total population of close to 300 million people. Add another hour or so, and the number climbs to around 1 billion. Our future depends on the success of efforts to promote prosperity in the region.

The Australian Government places a high priority on helping developing countries achieve food security. This is part of our aid program's basic objective of reducing poverty and achieving sustainable development. Australia made an official commitment to achieving food security at the 1996 World Food Summit in Rome.

Trade Liberalisation

Australia has two approaches to achieving global food security. The first relies on the promotion of a more open trading system.

We strongly support food security based on self-reliance rather than self-sufficiency.

A freer global trading system encourages economic growth in both developing and developed countries. We strongly support food security based on self-reliance rather than self-sufficiency. Together, domestic production and international trade can efficiently provide food security based on comparative advantage. But we recognise that some low-income countries with food deficits are concerned that the removal of trade protection may disadvantage them in the short term. Australia is committed to ensuring that those concerns are taken into account. We are also providing training to prepare these countries for the next round of multilateral trade negotiations and assistance to enable accession to the World Trade Organization (WTO).

Australia has been at the forefront of trade liberalisation through the reduction of protection and subsidies, particularly those involving agriculture. We also spearhead efforts to encourage further liberalisation, both for Australia and for our development partners, by taking an ambitious but pragmatic approach in forums like the WTO, and championing the interests of agricultural free traders through the Cairns Group, chaired by my colleague, Trade Minister Mark Vaile.

Why does this matter to developing countries? It matters because groups like the European Union spend around 50% of their budget on agricultural subsidies. How can a country like Bangladesh ever compete on the international scene when the Europeans subsidise agricultural production, marketing and export?

Australia's Pledge

Our second approach aims to increase the food security of our development partners through targeted activities funded by the aid program. I have made a pledge of $1 billion for food security for the four-year period from July 1998. The pledge is aimed not only at immediate food aid needs, but also at strengthening agricultural production, research and development, and skills and systems in developing countries. Activities include establishing food mapping systems and enhancing women's access to resources. We are already well advanced towards meeting that pledge.

The green revolution is the best known of the many successes of the CGIAR group. The concerted campaign to elevate the agricultural production of developing countries and of staple crops led to a rural transformation. New higher yielding crop varieties safeguarded some 300 million hectares of land from coming under cultivation during the last 30 years.

The challenge now facing us is to find sustainable ways to increase yields without causing further damage to our fragile environment. The complementarity between research and other aid activities must be fully exploited to ensure that the benefits are spread as widely as possible. Developments in biotechnology and genetically modified crops could deliver a second green revolution, and these new technologies must be safely put to use in the battle against world hunger.

The challenge now facing us is to find sustainable ways to increase yields without causing further damage to our fragile environment.

But increasing yields is only part of the answer. Globally there is at present no shortage of food. There are, however, distribution problems. There is also a serious shortage of income to buy food — in other words, a poverty problem.

Income growth is particularly important in rural marginal lands where poverty is rife and agriculture remains the predominant occupation. People in these areas need money, industries, markets and communications, within a framework of sound government policies. I will release a rural development strategy soon for the Australian aid program that will provide a framework for Australia's rural development aid activities.

Food Security and the Environment

The Asian region suffers from many environmental problems. Development and population growth are putting severe pressures on natural resources, as well as causing severe air, water and industrial pollution. Water shortages are a growing problem.

It is now two years since the onset of the East Asian economic crisis. I recently asked AusAID to commission a report on the impacts of the crisis on the environment. This report found that the crisis has created new environmental problems and has exacerbated existing concerns.

In particular, the economic crisis increased environmental pressures on rural areas. Illegal fishing, logging and poaching are on the rise. Migration of urban poor and unemployed to the countryside threatens rural land, water and forest resources. Changing international timber markets have spurred new plantation and forestry developments. Such developments need to be pursued, paying due regard to the environment. Plantation companies deliberately lit many of the fires that swept across Indonesia's outer islands in 1997 and 1998, in order to clear land cheaply, causing great environmental damage.

Australia is committed to assessing the environmental impacts of its activities.

Food security initiatives must not further exacerbate problems in the region's already fragile environment. Australia is committed to assessing the environmental impacts of its activities. All our aid projects are subject to stringent environmental impact assessment and must meet the same environmental management standards as development proposals in Australia.

One positive aspect of the crisis is the way in which it has precipitated genuine attempts at reform in the region. It has, for example, opened windows of opportunity for the reform of environmental management. Some governments, such as those in Indonesia and the Solomon Islands, have already begun reforming environmental and forest regulations. Such reforms can simultaneously help both food security and the environment.

Australia is helping to exploit these opportunities for reform by providing valuable assistance to environmental protection authorities throughout the region. Thirteen per cent of Australia's aid program, or $193 million, was spent on environment-related activities in 1998–99. Through a range of capacity building, institution strengthening, natural resource and renewable energy projects Australia is helping countries address environmental concerns, conserve biodiversity and cope with global climate change.

Growth is Needed

The major threat the economic crisis posed was that large numbers of people brought above the poverty line in recent decades might again sink below it. Australian aid-funded research shows that the major impacts of the crisis were on urban areas, and that impacts on rural areas were not as great as initially feared. The main effects were felt as a result of El Niño and La Niña. These combined effects were considerable but varied widely by country, region and crop. Indeed there have been some benefits, especially to farmers who gained from price rises induced by currency depreciation.

Now that our neighbours are recovering from the crisis, economic growth is needed in rural areas. The challenge facing us today is to find ways of producing higher yield crops while still conserving the essential natural resources upon which our future nourishment depends. Increasing yields have proven to be the key to increasing income on farms and in surrounding areas. Research into new technologies forms a basic building block for better farming and food security for the world's poor.

The challenge facing us today is to find ways of producing higher yield crops while still conserving the essential natural resources upon which our future nourishment depends.

Making a Difference

I can see at least four areas of obvious expertise where Australia can make a difference to help end world hunger.

Research

Australia is a world leader in agricultural research and in the application of that research. Australian agricultural methods have generated widespread interest internationally. For example, Australian systems for dryland farming of sheep and wheat and for integrated management of crop pests and diseases have been used as models in similar ecological zones in Africa, South America and Asia. Australia will continue to excel in agricultural research through the excellent work of the Australian Centre for International Agricultural Research (ACIAR). Agricultural research is a strategic flagship for the growth and development of Australia's primary industries, as we invest well above the OECD average of developed countries in agricultural research both at home and abroad.

Many Australian research scientists and academics, led by the late Sir John Crawford, have made prominent contributions to the outstanding work of CGIAR and the sixteen agricultural research centres that it maintains in various parts of the world. Australians head the international agricultural research centres dealing with wheat and maize, aquatic resources, soil and agriculture and biosciences. In fact, I see that Dr Eric Craswell from the International Board for Soil Research and Management will be presenting a session later today. Australians are also highly represented on the boards and staffs of the various centres. This is a clear reflection of the high reputation and the leadership role that Australia occupies in global agricultural research and development.

...agricultural trade liberalisation, combined with poverty alleviation measures, offers the best opportunity to achieve long term food security.

Trade reform

Some people argue that trade reform is not crucial in feeding the hungry of the world. But I believe that agricultural trade liberalisation, combined with poverty alleviation measures, offers the best opportunity to achieve long term food security.

Protectionist pressures remain a real threat to world trade, and could erode all the gains that have been won from the bitter lessons of the past two years. Barriers to trade are no guarantee of lasting economic benefit. They destroy international competitiveness and encourage artificial bubble-economies, which are usually short-lived and are never sustainable in the long run.

Through our leadership in the battle for trade reform and our efforts in the Cairns Group we will continue to champion the interests of agricultural free traders. By cooperating with our development partners in trade liberalisation we will help create markets for agricultural products and also promote food security.

Governance

A recent landmark study by the World Bank — *Assessing Aid: What Works, What Doesn't and Why* — has re-emphasised the crucial role of good governance in sustainable development. The study found that aid works best where there is a good policy environment. With sound country management, an additional one percent of GDP in aid translates into a one percent decline in poverty and a similar decline in infant mortality.

Developing countries that are quite similar in terms of natural resources and social structure have shown striking differences in the advancement of the welfare of their people, much of which can be attributed to different standards of governance. Governance is not just about government. It is about a good society — about how citizens voice their interests, mediate their differences and exercise their legal rights and obligations.

Activities to strengthen governance have been a key aspect of the Australian aid response to the Asian crisis. We gave substantial assistance for crisis-hit countries through bilateral aid programs. We established a $50 million, three-year economic and financial management package for the region, together with our $12 million Asia crisis fund. Our aid programs have also focused on other major governance and capacity building activities, to give officials skills to address the causes of the downturn in their countries. In addition, I convened a major international meeting of ministers and senior officials from 27 countries and 9 major international institutions on development cooperation responses to the Asian crisis. We will continue to promote good governance in all aspects of the aid program, including those aspects directly related to rural development and food production.

Technology transfer

We must continue to encourage the transfer of innovative technologies for the benefit of our development partners. The Crawford Fund's activities play an important role in sharing the benefits of Australian research with researchers and practitioners abroad. Its training schemes offer short-term, practical training for people from developing countries. Seminars like the one today are a valuable way for Australia to promote close working relationships between researchers and those making use of their research.

The Crawford Fund's activities play an important role in sharing the benefits of Australian research with researchers and practitioners abroad.

Australia's achievements in international agricultural research have been extraordinary. Those achievements are reflected in the fact that the Crawford Fund attracts support from outside the federal government for its activities.

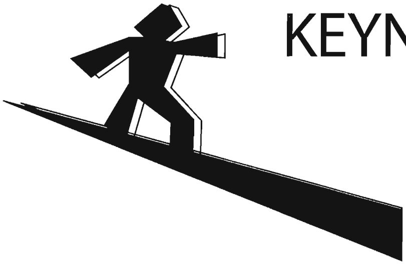
I am also happy to acknowledge its continuing excellence by announcing here that the Federal Government will maintain its support of the Crawford Fund into the year 2000, and beyond.

Conclusion

Ladies and gentlemen, there is no need for the people of the world to starve. Yet 800 million people are chronically undernourished in a world that can produce sufficient food for all.

Australia has amply demonstrated its leadership in helping developing countries achieve food security. Our shared achievements in international agricultural research over more than 25 years have benefited farmers in Africa, South America and Asia. We were there to help our neighbours when it counted, when they needed us most. And we have shown at home and abroad that we truly believe in the benefits of freer trade.

It would be arrogant to suggest that we, in Australia, have all the solutions. Significant problems remain, but I am heartened by Australia's ability to help our neighbours keep their balance on the food and environment tightrope. I face the future confident that we will continue our good work, and push towards the ultimate eradication of poverty and hunger from the face of the Earth.



KEYNOTE ADDRESS

PROFESSOR M.S. SWAMINATHAN, CHAIRMAN, M.S. SWAMINATHAN RESEARCH FOUNDATION, MADRAS, INDIA

Professor Swaminathan has made enormous contributions to agricultural science, food production, and research policy. He has been described as a living legend for his research into high-yielding wheat. Professor Swaminathan's research foundation promotes sustainable agricultural and rural development through the integration of traditional and innovative technologies. *TIME* magazine recently voted Professor Swaminathan one of the 20 most influential Asians of this century, in company with the likes of Gandhi and the Dalai Lama, for helping, through his research into plant genetics, to save most of Asia from starvation.

Walking the Tightrope

M.S. Swaminathan, Chairman, M.S. Swaminathan Research Foundation, Madras, India

Introduction

At the outset, I would like to express my gratitude to the Crawford Fund for giving me the privilege of visiting this beautiful and great country again to participate in the seminar on 'The Food and Environment Tightrope'. Delivering the Crawford lecture at the annual meeting of the Consultative Group on International Agricultural Research (CGIAR) in October 1990 (Swaminathan 1990), I made the following remarks.

> 'One day early in 1965 I had a call from an officer of the Planning Commission of the Government of India asking whether I could show a distinguished visitor from the World Bank around the wheat plots at the Indian Agricultural Research Institute (IARI), New Delhi. I asked what exactly the visitor would like to see and how much time he could spare. In reply, Sir John Crawford came on the line himself and said he would like to see the semidwarf wheat varieties in order to understand their yield enhancing potential. I asked whether he would like to see them in the experiment station or in farmers' fields. He immediately replied, "In farmers' fields." I took him to IARI's Jounti Seed Village where he spent a whole day squatting in farmers' homes, drinking the sugarcane juice and eating the pearl millet bread they gave him and enjoying himself thoroughly. At the end of the day, when I was taking him to his hotel, he said, "I now see light where there was only darkness".'

At the end of the day, when I was taking him to his hotel, he said, 'I now see light where there was only darkness.'

Thus began a strong personal friendship which lasted until his death. Sir John Crawford was a friend, philosopher and guide to me and to my family. I served with him on the first Technical Advisory Committee to CGIAR from 1971 to 1977. I would therefore like to take this opportunity to pay homage to the memory of a truly remarkable person, whose genius lay in his being simultaneously a vertical and a horizontal man. His summing up of complex issues at the end of long debates was always characterised by clarity, precision, and a delightful mixture of wit and wisdom.

Besides the unique contributions of Sir John Crawford to international agricultural research and development, many distinguished Australians have helped to build and shape several United Nations (UN) and other international organisations in the fields of food, agriculture and environment. In 1935, Frank L. McDougall wrote a memorandum on agricultural and health problems, in which he stated that 'it would argue a bankruptcy of statesmanship if it should prove impossible to bring together a great unsatisfied need for highly nutritious food and the immense potential production of modern agriculture'. At the League of Nations in Geneva in 1935, Viscount Bruce of Melbourne (earlier Stanley Bruce) made a strong case for the marriage of health and agriculture in an attempt to persuade the league, then being thwarted by insoluble political problems, to turn constructively to economic and social issues. Both Frank McDougall and Viscount Bruce played a key role in the establishment of the Food and Agriculture Organization (FAO) at Quebec, Canada, on 16 October, 1945 (Philips 1981), and Bruce was later elected as the first independent chairman of the FAO council. Sir Otto Frankel played a significant role in mobilising global scientific efforts in the area of conservation of plant genetic resources. James Ingram built the World Food Programme into an outstanding instrument for safeguarding global food security. Don Mentz launched the Centre for Agriculture and Biosciences International (CABI) on the path of self-reliance, professional excellence and scientific relevance. Numerous Australian scientists have served in key positions, both at the scientific and policy levels, in CGIAR institutions. Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Australian Centre for International Agricultural Research (ACIAR) serve as models for fostering a meaningful social contract between science and society.

One of Australia's great contributions to contemporary agricultural development has been the promotion of farm productivity based on the conservation and enhancement of natural resources …

One of Australia's great contributions to contemporary agricultural development has been the promotion of farm productivity based on the conservation and enhancement of natural resources, particularly land, water and inland and marine biodiversity. I had a glimpse of Australia's commitment to fostering economic growth without ecological harm when I was in Perth in January 1990, to preside over the General Assembly of the World Conservation Union (IUCN, formerly the International Union for the Conservation of Nature).

While the contributions of the government and professionals of Australia to sustainable economic and agricultural development in the Asia–Pacific region during this century have been praiseworthy, the challenges ahead will demand even more active sharing of

Australian experience and expertise with developing countries in this region. I shall give a brief survey of the challenges ahead.

The Challenge of Sustainable Agriculture

On the eve of the UN Conference on Environment and Development held at Rio de Janeiro in June 1992, the Union of Concerned Scientists published an open letter entitled 'World Scientists' Warning to Humanity', which stated that 'human beings and the natural world are on a collision course ... if not checked, many of our current practices put at serious risk the future that we wish for human society and the plant and animal kingdoms, and may so alter the living world that it will be unable to sustain life in the manner that we know'. Over 1600 scientists from leading scientific academies in 70 countries signed this warning, including 104 Nobel laureates.

Two recent publications, *Our Stolen Future* (Colborn et al. 1996) and *The Last Generation* (Morgan 1999), provide a picture of the grim future that awaits generations yet to be born, if we lose further time in restoring harmony between humankind and nature.

It is now widely acknowledged that an increasingly rapid loss of genes, species, ecosystems and traditional knowledge and wisdom limits our options for adapting to local and global change, including potential changes in climate and sea level. The Hadley Centre of the United Kingdom Meteorological Office has recently predicted that even if greenhouse gas emissions are cut, sea levels may rise by at least 2 metres over the next few hundred years. If the global community can limit emissions to 550 parts per million—twice preindustrial levels and 50% above today's levels—about two billion people can be saved from water shortages, low crop yields and increased coastal flooding, especially in India and Africa (Pearce 1999).

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The Global Biodiversity Assessment, published in 1995 by the UN's Environment Programme, estimates that about 13–14 million species may exist on our planet; less than 2 million of these have so far been scientifically described. Many invertebrates and microorganisms are yet to be studied in detail; in particular, our knowledge of soil microorganisms is still poor. Also, biosystematics as a scientific discipline is attracting very few scholars among the younger generation.

Another important paradigm shift witnessed in recent decades in the management of natural resources is a change in the concept of 'common heritage'. In the past, the atmosphere, oceans and biodiversity used to be referred to as the common heritage of humankind. Recent global conventions have resulted in this concept being altered in legal terms. Biodiversity is now the sovereign property of the nation in whose political frontiers it occurs. Further, the trade-related intellectual property rights (TRIPs) provisions of the World Trade Agreement have made it mandatory to cover products of genetic improvement with either patents or *sui generis* methods of intellectual property rights (IPRs) protection. Under the UN Convention on the Law of the Sea, nations with coastal areas have access to a 200-mile exclusive economic zone (EEZ). The Climate Convention and the Kyoto Protocol provide for both common responsibilities and those differentiated to countries. Thus, the global commons can be managed in a sustainable and equitable manner only through committed individual and collective action among nations. In the Asia–Pacific region Australia can play a catalytic role in fostering cooperation to both avoid and mitigate the adverse impact of climate change.

... Australia can play a catalytic role in fostering cooperation to both avoid and mitigate the adverse impact of climate change.

A Chinese proverb warns, 'If you do not change direction, you will end up where you are headed.' Since we do not want to reach where we are presently headed, what change of course should we bring about in the field of agriculture?

Ecstasy and Agony

As we say good bye to this century we can look back with pride and satisfaction on the revolution that the farm men and women of the Asia–Pacific region have brought about in contemporary agricultural history. While we can and should rejoice in the past achievements of our farmers, scientists, extension workers and policy-makers, there is no room for complacency. We face several new problems.

- Increasing population will lead to increased demand for food and reduced per capita availability of arable land and irrigation water.
- Improved purchasing power and increased urbanisation will result in higher consumption of animal products, leading to increased per capita food grain requirements.
- Marine fish production is tending to become stagnant and coastal aquaculture is facing environmental problems.
- There is increasing damage to the ecological foundations of agriculture, such as land, water, forests, biodiversity and the atmosphere, and there are distinct possibilities for adverse changes in climate and sea level.
- While dramatic new technological developments are taking place, particularly in the field of biotechnology, their environmental, health and social implications are yet to be fully understood.

Since land and water are shrinking resources for agriculture, the only option is to produce more food and other agricultural commodities from less per capita arable land and irrigation water. In other words, the need for more food has to be met through higher yield per unit of land, water, energy and time. It would therefore be useful to examine how science could further improve biological productivity without causing ecological damage. The 'evergreen revolution' would be an appropriate term for emerging scientific progress in this area, to emphasise that the productivity advance is sustainable, being rooted in the principles of ecology, economics, social and gender equity and employment generation.

... the only option is to produce more food and other agricultural commodities from less per capita arable land and irrigation water.

The green revolution has so far helped to keep the rate of growth in food production above population growth rate. However, this revolution resulted from research in the public interest, supported by public funds. In contrast, the technologies of the emerging gene revolution are spearheaded by proprietary science and can come under monopolistic control. How then can we harness the power of frontier science to promote an evergreen revolution on our farms?

The 20th century began with the rediscovery of Mendel's laws of inheritance. It ends with moving specific genes across sexual barriers with the help of molecular mapping and recombinant DNA technology. The impact of science and technology in every field of crop and animal husbandry, inland and marine fisheries and forestry has been profound. Let me illustrate this, taking the improvement of wheat production in India as an example.

The impact of science and technology in every field of crop and animal husbandry, inland and marine fisheries and forestry has been profound.

Wheat cultivation started in the Indian subcontinent over 4000 years ago. Wheat kernels have been found in the Mohenjodaro excavations dated 2000 BC. From that period up to August 1947, when colonial rule ended, Indian farm men and women developed the capacity to produce 7 million tonnes of wheat per year. Between 1964 and 1968, when semidwarf strains containing the Norin 10 genes for dwarfing were introduced in irrigated areas, wheat production rose from 10 to 17 million tonnes per year. In other words, 4000 years of progress was repeated in four years (Swaminathan 1993). During 1998–99, wheat production in India exceeded 70 million tonnes—i.e. a 10-fold increase in about 50 years.

Similar progress has been made in improving the production and productivity of rice, maize, soybean, potato and several other crops as well as in farm animals in many developing countries around the world. New technologies supported by appropriate services and public policies, as well as international scientific cooperation, have helped to prove doomsday predictions wrong

A world without hunger is now within our reach …

and have led to the green revolution becoming one of the most significant of the scientific and socially meaningful events of this century. A world without hunger is now within our reach, if every nation pays concurrent attention to improving food availability, access and absorption. Availability of food can be improved through ecologically sustainable methods of production. Enhanced economic access to food is possible through an employment-led economic growth strategy. The biological absorption of food in the body can be improved by ensuring availability of safe drinking water and by environmental hygiene. Steps should also be taken to enlarge the base of the food security basket by revitalising the earlier tradition of cultivating a wide range of food crops (MSRRF 1999).

Emerging farming technologies will be based on precision farming methods leading to plant-scale rather than field-scale husbandry. Farming will be knowledge intensive, using information from remote sensing, geographical information systems (GIS), global positioning systems (GPS), and information and computer technologies. Farmers in industrialised countries are already using satellite imagery and GPS for early detection of diseases and pests, and to target the application of pesticides, fertiliser and water to those parts of their fields that need them urgently. GIS is an effective tool for solving complex planning, management and priority setting problems. Similarly, remote-sensing technology can be mobilised in programs designed to ensure drinking water security.

Let me cite two examples of the value of these technologies from our recent work.

First, GIS was applied for determining priorities in a program designed to launch a total attack on hunger in the Dharmapuri district in Tamil Nadu, India. Socioeconomic data such as the percentage of the population who were poor, the percentage unemployed, literacy rates, and infant and maternal mortality rates were mapped in GIS. The layers were prepared for each factor and then overlaid to give a profile map showing the poorest villages, which needed to be accorded priority in the hunger-free area program.

… GIS proved to be an invaluable tool in developing strategies for the conservation and sustainable, equitable use of biodiversity.

Second, GIS proved to be an invaluable tool in developing strategies for the conservation and sustainable, equitable use of biodiversity. The Gulf of Mannar region in South India is a biological paradise. Unfortunately, anthropogenic pressures and the unsustainable use of coral reefs, seagrass beds and mangroves are causing serious damage to this priceless heritage. With financial support from the Global Environment Facility and technical advice from Dr Graeme Kelleher, formerly of the Great Barrier

Reef Marine Park Authority, the Government of Tamil Nadu is creating a Gulf of Mannar Biosphere Reserve Trust. The aim is to make all stakeholders regard themselves as trustees of this area. This evolution of the reserve into an area held in trust for posterity is an example of an idea becoming a reality—the vision of biosphere reserves for the 21st century, articulated by the United Nations Educational, Scientific and Cultural Organization (UNESCO) in Seville.

> 'Rather than forming islands in a world increasingly affected by severe human impacts, biosphere reserves can become theatres for reconciling people and nature. They can bring the knowledge of the past to the needs of the future.'

Biotechnology will play an increasingly important role in strengthening food, water and health security systems. The need for more effective and transparent mechanisms to assess the benefits and risks associated with transgenic plants and animals is highlighted by recent widespread public concern over genetically modified (GM) food. An internationally agreed biosafety protocol on the lines recommended in article 19 of the Convention on Biological Diversity (CBD) is an urgent necessity. Biotechnology companies should agree to the labelling of GM foods in the market. All food safety and environmental concerns should be addressed with the seriousness they deserve. Broad-based national commissions on genetic modification for sustainable food and health security should be set up, consisting of independent professionals, environmentalists, representatives of civil society, farmers' and women's organisations, mass media and the concerned government regulatory authorities. This move will help to assure both farmers and consumers that the precautionary principle has been applied when approving the release of GM crops.

Biotechnology will play an increasingly important role in strengthening food, water and health security systems.

Countries rich in biodiversity but poor in biotechnology are being adversely affected by nonadherence to the ethical and equity principles in benefit sharing contained in articles 8(j) and 15 of the CBD. The primary conservers, largely tribal and rural women and men, live in poverty, while those who use their knowledge and material for producing commercial products become prosperous (Swaminathan 1999). The invaluable contributions of tribal and rural families to conservation and enhancement of genetic resources have been recognised in the CBD, yet the political will to implement its equitable benefit sharing provisions is lacking. We need urgent steps to recognise and reward the contributions of indigenous communities to providing material of great importance to global food and health security. The three validated remedies shown in Table 1 stress the significance of

The invaluable contributions of tribal and rural families to conservation and enhancement of genetic resources have been recognised …

traditional knowledge and conservation efforts in helping to mitigate handicaps caused by ageing in human beings.

Table 1. Traditional medicinal remedies.

Country	Plant	Property
India	*Trichopus zeylanicus*	Helps to remove fatigue
India	*Bacopa monnieri*	Helps to improve memory
Tropical Africa	*Prunus africana*	Treatment for benign prostatic hyperplasis

Article 27(b) of the TRIPS component of the World Trade Agreement is now under review. All nations should agree to incorporate in this clause the ethics and equity principles enshrined in articles 8(j) and 15 of the CBD. The World Intellectual Property Organization (WIPO) has launched a study of the need to recognise the IPRs of the holders of traditional knowledge. When completed, this study will help to make the principles of ethics and equity the foundation of IPRs.

Emerging Scientific Revolutions

... we are experiencing three major revolutions in science and technology which will influence agriculture and industry in a fundamental manner.

Fortunately, as we approach the new century we are experiencing three major revolutions in science and technology that will influence agriculture and industry in a fundamental manner.

- *The gene revolution*—this provides a molecular understanding of the genetic basis of living organisms and the ability to use this understanding to develop new processes and products for agriculture, industry, the environment, and human and animal health.
- *The ecotechnology revolution*—this promotes the blending of the best in traditional knowledge and technology with frontier technologies such as biotechnology, space and information technologies, renewable energy and new materials.
- *The information and communication revolution*—this allows a very rapid growth in the systematic assimilation and dissemination of relevant and timely information, as well as a dramatically improved ability to access knowledge and communicate through low-cost electronic networks.

In principle, these three types of advances, when coupled with improvements in management and governance, greatly increase the power of a scientific approach to genetic improvement, management of natural resources and ecosystems, and local and regional development strategies. Ecotechnologies enable the adoption of the International Organization for Standardization

(ISO) standards of environmental management, ISO 9000 and ISO 14000. Most of the action in these rapidly developing scientific revolutions is occurring in industrialised nations, whilst new discoveries of great relevance to sustainable food and health security are covered by IPRs and are thus coming under the purview of proprietary science. It is the duty of organisations devoted to the public good to mobilise recent advances in science and technology to meet the basic needs of economically and socially underprivileged sections of the human family.

... new discoveries of great relevance to sustainable food and health security are ... coming under the purview of proprietary science.

The gene revolution

The past 10 years have seen dramatic advances in our understanding of how biological organisms function at the molecular level, as well as in our ability to analyse, understand and manipulate DNA molecules—the biological material from which all genes are made. The process has been accelerated by the Human Genome Project, which has poured substantial resources into the development of new technologies for working with human genes. These technologies, directly applicable to all organisms, have given rise to the scientific discipline of genomics, which has contributed to powerful new approaches in agriculture and medicine and helped to promote the biotechnology industry.

Several large corporations in Europe and the United States have made major investments in adapting these technologies to produce new plant varieties of agricultural importance for large-scale commercial agriculture. The same technologies have equally important potential applications for addressing food security in the developing world.

The key technological developments in this area are:

- *genomics*—the molecular characterisation of species;
- *bioinformatics*—data banks and data processing for genomic analysis;
- *transformation*—introduction of individual genes conferring potentially useful traits on plants, trees, livestock and fish species;
- *molecular breeding*—identification and evaluation of useful traits by use of marker assisted selection, which greatly speeds up traditional breeding processes;
- *diagnostics*—identification of pathogens by molecular characterisation; and
- *vaccine technology*—use of modern immunology to develop recombinant DNA vaccines for improved control of lethal diseases of animals and fish.

Let me cite one example from the work of M.S. Swaminathan Research Foundation (MSSRF) scientists to illustrate the value of the new tools. As a part of an anticipatory research program to meet the consequences of sea level rise due to global climate change, genes responsible for conferring the ability to withstand sea water intrusion were identified in mangrove species through molecular mapping. They have been transferred to annual economic plants through recombinant DNA technology.

Altogether unforeseen opportunities for creating novel genetic combinations have been opened up by new technologies.

Altogether unforeseen opportunities for creating novel genetic combinations have been opened up by new technologies. For example, the sequencing of the rice genome (*Oryza sativa* cv. Nipponbare) by an international consortium supported by the Rockefeller Foundation and the International Rice Research Institute (IRRI) will permit allele mining for all genes of rice and possibly for other cereals.

As mentioned earlier, there are widespread public concerns about the potential adverse impact of genetically modified organisms (GMOs) on human health, biodiversity and the environment. Some of these concerns are genuine. In order to take advantage of recombinant DNA technologies without associated harm to human or ecological health, it is important that every country has in place suitable institutional structures and regulations for biosafety, bioethics and biosurveillance. At the same time, there is need for greater investment of public funds for public interest research, the results of which can reach the unreached. For example, in food and agriculture, there is a need to strengthen both the national agricultural research systems (NARS) and the international agricultural research centres (IARCs) supported by CGIAR.

The ecotechnology revolution

Knowledge is a continuum. There is much to learn from the past in terms of the ecological and social sustainability of technologies. At the same time, new developments have opened up new opportunities for developing technologies, which can lead to higher productivity without adverse impact on the natural resources base. Blending traditional and frontier technologies leads to the birth of ecotechnologies with combined strengths in economics, ecology, social and gender equity, employment generation and energy conservation. For example, in the area of water harvesting and sustainable use, there are many lessons to be learnt from the Australian experience.

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There is a need to conserve traditional wisdom and practices, which are often tending to become extinct (Agarwal and Sunita 1997). The decision of WIPO to explore the intellectual property needs, rights and expectations of holders of traditional knowledge, innovations and culture is hence an important step in widening the concept of intellectual property. FAO has been a pioneer in the recognition of the contributions of farm families in genetic resource conservation and enhancement by promoting the concept of farmers' rights. Like WIPO, the Union for the Protection of New Varieties of Plants (UPOV) should also undertake the task of preparing an integrated concept of breeders' and farmers' rights. UPOV itself should be restructured to become a union for the protection of farmers' and breeders' rights.

The information technology revolution

New communication and computing technologies are already influencing life on our planet in a profound manner.

New communication and computing technologies are already influencing life on our planet in a profound manner.

- Access to the Internet will soon be universal, providing unrestricted low-cost access to information, as well as highly interactive distance learning. The Internet will not only facilitate interactions among researchers, but also greatly improve their ability to communicate effectively with potential users of their research knowledge.
- Computing makes it possible to process large-capacity databases, such as those for libraries, remote sensing, GIS and gene banks, and to construct simulation models. These have potential applications in ecosystem modelling and preparation of contingency plans to suit different weather probabilities and market variables.
- The software industry is continuously providing new tools that increase research productivity and create new opportunities for understanding complex agroecosystems.
- Remote sensing and other space satellite outputs are providing detailed geographic information useful for management of land and natural resources.

The promotion of ecotechnology development and dissemination, the effective adoption of integrated systems of gene and natural resources management and the effective harnessing of information technologies should become essential elements of the 'science and technology for basic human needs' movement.

Launching a Knowledge System for Sustainable Food and Livelihood Security

Explosive progress in science and communication has led to the christening of the communities who will live in our planet in the coming century as 'knowledge societies'. Information technology is beginning to play a pivotal role in stimulating and sustaining such societies. Let me describe in some detail an innovative experiment we are carrying out at MSSRF with a view to using information technology for the benefit of the rural poor. The experiment aims to provide information people need and can use in their daily lives. The whole program is based on need, driven by demand and controlled by the users. As we cannot hope to provide telephones, computers and other tools of technology to each household for a long time to come, we have chosen to reach the unreached through community access.

Opportunities for a learning revolution

... computer-aided knowledge dissemination mechanisms can help to reach the unreached and foster new voices and new leaders.

Results from our work indicate that computer-aided knowledge dissemination mechanisms can help to reach the unreached and foster new voices and new leaders. For success, a user-controlled, demand-driven system is essential. Use of the local language as the medium of communication ensures ease of access to the entire target population.

The MSSRF Knowledge System for Sustainable Food Security deals with three aspects of food security—availability, access and absorption—in an integrated manner.

- *Availability*—the first requisite is the adequate availability of food for home consumption and for markets. In the coming century, more food and other agricultural commodities will have to be produced from less per capita arable land and irrigation water. Increased production will be required to meet the needs of the growing population, to combat the undernutrition and malnutrition currently prevailing among 800 million children, women and men and to provide the increased volume of feed grains needed due to greater consumption of animal products in urban areas.
- *Access*—even if food grains, fruits, vegetables and animal products are available in abundance in the market, inadequate purchasing power inhibits access to a balanced diet among the economically underprivileged sections of society. Women and children are particularly vulnerable. Economic access to food depends on opportunities for remunerative employment and on multiple livelihood sources in the case of the landless poor. An important aspect of food security thus relates to the creation of opportunities for sustainable livelihoods. Fortunately, ecological farming is both knowledge and skill intensive. There is a need to spread information on opportunities for ecojobs in the farm and nonfarm sectors. Urban and peri-urban agriculture helps to link producers, the food processing industry and consumers in a symbiotic chain.

- *Absorption*—even if food is consumed in adequate quantities, biological absorption and utilisation of food in the body depends upon the availability of clean drinking water, environmental hygiene, sanitation and facilities for primary health care. Diarrhoeal diseases and liver ailments are common among infants and children living under insanitary conditions.

The goal of this system is the empowerment of rural women, men and children through information on ecological agriculture, sustainable livelihoods and the biological absorption and utilisation of food in the body. It is managed by local women at the village knowledge centre, where the computer-aided information system is operated. These centres can be coupled with training centres in order to create a cadre of ecoentrepreneurs.

The goal of this system is the empowerment of rural women, men and children …

Producing more but producing differently

The MSSRF Knowledge System for Sustainable Food Security provides information on soil health care, water, pest and energy management, postharvest technology, farming systems design and marketing. As the conservation of soil fertility is fundamental to sustained advances in productivity, farm families maintain 'soil health' cards and those possessing livestock are helped to maintain 'animal health' cards. The system aims to convert generic information on meteorological, management and marketing factors into location-specific details, so a high degree of interactive learning is built into the process.

The ecological farming database provides information on environmentally sound management of pests and ecofriendly methods of soil fertility and irrigation water management. The aim of the knowledge system is to help to spread an evergreen revolution in small farms. Precision farming methods help to lower the cost of production and enhance both income and ecological sustainability.

In the field of agriculture, there needs to be synchronisation in time and space of knowledge dissemination and the supply of inputs essential for deriving benefit from that knowledge. Thus it will be desirable to link the knowledge centre, not only with a training centre, but also with a single input supply.

Information empowerment and freedom from hunger

The village knowledge centre … helps everyone in the village to create a hunger free area.

The village knowledge centre not only enables farming families to produce more farm products without associated ecological harm, but also helps everyone in the village to create a hunger free area. An action plan for the elimination of hunger and malnutrition consists of the following seven steps.

1. The villagers themselves identify who the hungry amidst them are. These are generally the very poor without land, livestock, fish-pond or any other productive asset. They also tend to be illiterate.
2. A 'household entitlements' database provides information on all government, bilateral and international schemes available to rural families. The information is disaggregated according to age, gender and occupation. The families covered by the knowledge centre are given 'household entitlement' cards. They are encouraged to bring these cards to the centre and fill them up themselves with the help of the lady operating the computer, to help them to know what their entitlements are and how to access them.
3. A database on elimination of undernutrition or calorie deprivation indicates the schemes available for overcoming protein–calorie undernutrition and malnutrition. Information on projects run by civil society organisations is also provided.
4. A 'hidden hunger elimination' database deals with micronutrient deficiencies prevailing in the village. Usually, a pediatric survey is conducted to identify the extent of prevalence of deficiencies of vitamin A, iron, iodine and other micronutrients and information is provided on programs available for the total elimination of such deficiencies. The centre also organises interactions between affected families and those who provide remedies like iron, iodine-fortified salt and spirulina, and those who give advice on cultivation of appropriate vegetables and fruits in home gardens.
5. A 'plugging the leaky pot' database provides information on schemes available for clean drinking water, environmental hygiene and sanitation, latrines, primary health care and other methods of improving the biological absorption and retention of food in the body. Information is also provided on oral dehydration and other methods of managing diarrhoeal diseases, particularly among children.
6. An 'ecojobs' database provides information on opportunities for economically, socially and environmentally sustainable self-employment. The centre thus acts as a rural placement centre for remunerative self-employment. A wide range of onfarm and off-farm employment opportunities is included in the database. The jobs suggested are chosen on the basis of credit and market availability. For example, only goods for which there is a reliable market are recommended for production. The knowledge centre also becomes a place for interaction between credit and extension agencies and rural families, thereby triggering a 'new deal' for the self-employed.

7. A 'women and children' database provides information on projects available to preschool children, pregnant and nursing mothers and old and infirm persons. There is a particular focus on the nutritional health of pregnant women and children in the 0–2 year-age group. Information on reproductive health care and on other special programs for women is included in the database, together with community-managed support services, such as day-care centres for working mothers. This is essential because of the multiple burden shouldered by women, as a consequence of which they tend to remain overworked but underpaid or even unpaid.

Once a knowledge centre gets established, the rural families themselves can develop subsequent databases. The families must have a sense of ownership and be willing to provide space and meet the salary of the computer operators, who are drawn from the village itself; otherwise the knowledge centre is likely to become simply a supply-driven show piece. The centre also promotes monitoring of the impact of information empowerment. The following indicators are used: infant mortality rate; maternal mortality rate; low birth weight; sex ratio; incidence of adult malnutrition; percentage of workers performing unskilled operations; and incidence of micronutrient deficiency induced ailments. Depending upon the interests of rural families, other criteria such as the population supporting capacity of the ecosystem, per capita income and average life span can be included. The growth of the centre must be an evolutionary process, with information empowerment in areas relevant to meeting the basic human needs receiving overriding priority.

The families must have a sense of ownership ... otherwise the knowledge centre is likely to become simply a supply-driven show piece.

Professor Bruce Alberts, President of the US National Academy of Sciences, referred to the significance of the MSSRF Knowledge System for rural families in his anniversary address, delivered in Washington DC on 26 April, 1999. He said:

> 'Connecting scientists to each other is only the first step. Scientists everywhere must use these initial connections as a tool for spreading their knowledge, skills, and values throughout their own nations, including their local communities. By taking full advantage of new information technologies, the scientific community has an unprecedented opportunity to close the vast 'knowledge gap' between all peoples. How might this be possible?
>
> 'I want to highlight a wonderful example that points the way forward. The M.S. Swaminathan Research Foundation has established an experimental network in India that will soon connect more than 20 isolated rural villages to a wireless Internet service. About half of the population in most of these villages has a total family income of less than US$25 per month. The project is

The project is designed to provide knowledge on demand to meet local needs using the world wide web, and it does so through a bottom-up process.

designed to provide knowledge on demand to meet local needs using the world wide web, and it does so through a bottom-up process. The process starts with volunteer teams that help poll the villagers to find out what knowledge they want. Particularly popular thus far are women's health information, advice on growing local crops and protecting them from diseases, the daily market prices for these crops, local weather forecasts, and clear information about the bewildering array of programs that are provided by the Indian government to aid poor families. To participate, each village must provide a public room for the computer system, as well as the salaries for a set of trained operators. In return, the village receives the needed hardware and maintenance for the communication system, specially designed web sites in the local language that convey the requested information, and training programs for those villagers who have been selected to run their local knowledge system.

'Drawing on this concept, I envision a global electronic network that connects scientists to people at all levels—farmers' organisations and village women, for example. The network will allow them to easily access the scientific and technical knowledge that they need to solve local problems and enhance the quality of their lives, as well as to communicate their own insights and needs back to scientists.'

Thus, we now have an opportunity to develop a new form of computer-aided 'virtual college', linking scientists and resource-poor women and men living at a per capita income of US$1–2 per day. Such a college should be truly the product of partnership between the poor and those who have the requisite technological know-how and do-how. Australian agencies and institutions can assist in the development of a virtual college linking scientists in this region.

Australian agencies and institutions can assist in the development of a virtual college linking scientists in this region.

Lessons from development assistance for agricultural research

Agriculture, including crop and animal husbandry, forestry, fisheries and agroprocessing, is still the mainstay of the rural economies of most developing countries in the Asia–Pacific region. Although the share of agriculture in national gross domestic product (GDP) is gradually going down in many countries in this region, as a result of diversification of income sources, the onus for providing jobs or sustainable livelihoods still rests predominantly with the farm sector. In India, for example, the contribution of agriculture to national GDP is now only 30%; however, 60% of India's population of one billion depend on agriculture for their livelihood. Agricultural progress under such situations has to lead not only to more food production, but also to more jobs and income.

A majority of the 1.3 billion individuals who, according to the World Bank, now live on a daily income of less than US$1 belong to the categories of landless and resource-poor small farm families (Swaminathan 1999). Such landless families often migrate to towns and cities looking for jobs, leading to the growth of urban slums. FAO's *State of Agriculture Report* (FAO 1998) points out that rural nonfarm employment can help to reduce poverty substantially. In other words, an integrated onfarm and off-farm employment strategy is essential if agricultural progress is to lead to rural prosperity. Thus, the impact of development assistance has to be measured not only in the context of agriculture's pivotal role in strengthening national food and nutrition security, but also in terms of its effect on the livelihood security of the poor. The impact on the ecological foundations of sustainable advances in biological productivity must also be considered.

Agricultural progress depends on conservation and enhancement of land, water, biodiversity and forests, as well as on the prevention of atmospheric and ocean pollution and the protection of the ozone layer. It is against this background that development assistance provided by Australia has been particularly meaningful.

Taking the example of India, it is clear that development assistance has played a significant role in strengthening the research and educational infrastructure in agriculture. Between 1900 and 1947, the annual growth rate in food production in India was hardly 0.1%. Between 1970 and 1999 this rate grew to nearly 2.8%, helping to keep the growth rate in food production above that of the growth rate of population. How did India transform itself from a position of hopelessness on the food production front to being one of the leading agricultural producers of the world?

... development assistance has played a significant role in strengthening the research and educational infrastructure in agriculture.

India's independence was born in the backdrop of the great Bengal famine of 1942–43, which resulted in nearly three million deaths. Thus, an independent India accorded high priority to agricultural research and education. Today, the Indian Council of Agricultural Research (ICAR), the national coordinating and funding agency for agricultural research and education, supports one of the largest NARS in the world. The Indian NARS consists of 35 agricultural and veterinary universities, four national universities in agriculture, veterinary sciences, dairy and fisheries, and a large number of national institutes and advanced research centres all over the country. Interdisciplinary and interinstitutional collaboration is achieved through All India Coordinated Research Projects, which represent national grids of interdisciplinary experiments.

... *symbiotic partnerships were developed between leading and established North American universities and their newborn Indian counterparts.*

Unfortunately, government-based development assistance often lacks such flexibility and becomes supply driven.

Among development agencies, the United States Agency for International Development (USAID) was the earliest to extend support to developing agricultural universities on the model of the United States land-grant universities[1]. The first such university was established at Pant Nagar in the State of Uttar Pradesh in 1958. The manner in which the United States government extended its assistance was a novel one—USAID entrusted the task of helping in the development of one Indian agricultural university to one such establishment in the United States. In this manner, symbiotic partnerships were developed between leading and established North American universities and their newborn Indian counterparts. This partnership played a major role in human resource development and capacity building. It also helped to introduce a flexible system of farm education based on a trimester and course-credit system of curriculum organisation.

The Rockefeller and Ford Foundations played an equally significant role in helping India to develop its infrastructure for agricultural research, education and development. The Rockefeller Foundation helped to establish a postgraduate school at IARI, New Delhi. The IARI Postgraduate School, established in 1958, made it unnecessary for Indian scholars to go abroad for doctorate level training. But for this school, it would not have been possible to find the teachers needed to establish state agricultural universities. Another very significant contribution of the Rockefeller Foundation was the valuable scientific and financial support extended to the All India Coordinated Research Projects of ICAR, initially in the case of maize and pearl millet, and later in wheat and rice. The foundation also arranged visits from leading American agricultural scientists like Dr E.C. Stakman and Norman Borlaug. The Rockefeller Foundation's support during the period 1957–70 helped to stimulate the transition from yield stagnation in major crops to the green revolution.

The Ford Foundation played a key role in the development of rural infrastructure and extension services through the Community Development Programme, and assisted in the establishment of management schools in the country, including the Water Technology Centre at IARI. The generous assistance of both the Rockefeller and Ford Foundations during the 1950s and 1960s was particularly important, as it was flexible, dynamic, demand driven and able to fill critical gaps in ongoing work. Unfortunately, government-based development assistance often lacks such flexibility and becomes supply driven.

[1] The land-grant philosophy was developed in the United States and is based on teaching, research and extension. In the 1800s a land-grant institution was established in each state, to educate citizens in practical professions such as agriculture, home economics and mechanical arts.

The IARCs sponsored and supported by CGIAR provide a useful model for beneficial development assistance. For example, the International Maize and Wheat Improvement Center (CIMMYT) in Mexico and IRRI in the Philippines helped significantly in bringing about wheat and rice revolutions in several countries, including India. The success of these centres is due to the fostering of genuine research partnerships between NARS and IARCs and the attention paid to human resource development. IARCs provide meaningful models in the field of capacity building and sustainable collaboration.

Australian Assistance and Indian Agricultural Renaissance

I would like to draw attention to the significant role played by Australian development agencies in promoting the agricultural renaissance of India. The assistance extended to India's agricultural progress by the Australian government, through both the Australian Development Agency and ACIAR, has been catalytic. Australia helped to set up both the Central Arid Zone Research Institute (CAZRI) at Jodhpur and the Central Sheep and Wool Research Institute at Jhansi. India has over 16% of the world's farm animal population, but only 0.5% of the global grazing area. Hence, the new fodder grasses and fodder legumes developed at Jhansi with assistance from Australian research institutions have been very important in providing the nutritional requirements for India's dairy revolution. CAZRI helped to stabilise sand dunes and promote arid and semiarid horticulture and animal husbandry, and paved the way for the subsequent establishment by CGIAR of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) at Hyderabad in 1972. Australian scientists played a key role in helping to develop the research and training programs of the institute. ICRISAT helped India and other countries, including those in Sahelian Africa, to develop new varieties and agronomic technologies for elevating and stabilising the yields of sorghum, pearl millet, chick pea (*Cicer arietinum*), pigeon pea (*Cajanus cajan*) and groundnut (*Arachis hypogea*).

The assistance extended to India's agricultural progress by the Australian Government … has been catalytic.

The development assistance provided by Australian agencies and institutions in the field of agricultural research has taken a variety of forms.

- Developing local capability in the fields of agricultural education, research and extension.
- Strengthening and integrating NARS into a global grid of cooperative research institutions under the CGIAR umbrella and into regional partnerships through ACIAR.

- Assisting in the development of technologies for arid and semiarid environments.
- Promoting crop livestock integration, thereby strengthening household nutrition and livelihood security.
- Fostering multidisciplinary problem-solving research.
- Mainstreaming gender equity in research and training programs.
- Introducing the dimension of environment sustainability in the design of experiments.
- Linking production, processing and marketing in the form of an integrated chain.
- Promoting human resource development for sustainable advances in biological productivity.
- Conserving the ecological foundations essential for sustainable advances in agricultural productivity.
- Promoting policy research, since technologies will make a positive impact on agricultural production only if there is a proper match between technologies and public policies.

Technology is now acknowledged as the prime mover of agricultural progress.

It is now clear that the stronger its NARS, the greater will be the benefit to a country from international agricultural research. This realisation has led governments of many developing countries to strengthen their respective NARS. Technology is now acknowledged as the prime mover of agricultural progress. This in turn has helped to enhance the social prestige of agricultural scientists. Consequently, the younger generation is being attracted to careers in agricultural research and education. Farming is no longer considered to be a profession needing only brawn; intelligence or knowledge is equally important. The transition to science and knowledge-based agriculture was commemorated by the government of India in 1968 through the issue of a special stamp entitled 'Wheat Revolution'. The library building of IARI was depicted in the stamp to symbolise the advent of scientific agriculture. The policy of the government of Australia to strengthen NARS and IARCs concurrently is therefore the most meaningful pathway of development assistance.

Mutually Beneficial Partnerships: Lessons for the Future

... if there is strong political will at the national level, food aid can be converted into an opportunity for progress rather than being a cause for inertia and inaction.

The first lesson is that unless there is a strong national commitment and a sense of ownership in relation to externally funded projects, success will be uncertain. For example, concessional food aid has been both praised and criticised, particularly if it is extended in normal times to compensate for low agricultural productivity in recipient countries. Two examples from India show that if there is strong political will at the national level, food aid can be converted into an opportunity for progress rather than being a cause for inertia and inaction. In 1965–66, India experienced a severe drought and had to import over 10 million tonnes of wheat and other food grains, largely under the PL 480 program of the United States. Australia also extended assistance. In that same year the government of India initiated the high-yielding varieties program (HYVP) in wheat, rice, maize, sorghum and pearl millet in 32 million hectares. HYVP led to the green revolution and transformed the national and international mood from despair to hope with reference to India's agricultural capability.

Another example relates to milk production. In the 1960s and 1970s India received substantial assistance from European Union countries, New Zealand and Australia in the form of milk powder and butter oil. The money generated by selling these was used by the National Dairy Development Board to build milk cooperatives. Today, India is the world leader in milk production. Thus, where there is the necessary political will and action, short-term development assistance can be used as a catalyst for achieving long-term self-reliance.

A second lesson is the need for humility on the part of development assistance agencies. It is important to understand clearly the agroecological and socioeconomic conditions, and the cultural–spiritual values prevailing in a country, if there is to be a proper match between felt needs and development agency response. The attitude of the development agency should be one of sustained partnership, not one of patronage. A withdrawal strategy should be built into the design of assistance, so that the program does not collapse when the external agency withdraws.

The attitude of the development agency should be one of sustained partnership, not one of patronage.

A third lesson relates to building competence and self-confidence in the scientists belonging to NARS. In particular, attention should be paid to leadership training. Unless there are national scientists whose voice is listened to with respect by their political leaders, sustained progress will be difficult. This goal can be realised if development assistance is based on the principles of symbiotic partnership, sustainability and social relevance. Above all, development agencies should realise that to be effective, scientific leadership must be home grown and not externally imposed. Expatriate experts can never fill the void created by lack of strong national scientific leadership.

We are entering an era of expanded partnerships, not only between development agencies and NARS, but also with the private sector. In all cases, the ultimate goal should be to create a technological and policy environment that will enable every individual to have an opportunity for a productive and healthy life.

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Conclusions

To sum up, there is no time to relax on the food production front. It is obvious that we have to produce more, but in such a way that there are no adverse environmental or social impacts. Water is likely to be a serious constraint in many countries, and priority should be given to developing and spreading efficient water management techniques, including aquifer management, wastewater recycling and conjunctive use of surface and rainwater. Future agricultural production technologies should be based on integrated natural resources management. This is where Australian experience and expertise will be of particular value.

The world can produce enough food for a population of 10 billion by harnessing the untapped yield reservoir existing even with currently available technologies, if greater attention is given to soil health care and water management. We must defend the productivity gains so far made, extend the gains to semiarid and marginal environments, and work for new gains using blends of frontier technologies and traditional ecological prudence. The problem of generating adequate purchasing power to enable families living in poverty to have economic access to food will still confront us. This is where a job-led economic growth strategy based on micro-level planning, micro-enterprises and micro-credit will be of great help. Integrated production and postharvest technologies and onfarm and off-farm employment strategies will be needed to provide livelihoods for all in rural areas.

The current trend of an increasing rich–poor divide will have to be stopped if social conflicts are not to increase.

With increasing globalisation of economies, it will be necessary to agree at the international level that safeguarding and strengthening the livelihood security of the poor should be a major goal of liberalised trade. The current trend of an increasing rich–poor divide will have to be stopped if social conflicts are not to increase. Thus, we really are walking a tightrope in terms of achieving sustainable solutions to the problems of population, poverty and environmental degradation. The various international conferences held during this decade, starting with the Children's Summit held in New York in 1990 and ending with the World Conference on Science held in Budapest in 1999, have indicated possible solutions to these problems. It is now for nations to act individually and collectively so that we do not miss the opportunities opened up by science and technology and by democratic systems of governance for creating a food secure world. Australia has provided innovative leadership in developing international institutional structures and development assistance procedures. It should not only continue its philosophy of working for a better common present and future for humankind, but intensify its efforts to foster relevant partnerships in the Asia–Pacific region for launching and sustaining an evergreen revolution on the farms.

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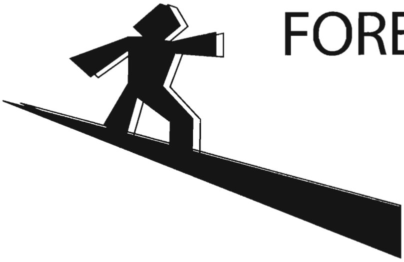

FORESTRY

PROFESSOR JEFFREY A. SAYER, DIRECTOR GENERAL, CENTER FOR INTERNATIONAL FORESTRY RESEARCH, BOGOR, INDONESIA

Throughout a distinguished career Professor Sayer has occupied senior positions at the Food and Agriculture Organization, the World Wide Fund for Nature, the World Conservation Union and the World Bank. He has worked extensively on the problem of reconciling conservation and development in the major tropical moist forest regions of the world. Professor Sayer has a BSc in botany and zoology and an MSc in nature conservation.

Forests: Maintaining the Balance

JEFFREY A. SAYER, DIRECTOR GENERAL, CENTER FOR INTERNATIONAL FORESTRY RESEARCH, BOGOR, INDONESIA

Introduction

Ten years ago precisely, in late November 1989, I organised a seminar in Perth, Western Australia, on realistic strategies for conserving tropical forests. The seminar took place during the general assembly of the International Union for the Conservation of Nature. Sponsored by the International Tropical Timber Organization (ITTO), its intention was to open up a dialogue between the tropical timber industry and the conservation community, to examine the ways in which conservation of biological diversity could be reconciled with industrial timber interests. The mere announcement of this seminar elicited a remarkably hostile response from the international environmental community.

At the time the battle lines were drawn up, the perceived wisdom of conservationists was that logging tropical forests was inherently bad. The objective of conservation was to halt logging; any hint of compromise represented a breaking of ranks and had to be resisted. The seminar went ahead and was a highly contentious and emotional event. However, it did lead directly to the development of guidelines for the conservation of biodiversity in production forests, eventually adopted by the ITTO, and to a widely accepted recognition of the high value that well-managed forests can have for conservation (Blockhus et al. 1992).

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The Perth seminar preceded the development of the World Bank Forest Policy in 1991. The bank tried to open up the process of formulation of this policy to public participation. Ensuing debate pitted the forces of conservation nongovernmental organisations (NGOs) against the forestry establishment. The NGO position was that tropical forests were a pristine wilderness that had existed outside the influence of humankind since time immemorial. These forests were seen as exceedingly rich in biodiversity, of potentially high value to people, existing in a fragile harmony and highly susceptible to any human-induced perturbation.

Landmark papers that revealed the fabulous species richness of tropical forests (e.g. Erwin 1982; May 1988; Simberloff 1986; Stork 1988) had profoundly influenced conservation thinking. Classic studies of island biogeography, and the concept of keystone species, influenced generations of biologists to believe that any fragmentation or disturbance of forests would lead to a cascading sequence of species extinctions and consequent ecological instability. The problem of tropical forests was simple; they were being destroyed by loggers. The solution was to halt commercial exploitation and the World Bank's forest policy was one weapon to achieve this.

The perspective of the timber industry was equally categorical. Forests were a major resource, generating economic activity and employment. Two hundred years of scientific forestry had demonstrated that yields of forest products could be sustained over several felling cycles and that environmental values could be maintained. The threat to forests came not from logging but from shifting agriculture. The best way to maintain forests was to enhance their value by intensifying sylviculture, thus making them more economically attractive than alternative land uses. The slogan of the forest industry was 'use them or lose them'. Round one in this fight went to the conservation lobbyists. The World Bank adopted a policy that focused attention on logging as the main villain and committed the bank to noninvolvement in any lending associated with logging primary forests.

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The subsequent decade has seen a higher level of international concern and debate about forests than ever before. Billions of dollars have been spent on projects to conserve forests but, in the inimitable words of United States Senator Jesse Helms, this money has all gone 'down the rathole'. Forests in tropical developing countries are in a worse state than ever and the institutions charged with their management are still in disarray. The 1990s have indeed been a lost decade for forests in middle-income and poor countries.

This paper makes the case that although the last decade has shown little progress in practical conservation measures it has been a period rich in debate and in science. Many of the myths that led to polarised positions a decade ago have now been challenged. The numerous field projects may not have achieved lasting impact on the ground but they have enabled us to learn about forests and the people who inhabit them. Mechanisms and understanding now exist to provide the basis for improved forest management in the 21st century. It begins to look as though commercial forestry will finally prevail as an important part of the solution rather than as the main problem. A fundamental problem is the total irrelevance of the rich world vision of tropical forest conservation to the three billion or more people who depend every day on forested land for their medicine, meat supply, fibre and agriculture. The major challenge, both globally and at a local level, is to reconcile these different agendas. This paper gives an account of how science has provided the basis for a better future for our forests and illustrates how new initiatives and approaches are providing solutions that meet some of our global objectives whilst creating jobs, products, services and income for people in the developing world.

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How Fragile are Forest Systems?

Much of the early concern for forest conservation was driven by the perception that forests, especially tropical rainforests, were inherently unstable. There was widespread advocacy of the view that these were finely balanced systems that could suffer ecological collapse if some species were removed or if the physical structure was modified. This view of forests was linked to the idea that most forests are stable over time. Science has now shown that most forests are remarkably dynamic.

Climatic and geomorphological changes have occurred at frequencies that encompass only a few generations of long-lived canopy trees. Most forests have reached their present condition as a result of long periods of human intervention. Even where people have had little impact and climates are stable, forests are constantly evolving. When a canopy tree falls, other species will often colonise the gap. We no longer believe that forest ecosystems are always evolving towards an ecological climax equilibrium.

Forests that have been logged, burned or otherwise disturbed will recover very quickly to something resembling their prior condition if they are protected. Far from being fragile, forests have repeatedly been shown to be remarkably resilient. There is little empirical evidence for any irreversibility when forests are disturbed. The one exception to this is fire; repeated burning will degrade forests and eventually eliminate them. The lesson is that it is not the intensity of disturbance of a forest that determines impact but rather the frequency of the disturbance. A forest will recover remarkably well from even very heavy logging damage, but repeated low-intensity logging accompanied by burning will convert forests to grasslands.

Use Them or Lose Them—True or False?

This old adage of many resource dependent industries has been subject to highly credible challenge by conservationists. There are simply too many examples of resources being used and then lost, and this is especially true of forests. The unfortunate

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reality is that in recent decades, the first-cut logging of forests in previously inaccessible tropical areas has often been associated with enormous social and environmental disruption. Business and political elites have made huge profits, with little attention given to questions of sustainability. But this destruction came at a time when the countries housing those forests were themselves struggling with the birth pangs of democracy. The institutions and legal frameworks needed to ensure equitable access to resources were not present—indeed the need for them had never existed. The laws and institutions regulating forest use in Europe evolved over a period of several hundred years of gradually increasing pressures upon the resource; in the tropics this process was compressed into 30 years.

In frontier situations where institutions are weak and the rule of law does not prevail, all resource management is problematic. In these situations it is not only sustainable forestry that is difficult to achieve, the record of attempts to establish national parks is no better. There does seem to be a period in the development of many countries when the principle of using resources or losing them does not apply. However, although sustainable forestry does not work when there is poor governance and weak civil society, this does not mean that it should not be part of the development perspective of the country in the long term.

Many countries are now moving towards more democratic and transparent systems of governance that will allow sustainable forest management to work. The move towards democracy and transparency is often driven by public pressure to improve resource conservation. Corruption and cronyism in the pillaging of forests have often been the first targets of emerging democratic governments. The existence of a Kuznet's curve for forests has been demonstrated—as civil society strengthens, the extent and quality of forests tends to improve.

In countries that have reached this stage of their development, conservation programs which emphasise local benefits appear to have a higher level of success than programs which attempt to lock forests away in totally protected areas. Forest area and quality is now expanding in many countries, largely in situations of multiple use. Forests are expanding on the island of Java, in southern China, in parts of India and in many parts of the developed world—but they are almost always being intensively managed for multiple products. In addition, selected tree species are being grown on farmlands, providing some of the goods and services formerly secured from forests. Totally protected areas only become attractive at much higher levels of social and economic development.

Biodiversity: Who Sets the Conservation Agenda?

It has been widely claimed that any fragmentation of forests would lead to major species extinction. For some species, and over very long geological periods, this may be true. But for most species, and over time scales to which most humans can relate, the empirical evidence is ambivalent. There has been a wave of interest recently in the idea of determining the minimal size of protected areas on the basis of the habitat requirements of the largest and widest-ranging species. But large wide-ranging species are almost all generalists that thrive in disturbed habitats (elephants, deer, tigers etc.). Disturbance-prone species are more often localised and have low capacities to disperse. There is a growing body of empirical evidence that even relatively small forest fragments will maintain the majority of their biodiversity over quite long periods of time (Zuidema et al. 1997). Similarly there is growing evidence of the ability of modified and disturbed forest systems to support high levels of species diversity (Fimbel et al. in press).

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It can be, and has been, argued that given our limited knowledge of forest biodiversity the onus should be on the manager to prove that an intervention will not result in the decline or extirpation of any species. Applying this argument to systems where only a small percentage of species have even been described raises numerous problems. The logical extrapolation of this approach would preclude any human modification of any natural ecosystem—clearly not something that society at large would find acceptable.

The opportunity costs of applying 'no regrets' approaches to complex forest systems are infinite. It makes far more sense to base biodiversity strategies on more explicit goals. Thus management tolerances could be defined in terms of a set of species or a species assemblage that should be maintained. This would provide a measurable and verifiable criterion against which management could be assessed and is something that could be negotiated between forest stakeholders.

Biodiversity targets are often stated in terms of conserving the full range of species occurring naturally at a site. It is also common to equate value with species richness. The problem with this is that it implies strongly that all species have equal value and thus that the more species one has the more valuable the forest. This clearly runs counter to observation of human behaviour. Value is based on the benefits people derive or expect to derive; as a result, people clearly value some species more highly than others—pandas receive more attention than soil microorganisms, condors more than mosquitoes.

There must be realistic assessment of the full costs of the sorts of biodiversity conservation programs being advocated, taking into account the costs borne by local people …

The problem is further complicated by variation in the value attached to different components of biodiversity. A museum taxonomist will attach different values to biodiversity than a subsistence farmer in the forests of the Amazon. As measures to conserve species will almost always incur costs, it is clearly important to know the relative values of species. These values cannot be dissociated from a willingness to pay and have to be offset against the opportunity costs associated with conservation programs. The issue often becomes how to weigh the direct dependence of the local community on utilisation of the forest against the desire of distant conservationists to keep the resource from being used. As choices always have to be made it is essential to confront reality; species have different values for different people and conflicting needs must be balanced. There must be realistic assessment of the full costs of the sorts of biodiversity conservation programs being advocated, taking into account the costs borne by local people whose use of the resource is limited or prohibited in order to maintain biodiversity.

Sustainability: One Size Fits All

The debate on forests has been bedevilled by an assumption that it is possible to make global generalisations about how forests should be managed. This 'one size fits all' approach to forest problems has been manifest in arid debates about whether or not sustainable forest management is, or is not, ecologically or economically viable. It has led to equally sterile debates about whether every piece of forests should be managed for multiple goods and services. There has been much protest against specialised production forestry with little biological diversity.

The pursuit of a global ideal fitting all forests has driven attempts to apply uniform criteria and indicators (C&I) to all forests, and to set global targets for 10% of all forests to be put into protected areas etc. This desire to categorise and generalise is common in many spheres of human activity but its prevalence in forestry is the subject of an interesting study by Scott (1998). In reality there is no single best way to manage any piece of forest; its use has to be the object of social choice. What a society chooses to do with any area of forest will vary from place to place and as economies evolve it will also change over time. Almost any decision about forest use involves trade-offs; choices have to be made about the balance between biodiversity, watershed values, recreation and timber. Use that leads to massive soil loss and the destruction of hydrological functions would unanimously be considered unsustainable, but within broad limits sustainability can take many forms. Some of the more recent work on indicators of sustainability recognises this.

The Montreal and Helsinki Processes set a bottom line, allowing comparisons between countries whilst permitting great flexibility at the national and local level on how sustainability is defined. Toolkits developed by the Center for International Forestry Research (CIFOR) include a software package that enables the user to tailor C&I to specific local needs (CIFOR 1999). This recognition that forest use is largely a matter of social choice represents significant progress over some of the doctrinaire approaches taken to forest problems in the recent past. It is reflected in the emergence of a number of new approaches to forestry, such as those adopted under the Canadian-led International Model Forest Network, the Australian Regional Forest Agreements and the Forest Ecosystem Management developed in the American Pacific Northwest. The so-called Malawi Principles for Ecosystem Management developed for the Convention on Biological Diversity are a good synthesis of modern thinking on holistic approaches to balancing the multiple demands that people place upon forests. The Malawi Principles are given in the accompanying box.

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This emerging recognition that the process by which decisions are made is more important than the decisions themselves provides us with an opportunity to unblock the logjam that is impeding progress on resolving forest disputes. This will strengthen the voice of local stakeholders in decision making about forests and diminish the ability of groups such as the World Bank or Greenpeace to exert hegemony over other peoples' forests. It will test the willingness to pay of some advocates of extreme conservation positions and force them to negotiate with the local people who often incur the opportunity costs imposed by strict conservation.

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Are Globalisation and Multinational Corporations a Threat to Forests?

Some parts of the forest industry are consolidating into very large corporations which move forest products at will across national boundaries. They have the ability to shift their production to low-cost and lightly regulated locations whilst accessing high-value markets. They are accused of causing a race to the bottom in seeking raw materials from places where environmental regulations are minimal (Korten 1995). This is especially true in the pulp and paper sector. This tendency is seen by many as posing a threat to locally adapted multiple use of forests. Economies of scale will favour corporations that intensify production in fast-growing monoculture plantations in a few favoured locations (Sayer and Byron 1996). Big corporate loggers will ride roughshod over weak local administrations and even more so over marginalised forest dwelling peoples.

These dangers do indeed exist. But globalisation and corporatisation also present some opportunities. Governments with weak forest administrations may find it easier to regulate a few

The Malawi Principles for Ecosystem Management for the Convention on Biological Diversity

- Management objectives are a matter of societal choice.
- Management should be decentralised to the lowest appropriate level.
- Ecosystem managers should consider the effects (actual or potential) of their activities on adjacent and other ecosystems.
- Recognising potential gains from management there is a need to understand the ecosystem in an economic context. Any ecosystem management program should:
  - reduce those market distortions that adversely affect biological diversity;
  - align incentives to promote sustainable use; and
  - internalise costs and benefits in the given ecosystem to the extent feasible.
- A key feature of the ecosystem approach includes conservation of ecosystem structure and functioning.
- Ecosystems must be managed within limits set by their ecological functions.
- Management should be undertaken at the appropriate scale.
- Recognising the varying temporal scales and lag effects which characterise ecosystem processes, objectives for ecosystem management should be set for the long term.
- Management must recognise that change is inevitable.
- The ecosystem approach should seek the appropriate balance between conservation and use of biological diversity.

large corporations than a multitude of fly-by-night entrepreneurs. The increasing sophistication of remote sensing and the range of sensitive indicators of sustainability now available should make it possible to regulate large operators from a distance. Increasingly, market and political forces are stimulating corporations to abide by codes of conduct and demonstrate greater social and environmental responsibility. '[Corporations] would have to be terminally foolish not to build long-term shareholder value by reorganising around a "triple bottom line" that promotes sustainability' (Zadek et al. 1997).

Governments with weak forest administrations may find it easier to regulate a few large corporations than a multitude of fly-by-night entrepreneurs.

Market forces alone will not favour locally managed multiple-use forests. The New Zealand solution, whereby the industry is based on intensive tree farms and conservation occurs in totally protected reserves, will be the default option. But there are lots of examples of countries that have put into place regulations and policies that favour more integrated outcomes. In Europe there are millions of forest owners closely linked to major industries, yet most of these forests are not monocultures, rather they are multiple-use forests that have environmental benefit. Outgrower schemes in which corporate sector investors draw upon small-scale forest producers to provide feed stock for large pulp mills are working effectively in the Philippines and Malaysia and are being tested in Indonesia. Australian research and experience could support this sort of initiative and be valuable in reconciling trade-offs between environment and development.

The choice of whether to integrate production and conservation functions or segregate them will vary from place to place. The ratio of forest resources to population density and the stage of economic development that a country has attained will lead to different outcomes in different places. But this is an area where government intervention will be needed to achieve outcomes with broad social acceptability. Governments and civil society can develop sets of environmental and social indicators to favour integrated outcomes. Certification, initially fiercely resisted by much of the corporate sector, is increasingly being actively pursued and this bodes well for improving the balance between different forest uses.

Will Intergovernmental Processes Have Failed Without a Forest Convention?

In the late 1980s and early 1990s conservationists took the view that an international forest convention was required to force delinquent countries to better conserve their forest resources. Not surprisingly, the countries in question resisted this perceived violation of their sovereignty and opted for a 'nonbinding statement of principles' and the Intergovernmental Panel and subsequent Forum on Forests. In the late 1990s, when a number of countries indicated their willingness to negotiate a convention, the campaigning NGOs reversed their position, realising that they would be excluded from a formal negotiating process. The lack of concrete outcomes from the decade of intergovernmental processes has led some observers to dismiss the debates as inconsequential and unhelpful. But one could argue that global generalised regulation of the governance of local forest resources was never a desirable outcome. Those attributes of forests that are genuinely global public goods—biodiversity and carbon storage functions—are dealt with by their own conventions. The establishment of level playing fields for trade is being addressed through the Montreal, Helsinki and various other regional C&I processes. The intergovernmental processes have led to much better shared understanding of the complexity of the problems and have fostered a plethora of regional, national and local initiatives to sustain forests. The push for a convention was driven by the 'one size fits all' view of forests. The progress that has been achieved has been in moving away from that towards far more realistic local and regional ecosystem approaches to forests as well as focusing on stronger commitment to action in areas that fall between gaps among existing legal conventions.

... one could argue that global generalised regulation of the governance of local forest resources was never a desirable outcome.

Conclusions

> 'Ecosystems are moving targets with multiple potential futures that are uncertain and unpredictable. Therefore, management has to be flexible, adaptive and experimental (Holling and Meffe 1996).'

Nowhere is this more true than in forests. There are lots of ways to manage a forest and many can claim to be sustainable. It is for this reason that achieving and maintaining a balance in allocating forest resources remains a challenge. Defining and defending rigid positions on forests issues is not helpful. Polarised negotiations lead to fragmented and segregated forest uses. There may be situations where this is a perfectly acceptable outcome but in many places the optimal environmental and social outcomes will come from more balanced and integrated forest use. National and management unit level C&I are leading us in the direction of locally adapted uses. The convergence of concepts and approaches in a number of countries that are adopting what can generically be referred to as 'ecosystem approaches' is encouraging. It suggests the emergence of a shared understanding of ways in which the often conflicting interests of the wide range of local, national and global forest stakeholders

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can be reconciled. The target of conservation should therefore shift. We should no longer be focusing on conserving pristine nature, or as many species as possible. We should recognise that even if left completely alone by humans, natural forces will make forests evolve rather than maintain a fixed situation. We should be conserving examples of forests that demonstrate a harmonious and sustainable relationship between humans and forests. We urge governments, civil society and the private sector to recognise the value of conserving outstanding examples of harmonious and sustainable human–forest relationships.

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DR PEDRO SANCHEZ, DIRECTOR GENERAL, INTERNATIONAL CENTRE FOR RESEARCH IN AGROFORESTRY, NAIROBI, KENYA

Dr Sanchez has been Director General of the International Centre for Research in Agroforestry (ICRAF) since October 1991. His distinguished professional career has been dedicated to improving the management of tropical soils for sustained food production and protection of the natural resource base. He has chaired or been a member of committees of several international organisations, and founded the 'alternatives to slash-and-burn' program. A native of Cuba, Dr Sanchez studied at Cornell University before joining the faculty of North Carolina State University, where he became Professor Emeritus of Soil Science and Forestry. Dr Sanchez is Adjunct Professor of Tropical Conservation at Duke University and honorary professor of the Universidad Nacional de la Amazonia Peruana. He has been decorated by the governments of Colombia and Peru and has received the International Soil Science Award and the International Service in Agronomy Award. Dr Sanchez is the author of numerous publications and is co-editor in chief of *Agroforestry Systems.*

Trees on Farms: Improving Land, Improving Livelihoods

Pedro Sanchez, Director General, International Centre for Research in Agroforestry, Nairobi, Kenya

The Problems of the Rural Poor

Poverty in the developing world is spiralling out of control and the gap between rich and poor is increasing. Three billion of the world's people now exist on less than US$2 per day, 1.3 billion on less than US$1 per day, and 800 million go hungry every night. What this means for the poor is a major decline in access to food for the family, education for the young, particularly girls, and health care for the sick and aged.

Given the poor state of most of the developing world's rural areas, such problems will not be easy to overcome. However, one way of achieving them, a pathway out of poverty towards prosperity, is increasingly being recognised—agroforestry. The innovations produced and evaluated and applied in this still relatively new field of research are all aimed at turning these objectives into reality.

...a pathway out of poverty towards prosperity is increasingly being recognised—agroforestry.

The Agroforestry Research–Development Continuum

Stated very simply, agroforestry is 'trees on farms'. It is a traditional practice of growing trees on farms for the benefit of the farm family and the environment. Through the International Centre for Research in Agroforestry (ICRAF), agroforestry has been brought from the realm of indigenous knowledge into the forefront of agricultural research in less than two decades, and has succeeded globally as a sustainability-enhancing practice that combines the best attributes of forestry and agriculture. ICRAF works throughout Africa, Latin America and Southeast Asia. The government of Australia continues to be a reliable investor in ICRAF's mission. Senior Australian scientists occupy leadership positions in the Board of Trustees and senior management of the centre.

About 1.2 billion people in the developing world (20% of the world's population) depend to a major extent on the products and services of agroforestry.

About 1.2 billion people in the developing world (20% of the world's population) depend to a major extent on the products and services of agroforestry. Agroforestry trees provide both products and services. They improve soil fertility by adding nutrient levels in soils, providing the basis for increasing food security, and yield products such as fuelwood, fodder, fruits, timber and medicines, which farm families use or market to bring in much-needed extra income. Some of these are high-value products that well-to-do people want to buy—a sure way to help eliminate poverty. Agroforestry trees protect the environment through controlling erosion, conserving water, increasing biodiversity, storing carbon and reducing greenhouse gas emissions. Also, developed countries are increasingly benefiting from agroforestry. A clear example is the use of trees to deepen saline water tables in Australia.

In order to promote the adoption of appropriate agroforestry practices, ICRAF has been structured to provide a research–development continuum, unique among international centres supported by the Consultative Group on International Agricultural Research (CGIAR). Strategic research innovations produced by the centre's Research Division are evaluated and applied by the Development Division in collaboration with more than 400 active partners—farmer organisations, researchers, national agricultural research systems, nongovernmental organisations (NGOs), advanced research institutes and extension services. Those farmers who have participated with ICRAF in onfarm research, or who have adopted the practices, can best sum up the value of agroforestry innovations. Some of their comments are given below.

What the Farmers Say about Agroforestry

Our major impact in eastern and southern Africa to date has been replenishing soil fertility. The problem of the high cost and general unavailability of imported fertilisers was addressed in an innovative way—by bringing the missing natural resources, nitrogen and phosphorus, from where they are found in the region into the farmers' fields. To produce nitrogen, farmers are planting their fields with legume trees, which flourish during the off-season. Phosphorus is being derived from indigenous rock phosphate deposits and a nutrient-rich local roadside shrub, *Tithonia diversifolia*, the Mexican sunflower. These trees have other benefits: they make farmers self-sufficient in fuelwood; recycle other nutrients; suppress the terrible parasitic weed striga; and fix carbon in the soil. In turn, increased soil fertility is allowing farmers to shift from low-value, subsistence products such as maize, to high-value vegetable and tree crops, thus putting more money into the farmers' pockets. The farmers' own words testify to the benefits.

... increased soil fertility is allowing farmers to shift from low-value, subsistence products such as maize to high-value vegetable and tree crops ....

Sinoya Chumbe of Kampheta village in Eastern Province, Zambia, says, 'Agroforestry trees have restored my dignity. My family is no longer hungry; I can even help my neighbours now.'

Says Martin Onanda, chief of Luero village in Nyanza, Kenya, 'For the first time there have been no hunger periods in this village. Only two ears of maize have been reported stolen this year.'

Oliver Zulu, a farmer in Chipata, Zambia, explains, 'Before, I had to choose between buying fertilisers or sending my children to school—the soil here is so poor. Then I learned about sesbania tree fallows and began to plant them.' His wife Ester adds, 'I am now harvesting bumper crops of maize, the family's income has improved, I have enough money for school fees, and Oliver is training other farmers.'

Says Charles Ngolo of Ebuyango in Kenya's Western Province, 'My wife and I are living the "tithonia life". I built a house with a tin roof and we are going to be able to send our children to school.'

Another Zambian farmer, Grace Mbewe, has a very personal success story to tell. 'At one time, we never could get enough food to feed our family of 10. Other farmers called us failures. Then we heard about tephrosia and began planting it. Our maize crop jumped from one-and-a-half oxcarts in 1997 to three-and-a-half in 1998.' (*Tephrosia vogelii* is a nitrogen-fixing shrub used as fallows.)

Monica Oketch, a farmer in Soso village in western Kenya, was experiencing a problem with the weed *striga in* her fields. She says, 'I had a lot of striga in one of my fields but after I planted sesbania fallows, it disappeared. The fallows also gave me quite a bit of wood for cooking.'

Peter Sikobe of Sauri village in western Kenya combined tithonia with rock phosphate from Tanzania. He explains, 'When I use tithonia and rock phosphate on my crops the plants are always green and healthy. The first time I used them I got twice as many tomatoes as usual, so I doubled the size of my tomato plot so that I would have extra to sell at the market for cash.'

The number of farm families using these technologies in Africa has jumped from 500 in 1997 to as many as 50 000 in 1999. This number is still only a drop in the bucket. Our challenge is to scale up to tens of millions of farm families to make a major difference in eliminating hunger and poverty. We are also working in other parts of the world with major potential.

Our challenge is to scale up to tens of millions of farm families to make a major difference in eliminating hunger and poverty.

From Poverty to Prosperity via Partnership

ICRAF and landcare in the Philippines

Farmer-driven organisations in the village can aid in developing and implementing more sustainable farming practices that conserve natural resources. Among the various organisational models for enhancing local initiative in addressing land degradation challenges, Landcare, an idea that originated in Australia, is of particular interest.

Through this movement, local communities tackle their agricultural problems in partnership with public sector institutions. The distinguishing marks are that they are voluntary and self-governing and focus on problem-solving resources within the community. Experience in the Philippines and in Australia has suggested that such an approach can provide a means to share technical information efficiently, spread the adoption of new practices, enhance research, and foster farm and watershed planning processes. These models are similar to the topic-focused village and farm groups found in Africa.

ICRAF and its partners have learned important lessons from observing the evolution of a participatory approach to conservation farming in the upland maize-growing municipality of Claveria of northern Mindanao in the Philippines. Natural vegetative filter strips, a farmer development, provided the impetus for the rapid spread of conservation farming technology. Little labour and no capital were required to establish effective protection for continuous farming on slopes as steep as 50%.

Says Claveria farmer Judito Joban, 'I began to cultivate this land in 1990. Heavy rains eroded not only the soil but also my crops. Some time ago I heard about natural vegetative strips. I adopted the technology in my field and I have observed that it requires less labour and is effective in controlling erosion.'

These systems provided a foundation for upland farmers to diversify, planting fodder grasses and legumes, fruit and timber trees and other cash perennials. This diversification helped to provide food security and alleviate poverty while conserving the fragile sloping environments. Diffusion of conservation farming technology has been greatly enhanced by the evolution of local landcare groups. The core of this landcare model is effective local community groups, working in partnership with local government, the Philippine Department of Agriculture and ICRAF. There are now 62 village-based landcare groups and more than 2000 farmers involved in Claveria. They have established more than 1500 conservation farms and over 200 community and household nurseries, entirely with local resources. The movement has now spread to other municipalities in northern and central Mindanao.

Diffusion of conservation farming technology has been greatly enhanced by the evolution of local landcare groups.

The essential elements of the approach are: a flexible set of proven technologies for smallholder agroforestry and conservation farming; farmer exposure to these technologies through onfarm observation and trial; and development of a farmers' organisation to diffuse knowledge about the technologies within the municipality. If these steps are successful then financial support is available from local government, at municipal and village level, to enhance sustainability.

Another farmer, Samuel Abrogaro, says, 'When I first heard about the landcare movement I was doubtful. Then I saw how farmers conserved the area and how their yields increased. I was convinced. Landcare taught me about soil conservation and solutions for better production. In my understanding, this will help me conserve my land and increase production. At the same time I saw how we could also conserve the environment'.

When researchers analysed the current experience with the landcare approach, they recognised that the cost to implement it in new municipalities would be modest. This is because implementation of the technologies is well within the farmers' own capabilities. Even the development of effective community tree nurseries has proven to be quite practical through volunteer effort alone.

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If the landcare organisation proves to be useful within the community, the municipal and local governments have an incentive to provide financial support to accelerate the spread of conservation practices and tree planting. This ensures sustainability more effectively than dependence on outside resources.

The approach has attracted the attention of the national government, which sees the movement as a foundation upon which to build an effective community-based approach to sustainable agriculture and natural resource management. There appears to be potential for enhancing this grassroots approach in other parts of the tropics of Southeast Asia, as well as in Africa and Latin America.

Alternatives to slash-and-burn agriculture

ICRAF leads the Alternatives to Slash-and-Burn Consortium (ASB). The consortium's research is aimed at developing profitable and sustainable production systems to increase incomes and help reduce tropical deforestation. It links seven international agricultural research centres and more than 100 national research institutes, universities and NGOs in Southeast Asia, Latin America and West Africa.

Soon after its founding, ASB's members began measuring carbon at representative sites in the natural forests and agricultural production systems of five participating countries. Carbon dioxide is the most important of the greenhouse gases that

An estimated 25% of carbon emissions comes from the conversion of tropical forests to other land uses.

causes global warming. An estimated 25% of carbon emissions comes from the conversion of tropical forests to other land uses. Storing carbon in trees and in the soils underneath them—both by protecting existing forests and by re-establishing tree cover elsewhere—can buy the world a little time while it learns how to reduce the consumption of fossil fuel that provides the other 75% of global carbon dioxide emissions.

Results from all three of ASB's research regions have demonstrated that agroforestry systems store carbon more effectively than annual cropping systems or pastures and grasslands. Agroforestry systems can sequester up to 35% of the carbon that was stored by a primary forest, compared with a maximum of only 10% in annual cropping systems, pastures or grasslands. While carbon sequestration is important to the global community, farmers must make money in the process; examples given below illustrate how this can be achieved.

High-value Phytomedicinals: Powerful Antidotes to Poverty

Over-the-counter sales of herbal medicines exceeded US$5 billion in 1998. In developing countries, their consumption has long been high, not only because they reduce dependence on expensive imports of western drugs but also because many are very effective. They also increase access to health care by poor people, especially in rural areas where clinics and drug stores are scarce or poorly stocked.

Even in industrialised countries the popularity of herbal medicines is growing, as confidence in their performance increases. This rapidly expanding market is now providing opportunities for developing countries to increase their exports and earn much-needed foreign exchange. It also affords opportunities for small-scale farmers to boost their incomes.

Sixty-five per cent of all medicinal plants are trees …

Sixty-five per cent of all medicinal plants are trees and ICRAF is actively promoting the cultivation of medicinal trees in smallholder agroforestry systems as a viable means of increasing farm incomes whilst conserving biodiversity. One example of this activity is with *Prunus africana*, a tree whose bark has a high cash value as a remedy against the prostate gland disorders that affect many men over the age of 50.

Until a decade or so ago, the only cure known to doctors in developed countries was an operation to remove the part of the gland that compresses the urinary tract and causes pain. In contrast, the medicinal properties of prunus have long been known in parts of Africa, where the bark is pounded to powder, water is added, and the resultant red liquid is drunk as a remedy, not only for prostate disorders, but also for stomach ache. Since western science 'discovered' prunus, thousands of sites on the Internet advertise prostate remedies based on prunus bark powder. Global trade in the product has been estimated at more than US$220 million, a figure that is expected to double or triple in the next 10 years.

The downside of this runaway demand is that the slow-growing evergreen—found in the moist highlands of half a dozen African countries—is fast disappearing from the forests and is threatened with extinction in some parts of Africa. At one time, the bark was harvested in sustainable fashion; only small pieces were taken from individual trees, thus allowing the regeneration of the removed portion. However, to satisfy increased demand for this natural remedy, many of the harvesters resorted to cutting down entire trees. With this in mind, ICRAF researchers and partners in Africa and Europe are working to domesticate this valuable medicinal tree and convince small farmers to plant it on their land and harvest it sustainably. The endangered tree will thus be saved from extinction and, as a cash crop, will provide long-term extra income for the poor farmer and his family.

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Farmers are being encouraged not only to cultivate the trees on their land, but to establish nurseries and tree stands where seeds and seedlings can be produced for sale to other farmers—a long-term sustainable practice to ensure that the endangered *Prunus africana* will be around to help future generations of prostate sufferers.

Trees Provide an Alternative Source of Income for Peruvian Farmers

In an effort to diversify the income-producing crops available to farmers in Peru's Amazon region, ICRAF and its research and development partners in the country are seeking to increase the range of high-value tree species and products available to farmers. One such tree that is growing in popularity with small-scale farmers in the region is *Calycophyllum spruceanum*, known locally as capirona.

Capirona is a fast-growing tree that produces hardwood for timber and building poles. It also makes excellent charcoal and can be burned directly as firewood. In a region fast filling up with people, these are qualities that make the species much in demand. Even farmers who know the tree do not always manage it well and often are not aware of the full range of products they can get from it. In Peru, the Ucayali Region Reforestation Committee has reported a high, unmet demand for capirona seeds and seedlings from farmers, government and NGOs. Farmers could thus add to their income by producing and selling high-quality seed and seedlings.

... despite capirona's potential, until recently its seed had never been systematically collected to evaluate genetic differences in tree growth, wood quality and other commercial characteristics.

However, despite capirona's potential, until recently its seed had never been systematically collected to evaluate genetic differences in tree growth, wood quality and other commercial characteristics. Now, four national bodies—the Ministry of Agriculture, the Ucayali Region Reforestation Committee, the National Institute for Agricultural Research, and the Institute for Research in the Peruvian Amazon—are collaborating with ICRAF to collect seed and evaluate the material on farmers' fields. The ministry and ICRAF will jointly construct a tree-seed bank, the first of its kind in the region. Operated by the ministry, the seed bank will service reforestation projects and increase the supply of high-quality seeds and seedlings to farmers.

Diversifying Cocoa Agroforests in Cameroon

Cocoa farmers are continually at the mercy of world markets for their product, the price of which often fluctuates wildly. When world cocoa prices crash, as they have done several times in the past, their income disappears and there is no money to buy food. People cannot live on a diet of cocoa beans.

One way to diversify production in the cocoa agroforests is by planting fruit trees that provide products that can be eaten or transformed into higher-value commodities ...

One way to diversify production in the cocoa agroforests is by planting fruit trees that provide products that can be eaten or transformed into higher-value commodities such as sauces, spices and condiments. One of the most popular of such income-earning trees is the bush mango, whose fruit resembles a smaller version of the domesticated mango. The pulp of the fresh fruit is eaten but it is the nut which provides the most valued part of the tree—the kernel. It commands a high price as a delicious condiment for soups and when pounded into a paste can be used in cooking as a substitute for groundnuts. Once dried, both kernel and paste can be safely stored for up to a year, an important property in a region where refrigeration is often nonexistent.

Many farmers have been reluctant to plant bush mango seedlings alongside their cacao plants because it can take from 10 to 15 years for the young plants to produce fruit, too long a time for most farmers to wait for returns on their planting. However, ICRAF and its Cameroon research and development partners are encouraging farmers to experiment with a propagation technique known as marcotting, which reduces the time from planting to fruit harvest to as little as three to five years. This remarkable improvement has made growing the bush mango a much more attractive proposition for farmers.

Securing Property Rights for Forest Margin Agroforesters in Indonesia

The complex agroforests of Sumatra, Indonesia, are indigenous systems created over generations by people living at the margins of tropical rainforests. After slash-and-burn was carried out, food crops were planted along with coffee, pepper, fruit trees and the resin-producing damar tree. The trees eventually produce high-value products such as fruits, resins, medicinals, and high-grade timber. However the villagers in Krui, Lampung Province, who depend on these complex agroforests, did not have land tenure, since their agroforests were classified as State Forest land. This created a great deal of uncertainty among Krui farmers. In 1998, ICRAF work on the relationships between people, trees and property rights in this area led to the achievement of two major milestones.

Firstly, in early 1998, the Indonesian Minister of Forestry signed a historic decree recognising the rights of the Krui people in Sumatra to manage and harvest products from their complex, multistrata agroforestry systems. Research conducted by ICRAF and its partners had demonstrated the value of those systems. The efforts of a unique coalition of local people, government officials, NGOs and research institutes, including ICRAF, resulted in the development of policy options to protect the systems.

In 1994 Pak Hedrus, one of the Krui agroforesters, said to a television crew, 'Up to now, the government does not know what to make of this land. We are trying to explain that it is a forest garden and not a virgin forest.' Pak Hedrus now knows that the government has become aware of the significance of this land.

'Up to now, the government does not know what to make of this land. We are trying to explain that it is a forest garden and not a virgin forest.'

ICRAF and its partners must now look beyond the Indonesian decree. Many areas of the country share the beneficial features of the Krui agroforests but have limited local capacity for management of their forest resources. Also there are conflicts between competing resource-users and environmental concerns. With assistance from ICRAF, the government is developing a two-track approach to accommodate the diversity of local circumstances—one track for situations like Krui, where systems are already in place, and another for less developed situations. The second milestone was reached in December 1998, when the new Minister of Forestry and Plantations asked ICRAF to help develop this approach as a nationwide policy.

Recognising the need to develop policy options for situations less ideal than Krui, ICRAF and its partners established a new research site at Sumba Jaya in June 1998. The official view is that the coffee-based systems that predominate in Sumba Jaya threaten watershed functions. Sumba Jaya farmers, who are settlers, have been in conflict with the government over use of this land for some time. New research at Sumba Jaya seeks to understand what communities and governments can do to meet social, economic and environmental objectives more effectively.

Development in the Sahel: Fences that Come Alive

The Sahel, which stretches across Africa just south of the Sahara desert, has one of the harshest and most unforgiving climates in the world. Desertification, infertile soils, high temperatures, low rainfall, droughts that can last for years—these are the challenges that face the nearly 50 million people who make their home there. Most of them face a daily struggle just to feed themselves.

To address such challenges, ICRAF, together with international and national partners, has developed agroforestry innovations that emphasise the enormous value of adding trees and shrubs to agricultural production systems of the region. One of the most important, and popular, innovations is the improved 'live fence' that protects dry-season vegetable gardens and other high-value crops from devastation by free-ranging livestock.

One of the most important, and popular, innovations is the improved 'live fence' that protects dry-season vegetable gardens...

Dry-season gardens are increasingly important to people in the region. Fast-growing urban areas have created a demand for different types of market produce, a trend that is likely to grow. In rural areas, where poverty can be extreme, this is an excellent opportunity for farmers to earn cash and also generates a demand for labour—both of which can help in the fight to eradicate poverty.

Traditionally, such gardens have been protected from the predations of livestock by 'dead fences' made from thorny branches, or stalks of millet and sorghum. Collecting such materials is arduous and time-consuming and the fences are easily destroyed by termites, wind and animals. Also, in many parts of the Sahel, wood for such fences is no longer available. When live fences were used in the past, they were constructed from species that did not provide products.

ICRAF and its partners decided to focus their research on species that would create fast-growing fences and also provide services, as well as products that farmers can use at home or can sell at local markets. Trials with many species in a range of soil and climatic conditions identified four species that were particularly suitable—*Ziziphus mauritiana*, *Acacia nilotica*, *Acacia senegal* and *Bauhinia rufescens*. They provide high-value products such as fruits, medicines, fodder, tanning agents and gums. An in-depth financial analysis of such fencing strategies in Burkina Faso has shown that, even with the initial investment for establishing the live fence, farmers can bring in an additional US$40 a year. This is a significant increase in a region where farm family incomes range between just US$250 and US$350 annually.

Saving Lake Victoria—Thanks to Satellite Images and Agroforestry

Poverty and environmental degradation are inextricably linked—as can be seen around Lake Victoria, where both occur on a vast scale. The world's second biggest freshwater lake is dying from a lethal cocktail of urban waste and nutrient run-off from agriculture. Particularly serious is the process of eutrophication—water pollution caused by excessive nutrients, especially phosphorus. Besides triggering blooms of toxic algae and causing massive fish die-offs, the oversupply of nutrients is associated with the spread of the water hyacinth, an aggressive floating weed that has covered nearly 700 square kilometres of the lake's surface in less than a decade.

The world's second biggest freshwater lake is dying from a lethal cocktail of urban waste and nutrient run-off from agriculture.

The weed starves fish and plankton of oxygen and sunlight and reduces the diversity of other aquatic plants. It also destroys much of the lakeside economy, eliminating the local fishing industry and cutting off communities by blocking the channels used by boats.

Until recently, the sources of such excessive nutrients were unknown—urban wastes are easy to trace, not so agricultural run-off. However, using Landsat images, ICRAF landscape ecologists discovered a plume of nutrient-rich sediment being carried from three rivers flowing into Lake Victoria from the Kenyan side. The scientists have now tested the soil particles from the particular area of the lake where the plume appeared. By sampling the soils just above the confluence of the rivers, the scientists have narrowed the problem down and have identified those parts of the valley system producing the most nutrients. This soil testing work is also important in detecting nitrates, which, unlike phosphates, do not show up on satellite imagery.

The next phase of this project will involve the application of agroforestry innovations by ICRAF and its partners in areas from which nutrient-rich sediment is being washed into the rivers, so that the flow can be reduced or even curtailed completely.

Conclusion

Farmers in marginal areas of the tropics are beginning to win some battles in the war against poverty, famine and environmental degradation; paths towards prosperity are being uncovered. One of the most important of such paths is that of agroforestry, where trees on farms can not only improve the land but also significantly improve the livelihood of farmers and the health of our planet.

... paths towards prosperity are being uncovered. One of the most important of such paths is that of agroforestry ...

Dr Glen Kile, Chief, CSIRO Division of Forestry and Forest Products, Canberra, Australia

Dr Kile's major research interests have been in forest and tree health. He has undertaken pioneering work on some indigenous diseases in Australia's native forests through work in Tasmania and Victoria. After graduating from the University of Tasmania with a PhD in agriculture in 1971, Dr Kile joined the Forest Research Institute, which in 1975 became the CSIRO Division of Forest Research. He took up the positions of Program Manager for Hardwood Plantations in the Division in 1987, and Chief of the CSIRO Division of Forestry in 1992. For the past three years Dr Kile has headed the Division of Forestry and Forest Products.

Planted Forests for Food, Fibre, Fuel and Fulfilment

GLEN A. KILE, CHIEF, CSIRO DIVISION OF FORESTRY
AND FOREST PRODUCTS, CANBERRA, AUSTRALIA

Introduction

Forests are an integral component of the global life support system; they are critical in carbon, energy and water fluxes and they are the major reservoir of terrestrial biodiversity. The world's current forest cover is 3454 million hectares, reduced by an estimated 236 million hectares between 1980 and 1995. In addition to the loss of forest cover, significant but unquantifiable effects on forest condition (species diversity, tree density and age structure) occur through human disturbance, fire and pest outbreaks. The central role of forests in environmental and human welfare has ensured their high profile amongst international environmental policy issues.

Forests have been estimated to provide environmental services valued at US$4.7 trillion (Costanza et al. 1997). Demand for timber and fibre rises in line with population growth and economic development, with current global removals estimated at 3.5 billion cubic metres per year. Approximately 55% is used for fuelwood and charcoal and 45% for industrial roundwood. Demand is expected to increase by 2.4–2.8% per year over the next decade. Nonwood forest products like foods, medicines and fibres are important locally, and some enter trade in significant quantities. Particularly in developed countries there is increasing demand for forest preservation, based on wilderness and existence values. Out of this complex milieu of competing and expanding demands for forest goods, services and values the global community seeks to develop more sustainable forest management systems.

Out of this complex milieu of competing and expanding demands for forest goods, services and values the global community seeks to develop more sustainable forest management systems.

Opportunities to increase world wood supply in future will largely depend on plantations...

Planted forests are playing an increasingly important role in meeting the world's requirements, particularly for wood and fibre, but also for food security, the supply of nonwood forest products and environmental services. Binkley (1997, 1999) portrays a major global transition over the next 50–100 years from natural forest utilisation to increasing dependence on planted forests, with capital, labour and knowledge substituting for land through more intensive management. This is the path agriculture has taken over a very long period and fisheries are increasingly taking the same route through aquaculture.

Planted forests come in many forms and for many purposes. They range from industrial tree farms to blocks, belts, rows or other configurations of trees integrated into farming systems. In this presentation I would like to focus on the role of planted forests—industrial to farm forests—in helping to meet the needs of the expanding global population in terms of food, fibre, fuel and fulfilment.

Plantation Resources and Wood Supply

Globally, data on planted forests is bedevilled by problems of definition and inadequate inventory data in terms of both area and productivity. ABARE–Jaakko Pöyry (1999) estimated the area of industrial plantations—defined as plantation resources established with the primary purpose of supplying roundwood for sawntimber, veneer and pulp—at 116 million hectares, although the effective area commercially and economically viable for wood production was estimated to be about 94 million hectares. Pandey and Ball (1998) cited somewhat higher figures (138 million hectares total plantation, 120 million hectares industrial) with an estimated annual global plantation establishment rate of 6.5 million hectares per year.

Assessing the contribution of planted forests to global wood supply is even more difficult and any figures must be considered indicative only. ABARE–Jaakko Pöyry (1999) estimated that plantations, at around 3% of total forest resources in area terms, currently supply 30–35% of the world's industrial roundwood and 10% of fuelwood. This is expected to rise to 44% by 2020 and 46% by 2040. In volume terms, supply from plantations is expected to increase from 624 million cubic metres in 2000 to 1043 million cubic metres by 2040.

Opportunities to increase world wood supply in future will largely depend on plantations because of the static or decreasing supply from natural forests due to deforestation, past overexploitation, greater reservation for other nonwood uses or values and increased costs of access and extraction. If wood maintains its competitive position in relation to substitute materials, Sutton (1999) estimated that a global wood harvest of 6 billion cubic metres per year would be required, for a forecast global population of around 10 billion in 2050, consuming 0.6 cubic metres of wood (industrial and fuel) per capita. This is 2.5 billion cubic metres more than wood consumption in the mid-1990s. Using a variety of assumptions, Sutton suggested that the world could require a minimum additional area of planted forest of 100 million hectares to meet such a demand. This represents most of the land that is suitable for planted forests and is currently surplus to food production, but is not already in use for forests.

Definition of forest plantations

Forest plantations are simply defined; they are trees that have been established artificially through the intervention of people. They may have been, and often are, planted as seedlings, but sometimes they are established from seed.

Compared with natural forest they have a simple composition of one or, at most, a few dominant tree species, which are usually chosen for their fast growth. They have a simple structure and usually one age class. They are generally established with one overriding objective.

However, deriving data by application of the definition is not simple. Regeneration may be natural, supplemented with planted trees, making it difficult to give a figure for what is planted and what is natural.

It is relatively easy to estimate the area of trees planted in blocks, but not the area of trees established in small groups, in lines beside roads, railways or canals, as windbreaks, shelterbelts or for amenity. Where trees are integrated into other land-use systems, not only their extent may be unclear, but also their potential production, location and social and economic costs and benefits.

Poor management may mean that reported figures of plantation areas or their contribution to the national economy may be overestimated, but lack of reliable sample surveys may make the derivation of actual areas unreliable. The need for reliable inventories of forest plantation resources must represent an important task for the future that will lead to the development of new techniques for plantation and volume assessment.

Source: Ball 1998

About 55% of the annual global wood harvest is used in the form of fuelwood or charcoal for energy production ...

Fuel from Planted Forests

About 55% of the annual global wood harvest is used in the form of fuelwood or charcoal for energy production, particularly in the rural and domestic sectors of developing countries. Wood fuels account for about 7% of the world's total energy supply and around 15% in developing countries.

Sutton (1999) did not differentiate between industrial and fuelwood production in his calculations for future requirements for new planted forests but it seems likely that overall demand for wood for energy will increase in the future. This is a result of new, more efficient energy production technologies and improving competitiveness with alternative energy sources. Environmental concerns could provide an opportunity for wood fuels to form part of a substitution strategy to reduce carbon dioxide emissions from fossil fuels. Many countries are changing policy to encourage the development of renewable energy resources, including sustainably produced biomass. For example, Finland has targeted a 25% expansion in wood energy production by 2005. Ratification of the Kyoto Protocol could further stimulate the wood energy sector (FAO 1999). Planted forests were estimated to contribute 10% of the wood currently used for energy production (ABARE–Jaakko Pöyry 1999) but there are significant opportunities to expand the supply or substitute for traditional sources, especially when excessive collection of fuelwood can contribute to the degradation of natural forests.

In many countries planted forests contribute in a significant but unquantifiable way to domestic and rural energy supply through the collection of litter, twigs and branches and use of residues remaining from converting wood to various primary products. Purposeful establishment of forests for bioenergy has been less widely practised, although there has been significant developmental work on short-rotation coppice crops in some northern hemisphere countries. Forests for energy have certain advantages: they can be established close to the point of utilisation; they can be produced on short rotations; wood can be the byproduct of other forest management; and wood can be substituted or mixed with other fuels such as coal at relatively low cost. Wood fuels can make a contribution to reduced dependency on fossil fuels, and plantation management systems have a lot to offer as production systems.

Wood fuels can make a contribution to reduced dependency on fossil fuels...

Food and Nonwood Products from Planted Forests

Food security is defined as economic and physical access to food of all people at all times. In a world where more than one billion people already live below the poverty line and global population could increase to 10 billion by 2050, to increase food supply without causing further extensive degradation of the natural resource base will require significant change and innovation in production systems.

Planted forests grown primarily for wood production can perhaps make only limited or supplementary contributions to food supply through products such as mushrooms, honey, nuts or fodder for domestic animals. Planted forests or wood producing trees in farming systems will, however, create many indirect benefits: improved and sustainable agricultural productivity; increased shade and shelter; beneficial effects on soil properties and management of watertables; and cash income derived from trees and forest products.

There will be increasing demand for tree planting to ameliorate various forms of environmental degradation including the sequestration of carbon dioxide. New resource rights, such as carbon credits, could enhance the profitability of planted forests.

Greater opportunities perhaps lie in the domestication of a wider range of tree crops, either for food or other nonwood products, and their integration into agroforestry systems in a commercial but sustainable way (Leakey and Izac 1996). Such developments could be particularly important for small-scale subsistence farmers in the tropics and the subtropics. However, if production systems develop to large-scale plantations there are concerns that those most in need of improved food security will not benefit to the same degree.

Fulfilment—Sustainable Management of Planted Forests

Definitions of fulfilment such as 'completing one's obligations', 'satisfaction' or 'contentment due to performance' can be applied to encompass the role of the entire global community as stewards of natural resources for future generations. We might reach a state of fulfilment when we can demonstrate sustainable forest management in the broad 'triple bottom line' sense—economic, environmental and social. On present evidence we have a long journey ahead.

We might reach a state of fulfilment when we can demonstrate sustainable forest management in the broad 'triple bottom line' sense—economic, environmental and social.

In natural forest the primary focus of sustainable management is the maintenance of ecological processes, with secondary considerations of growth, yield and multiple uses (Berlyn and Ashton 1996). In an artificial system such as an industrial plantation the primary objective is wood production. In this context Nambiar (1996b) has defined sustainable plantation forestry as land-use practices and tree farming systems which maintain or enhance:

- the economic viability of wood production;
- the natural resource base, especially soil and water; and
- other production systems which may be integrated with tree farming.

The goals of sustainable plantation forestry may then be defined and monitored in a practical sense to ensure:

- the trend in productivity is maintained or increased over successive harvests while conserving or enhancing the natural resource base;
- plantation management practices per se do not adversely affect the environment; and
- plantation forestry is economic and contributes to prosperity.

During the last decade we have seen a major paradigm shift from traditional management for sustainable yield to a more integrated approach to sustainable forest management.

In the plantation context we are generally concerned with the economic wood yield although this is only a proportion of the total biological productivity (biomass) produced on a site. Thus, it is important to differentiate between sustained yield and sustained productivity (Nambiar 1996a). The former may be possible in the short term by increasing the intensity of management inputs, but to sustain yield and productivity in the long term the natural resource base (soil and water) must be conserved or enhanced. During the last decade we have seen a major paradigm shift from traditional management for sustainable yield to a more integrated approach to sustainable forest management.

Maintenance or improvement of productivity of plantations over successive rotations is thus a critical element of sustainable production forestry. Key to this will be the intensity of harvest and interrotation management (Fig.1). As pointed out in Nambiar (1996b) this phase provides a window of opportunity to correct past mistakes and introduce scientifically based silviculture and superior genotypes, and place the next plantation on a sound management footing.

Management will be most important on sites that are low in available nutrients and water, harvested regularly and vulnerable to soil damage, including erosion and compaction. One of the best researched examples of yield decline in plantation forestry occurred in second-rotation radiata pine plantations established in South Australia and western Victoria on podsolised[1] sandy soils that are low in organic matter and nutrients (Keeves 1966; Nambiar 1996b). Intensive research led to revised forest

[1] Podsol is acidic, infertile forest soil with an upper layer depleted of colloids, iron and aluminium compounds and a lower layer in which these have accumulated. It is difficult to cultivate and is found over vast areas in northern North America and Eurasia and is common in eastern Australia.

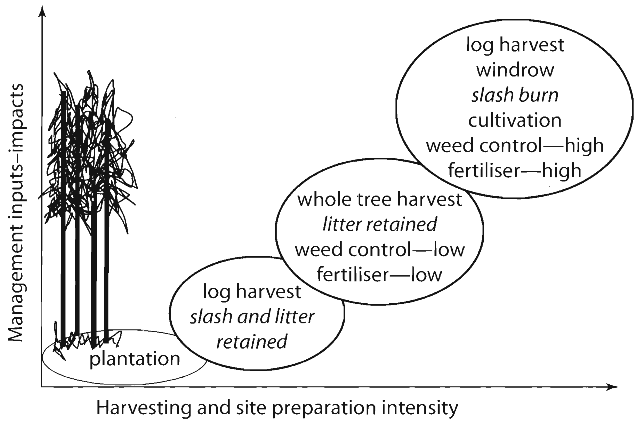

Figure 1. Intensity of harvest and interrotation management are critical issues for long-term productivity (Nambiar and Brown 1995).

management practices. Combined with ongoing genetic improvement these not only arrested the decline but substantially increased the yield in succeeding crops.

In terms of sustainability, fast-growing short-rotation plantations must be appreciated for what they are—one element in our capacity to satisfy demand for wood and wood fibre. They are akin to long-rotation agricultural crops. It is unrealistic to expect that we can sustain the productivity of such plantations at economically attractive rates and maintain soil quality without inputs such as fertiliser and weed control (Nambiar 1996a,b). While low-input, multispecies plantations are considered by some as likely to be more sustainable, the productivity of any plantation will probably parallel the intensity of management inputs and there is no clear evidence to support the contention that monoculture plantations are less sustainable than mixed-species planting.

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Environmental aspects of planted forests involve avoidance of off-site effects, such as herbicide movement, impacts in water quality from chemicals and mobilisation of sediment. Planning and operational procedures to achieve these ends are generally understood, if not always applied. Provided they are not replacing indigenous forest, plantations may also contribute to conservation of biodiversity in a number of ways: providing habitat for indigenous species; buffering indigenous forest elements; and improving connectivity between forest remnants (Norton 1998). While forest managers may not see trade-offs with production as desirable, a landscape approach to forest management and modifications to species composition or management regime could produce more desirable outcomes in environmental terms (Norton 1998).

A wide variety of cultures, environments and levels of economic development ensure that social impacts of planted forests will be a matter of ongoing debate.

A wide variety of cultures, environments and levels of economic development ensure that social impacts of planted forests will be a matter of ongoing debate. Issues relevant to social acceptability of planted forests in different situations around the world include clearing of natural forest or other natural ecosystems for plantations; rights of indigenous people and recognition of traditional land tenures in large-scale development; competition for farmland and water resources; and the use of monocultures and exotic species.

At the same time, opportunities for development of planted forests are improving with a general move towards a more participatory approach to forest management. This is being achieved through changes in forest policy and legislation in many countries and the strong role of the private sector in planted forests development, from large-scale industrial companies to small growers. These new initiatives are creating greater opportunities to develop innovative investment and contractual arrangements to satisfy the economic, social and environmental objectives of the participants.

Conclusion

As we seek paths to more sustainable human societies we are continually confronted by differing philosophies of life and views on the role of humankind. This conflict is encapsulated in the following comment from Meadows (1972), quoted in Kile (1995):

> 'On one side of the argument, then, were the Cornucopians or 'technological optimists'. On the other side were the Ecotopians and neo-Malthusian pessimists. Between these quasi-religions was an irreconcilable abyss. "We see no objective way of resolving these very different views of man and his role in the world", concluded Meadows. "It seems to be possible for either side to look at the same world and find support for its view. Technological optimists see only rising life expectancies, more comfortable lives, the advance of human knowledge, and improved wheat strains. Malthusians see only rising population, destruction of the land, extinct species, urban deterioration, and increasing gaps between the rich and the poor".'

An expansion of planted forests represents the major opportunity to maintain significant areas of natural forests…

Maintenance of a large global forest estate is critical to sustainable development in all aspects of the triple bottom line—economic, environmental and social. An expansion of planted forests represents the major opportunity to maintain significant areas of natural forests for nonwood values and uses in the face of increasing population and rising demand for wood for industrial and energy uses. Planted forests in their many forms can be complementary and integrated with natural forests and agricultural systems, meeting purposes beyond the primary role of wood production.

Intensive management of planted forests is a relatively new innovation and in most cases our experience does not extend beyond 3–5 rotations. Therefore a significant opportunity remains for research to improve productivity and management to maximise the economic, environmental and social benefits that planted forests can provide. They must be an accepted part of our production systems if we are to walk the food and environmental tightrope successfully.

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LAND MANAGEMENT

DR ERIC CRASWELL, DIRECTOR GENERAL, INTERNATIONAL BOARD FOR SOIL RESEARCH AND MANAGEMENT, BANGKOK, THAILAND

Dr Craswell's current focus is on the relationship between poverty and land degradation, and promotion of sustainable land management. Since 1976, Dr Craswell has gained international experience at a variety of institutions, including the International Fertilizer Development Center in Alabama; the International Rice Research Institute in the Philippines; and the Technical Advisory Committee Secretariat of the Food and Agriculture Organization in Rome. Dr Craswell started his career as a soil scientist at the Queensland Wheat Research Institute and coordinated ACIAR's Land and Water Resources program from 1983 to 1996.

Save Our Soils—Research to Promote Sustainable Land Management

ERIC T. CRASWELL, DIRECTOR GENERAL, INTERNATIONAL BOARD FOR SOIL RESEARCH AND MANAGEMENT, BANGKOK, THAILAND

Introduction

Developing country agriculture has made enormous production gains during the last three decades, largely due to the adoption of modern crop varieties and improved soil, pest, nutrient and water management technologies in high-potential areas. However, two interdependent caveats take some of the shine off the success of the green revolution. Firstly, the benefits of modern science have bypassed millions of rural poor in low-potential areas. Secondly, land degradation and environmental pollution continue to affect the future productivity of both high- and low-potential areas, limiting the capacity of agriculture to provide sufficient staple food at affordable prices for a global population that will reach 7.5 billion in 2020 (Pinstrup-Andersen et al. 1999). In addition, the agricultural sector will have to respond to increased demand for high-value and better-quality animal products, fruits and vegetables as incomes in developing regions rise. Producing and distributing food equitably is challenge enough, but achieving the required production gains without causing irreparable damage to the already extended land and water resource base looms as an almost insurmountable problem.

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This paper analyses the impacts of agricultural intensification on land degradation, the need for strategic investments to counter the negative impacts, and the way forward to promote sustainable land management in the tropics.

Agricultural Intensification and its Impact

The pace of agricultural intensification is driven by growth in demand for food and fibre, by the imperative for income growth and by the underlying and relentless increase in population in developing regions. The global capacity to produce food is theoretically several times larger than the requirements of a global population of 10 billion, projected for the year 2040, provided sufficient inputs are used efficiently (Penning de Vries 1999). This is true in theory even if household incomes limit neither food consumption nor the amount of animal protein in the diet. There is the potential to produce sufficient food globally, even if significant land degradation occurs. Reality presents a less favourable picture because some countries place high priority on food self-sufficiency for security reasons, and many people in marginal areas have low productivity, low incomes and food insecurity at the household level. As mentioned above, recent gains in agricultural production in the densely populated Asian region have derived from high-potential areas, mainly irrigated alluvial deltas and plains that are intensively cultivated to rice. Governments and development agencies have invested heavily in these areas, where the intensive production of staple grains has met demand and kept grain prices low for the urban poor through pricing policies that benefit the consumer. However, high-potential areas are not without problems of land degradation, and evidence is accumulating that yield growth is stagnating in the irrigated rice and wheat growing areas of Asia. More efforts are needed to address land degradation in order to protect breadbasket regions such as the Indo-Gangetic plain. Continued high productivity from these areas is essential, not only to provide food for urban populations, but also to reduce pressure for deforestation and the intensification of agriculture on marginal lands at the national level.

More efforts are needed to address land degradation in order to protect breadbasket regions …

The interrelation between poverty, agricultural intensification and nutrient decline is shown in Figure 1. Land drained of its nutrients cannot support sufficient vegetation to protect the soil surface against water and/or wind erosion. Water erosion is the most serious degradation problem, estimated to cause the loss of 75 billion tonnes of soil, worth US$400 billion, per year (Eswaran et al. in press). Despite increasing urbanisation, more than two-thirds of the population in many developing countries live in rural areas. The problems are particularly severe in Asia, where average arable land per capita is less than 0.15 hectares, lower than any other region in the world. The Asian Development Bank (ADB) estimates that during the last 30 years, one-third of agricultural land has been degraded (ADB 1997). According to calculations by Penning de Vries (1999), East and South Asia will not be self-sufficient in food by the year 2040 if land degradation continues at a high rate. In comparison with most other regions of the world, the Asian region is a danger zone in relation to food security.

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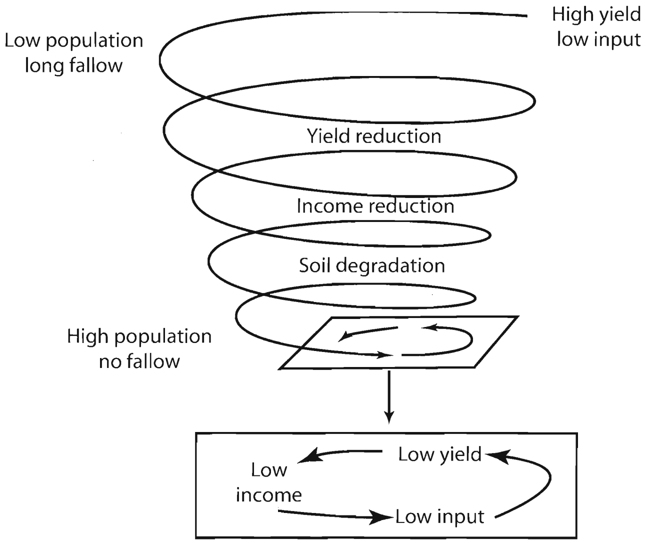

Figure 1. The downward spiral to the poverty trap (McCowan and Jones 1992).

Estimates of the costs of land degradation commonly ignore off-site economic impacts, such as damage to coastal fisheries and tourism and lost water storage capacity. Net outflows of sediments to the oceans in Asia illustrate the net national costs of soil erosion to countries in the region (Fig. 2). Annual costs in terms of nutrient replacement (US$3 per tonne of sediment) total more than US$27 billion, representing a major loss to countries of the region. Also noteworthy is the estimate that the average cost of nutrient replacement to the economies of countries of sub-Saharan Africa is 7% of the agricultural gross domestic product, but reaches as high as 20% in countries such as Niger (Drechsel and Gyiele 1999). The national nutrient balance of agricultural lands in subSaharan African countries is related linearly to population density (Fig. 3). However, more work is needed to disaggregate such data and gain a better understanding of the distribution of nutrient decline and its impact on different lands, such as high- and low-potential rural areas and land used for peri-urban agriculture.

Figure 2. Net ocean outflows of sediments in Asia expressed as US$ millions, based on nutrient replacement value of US$3 per tonne of sediment (Milliman and Meade 1983).

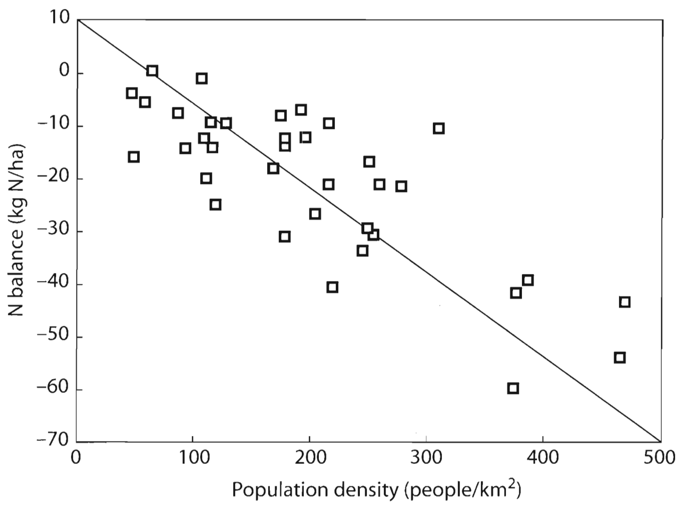

Figure 3. Relationship between agricultural nitrogen balance and population density for countries in subSaharan Africa.

The nexus between poverty and the degradation of the environment lies at the heart of the problem, but is not well understood. Figure 4 shows the relationship between income and environmental degradation and provides some insights into the strategy needed to tackle the problem. At very low incomes (e.g. with shifting cultivators at low population pressure) the degree of degradation is low. However, as population grows and/or there is greater demand for higher income, the need to exploit the resource base leads to increased degradation. It reaches a point where income is sufficiently high for the conservation ethic and the political will to grow, leading to increased environmental protection.

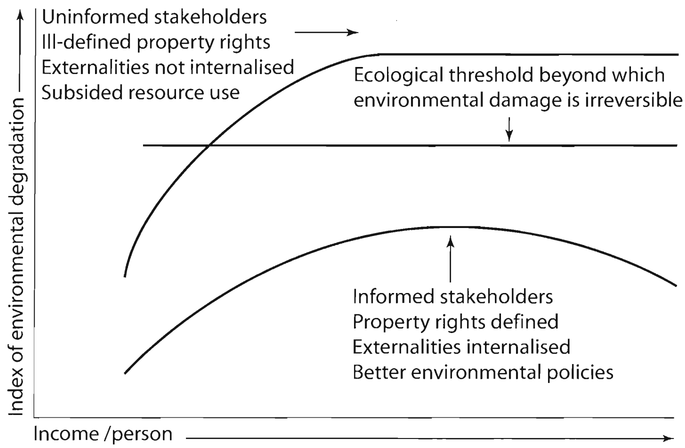

Figure 4. The relationship between income and environmental degradation.

Strategic investment

The starting point for strategies to promote sustainable land management is a mechanism for prioritising problem areas. However, the scope of land degradation problems geographically, economically, ecologically and demographically is not well documented either within or across regions of the globe. Such information is needed to guide the investments of governments, and international research and development agencies. At a national level, planners and policy-makers need to have proper inventories of land and water resources, as well as a clear understanding of productive capability and potential threats. Recent research by the International Food Policy Research Institute (IFPRI) suggests that the higher marginal rates of return from low-potential and marginal lands make investments in these areas much more attractive to governments than high-potential areas (Fan and Hazell 1999). As these areas are also home to large numbers of the rural poor, investment in marginal lands can help combat poverty and slow migration from rural areas to the cities.

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The valuable work of the International Soil Reference and Information Centre...has greatly helped our understanding of the global scope and severity of human-induced degradation problems ...

Strategic investments by governments therefore require an understanding of the dynamics of the resource base under agricultural intensification (pressure–state–response) so that areas most under threat, the so-called hot spots, can be identified for high-priority interventions. Furthermore, it is essential to study lands where sustainable management practices have been successfully introduced so that the lessons learned can be factored into future strategies. The resource management domains (RMDs)[1] concept provides a means for integrating social, economic, climatic, terrain, vegetation, soils and other data. This allows domains to be defined on the basis of resource management options so that specific issues can be addressed. Thus, RMDs can be used to set priorities for addressing poverty and for assessing the degree of threat to the resource base. RMDs can also be used to define recommendation domains for new technologies and approaches to sustainable land management, and for targeting policy interventions (Dumanski and Craswell 1998). Fragile or threatened lands under pressure from agricultural intensification, representing a wide range of high-priority problems (Greenland et al. 1994), include:

- tropical hillsides and mountain areas
- tropical acid soils
- desert margins
- nutrient depleted areas
- rice–wheat irrigated lands
- saline areas
- forest margins
- peri-urban lands
- coastal lands misused for mariculture

The valuable work of the International Soil Reference and Information Centre (ISRIC) has greatly helped our understanding of the global scope and severity of human-induced degradation problems (Oldeman et al. 1991). However, data on the extent and dynamics of threatened areas in the context of RMDs are few and fragmented. The steeplands of Asia and the

[1] Dumanski and Craswell (1998) defined an RMD as a spatial unit encompassing the environmental and socioeconomic characteristics of a recognisable unit of land, including the natural variability that is inherently characteristic of the area. An RMD can be defined at the field scale if the intent is to differentiate management practices used by farmers, or at board scale if the intent is to relate to management implications imposed through policies or programs. It can also be defined at any level in between, provided that the linkages among the levels are illustrated.

Pacific provide a useful example to illustrate the RMD concept and the type of information needed to devise effective strategies. The population of the tropical steeplands of Asia is estimated by IFPRI to be 263 million, many living in poverty, and represents 36% of the rural poor in the humid tropics. As an RMD the Asian and Pacific steeplands have many biophysical and socioeconomic characteristics in common (Craswell and Maglinao 1999).

- The soils are generally acid with low inherent fertility that declines rapidly under continuous cultivation without external inputs.
- Slopes are steep and soil erosion is the major land degradation process.
- The climate is warm, humid or subhumid, and tropical or subtropical. Rainfall intensities in the wet season are generally high.
- The native vegetation is commonly rainforest, but large areas have been logged over, subjected to shifting cultivation and covered with pernicious weeds like *Imperata cylindrica*. ADB (1997) estimates that one-half of forest cover was removed during the last 30 years.
- Steepland areas are remote and have been bypassed by government development schemes.
- The shifting cultivators in many areas are ethnic minorities, but upper catchments are increasingly being inhabited by lowland people unable to find land to cultivate elsewhere. The area cultivated every year to subsistence food crops such as rice and maize is increasing.
- To relieve pressure on existing forests, many governments now require the shifting cultivators to abandon their nomadic lives and settle in one place, but land tenure insecurity remains a problem.
- Off-farm employment through migration to cities and to other countries in the region is a major source of income.

The Asian financial crisis caused major loss in income, and remigration from the cities to rural areas. Consequently increased pressure is being placed on the land resources and social services in the marginal steepland areas. These recent changes illustrate the interdependence between urban and rural areas. They also emphasise the overriding influence of economic development and growth on the state of the environment and on efforts to promote sustainable land management.

At a global level, the fight against land degradation is failing.

Global land-use transformation

At a global level, the fight against land degradation is failing. Millions of farmers continue to cultivate land in ways that damage the soil and water resources. Successes are being recorded, but in most countries the soil conservation community has failed to marshal resources, develop understanding, mobilise public and political will, and generally 'deliver the goods' on sustainable land management. A major paradigm shift is needed that will take account of the many dimensions of sustainable land management: social, economic, productivity, security and resource protection. The new paradigm must bring to bear knowledge gained from research in a wide range of disciplines. Most importantly, it must be client-orientated and targeted at farmers as the ultimate beneficiaries, so that appropriate solutions to land management problems can be found. Lastly, the paradigm should utilise the modern tools of information science to help deal with the complexity of the concepts and reality of sustainable land management.

Sustainable land management requires the adoption of land-use systems that are more productive and efficient, secure, conserving and restorative, and socially and culturally acceptable. Land managers require improved scientific information about sustainable practices to supplement their indigenous knowledge. More effective delivery systems for this information are also needed. Information delivered to the end-users is an essential, but not sufficient, requirement to ensure that land is managed sustainably. Governments must create an enabling environment and, in some cases, provide incentives to assist land users towards sustainable land management. Policy-makers must also reconsider commodity price disincentives that lead farmers to devalue their land.

Governments must create an enabling environment ... to assist land users towards sustainable land management ...

Greater efforts are needed to define sustainable land management, particularly in terms of the trade-offs between different social, economic and intergenerational objectives. An important area of progress is the identification of land quality indicators that provide a better basis for determining whether or not sustainability is being achieved (Lefroy et al., in press). Decision support systems can help extension workers and researchers deal with the complexity of sustainable land management. We also need a better understanding of the impact of land management at the local level on global environmental concerns, such as loss of biodiversity and global change. In particular, the costs of land degradation, or conversely the benefits of sustainable land management, should be calculated in economic and social terms that grab the attention of policy-makers, as attempted in earlier sections of this paper. In some countries this is a prerequisite for gaining adequate support for programs promoting sustainable land management.

Irrespective of progress in improving the theoretical and conceptual base for work on sustainable land management, efforts must be concentrated on applying existing knowledge to productivity improvement and the protection of land and water resources. Lessons learned indicate that the key to success is direct involvement of land managers and their communities at all stages of the process. This is illustrated by the farmer-adapted hedgerow systems developed by participants in projects of the International Board for Soil Research and Management (IBSRAM)—the *ASIALAND* and *PACIFICLAND* networks on sloping lands. At the instigation of Asian and Pacific island farmers, these systems consist of contour plantings that incorporate cash crops such as bananas, teak, forage grasses, pineapples, ornamentals and tropical fruit trees. They protect the steep slopes while providing income that improves the livelihood of poor farmers and enables them to purchase inputs to replenish soil fertility. The indigenous knowledge of farmers provides a good starting point for a dialogue between farmers and scientists. The goal must be to utilise scientific knowledge and indigenous knowledge together to improve land management.

Solutions based solely on biophysical understanding and on technologies have proven to be generally ineffective. By offering an alternative to the failed traditional 'techno-fix' approach, the new bottom-up, participatory or community-based approaches have proved effective at the watershed or catchment level. The move towards integrated catchment management is proving successful in a number of developed countries such as Australia, where there is a high level of income and environmental awareness. Off-site impacts of soil erosion on recreational waterways and water supplies to urban areas dominate the political and community interest, rather than on-site impacts on the productivity of agricultural land. By involving communities in all parts of the landscape, the new paradigm ensures that key problems are better defined and solutions more effectively implemented. The landcare movements in Australia and New Zealand are often held up as a successful model for land conservation in developed countries.

By offering an alternative to the failed traditional 'techno-fix' approach, the new bottom-up, participatory or community-based approaches have proved effective at the watershed or catchment level.

Unfortunately many developing countries have neither the financial resources nor the infrastructure to provide a framework for integrated catchment management or landcare approaches. Nevertheless, farmers in some areas have been able to develop associations and community groups that can operate effectively at the catchment level. This often requires support from nongovernment organisations and/or donor-funded catchment management groups. The success of these approaches depends heavily on the policy environment, particularly in relation to land tenure and property rights. Communal decisions about the location of contour banks and waterways within catchments present a high level of complexity. The recent introduction of tools to assist multiple objective decision making holds some promise for dealing with this complexity.

Transforming the global farm to a state of sustainability is a major challenge. Success in every corner of the globe will depend on the rate at which we can eradicate poverty, contain population growth and inform people at all levels, from farmers to policy-makers, about the need to protect the land and water resource base. The livelihoods of current and future generations depend on it.

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Dr David Farrell, School of Land and Food, University of Queensland, Australia

Dr Farrell was born in Ireland and educated in England, Canada and Australia. Until recently he held a personal chair in the School of Rural Science at the University of New England. In 1994 Dr Farrell moved to the University of Queensland and also became director of the Queensland Poultry Research and Development Corporation until his resignation in 1998. Dr Farrell travels widely, mainly throughout Asia, and from 1983 to 1986 worked in Indonesia in agricultural development, a major interest of his for several years.

Recipe for Disaster? Where Do We Find the Ingredients to Feed Our Livestock?

DAVID J. FARRELL, SCHOOL OF LAND AND FOOD, UNIVERSITY OF QUEENSLAND, AUSTRALIA

> 'The growing demands for animal protein in Asian nations—and consequently for feed grains—simply cannot be met due to limitations of yield and available acreage. If world consumption of animal protein rises to 75–80% of North American levels, based on current yield and available land, we will need three or more Earths to produce it' (Oliver 1998).

Introduction

By the time this paper is published, the population of the world will exceed six billion. It has taken only 12 years for the last one billion to be added; the next billion will be here by about 2010, and in the next 50 years the population will increase by another 50%, even though the population growth rate may be slowly decreasing. In another 25 years the population of India will be greater than that of China, and today their combined populations exceed 2.2 billion—almost one-third of the world's people. But a comparatively small segment of this population will be affluent—today well over two-thirds of the human population live in low-income countries, and the majority live below the poverty line. In 1993, Professor Derek Tribe, who until recently was executive director of the Crawford Fund, predicted in an address to a symposium on the future of agriculture:

> '... within 40 years Asia will represent the major share of the wealth of this world and will be richer than North America and Europe put together ... The food requirements will not include more rice or cassava, but products such as wheat, meat, dairy produce, fruit and vegetables as a result of increases in income'.

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The recent economic downturn, which commenced in July 1997 in many low-income countries, particularly in Southeast Asia, will change Professor Tribe's predictions only slightly, perhaps by 5 or 10 years. Countries such as Vietnam, China and India have been less affected than others in the region and these economies continue to expand and prosper, albeit more slowly than anticipated. Despite the economic downturn, forecasts for 1999 and 2000 predict increased growth in several countries examined (Table 1).

Table 1. Actual and forecast per cent economic growth in selected countries of East and Southeast Asia (1996–2000).

	1997 GDP[a]	Actual			Predicted	
	(US$)	1996	1997	1998	1999	2000
China	860	9.8	8.5	7.5	7.0	6.5
Taiwan[b]	NA	5.8	6.9	4.9	5.0	5.1
Indonesia	440	7.0	5.2	−14.0	−0.2	3.0
Japan	38160	4.0	0.7	−2.8	0.2	1.0
Malaysia	4530	7.5	7.4	−6.5	2.5	4.5
Philippines	1200	5.1	5.0	−0.1	2.0	2.5
Singapore	32810	6.2	6.1	1.5	3.0	4.2
South Korea	10550	7.1	5.7	−5.5	3.0	5.1
Thailand	2740	7.0	−0.2	−8.0	6.0	3.0

[a] Gross domestic product per head per year (Anon. 1999a)
[b] Listed as Chinese Taipei
NA—not available
Adapted from Rodriguez and O'Donnell (1998) and Penm (1999)

There will be greater competition not only for food to maintain the growing human population but also for feed for livestock. It is against this backdrop that we consider our options, make forecasts as to whether, or for how long, we can feed our human and livestock populations, and ask if a 'recipe for disaster' is looming.

Others have recently attempted to grapple with this area. Delgado et al. (1999) have approached the problem in a comprehensive, complex and detailed way, using a global food model. However, their statistical data do not often go beyond 1993–94 and considerable changes have occurred in livestock production since that time. Also there are serious omissions, including failure to consider the competition between human food and livestock feed that will inevitably occur in the future.

Australia is becoming an increasingly important contributor to the Asian economic community, and those countries immediately to our north will increasingly rely on our food and feed. It is mainly in this region that higher economic growth will occur, but almost all of the arable land there is now cultivated, some would say overcultivated (Leng and Devendra 1995). Although clearing of forests and the

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cultivation of marginal land, particularly in low and irregular rainfall areas, may serve as a temporary measure to increase grain production, this land is unlikely to produce reliable or sustainable yields. By the year 2040, world agricultural output may need to triple to meet the demands of the expected nine billion inhabitants (Avery 1996). Increased use of fertilisers, herbicides and pesticides, improvement of grain cultivars through genetic modification and greater use of irrigation will increase yield at a substantial cost to the environment (Leng 1995). However, these inputs will certainly not meet Avery's predicted requirements for grain production, nor those of Oliver (1998), and are unlikely to be sustainable in the long term. The green revolution based on these costly and substantial inputs is now being seriously questioned; for example, the social and ecological cost in India has been quite staggering, with soil fertility in particular deteriorating, largely due to overuse of fertilisers and pesticides (Rao 1998). In South China, where wetland rice production was traditionally integrated with herding of ducks, increased use of high-yielding rice cultivars, herbicides, pesticides and fertilisers has almost eliminated the duck farmers, who are often landless. Extensive use of chemicals and chemical fertilisers has greatly reduced live feed in waterways and flooded rice fields (Professor Liu Fuan, South China Agricultural University, personal communication).

Economic growth brings opportunities for people to improve their standard of living, invariably accompanied by a greater demand for animal protein. Beyond a gross national product (GNP) of US$1000 per year, consumers in countries where rice is the staple diet start to substitute high-quality foods for rice (Fischer 1995). When GNP increases to more than US$3000 per year, demand for animal products starts to rise, with a concomitant reduction in human population growth (Leng 1999). But we have failed to link financial aid to low-income countries with measures to reduce population growth. Such a requirement would impress on these countries that the problem is not only a shortage of food but also too many mouths to feed. Those that face the greatest difficulties are countries where low incomes and low economic growth are accompanied by large population increases.

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Consumption of animal protein rises to a maximum of around 25.5 kilograms per year as gross domestic product (GDP) increases to the level found in high-income countries (Gill 1998a). In very affluent societies, the positive relationship between per capita income and meat consumption eventually plateaus (Delgado et al. 1999).

The large increase in animal production in developing countries over the past 30 years will certainly continue. Poultry production is the most rapidly growing livestock industry, followed by pig meat, because these industries are best positioned to respond rapidly to increased demand for animal protein, thanks to portable and adaptable production technology. The high concentrations of animals involved can cause serious environmental problems and pose a threat to public health, particularly in countries with high population densities. The recent transmission of avian influenza to humans in Hong Kong, and of the Nipah virus from pigs to humans in Malaysia, are examples of what can happen. However, in many low-income countries livestock serve a wide variety of functions. Not only are they a valuable source of protein: they also provide draught power; hair and hide; manure for fuel, fertiliser and building; fat for cooking; a savings bank; and other services (Vercoe et al. 1997). Recent publications on sustainability of livestock production systems have little relevance to low-income countries, dealing almost entirely with the European situation, although a paper by Gibon et al. (1999) focuses on southern Africa. Sustainability in agriculture must be an *approach*. This has been summarised as follows:

> 'The development of an ethical and interdisciplinary approach to problem solving and decision making, which takes into account present, future, local and distant impacts on agriculture, the economy, the natural environment, and the interests of others' (Morrow 1998).

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One of the most disturbing aspects of food and feed production is the wastage of human food, particularly in affluent countries. Table 2 presents data on food wastage in the United States—the wastage of 32% of grain products and 25% of all food is nothing less than disgraceful.

Table 2. Food supply and food wasted in the United States.[a]

Commodity	Food supply (million tonnes)	Food waste (million tonnes)	% Waste
Grain products	20.7	6.6	32
Fruit	22.0	5.1	23
Vegetables	28.7	7.3	25
Dairy products	34.7	11.5	33
Red meat, poultry and fish	23.4	3.7	16
Eggs	3.6	1.1	31
Dry beans, peas and lentils	1.0	0.2	20
Nuts	0.8	0.1	13
Sweeteners	17.6	5.4	31
Fat, oils	9.9	3.0	30
Total	162.4	44.0	27

[a] Harvest losses not included
Adapted from Zeidler (1998)

Animal Products

In order to estimate the future needs of the compound or manufactured feed industry, it is necessary to identify the various livestock sectors, determine current feed needs and estimate future requirements on the basis of their predicted expansion. Table 3 shows projected demand for livestock products in Asia to 2020 (Rosegrant et al. 1995). To date these predictions have been shown to be very conservative.

Table 3. Projected per capita demand for livestock products in Asia (kg/year).

Livestock products	South Asia			Southeast Asia			East Asia (excluding Japan)		
	1990	2010	2020	1990	2010	2020	1990	2010	2020
Beef	1.2	1.4	1.5	2.5	4.5	6.0	1.3	2.3	3.1
Pig	0.3	0.4	0.4	5.5	8.6	10.5	18.8	30.6	38.2
Sheep meat	1.0	1.1	1.2	0.3	0.5	0.7	0.7	1.0	1.2
Poultry meat	0.5	0.6	0.7	4.2	6.9	8.5	3.0	5.2	6.5
Eggs	1.3	1.6	1.8	3.3	5.5	7.0	6.8	10.9	13.6
Milk	63.4	84.9	95.3	3.2	3.8	3.5	7.7	9.3	10.2

Source: Rosegrant et al. (1995)

Egg production

In 1998, global egg production for all purposes was 48 million tonnes, of which China produced 37% and the entire Asia–Pacific region 52% (Anon. 1999a). As 3.2 kilograms of feed are needed to produce 1 kilogram of eggs for table consumption (Gill 1999), the current requirement for feed is 154 million tonnes. The potential feed market for layers is currently 285 million tonnes of compound feed per year (Gill 1999), although this figure can be reduced to 180 million tonnes of manufactured feed, as not all birds are fed on compound feed. Thus the estimate of 154 million tonnes made here is very conservative. The growth of the egg industry worldwide was 2% from 1997 to 1998. If it continues to increase at this rate, then 200.5 million tonnes of feed will be required by 2010, of which 75%, or 150 million tonnes, will be grain. The increasing use of eggs in India is likely to have a large impact on future requirements for layer feedstuffs. India is the fifth largest egg producer in the world, with an annual per capita consumption of 1.5 kilograms (Anon. 1999a).

Poultry meat

Apart from duck meat, broiler production has been the most rapidly growing animal industry in Asia and the world. Chickens convert feed to meat more efficiently than any other domestic livestock and produce the most affordable meat, which is also low

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in fat. In 1998, 51.2 million tonnes of broiler meat was produced. An increase in production of only 1.2% from 1997 to 1998 was due mainly to the economic downturn in Asia. The United States Department of Agriculture (USDA) forecast a 4% increase, for selected countries, from 1998 to 1999 (Anon. 1999a). The United States is the largest producer of broiler meat, with almost 25% of market share in 1998, and is also the largest exporter.

World output of poultry meat from all sources (broiler, turkey and duck) was 58.5 million tonnes in 1998 (Anon. 1999a). A conservative estimate of the total amount of compound feed required to support this production is 129 million tonnes, including 96 million tonnes of grain (Gill 1999). And what of future needs? Demand for chicken meat has increased dramatically in almost every region in the world over the past 10 years. The recent signs of an upturn in the Asian economy will be an important factor in determining global feed needs by 2010, as demand for poultry meat in Asia has, until recently, been running as high as 8% per year. China and India are the important economies within Asia. Chicken meat is rapidly becoming more widely accepted by Indians who have been traditionally vegetarians. Annual consumption is currently 0.5 kilograms per person and GNP is $370 (Anon. 1999a); thus, there is potential for substantial increase in consumption, particularly with a middle-class population estimated at around 250 million (Pandey 1998). Almost 75% of all Indians are now nonvegetarian and for 92% of these chicken is the meat of choice. A predicted annual increase of 6.0% in global poultry meat growth has been used in the calculations here, to account for a slower rate of growth in most regions outside Asia. Based on the figure of 6%, by 2010 the requirement for compound feed for all poultry meat industries is estimated at 259 million tonnes, of which 194 million tonnes will be grain. This accords with Food and Agriculture Organization (FAO) predictions on world poultry meat production for 2005 (Anon. 1999a).

Pig meat

The past two years have seen a severe downturn worldwide in the price of pig meat, indicating an oversupply. In Malaysia, the Nipah virus resulted in the need to destroy almost one million pigs, while Taiwanese pig production has declined by more than 20%, due to a recent outbreak of foot-and-mouth disease (Gill 1999). However, global pork production continues to increase, doubling over the past 20 years (Anon. 1998b). During this time, the average carcass weight has increased from 67 to 77 kilograms as production efficiency has improved. The highest per capita pig consumption is not in China but in Spain, with 58.5 kilograms, followed by Germany (56.4 kilograms). However, only 40% of all pig meat is produced outside Asia (Anon. 1999c).

The most recent estimate from FAO for world annual pork production is 83.6 million tonnes (Anon. 1999c). In 1998, per capita consumption in China, the world's largest pig producer, was close to 29.5 kilograms per year or over 37 million tonnes (Anon. 1999c). The annual increase in sow numbers in China from 1991 to 1998 was one million, compared to 0.8 million in the rest of Asia, where the increase was mainly in Vietnam (Anon. 1999d). Clearly, growth in China will largely dictate future feed needs for pig production. World pig slaughtering rose by 3.2% during 1997–98, and for China alone by 7% (Anon. 1999e), although pig meat prices slumped. Despite predictions of a fall in production of 1.3% in the United States and of 4.5% in Russia, the projected global increase in 1999 is 3% (Anon. 1999b). Although feed efficiency is normally about 2.5 kilograms per kilogram of pig meat, the inclusion of feed for the parent stock increases this requirement to at least 3.3 kilograms. Thus, the current 83.6 million tonnes production of pig meat translates into 276 million tonnes of feed, of which about 193 million tonnes is likely to be grain. In practice, pigs are also fed byproducts, which replace some grain. Based on a modest global growth of pig production of 4%, 425 million tonnes of feed, of which 297 million tonnes would be grain, will be needed by 2010. This figure may need some adjustment as many pigs in Asia are now given feed other than grain and protein concentrate.

Clearly, growth in China will largely dictate future feed needs for pig production.

Other animal industries

It is difficult to obtain detailed and reliable data on compound feed usage by other animal industries such as dairy cattle, beef cattle, finfish, shellfish and 'other' (mainly pet food). In 1997, world beef consumption was 57 million tonnes (11 kilograms per person), similar to that of poultry meat (FAO 1999). Farmed fish production was 22 million tonnes, cheese 15 million tonnes and sheep and goat meat 12 million tonnes. Comparatively few ruminants would be given manufactured feed.

Total world compound feed production in 1998 was 575 million tonnes, down from 605 million tonnes in 1997 (Gill 1998a). Using this amount and the distribution shown in Figure 1, dairy production accounted for 98.7 million tonnes of compound feed, beef 51.8 million tonnes, finfish and shellfish 28.8 million tonnes and 'other' 17.5 million tonnes.

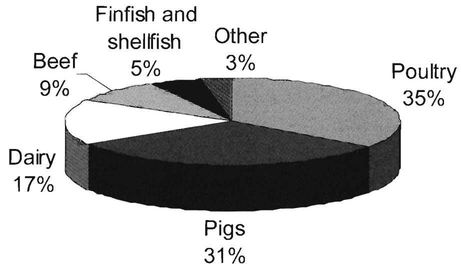

Figure 1. Distribution of compound feed in 1998 (Gill 1999).

Spectacular annual increases in milk production have been recorded in Thailand...and Indonesia ...

It is difficult to forecast increases in production of these other livestock products over the next 11 years. Low-income countries usually increase their milk consumption significantly as GDP increases, although people in some countries in Asia do not normally consume milk or dairy products. In Pakistan and India milk and dairy products are traditionally consumed, and demand is likely to increase substantially (Vercoe et al. 1997). Spectacular annual increases in milk production have been recorded in Thailand (24.1%) and Indonesia (13.4%) (Devendra 1995), and milk production is forecast to expand significantly in low-income countries (Delgado et al. 1999).

Beef production is more difficult to predict; it will certainly increase in low-income countries where beef is traditionally eaten, but growth is likely to be slow. Although little or no grain is used in aquaculture, fish do need very high protein diets and the industry is expanding rapidly, with fish consumed in most countries. Production increased from 15.4 to 23.6 million tonnes between 1990 and 1997 (FAO 1999). In the 'other' category, pet food (14.6 million tonnes in 1997, Hendriks 1999) and horse feed make major contributions. Again this is a small, but rapidly growing, component of the feed industry.

For the purposes of prediction, it is estimated that the dairy industry will increase by 1%, beef by 2%, aquaculture by 8% and 'other' by 3.5% each year to 2010 (FAO 1999). The total requirement for compound feed for these three categories in 1998 was 197 million tonnes, of which 122 million tonnes was grain. By the year 2010, the estimated feed required will be 285 million tonnes, including 179 million tonnes of grain.

If the predicted increases in demand for shown in Table 4 are correct, then by 2010 there will be a requirement for 55% more compound feed and 50% more grain. This translates into an additional 414 million tonnes of feed, of which 264 million tonnes will be grain and the balance protein concentrate. Also included in Table 4 for comparison are growth rates for some of the livestock sectors from 1982 to 1994.

Table 4. Summary of estimates of actual feed and grain in 1998 and predictions for 2010 (million tonnes).

Commodity	1998		Predicted growth (%) to 2010	Annual growth (%)[a] 1982–1994		2010	
	Feed	Grain component		D[b]	L[c]	Feed	Grain component
Eggs	156.7	117.5	2.2			200.5	150.3
Poultry meat	128.7	96.5	6.0	3.1	7.6	258.9	194.2
Pig meat	276.0	193.2	4.0	0.6	6.2	428.4	297.0
Dairy	98.7	78.4	1.0	0.5	3.1	120.0	96.0
Beef	51.8	41.4	2.0	0	3.2	65.7	52.6
Aquaculture	28.8	0	8.0			72.5	0
Other	17.5	2.6	3.5			26.4	4.0
Total	758.2	529.6				1172.4	794.1

[a] Predicted by Delgado et al. (1999)
[b] D=developed country
[c] L=developing country

The total amount of compound feed and grain used in 1998 (Table 4) is well in excess of that reported by feed manufacturers (Gill 1999), partly because not all livestock are fed intensively. Over 70% of poultry and pigs in China are kept in small numbers and fed largely on byproducts. In Indonesia, around 250 million scavenging village chickens are largely unmanaged and given little feed. In Asia, where 90% of all ducks are found, the majority of ducks scavenge for feed in the rice fields and may occasionally be fed small amounts of grain. However, these systems are changing as improved genotypes are being introduced, particularly in China. Such breeds fail to reach their genetic potential in most 'backyard' systems, so more animals are being housed intensively and will thus require manufactured feed. The ratio of total cereal feed use to total meat production in the early 1990s has been calculated as 1.4 to 1 in China and 3.6 to 1 in the United States, reflecting the use of other feed sources in China. Other factors discussed below also suggest that the feed requirements forecast in Table 4 will substantially exceed global production of manufactured feed.

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Feed Supply

There are reasonably accurate figures for manufactured livestock feed produced (Gill 1999). In many parts of the world, intensive livestock have been fed traditionally on corn/soybean diets, ingredients heavily promoted by the United States, who are major exporters of these and other coarse grains. Worldwide, there is great reliance on these feedstuffs, but the economic downturn in Asia has significantly reduced demand, resulting in a surplus of both maize and soybeans. In 1997, maize sold for

US$3 per bushel; currently it is US$2.10 and is expected to reach US$1.70 in early 2000 (Welsh 1999). At the same time, soybean meal reached its lowest level for 27 years at US$122.5 per tonne. As a consequence, production of manufactured animal feed declined by 30 million tonnes from 1997 to 1998, the first such decline in almost 50 years, although it is still worth US$88 billion (Gill 1999). Most would agree that this is a temporary decline, fuelled by the Asian monetary crisis, serious disease outbreaks in Taiwan and Malaysia's pig herds and the continuing economic problems of Russia, whose current compound feed usage is only 13.9 million tonnes, compared with around 60 million tonnes per year in the early 1990s (Anon. 1996). Although this depressed feed market may last another one or two years, there are definite signs of an economic upturn in many countries in Asia. Only a few countries in the region were directly affected by the monetary crisis that started in July 1997, but the impact was widespread.

How can one reconcile the actual compound feed usage for 1998 of 575 million tonnes (Gill 1999) with the estimate of 758.2 million tonnes shown in Table 4? There are a number of reasons for the discrepancy. Many farmers, particularly those producing pork and eggs, mix their own livestock feed on farm, many dairy farmers supplement their grazing cows with grain alone, while feedlot cattle are given diets that are predominantly home mixed and high in grain. Small village poultry and pig producers, mainly in low-income countries, may supplement their stock on an irregular or seasonal basis with grain. A substantial amount of feed production may be informal, that is, not produced by members of a manufacturer's association. For example, around 40% of South Africa's feed industry is estimated to fall into this category (Bekker 1998). Informal feed production has been omitted from Gill's figure of 575 million tonnes of manufactured feed. If we now include an additional 40% for the informal sector, the total feed produced in 1998 would amount to 805 million tonnes, which exceeds the 758 million tonnes shown in Table 4.

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The predictions for manufactured animal feed and grain shown in Table 4 may be controversial but they are not unique. For example, for the chicken meat industry alone it is forecast that if per capita consumption reaches 15.5 kilograms per year by 2010, feed requirement will be 185 million tonnes (van der Sluis 1997). Avery (1999), of the Hudson Institute in the United States, forecasts a 250% increase in meat consumption by 2030 if the four billion Asians increase their animal protein consumption to 60 grams per day, the amount of animal protein currently consumed in Japan.

Not all countries feed their intensively housed livestock on maize and soybeans. These ingredients give a yellow colour to the skin and shanks of poultry and also to egg yolk, and this is unacceptable to consumers in some countries (including Australia). Where barley, triticale, wheat and sorghum are fed, skin and shanks are white and egg yolk is normally a pale yellow. Thus, despite the current very low price of maize, producers must feed other grains because of consumer acceptance. Table 5 shows the production of major grains in selected countries and the world in 1991 and in 1998. Except for coarse grains, all categories increased during this time. Protein sources other than soybean

Table 5. World grain production and grain production in selected countries (million tonnes) in 1991 and 1999 and changes during this time.

		1991	1999	Change (%)
Paddy rice	Asia (D[a])	463	533	15.1
	Australia	0.8	1.3	62.5
	China	185	201	8.6
	West Africa	14	18	28.6
	World	519	587	13.1
Wheat	Australia	11	22	100.0
	China	96	114	18.8
	Europe	183	176	−3.8
	India	56	71	26.8
	United States	67	63	−6.0
	World	546	578	5.9
Maize	Argentina	8	13	62.5
	Australia	0.2	0.4	100.0
	Brazil	27	33	22.2
	China	99	129	30.3
	Europe	58	71	22.4
	United States	190	238	25.3
	West Africa	40	39	−2.5
	World	494	600	21.5
Coarse grains[b]	Africa	39	37	−5.1
	Australia	7.2	8.2	13.9
	China	20	19	−5.0
	Europe	169	133	−21.3
	India	21	22	4.8
	United States	29	24	−17.2
	World	329	296	−11.1
Soybeans	Argentina	11 (5)[c]	18 (9)[c]	63.6
	Australia	0.06	0.11	83.3
	Brazil	15 (11)[c]	31 (15)[c]	106.7
	China	10	14	40.0
	United States	54 (25)[c]	76 (31)[c]	40.7
	World	103	158	53.4

[a] Developing
[b] All cereal grains excluding maize, rice and wheat
[c] Soybean meal (1998)
Source: FAO (1999)

meal, including seed meals such as sunflower and rapeseed, and grain legumes such as lupins, field peas and faba beans, are used in substantial quantities to feed livestock. Oilseed cake production increased from 149 million tonnes in 1991 to 200 million tonnes in 1998 (FAO 1999). Oilseed cake is used almost exclusively to feed livestock, but probably includes soybean meal. The withdrawal of meat and bonemeal from animal feeds in the European Union (EU), as a result of the outbreak of bovine spongiform encephalopathy in the United Kingdom, has removed several million tonnes of a high-quality protein source from the European feed market. The use of poultry offal meal and fishmeal in the EU may also become an issue in the future, thereby putting more pressure on other protein supplements.

The United States produced 238 million tonnes of maize in 1999, Brazil 33 million tonnes and the Argentine 13 million tonnes. The United States is expected to export 47 million tonnes of maize in 1999–2000. Most of the soybean meal produced by the United States is used within the country. It is difficult to get accurate data on grain production, particularly for China, where production of all grains is forecast to be 500 million tonnes in 1999 (IGC 1999).

Arable land use worldwide and in Southeast Asia has not increased over the last six years (FAO 1999), suggesting that the increases in grain production shown in Table 5 were achieved by greater inputs and use of high-yielding cultivars, or by displacement of some coarse grains by other grains. Maize production in the United States and China has increased by over 25% in the past seven years, while world production of soybeans increased by 53% during the same period. Maize has the greatest potential to cause environmental damage compared to other feed crops (Delgado et al. 1999).

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It is inconceivable that these predicted increases in grain production can be sustained over the next 12 years without substantial cost to the environment. Increases in rice and wheat production have largely kept pace with increases in human population, such that per capita production remained essentially the same from 1990 to 1997 (FAO 1999).

Human Food

Of great concern is not only the unequal distribution of grains but their unacceptable wastage in human foods in countries such as the United States (Table 2). The figures given exclude harvest losses, and wastage may be just as high in other high-income countries. If wastage alone could be tackled, together with redistribution of surplus edible grains, there would be little to worry about in feeding the projected one billion increase in human population by 2010. From past experience, this is unlikely to occur.

In order to assess the potential for producing the additional cereals and other feed grains required for livestock production, it is necessary to calculate how much food grain will be required to sustain the extra one billion population predicted for 2010. Assumptions must be made as to where the increase will occur—on the basis of past population increases and current projections, the majority will take place in Asia. Although China claims to have virtually no population increase, this is highly debatable, for example, increases ranging from 1.1% to 2.9% have been predicted by Vercoe et al. (1997), while others suggest that the population of China will have increased by only 121 million by 2010 (Anon. 1999a).

It is assumed here that 650 million of the one billion additional humans will be in Asia (Anon. 1999a) with the balance in Latin America and subSaharan Africa. Per capita annual production of paddy rice in 1997 in Asia was 132 kilograms, while average annual yield was 3.8 tonnes per hectare (FAO 1999) and declining (Devendra 1995). Given that yield per unit of land is unlikely to increase (Fischer 1995), an extra 86 million tonnes of paddy rice and 23 million hectares of arable land will be needed to feed the increased human population in Asia. However, this will provide an additional 8 million tonnes of rice bran as animal feed.

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It is difficult to estimate the additional food needs of the remaining 350 million humans by 2010. Assuming that their cereal grain needs are wheat, or wheat equivalent with a per capita annual production of 72 kilograms, this translates into 25.3 million tonnes of wheat and 9.3 million hectares of land, at an average yield of 2.7 tonnes of wheat per hectare, if there is no wastage. The total additional food grain required by 2010 is therefore estimated to be 111 million tonnes, which will be offset by 8 million tonnes of rice bran and 2 million tonnes of wheat bran as potential animal feeds. No account is taken here of other foods needed, but some of these will be factored in to some extent when we examine the feed set aside for increased livestock production and animal protein.

In 1999, world wheat consumption is expected to exceed production by 12 million tonnes, but current world stocks of 115 million tonnes could theoretically meet the additional predicted grain needs of humans by 2010. There is even more coarse grain in storage and production is forecast to equal demand in 1999 (IGC 1999). Leng (1994) is critical of grain surpluses and stated:

'... it is crazy economics to use up resources and pollute the atmosphere through surplus grain production and to then attempt to recoup expenditure through direct use of these in intensive animal industries (pigs, poultry and dairying)'.

This increased requirement for food grains predicted for 2010 is probably a substantial underestimate. For example, in China the daily energy intake of an urban population is 9 megajoules per day, while that of a rural population is 11 megajoules per day (Chen and Ge 1994). Per capita grain consumption in China was over 175 kilograms of white rice and wheat per year, or 8 megajoules per day (IGC 1999). The calculation made here for paddy rice is equivalent to only 91 kilograms of white rice per year, or 4 megajoules per person per day. In 1993, energy derived from animal products was only 15% in China and 11% in other developing countries (Delgado et al. 1999). Thus more than half of the daily energy intake needed is unaccounted for—a substantial amount of this deficit will be made up by increased consumption of grain.

Similarly, the calculation for wheat consumption of 72 kilograms is only 3.2 megajoules of energy per person per day, resulting in an even greater shortfall in energy needs. These estimates for grain are much less than half those theoretically required but are to some extent offset by some generous allowances made for livestock needs. Furthermore, large quantities of starchy roots and tubers are eaten by many in low-income countries.

Supply of Additional Land, Food and Feed by 2010

The projected need for 23 million hectares of arable land for rice production is unlikely to be met from Asia. If it is, then production is likely to be unsustainable, with high environmental costs such as loss of soil and increased gaseous pollution of the atmosphere. India, often cited as a successful example of the green revolution, still has over 61% of its population in the category of 'multidimensional human deprivation', and the long-term sustainability of this revolution is questioned (Rao 1998). In many countries where grains are grown, rainfall is unreliable, resulting in periodic drought. For example, maize production in the United States was 161 million tonnes in 1993, compared to 257 million tonnes a year later. In 1994, Australia produced 9 million tonnes of wheat, compared with 22 million tonnes in 1996 (FAO 1999). Fluctuations in world food supply have had disastrous effects on some countries, causing widespread starvation. The problem is generally inequitable distribution of the food supply rather than a shortage of food. Thus, as the world

India, often cited as a successful example of the green revolution, still has over 61% of its population in the category of 'multidimensional human deprivation'...

population steadily increases, a growing number of that population will be at risk. It should be restated that the projected increase in livestock products shown in Table 4 will mainly benefit those from the growing affluent group in low-income countries, not those who need it. As the affluent group increases in size it distorts national GNP, giving the misleading impression that all persons are benefiting equally from an increase.

... the projected increase in livestock products ... will mainly benefit those from the growing affluent group in low-income countries, not those who need it.

Because of the recent economic downturn in many Asian countries and depressed feed prices, there is a temporary surplus of grain and other animal feedstuffs, whilst prediction of current harvest yields is optimistic. A global surplus of about 28 million tonnes of soybeans and 115 million tonnes of wheat, as well as 55 million tonnes of maize in the United States alone, is predicted for 1998–99 (van der Westhuizen et al. 1999). Despite these surpluses, FAO (1999) warned that by the end of the 1999–2000 season cereal stocks could be below the minimum considered necessary to safeguard global food security.The possibility of regularly redistributing an additional 111 million tonnes of food grains for the extra one billion people by the year 2010 seems remote.

Rice is not generally used as a livestock feed, except when damaged and broken (about 10% of polished rice). However, it is probable that other food grains will have to be substituted for rice, given that constraints on arable land and reductions in yield preclude the possibility of producing sufficient rice for human consumption, particularly in the Asian region. A crop reduction of only 3% in Asia would result in a decline of 10 million tonnes of rice (IGC 1999). Indonesia, a country which embraced the green revolution and until recently was a net exporter of rice, had to import a record 6.1 million tonnes of milled rice in 1998 (IGC 1999). The severe economic downturn in Indonesia highlighted the great reliance of developing countries on imported consumables such as chemical fertilisers, pesticides and herbicides necessary to increase production of high-yielding rice cultivars. When importation was not possible, production essentially collapsed. The Indonesian government has recently introduced a program of self-sufficiency (Hatmono 1999). China, also once a net exporter of grain, is now a net importer, and is predicted to be the largest producer of compound feed by 2010 (Anon. 1997).

Where can savings be made? If wastage of grain products could perhaps be reduced from its current level of 32% to about 10% in the United States and other affluent countries, this would easily meet the extra 25 million tonnes of wheat needed by 2010. It could also provide some of the grain that may be required to substitute for the extra 86 million tonnes of paddy rice required

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as human food by then. Use of arable land is changing, with more high-value cash crops being produced, reducing land available for growing grain. However, some grains, such as sweet lupin, grow on poor, sandy soils and return nitrogen to the soil. Cassava also yields well under dry conditions and on poor soil, and is grown widely as a human and animal food; production has increased from 152 million tonnes in 1990 to 165 million tonnes in 1997 (FAO 1999). Both sweet lupin and cassava are used as foods and feeds.

Greater use of agricultural byproducts and waste products for livestock is another viable option. Although these are not easily incorporated into compound feeds for logistical reasons, such as feed mill design, some byproducts are already in use in small-scale village livestock production. Often these byproducts are highly fibrous, such as copra meal, palm kernel cake and other oilseed meals; therefore they are not as suitable for poultry as for pigs. Although there is potential for some expansion of byproduct use, it is unlikely to impact significantly on future feed for nonruminant livestock or food needs. An outcome of the recent monetary crisis in Asia is that low-income countries not only will have less arable land to produce suitable crops for livestock feed, but also are unlikely to have the foreign exchange to import the necessary feed and infrastructure. The recent collapse of the intensive poultry industry in Indonesia is an excellent example of this (Hutagalung 1998).

Better use of our feed resources and increasing nutrient yield (for example, by supplementing feed with enzymes) could improve energy content of grains other than maize. Genetic engineering can increase the oil content of maize and the concentration of some key amino acids in grains. However, such modifications have implications for cost and sometimes for yield; also it is difficult and expensive to track modified grains from the farm gate to the feed manufacturer. The cost of crystalline amino acids is decreasing rapidly and they could potentially improve protein quality, reducing reliance on expensive protein supplements, which may constitute up to 25% of the diet of nonruminant livestock. However, many traditional protein supplements will need to be replaced with grain.

Producers of feed for export

Out of a total of 70 million tonnes of maize exported worldwide in 1999, the United States is expected to export 48 million tonnes, much of it to Japan and Korea (IGC 1999). Australia, Canada and South America are also important exporters of wheat, whilst China, the largest grower of wheat, is now a net importer. Wheat exported by all countries in 1999 is estimated to be 100 million tonnes, of which about 17% will be livestock feed, whilst about 10% is normally unsuitable for human consumption. Future increases in wheat produced and exported will be mainly for food. In 1997, the major exporters of soybean meal were Brazil (10 million tonnes), Argentina (8.1 million tonnes) and the United States (6.4 million tonnes) (FAO 1999). Most of the 31 million tonnes of soybean meal produced by the United States in 1997 was used within the country. Asia imported 9.5 million tonnes of soybean meal and 24.4 million tonnes of maize, although it re-exported small amounts of these feedstuffs.

What of the Future?

A summary of the projected needs for arable land, grains and protein concentrate is given in Table 6. No account is taken of cereal byproducts, such as rice and wheat bran, which can be fed to ruminant livestock and in small amounts to nonruminants, and offset the feed requirements shown in Table 6 to a small extent.

Table 6. Summary of predicted additional grain needs, protein concentrate and arable land area that will be needed by 2010.

	Humans	Livestock	Total
Grains (million tonnes)	111 (30%)[b]	264 (70%)[c]	375
Protein concentrate[a] (million tonnes)		150 (29%)[d]	150
Arable land (million hectares)	32	135	167

[a] Soybean meal or equivalent (yield 2.2 t/ha)
[b] Per cent of grains
[c] Wheat 40 million tonnes (yield 2.7 t/ha), maize 224 million tonnes or equivalent (yield 4.3 t/ha)
[d] Per cent of total food and feed

Source: Based on data in Table 4 and values given in the text ('Supply of Additional Land, Food and Feed')

The combined additional needs predicted for 2010, of over 500 million tonnes for human food and animal feed and 167 million hectares of arable land, cannot be met even with the most optimistic forecasts. Use of alternative feeds and manipulations to improve production and nutrient yield will make only small inroads because we are fast approaching the asymptote in the 'law of diminishing returns'; that is, it will take large and costly inputs to produce a small increase in production.

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Resistance to genetically modified crops and livestock is increasing, as are concerns about how we house, feed, slaughter and process our animals.

In high-income countries, consumers are demanding safe and wholesome foods. This was demonstrated in May 1999, when the pesticide dioxin was found in high concentrations in poultry feed in Belgium, with catastrophic effects on consumption of poultry products in Europe. There is great concern about how farmers produce acceptable meat and eggs, particularly in Europe, and cages for hens will be banned in the EU after 2012. Resistance to genetically modified crops and livestock is increasing, as are concerns about how we house, feed, slaughter and process our animals. Environmental issues, such as high levels of phosphorus and nitrogen in animal effluent, are of great concern. Demand for organically grown grains to feed livestock, eggs from free-range hens, and meat from free-range chickens and pigs is increasing, particularly in much of Europe. In the EU, the removal of antibiotics and certain other feed additives used to increase growth rate and/or maintain animal health is now based mainly on public perception rather than on scientific evidence regarding food safety. As a result of stricter legislation, the cost of producing compound feed and caring for livestock will increase significantly, and animal products will become less affordable, resulting in reduced animal production. Consequently, the demand for feed grains will be reduced.

In low-income countries, these concerns are generally unimportant; people are primarily interested in animal protein per se. Frequently, conditions do not allow high standards of hygiene such as water quality, although there are exceptions where stringent requirements are met to support a meat export trade, such as in Thailand, Malaysia and China. Inevitably, competition for grains and other feedstuffs will increase among importing countries with expanding affluent populations. These and other factors will make livestock products more expensive, thereby slowing demand and considerably altering the predictions made here.

One option is to import meat rather than the feed grains and infrastructure needed to support the industry. For example, the Russian Federation imported 1.3 million tonnes of poultry meat in 1997, largely from the United States, while China imported 0.80 million tonnes in 1998 but exported 0.19 million tonnes to Thailand (Anon. 1999a). The most likely scenario is that intensification of livestock production will slow down considerably and instead the focus will be on much smaller production systems that will be integrated and sustainable within countries, particularly in Asia. Livestock will be given a combination of byproducts and locally produced feeds. There are many advantages to this approach, such as the reduction of adverse environmental effects; nitrogen and phosphorus in effluent can be applied much more easily and liberally to the large areas of available land, and valuable organic matter returned to the soil.

In many parts of the world, intensively produced pig and poultry meat is not widely accepted, being perceived as lacking in flavour compared to meat from slower growing, more traditional breeds. In China and Japan several local breeds of poultry are being used in selection programs; the birds are often more adaptable to local conditions and more resistant to disease than imported breeds, although these gains are at the expense of growth rate and feed efficiency. An important advantage of a decentralised, integrated approach to rural development would be a reduction in the large number of villagers moving from rural areas to cities that is occurring in most of Asia, with disastrous consequences. In addition, these systems could be integrated with aquaculture, as is already happening in some countries in Asia.

Leng (1995) and Ørskov (1999) have proposed that the huge amounts of unused crop residues derived from grain, estimated at well over 2 billion tonnes per year, could be used to feed small and large ruminants. For efficient use, straw needs to be supplemented and/or treated with steam, urea, hydrogen peroxide, ammonia or sodium hydroxide to increase its utilisation. The 55 million tonnes of rice bran, 13 million tonnes of cottonseed meal and 60 million tonnes of wheat bran produced each year (FAO 1999), none of which are particularly suitable as nonruminant feeds, could be used as straw supplements. Leng (1995) cites an example in China of three million cattle being fattened on ammonia-ensiled straw. Not only could these crop residues be used for ruminant livestock; they could also be rendered suitable for other livestock and for humans through being treated with enzymes to release the energy in the hemicellulose and cellulose fractions (Ørskov 1999).

Although these proposals go a long way towards meeting the future demands for animal protein, such systems could take many years to establish, would be costly and would involve a considerable increase in ruminant numbers. Livestock might be concentrated in small areas, which could harm the environment, and production of methane and nitrous oxide, the most potent greenhouse gas, would increase. Nevertheless, this approach could be an effective way to significantly increase meat production, and FAO has set up a pilot project in southern China to research the viability of such a system (Leng and Devendra 1995).

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Concluding Remarks

The predictions made here that by the year 2010 we will need an additional 414 million tonnes of animal feed, of which 264 million tonnes will be grain, and a further 111 million tonnes of grain for human food, are not unrealistic. Delgado et al. (1999) predict an additional requirement for 292 million tonnes of grain by 2020 compared with 1993. China alone is predicted to need to import 300 million tonnes of grain by 2010 (Leng 1995). FAO figures, which make no special provision for livestock, suggest that food production must double in the next 30 years to meet the needs of humans. If we combine these forecasts with those of Avery (1996) and Oliver (1998), we do indeed have on our hands a recipe for disaster.

... food production must double in the next 30 years to meet the needs of humans.

There is no arable land left to cultivate and by 2010 availability of land in developing countries will shrink from 0.85 to 0.4 hectares per person (FAO 1999). Between 1988 and 1993 food produced per head of population fell in 99 countries, in part due to land degradation. Between 1950 and 1990, 9 million square kilometres, an area the size of China, was 'moderately degraded', a further 3 million square kilometres was 'severely degraded' and almost 100 000 square kilometres was 'beyond restoration' (FAO 1999). A disturbing aspect is our Australian agricultural practices, which Commonwealth Scientific and Industrial Organisation (CSIRO) soil scientist John Williams described as 'the road to suicide' (Lowe 1999). Williams puts the annual cost of soil degradation at an underestimated $2.4 billion. This tells rather a sad story about mankind's concern for the environment and its ability to husband the land.

Is there a solution to this looming crisis? The president of a Canadian biotechnology company maintains that agricultural biotechnology holds the solution and 'is limited only by the imagination of its practising scientists' (Oliver 1998). However, there is considerable opposition in many western countries, including the United States, to genetically modified foods and feeds, even if biotechnology can produce yield increases, and the collapse of the United States market for genetically modified maize by the year 2000 has been predicted (Kleiner 1999). Currently, 55% of all soybeans grown in the United States are from genetically modified seed. Japan imports 6% of the United States maize crop, with further amounts going to South Korea, Taiwan and Mexico. There is concern that these countries will demand nonmodified grains—already two Japanese breweries have stated that they will stop using genetically modified maize (Kleiner 1999). In addition, increased chemical inputs, especially fertilisers, will be required. Intensive livestock production, based on cereal grains, may become unacceptable or uneconomic in most developing countries.

There are a number of different options as to how we proceed.

1. We can continue to clear the world's forests, degrade the environment and endanger wildlife

2. We can produce livestock products much more expensively and reduce demand, thereby altering predictions and removing animal protein from the menu of the needy

3. We can match our livestock production with available resources. Under these circumstances the needy are much more likely to afford animal protein because it will be produced largely in small-scale, integrated village production systems, sometimes including aquaculture.

The fragile nature of intensive livestock systems and their undue reliance on outside resources was clearly illustrated by the sudden and recent collapse of these systems in Indonesia and there are lessons to be learnt from this. If we are to stay on the tightrope of matching production with demand for food and feed, we must examine closely what and how we feed our livestock and also ask whether we are feeding the right livestock to meet our future needs for animal protein.

The fragile nature of intensive livestock systems and their undue reliance on outside resources was clearly illustrated by the sudden and recent collapse of these systems in Indonesia ...

My role here is not to provide solutions but to present the facts as accurately as possible and to forecast feed requirements by the year 2010, using the most reliable available data. If we look at the past, and from that predict the future, the outlook is grim. Those that have will get more; those that have little will likely get nothing. Despite the enormous sums of money that have been contributed during the past 50 years to alleviate poverty, despite all the research that has gone into improving crop yield and livestock production, 800 million are still clinically malnourished and more than 1.1 billion live in absolute poverty. If we look at countries that had a GNP of less than US$1000 in 1994, the increase to 1998 has often been sufficient only to keep pace with inflation. Indonesia's GNP dropped from $1155 in 1996 to $436 in 1998 (Bastonus 1999). Clearly, we in high-income countries have shown little genuine concern and a reluctance to assist our less well-off neighbours. Where countries have offered assistance, their efforts have generally met with only modest success. It is well known that 80% of the world's wealth is in the hands of 20% of the world's population and this is unlikely to change significantly in the next decade. When coupled with the deplorable wastage of food and the way we manage our soils, there is no reason to assume that the situation will change substantially by 2010. One thing is certain: you cannot have indefinite growth in a finite world. Yes, there is a crisis on our hands; there are several suggestions as to how this could be tackled, but very few viable solutions. Douthwaite (1992) concluded:

> 'The planet needs a pause. Humankind must cease its damage, its increasing. Then after a generation or two of quiet, our successors can think again.'

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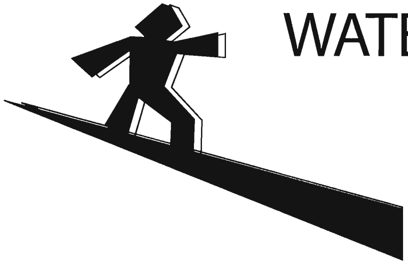

WATER MANAGEMENT

Dr S.A. Prathapar, Director, Pakistan National Program, International Water Management Institute, Lahore, Pakistan

Dr Prathapar was appointed as the Research Coordinator for the International Water Management Institute's Program in Pakistan in November 1996, and was designated as its Director in April 1998. He specialises in irrigation management, and has over 100 technical publications to his name. Dr Prathapar obtained his honours degree in agriculture from the University of Sri Lanka, and then took masters and doctoral degrees in agricultural engineering at Texas A&M University in the United States. He was employed as a postdoctoral fellow at the University of Arkansas before migrating to Australia in 1987 to join the CSIRO Division of Water Resources, Griffith, New South Wales as a research scientist.

Water Shortages in the 21st Century

S.A. Prathapar, Director, Pakistan National Program,
International Water Management Institute, Lahore,
Pakistan

Introduction

Like human populations, freshwater supplies are distributed unevenly among and within countries around the globe. This discrepancy has already resulted in water scarcity in some countries and regions. The continued growth of global and national populations and the consequent increased demand for water, a finite resource, will cause water scarcity in even more countries and regions in the future.

In many countries, socioeconomic development depends on water. Governments and development agencies have recognised this and invested heavily in projects to develop water resources during the 20^{th} century. Currently, opportunities for further development are limited, due either to the absence of water or to a lack of financial resources.

In many countries, socioeconomic development depends on water.

This paper considers the key factors contributing to water scarcity during the 21^{st} century (demography and water availability), potential consequences for global food security and ways and means to increase productivity of water. It draws heavily on studies from the International Water Management Institute (IWMI) by Seckler et al. (1999) and Molden and Sakthivadivel (1999). Demographic data and projections were obtained from the United Nations Population Division *World Population Prospects* 1998 revision (in press).

Global and Regional Demographic Trends

In mid-1998 the world population was 5901 million, with 4719 million (80%) in the less developed regions and 1182 million (20%) in the more developed regions. Asia accounted for 3585 million, i.e. 61% of the world total. During the last two years, Africa's population (749 million in 1998) became larger than Europe's (729 million). The population of Latin America and the Caribbean is estimated at 504 million, and that of North America at 305 million.

Over the next 30 years, almost 98% of global population growth is expected to take place in developing countries.

Between 1995 and 2000, the world population grew by 1.33% per year, adding an average of 78 million people each year, and it reached the six billion mark in October 1999. World population in the mid-21st century will be in the range of 7.3 to 10.7 billion, depending on future fertility trends. These figures are from the recently released 1998 revision of the official United Nations population estimates and projections.

Population growth rates vary greatly among regions and even among countries within the same region. One division is that between industrialised countries and developing countries. The more developed regions, collectively home to 1.19 billion people, include Australia, New Zealand, Japan, Europe, and North America. On average, population growth in these regions is almost 0.3% per year. This rate is projected by all but the highest estimates to dip below zero before 2025, as fertility and the proportion of people of childbearing age continue to decline. The population of less-developed regions is estimated at 4.6 billion and is growing at a rate of 1.6% per year. Over the next 30 years, almost 98% of global population growth is expected to take place in developing countries.

Africa's high rate of population growth masks variations within the continent. Rates of growth fluctuate from 2.0 and 1.6% in northern and southern Africa to 2.5 and 2.7% in western and central Africa, while the average for the continent is about 2.4%. Similar contrasts are found in southern and central Asia. The population of the region, which includes the Indian subcontinent, Iran and five former Soviet republics, is projected to increase by about 50% over the next 30 years, from less than 1.5 billion to 2.0 billion, under the United Nations' medium variant. While Pakistan's fertility rates remain obstinately high, family size in Bangladesh is now steadily declining. India presents a mixed picture, with high rates in the north of the country and low ones in the south. Rates of population growth in the rest of Asia range from around 1% in China, South Korea and Thailand to more than 2% in Cambodia, Malaysia and the Philippines.

Global Water Resources

Only a small fraction of global water resources is consumable by humankind: approximately 97% is considered saline; 2.25% is trapped in glaciers and mountain ice caps; 0.72% is stored in freshwater aquifers; and only 0.03% is found in streams and freshwater lakes. Most of the freshwater (69%) is used for agricultural production, another 23% for industries and the remaining 8% for domestic purposes.

Global evaporation and precipitation are in balance, confirming that water is a finite resource. This is evident from Table 1.

Table 1. Global water balance

	Area (million km^2)	Evaporation (mm)	Run-off (mm)	Precipitation (mm)
Land	134.8	480	320	800
Ocean	361.3	1400	130	1270

Water Scarcity

In a recent study Seckler et al. (1998) estimated that nearly 1.4 billion people live in regions that will experience severe water scarcity within the first quarter of the next century. This amounts to a quarter of the world's population or a third of the population of developing countries.

... nearly 1.4 billion people live in regions that will experience severe water scarcity within the first quarter of the next century.

Slightly more than one billion people live in regions that will face absolute water scarcity by 2025. Even at high levels of irrigation efficiency, by 2025 these regions will not have sufficient water resources to maintain 1990 levels of per capita food production from irrigated agriculture and still meet reasonable water needs for domestic, industrial and environmental purposes. People in these regions will therefore have to reduce water use in agriculture and transfer it to other sectors, meaning that less food will be produced locally and more will be imported.

An additional 348 million people face severe economic water scarcity. They live in regions where the potential water resources are sufficient to meet reasonable water needs by 2025 only if massive water development projects are embarked on, at enormous cost and with the possibility of causing severe environmental damage.

The 118 countries included in the study have been classified into two broad groups excluding China and India, according to the nature and degree of their projected water scarcity in 2025.

Group 1: Absolute water scarcity

The countries in this group are projected to be in a state of absolute water scarcity by 2025. These countries do not have sufficient annual water resources to meet reasonable per capita water needs for their rapidly expanding populations. They will almost certainly have to reduce the amount of water used in irrigated agriculture and transfer it to the other sectors, causing them to import more food. While this is a viable option for countries with foreign exchange earnings, it will impose additional burdens on others, many of which are already suffering large deficit accounts.

One of the most difficult problems encountered in the IWMI study is that the international data set used in the study is at the country level, not at the level of regions within countries. These country-level data hide massive regional differences in water scarcity. This is an especially important problem for two of the largest countries, China and India. North China is very dry, while south China is very wet. Similarly, east India is very wet while the west and the south are very dry. Large numbers of people live in all these regions.

Subsequent study of these countries leads us to believe that around one-third of the population of both China and India live in regions that should be classified in the 'absolute water scarcity' group. This amounts to 381 million people in China and 280 million people in India, a total of 661 million people. This increases the population with absolute water scarcity to just over one billion. Other large countries, such as Mexico and Nigeria, also have pronounced regional differences in water scarcity. The grouping of these countries has not been changed here, pending further research, but their existence tends to make the estimate of one billion conservative.

This increases the population with absolute water scarcity to just over one billion.

Group 2: Economic water scarcity

The remaining countries, categorised by economic water scarcity, do have sufficient potential water resources to meet projected 2025 requirements, but many of them need to embark on massive water development programs in order to make use of these resources. Thus, they face varying degrees of economic scarcity in 2025. These countries have been placed in three subgroups based on the withdrawal projection for 2025 as a percentage of 1990 (assuming significant improvement in irrigation efficiency).

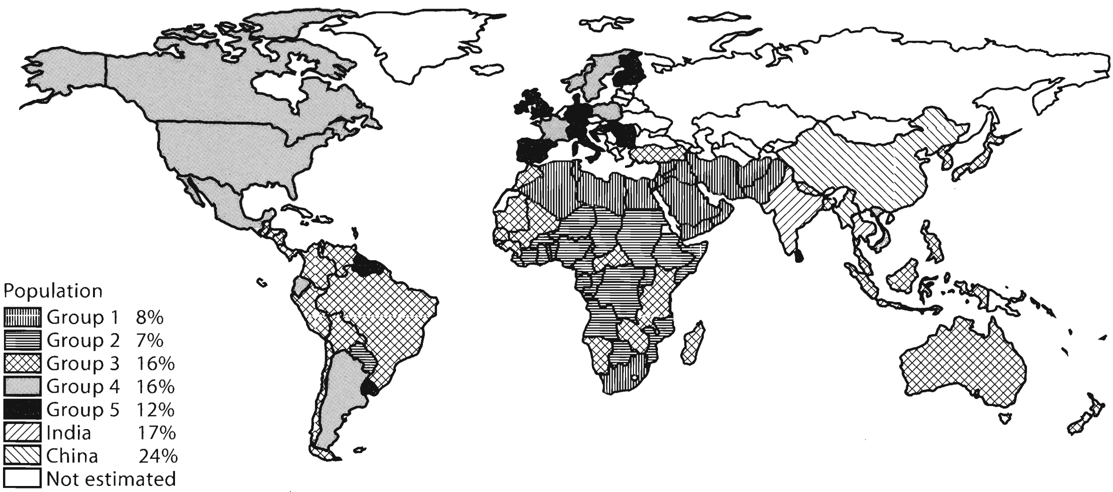

Figure 1. IWMI indicator of relative water scarcity.

Figure 1 shows the IWMI indicator of relative water scarcity. Countries in group 1 have to more than double the amount of developed water supplies by 2025 to meet reasonable needs. These countries, with 348 million people, are mainly in subSaharan Africa. It will be extremely difficult to find the financial and other resources to achieve this rapid pace of water development. If the population of these countries is added to those suffering absolute scarcities it amounts to 1.386 billion people—26% of the world's population in 1990, and 33% of that of developing countries.

Countries in group 2 also need to increase water development by between 25% and 100%. But, as indicated in Figure 1, many of these countries in Latin America, North Africa and East Asia have more resources to achieve that objective.

Finally, there are a large number of countries in group 3, comprising 28% of the population of the countries studied, that have only a modest requirement (less than 25%) for additional water development. Indeed, with increased irrigation efficiency some of these countries have zero or even negative needs for water development. The average increase in water use for this group is only 5%. Most of these countries are in North America and Europe.

Water scarcity and food security

Currently, global food supplies are made up of 77.5% agricultural, 16% livestock and 6.6% fisheries products. Population growth is expected to increase the demand for cereal by 1.27%. At present, irrigated agriculture produces 40% of all food, and consumes 69% of all freshwater resources. To meet the projected demand for food, irrigated agriculture will require an additional 17% of freshwater resources (Serageldin 1999).

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During the next 25 years, urban population is expected to increase significantly. In 1990, 43% of the global population were in urban areas; this is expected to increase to 61% in 2025. The food consumption pattern of the urban population with higher income will shift from predominantly cereal to animal products. This will increase the demand for domestic water supplies, and reduce water available for irrigated agriculture.

Fresco and Rabinge (1997) noted that over the next 40 years, as much additional food will need to be produced as humankind has produced since agriculture began. This can be achieved by increasing one or more of the following:

- area under agriculture;
- productivity per unit area; and
- productivity per unit of water.

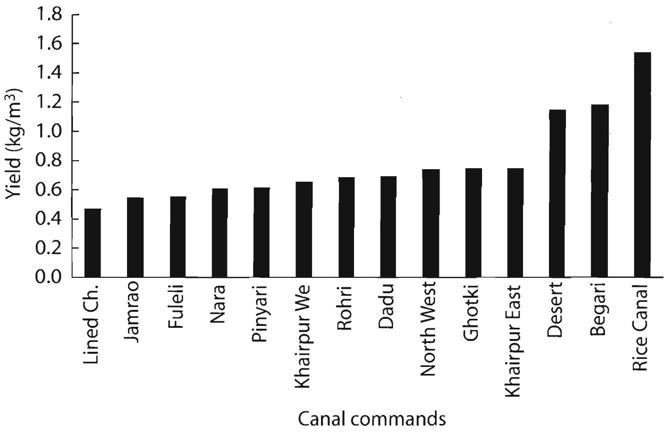

Figure 2. Variation in productivity per unit water applied, Sindh province, Pakistan.

Improving the Productivity of Water Agriculture

Agricultural productivity in many parts of the world remains far below its potential.

Agricultural productivity in many parts of the world remains far below its potential. Figure 2 shows the variation in wheat yield among canal commands of Sindh province, Pakistan. Despite similar agroclimatic conditions, there is a high variation in yield, which could be largely attributable to water management practices.

Molden and Sakthivadivel (1999) identified four major outflow categories for water in water basins; namely, beneficial depletion, nonbeneficial depletion, uncommitted outflows and committed water. General strategies for improving productivity can be identified, pertaining to each of these categories:

- increase the productivity per unit of beneficial depletion (crop transpiration in agriculture);
- reduce nonbeneficial depletion, including pollution;
- reduce uncommitted outflows either through improved management of existing facilities or through development of additional facilities; and
- reallocate water to higher valued uses.

Within each of these broad strategies, more detailed strategies can be identified, as listed below. The choice of strategy for increasing water productivity will be guided by economic and social factors. Choice may be constrained by existing water rights (especially when there are options of reallocation), local availability of water and cost-effectiveness. For example, it may be more cost-effective to reuse water through pumping than to modernise existing infrastructure to increase beneficial depletion of available water.

Increasing productivity per unit transpiration

In many cases, water available for agriculture will decrease in the future as water is reallocated to industrial and urban sectors. An important means of achieving increased productivity will be to get more from the amount of water that is beneficially depleted by agriculture. This can be achieved in a number of ways:

- *Changing crop varieties.* Plant breeding plays an important role in developing varieties that yield more mass per unit transpiration. Keeping transpiration constant, more mass can be obtained, resulting in increased water productivity. Alternatively, for the same mass of production, transpiration can be reduced, yielding water that can be made available for other uses.
- *Crop substitution.* People can switch to a crop that consumes less water, or one with a higher economic or physical productivity per unit of water consumed by transpiration.
- *Deficit, supplemental or precision irrigation.* With sufficient water control, it is possible to achieve more productivity per unit of water by irrigation strategies that may not meet full evapotranspiration (ET) requirements, but instead increase returns per unit of ET.

... water available for agriculture will decrease in the future as water is reallocated to industrial and urban sectors.

Reducing nonbeneficial depletion

Reduction in nonbeneficial depletion can be achieved in a number of ways.

- *Decrease nonbeneficial depletion* by:
  - reducing evaporation from water applied to irrigated fields (reducing the evaporation part of ET) through special irrigation technologies like drip irrigation, through agronomic practices such as mulching, or by changing the planting date to match with periods of less evaporative demand; and
  - reducing evaporation by controlling evaporation from fallow land, decreasing areas of free water surface, decreasing phreatophytes and controlling weeds.
- *Reduce flow to sinks* by interventions that reduce deep percolation and/or surface run-off where this water presently flows to sinks.
- *Control pollution* by:
  - reducing flows through saline soils or through saline groundwater to reduce mobilisation of salts into irrigation return flows;

- shunting saline or otherwise polluted water directly to a sink and avoiding the need to dilute it with freshwater; and
- utilising a basin-wide irrigation strategy that limits reuse of return flows.

It is often the case that facilities for using water resources are not managed to their fullest extent ...

Tapping uncommitted outflows

It is often the case that facilities for using water resources are not managed to their fullest extent, resulting in outflows that exceed downstream commitments. Improved management of these facilities is an important consideration in reducing utilisable outflows. Alternatively, it may be more cost-effective to employ additional storage, diversion or reuse facilities (including groundwater pumping) for this water. General means of tapping these outflows are to:

- improve management of existing facilities to obtain more beneficial use from existing water supplies. There are a number of policy, design, management and institutional interventions that will allow an expansion of irrigated area, increasing cropping intensity, or increasing yields within the service areas;
- add storage facilities and release water during drier periods. The storage could take many forms besides impoundment behind reservoirs, including storage in groundwater, and storage in small tanks and in ponds on farmers' fields; and
- reuse return flows to increase irrigated areas through gravity and pump diversions.

Reallocating water between uses

Productivity of water can be dramatically different between uses. The value of water for municipal and industrial uses is generally much greater than that for agriculture. An option for increasing productivity of water is to reallocate water from lower- to higher-value uses. As a result, downstream commitments may change, and any reallocation of water is likely to have serious legal, equity and other social considerations that must be addressed.

Conclusion

Over thousands of years of human development, water has been a plentiful resource in most areas, amounting virtually to a free commodity. Now the situation is changing abruptly to the point where, particularly in the more arid regions of the world, water scarcity has become the single greatest threat to food security, human health and natural ecosystems. Seckler et al. (1998) estimated that nearly 1.4 billion people, amounting to a quarter of the world's population or a third of the population in developing countries, live in regions that will experience severe water scarcity within the first quarter of the next century. Slightly more than one billion people live in regions that will face absolute water scarcity by 2025. Around 348 million more face severe economic water scarcity, living in regions where the potential water resources are sufficient to meet reasonable water needs by 2025, but expensive and potentially environmentally damaging water development projects will be needed to achieve this objective.

... water scarcity has become the single greatest threat to food security, human health and natural ecosystems.

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Dr Ed G. Barrett-Lennard, Interim Director, Centre for the Management of Arid Environments, Kalgoorlie, Australia

Dr Barrett-Lennard is a group leader within Agriculture Western Australia and is a prominent advocate of the need to develop productive uses for saltland. He is author/editor of three books and more than 50 other publications. In the 1990s, Dr Barrett-Lennard managed two ACIAR projects on the use of saltbushes as a forage for Pakistan and Australia. In 1996 he was awarded the Pakistan Agricultural Research Council Shield for his role in the development of saline agricultural systems in Pakistan.

Salt of the Earth: Time to Take It Seriously

Ed G. Barrett-Lennard, Interim Director, Centre for the Management of Arid Environments, Kalgoorlie, Australia

Introduction

This paper argues for the implementation of saline agricultural systems in both developing and developed countries, including Australia. To develop and adopt these systems, there will need to be:

- major new community investments in research, development and extension; and
- a change in community consciousness as to what is possible for saltland.

The ideas presented here are based on the professional experience of the author in the development of saline agricultural systems in Western Australia, and in Pakistan, in two projects funded by the Australian Centre for International Agricultural Research (ACIAR).

This paper has four major themes:

- salinity is a world problem of increasing significance;
- salinity has acute adverse effects on communities, especially in developing countries;
- saltland is a potentially productive resource; and
- urgent research and development is required if we are to develop the industries necessary to avoid acute dislocation of affected communities.

Global Scale of Salinity Problem

Salinity induced by human activity occurs on at least 80 million hectares of land that were originally suitable for some form of agriculture (Table 1). This has mostly been caused by increased seepage (associated with irrigation or the removal of deep rooted vegetation), the development of shallow watertables, and the remobilisation of salt stored in the soil profile to the soil surface. Salinity is a particular problem in irrigated land; more than 25% of irrigated land is saline in Egypt, Iran, Iraq, India, Pakistan and Syria (Choukr-Allah 1996).

Salinity induced by human activity occurs on at least 80 million hectares of land that were originally suitable for some form of agriculture...

Table 1. Extent of secondary salinity.

Continent	Secondary salinity[a] (million hectares)
Africa	14.8
Asia	52.7
South America	2.1
North and Central America	2.3
Europe	3.8
Australasia	2.5
Total	78.2

[a]Values are from Ghassemi et al. (1995), except Australasia, which are from Robertson (1996) and Ferdowsian et al. (1996)

In the absence of a radical redesign of irrigated and dryland agricultural systems, it appears likely that salinity will affect substantially greater areas in the future. Quantification of future salinisation requires a capacity for modelling landscape processes. The estimates for Australia can be considered to be indicative—we currently have about 2.5 million hectares of salinity induced by human activity (Robertson 1996) and hydrological modelling suggests that around 15 million hectares could be at risk.

Impacts of Salinity on Communities—Indicative Data from Pakistan

... salinity is highly damaging to economic prosperity and morale in agricultural communities, especially in developing countries.

The limited available data suggest that salinity is highly damaging to economic prosperity and morale in agricultural communities, especially in developing countries. The data for Pakistan illustrate this.

During the period 1994–96, the Joint Satiana Pilot Project conducted socioeconomic surveys of eight villages in the Satiana area[1] of the Punjab, a highly salt-affected area, and two adjacent villages from a nonaffected area, which were used as a control. By every criterion of development examined, the villages from the Satiana area were worse off than the adjacent villages from the control area, exemplified by the following data.

- *Literacy.* Literacy, especially of women, has been nominated as one of the major means by which developing countries begin to control population growth (Haq 1997). In the salt-affected Satiana area, 56% of men and 91% of women were illiterate. These figures are substantially worse than for Pakistan as a whole, with rates of 51% for males and 77% for females (Haq 1997).

[1] The Satiana area was once regarded as one of the most productive districts of Pakistan. Salinity in the area was caused by the rising of watertables following the opening of the Lower Gugera Branch and Burala Branch Canals in 1892. At present, about 22% of land is affected by salinity, 9.7% is 'totally affected' and 12.2% is partially affected' (Ijaz and Davidson 1997).

- *Health care.* People in salt-affected areas have poor access to basic health care facilities; in the Satiana area only one out of eight villages surveyed had a health clinic.
- *Typical household goods.* With their reduced purchasing power, people from the highly salt-affected Satiana area had substantially poorer access to all the basic household equipment surveyed than did people from the control villages (Fig. 1).

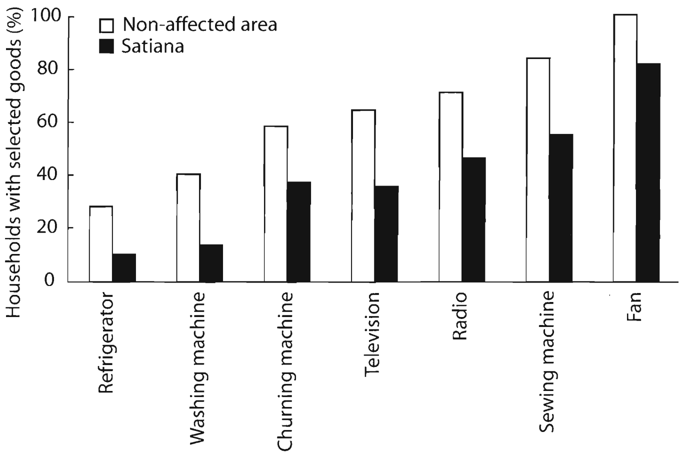

Figure 1. Ownership of household goods in the highly salt-affected Satiana region and an adjacent region that is not affected (Ijaz and Davidson 1997).

The Vision—Saltland as a Productive Resource

For saltland industries to flourish, we need an understanding of three capabilities: those of the land, the plants and the markets, which can be represented by three intersecting circles (Fig. 2). What we need is the right plant (or combination of plants) at the right location in the landscape, producing products of greatest commercial value.

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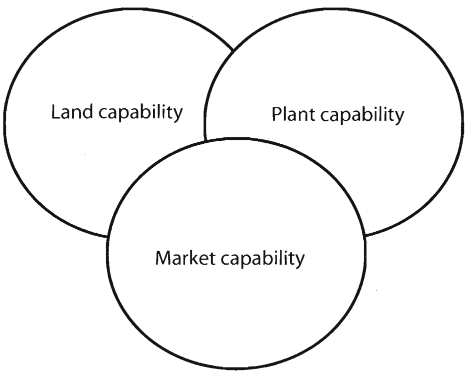

Figure 2. Understanding three capabilities leads to successful industries on saltland.

In our experience, examination of the opportunities presented by plants, land and markets shows that nearly all salt-affected land is capable of some productive and profitable use. In Western Australia we expect to use saltland in the future for the production of meat, wool, fish, fuelwood, specialist timbers, sequestered carbon, essential oils and organic chemicals.

However, the scope may be even wider in developing countries where farmers directly use much of their own produce. We have recently identified 23 different plant species that will grow under a range of saltland conditions in Pakistan, capable of fulfilling or producing 25 different functions/products (Table 2).

Table 2. Functions/products from salt-tolerant species in Pakistan (Qureshi and Barrett-Lennard 1998).

Use	Species[a]	Use	Species[a]
Amenity value	3, 17, 20, 21	Lac	23
Charcoal	6, 12, 17, 22, 23	Land reclamation	11, 17, 19
Cineole	9	Methane (biogas) substrate	11
Erosion control	1, 3, 6, 17, 22	Mushroom substrate	11
Ethanol production substrate	11	Nitrogen fixation	6, 12, 14, 16, 19, 20
Fodder	1, 2, 3, 7, 8, 11, 12, 14, 16, 17, 19, 20, 23	Posts/poles	1, 3, 6, 12, 14, 16, 17, 20
Fruit	10, 13, 15, 18, 21, 23	Pulp	6, 9, 12, 20
Fruit juice	10	Roofing	15, 19
Fuelwood	1, 2, 3, 6, 9, 12, 14,16, 17, 19, 20, 21, 22, 23	Sugar	15
Green manure	19	Tannin	2
Gum	2	Timber	2, 3, 9, 14, 16, 17, 22, 23
Hay	7, 8, 11	Windbreak	1, 20, 21, 22
Honey	3, 9, 14, 16, 17		

[a] The species were as follows: 1, *Acacia ampliceps* (salt wattle); 2, *Acacia nilotica* (gum arabica); 3, *Albizzia lebbek* (lebbek); 4, *Atriplex amnicola* (river saltbush); 5, *Atriplex lentiformis* (quailbrush); 6, *Casuarina equisetifolia* (coastal sheoak); 7, *Chloris gayana* (rhodes grass); 8, *Elytrigia elongata* (tall wheatgrass); 9, *Eucalyptus camaldulensis* (river red gum); 10, *Grewia asiatica* (phalsa); 11, *Leptochloa fusca* (kallar grass); 12, *Leucana leucocephala* (leucana); 13, *Manikara zapota* (sapodilla); 14, *Parkinsonia aculeata* (parkinsonia); 15, *Phoenix dactylifera* (date palm); 16, *Prosopis cineraria* (jand); 17, *Prosopis juliflora* (mesquite); 18, *Psidium guajava* (guava); 19, *Sesbania bispinosa* (dhancha); 20, *Sesbania sesban* (jantar); 21, *Syzygium cuminii* (rose apple); 22, *Tamarix aphylla* (salt cedar); 23, *Ziziphus mauritiana* (Indian jujube).

Saline agricultural systems will probably be of greatest value when they complement existing activities on the farm. Consider the following example from Pakistan (Qureshi and Barrett-Lennard 1998). At present, farming systems in the Punjab make little or no use of trees or perennial forages. Under these conditions we see a range of effects:

- *poor crop production*—yields are adversely affected by nutrient deficiencies, salinity and waterlogging. As there is a shortage of fuelwood, farmyard manure is burnt as fuel;
- *poor animal production*—productivity is affected by low levels of fodder production; and
- *deteriorating land resource*—in many instances watertables are still rising; the problems of poor crop production and fodder deficiency therefore increase in magnitude.

This picture could change if salt-tolerant trees and saltbushes were established on land too waterlogged and saline for the growth of crops. Under these conditions we expect no decrease in the area of nonsaline land sown to crops, but a large increase in the total productivity of the farming system. Some of the anticipated changes are listed below.

- Trees and saltbushes growing on the waterlogged saline land lower the watertables beneath the saltland and the marginally affected land that is still cropped. The land resource becomes more productive because of decreased waterlogging and salinity. The marginal land now produces crops of higher yields.
- Salt-tolerant trees are used as fuel, ensuring that farmyard manure can be returned to the fields as fertiliser. This further improves crop yields.
- Saltbush leaf is mixed with crop straw residues to produce a useful fodder. This allows crop production on nonsaline land that has been previously reserved for the production of fodders like berseem and lucerne.

Research and Development—Imperatives and Opportunities

Realising the potential of salt-affected land for productive use will require a major future commitment to research and development. The three capabilities listed in Figure 2 constitute a useful framework around which to reassess priorities.

Realising the potential of salt-affected land for productive use will require a major future commitment to research and development.

Defining market capability

There is an urgent need to assess the relative marketability of saline agricultural options. We are not aware of any such analysis having ever been done for prospective saline agricultural products in Australia or in any other country. This is curious given that it is the *selling* of products that generates the revenue stream that provides farmers with the incentive to invest in new systems. An increasing range of uses for saline resources will be on offer, some of which may be in innovative new industries. The enterprise a farmer chooses will be determined by the availability of information about prices, size of market, scale of competition, requirements for transport, and the availability of appropriate community infrastructure.

Defining land capability

Techniques are needed for assessing the capability of saltland so farmers can locate their new saline agricultural enterprises in optimal locations. At present, land capability surveys do not distinguish between different types of saltland. Ecological zonation in naturally saline environments can give important information about the processes that affect land capability. In Western Australia, we have suggested that saltland should be classified as being of 'low', 'moderate' or 'high' productivity, based on the degree to which it is affected by salinity, waterlogging and inundation (Barrett-Lennard 1999). Increasingly, the occurrence of these stresses and their severity can be measured or predicted using combinations of on-ground surveys, airborne geophysics and hydrological modelling. Such techniques could be used to develop a robust predictive capacity for matching saline agricultural enterprises to sites.

Defining plant capability

Significant opportunities exist for building new saltland industries, based on salt-tolerant plant species found in naturally saline soils.

Significant opportunities exist for building new saltland industries, based on salt-tolerant plant species found in naturally saline soils. There is an urgent need for prospective material to be collected, tested for adaptation and integrated into saline agricultural systems.

Collection of prospective material

The collection of salt-tolerant plants has been an ad hoc activity over the last 30 years. Some collections, such as that of Malcolm et al. (1984), have become degraded as agencies have developed other interests. Others, like that of the Australian Tree Seed Centre, have focused only on specific vegetation types. Establishment of appropriately maintained, secure salt-tolerant germplasm collections in Australia and overseas is necessary.

Adaptation testing

Saltland is subject to three major stresses that affect growth and survival—salinity, waterlogging and inundation.

Saltland is subject to three major stresses that affect growth and survival—salinity, waterlogging and inundation. Adaptation testing in natural and controlled environments needs to assess how plants respond to these factors and their interactions.

- *Salinity*. Although nearly all crop plants are sensitive to salinity, we do have access to a group of highly salt-tolerant plant species known as halophytes. Some of these will withstand salt concentrations in excess of those found in sea water. In general, plant responses to salinity are well understood. Relevant proceedings, reviews and bibliographies include Aronson (1989), Barrett-Lennard et al. (1986), Greenway and Munns (1980), Munns et al. (1983), and Maas (1986).

- *Waterlogging.* Plants use energy to decrease the uptake of salt at the root surface. Waterlogging can damage salt exclusion mechanisms by causing soils to become oxygen deficient, resulting in energy deficient plants (Barrett-Lennard 1986). Research on native Australian species shows that some species have exceptional tolerance to waterlogging under saline conditions (Moezel et al. 1988). In general, our knowledge of the responses of plants to the interaction of waterlogging and salinity is poor. Reviews on the effects of waterlogging on plants in saline environments include Barrett-Lennard (1986) and Qureshi and Barrett-Lennard (1998, Section 4.2).
- *Inundation.* Inundation covers plant shoots with water, preventing the exchange of gases between leaves and the air. It appears that inundation, even for a few days, can decrease the survival of most plant species. Apart from rice, there are very few welldocumented examples of the effects of inundation on plants.

Integration into systems

One recent innovation has been the idea of using combinations of plant species to maximise the productive value of saltland. In these schemes halophytes are used not directly as 'crops' but to improve site conditions by lowering local watertables; this can enable better growth of adjacent species of higher economic value. Examples of these systems are given below.

- The growth of salt-tolerant trees and crops in alley farming systems in Pakistan (Qureshi and Barrett-Lennard 1998). In this case the rows of trees act as 'drains', lowering shallow watertables and enabling better growth of interrow crops (Fig. 3a).
- The growth of mixtures of saltbushes and balansa clover on saltland in southern Australia (Barrett-Lennard and Ewing 1998). In this case the saltbushes act primarily as ground water pumps, thereby enabling better use of the higher-quality balansa clover forage (Fig. 3b).

The use of combinations of plants provides major opportunities to base saltland industries on the growth of only moderately adapted species. There is a need to look much more widely for further combinations of plant species for testing.

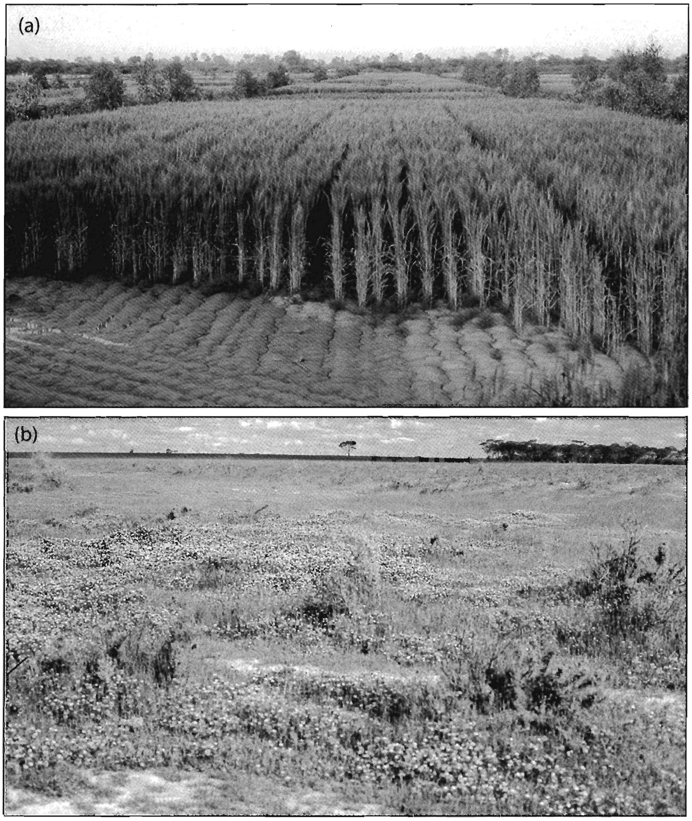

Figure 3. Combination of salt-tolerent perennial species can improve the growth of adjacent annual species.

(a) *Eucalyptus camaldulensis*/wheat alley farming system in the Punjab of Pakistan.

(b) Mixtures of saltbush (*Atriplex* species) and balansa clover (*Trifolium michelianum*) in south-western Australia.

We now recognise that about 15 million hectares of our prime agricultural land are at risk.

Concluding Comments

The magnitude of the salinity problem that we face in Australia has dramatically expanded over the last few months. We now recognise that about 15 million hectares of our prime agricultural land are at risk. Many of our developing country partners will face problems of similar scale. Given this impact, it is reasonable to suggest that salinity of agricultural land will be one of the significant human rights issues of the 21st century. It is essential that income-generating agricultural systems are developed for salt-affected land. There are two major tasks.

Task 1 — Get the science right

As we have noted above, the imperative is to develop robust industries based on a sound knowledge of the capabilities of plants, land and markets. Establishing a creative environment through targeted funding programs is essential. Australia has not invested extensively in the development of saline agriculture over the last five years. However, funding has been sufficient to generate a small technical capacity in each State and for this to become networked at a national level through the National Program on Productive Use and Rehabilitation of Saline Land (the PURSL group)[2]. In addition, the development of international networks has been facilitated through the involvement of Australian scientists in international projects, for example the establishment of the International Bio-Saline Research Centre at Dubai and various research projects funded by ACIAR. A substantial escalation is needed in activities at both the domestic and international level. Escalation at the domestic level appears assured as Australia's National Dryland Salinity Program has announced that it will embrace the need for productive use of saline land in its second phase. There remains the question of how we expand our international linkages. ACIAR's investments have been valuable, but perhaps a funding program of a more substantial nature is now required.

We need to engender a change of consciousness about what is possible on saltland.

Task 2 — Change community consciousness

The second critical task that we face may be less obvious than the first. We need to engender a change of consciousness about what is possible on saltland. In the case of productive use of saline land, one of the largest problems that we face lies in the scepticism of communities—farmers, researchers and agencies. There are times when 10000 years of prior human experience seems to call out, 'It can't be done'. In the face of this scepticism we should remember that the salinisation of land does not mark the end of living systems. We need to change our view of the problem—it is not a problem but a resource.

Here is an example of what we mean by a change of consciousness. Many farmers in Western Australia have thought of salinity as a form of 'land cancer'. What a terrible metaphor that is. When we think of cancer, we think of debilitating disease with little prospect of cure; the analogy is not remotely appropriate to the facts. We have suggested the adoption of an alternative analogy (Qureshi and Barrett-Lennard 1998)—saltland should be considered as 'subirrigated' land, i.e. land that is irrigated from below, albeit with saltier water than one would normally use for irrigation. When considered in this quite accurate perspective, agricultural options for saltland automatically come to mind.

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[2] The activities of the PURSL group have been described by Barson and Barrett-Lennard (1995) and Malcolm (1996).

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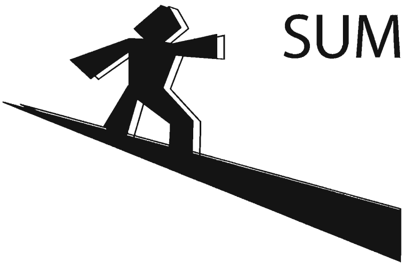

SUMMING UP

Dr Lloyd T. Evans, CSIRO Plant Industry

Dr Evans completed degrees in agriculture and science in New Zealand, a doctorate at Oxford as a Rhodes Scholar, and post-doctoral research in California. In 1956 he joined the CSIRO Division of Plant Industry with responsibility for design and management of its phytotron, and from 1971 to 1978 was chief of that division. Throughout a long and distinguished career Dr Evans has been a member of the Consultative Group on International Agricultural Research (CGIAR) Technical Advisory Committee and has served on the Boards of Trustees of the International Rice Research Institute (IRRI) and the International Maize and Wheat Improvement Center (CIMMYT). A Fellow of the Australian Academy of Science and the Royal Society of London, Dr Evans is the author of many well-known texts, including *Feeding the Ten Billion: Plants and Population Growth* which he wrote to mark the 200th anniversary of the publication of Malthus's seminal *Essay on the Principles of Population.*

The Food and Environment Tightrope — Will We Fall Off the Tightrope?

Lloyd T. Evans, CSIRO Plant Industry

The title of my paper was given to me by the organisers of this seminar, and since our keynote speaker, Professor Swaminathan, walked the tightrope so eloquently in his discussion of the 'evergreen' revolution, it may seem ungracious of me to question the imagery. But my tightrope-walking colleagues (and there are many of them these days) tell me that the tighter the rope, the easier it is to walk.

Most of us would associate the world's population growing faster than the food supply with a tightening of the rope; hence the imagery of walking the tightrope may falter. But in another sense the analogy is very apt for the present and for likely future situations. The world's rope has many strands and, while the rope as a whole may hold and we may make it across with enough food for all, some of the weaker strands may fail. In essence, this is the present situation — the world as a whole produces enough food for all while 840 million of us are still chronically undernourished. This situation was the abiding concern of Sir John Crawford, a great Australian, whose name is associated with this seminar and who played a crucial role in the establishment and evolution of international centres for agricultural research under the aegis of the Consultative Group on International Agricultural Research (CGIAR).

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So, although population growth has not been discussed specifically today, I must mention it briefly because it will determine how much additional food is needed, how much forest is logged or converted to arable land and, thereby, how much pressure is put on the world's soil, water, atmospheric and biological resources.

The good news is that the population projections of the United Nations for the middle of the next century have been progressively reduced in recent years. The median projection for 2050 has fallen from more than 10 billion several years ago to under nine billion this year, i.e. less than 50% more than the present population. The low projection of 7.7 billion is only 28% more than our present number. The bad news is that countries like Italy and Spain, which currently have the lowest fertility rates, and even countries like China, are concerned about the increasing imbalance between their active and their retired populations. Thus, we may yet witness a third demographic transition — either to higher birth rates or to the decline and fall of the human empire.

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How have the world's food needs been met so far? Until 1960, when the world population reached three billion, the area of arable land increased in proportion to population (Evans 1998). Since then the arable area has increased only slightly (0.2% per year), but population growth has been matched by an increase in average yields per hectare of all cereals, the major source of our dietary calories and proteins, via both food and feed. This one-to-one matching of population growth and cereal yield may be a fortuitous result of two opposed effects. On one hand we have an increasing food intake per person, especially of animal products, tending to push the line upwards; on the other hand an increasing proportion (currently 80%) of the world's population lives in developing countries, pulling the line downwards. Whatever the reason, it is clear that Malthus got it wrong 200 years ago when he argued that food supply could not increase geometrically like population, and it seems that Boserup (1965) may have been right in asserting that agricultural intensification is driven by population growth. Agricultural intensification gets a bad press these days, but the alternative to intensification since 1960 would have involved doubling the arable area and cultivating a further 1.4 billion hectares, reducing the area presently under forest by almost half.

In looking ahead we can expect these trends to continue, at least for some time. I have therefore indicated possible limits to cereal yields for the main regions of the world (Fig. 1), based on estimates by Linnemann et al. (1979) of potential world average yields as determined by climate, soils and water availability. A subtraction of 42% has then been made to adjust for average global losses sustained due to pest, disease and weed problems, as found in the comprehensive surveys by Cramer (1967) and Oerke et al. (1994). These estimates suggest that, through intensification, there is enough scope for the requisite increases in

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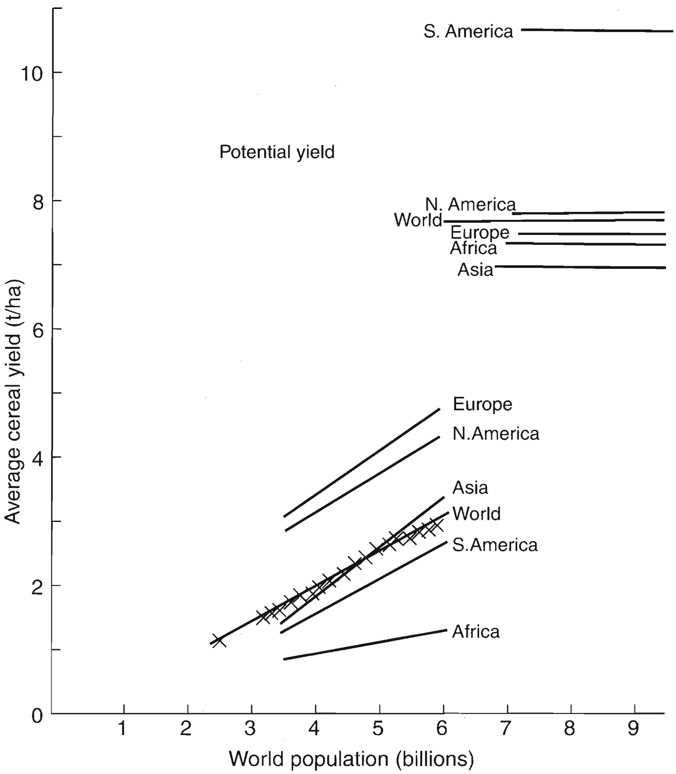

Figure 1. Regressions for the increase in average cereal yields for the world (x) and its major regions between 1965 and 1998, together with estimates of likely maximum yields using the potential yields estimated by Linnemann et al. (1979) reduced by 42% to take account of the average losses to pests, diseases and weeds in the surveys by Cramer (1967) and Oerke et al. (1994).

cereal yields to feed the 10 billion, and that we will not fall off the tightrope, although the regression for Africa indicates disturbingly slow progress in the region that has by far the highest birth rate.

If the necessary yield increases cannot be obtained, is there sufficient potentially arable land? Several independent estimates suggest that there is more than enough for at least a doubling of the arable area, albeit using land that is less fertile, less accessible or preferred in its present vegetation. However, approximately 2 million hectares of currently arable land are lost to erosion each year, another 2 million to salination and toxification, and an estimated 8 million per year to urban sprawl, i.e. almost 1% of arable land is lost each year. Serious though soil degradation is, as emphasised by Eric Craswell, urbanisation is far more so, not only in scale but also because it often takes the best agricultural land. Moreover, demographers project that virtually all further population growth will be accommodated in urban areas (Dyson 1996).

... in vulnerable environments there can be great advantages in coordinating agroforestry approaches at the catchment or watershed level, preferably with community-based and partnership approaches.

The arable land lost is replaced by further clearing, increasing the arable area by 3.3 million hectares per year, for a total amount converted of 15.3 million hectares per year. This is close to the figure of 15.7 million hectares per year for the reduction in forest area quoted by Glen Kile, implying that most cleared land ends up as arable, until it becomes urban. On the other hand, planted forests now occupy 10% as much land as is taken up by crops, and we are beginning to see plantation forests competing not only for hilly pastureland, but even for prime arable land, although so far only to a small extent. Certainly, in many environments, especially those subject to severe erosion, the complementary planting of trees and crops in various kinds of agroforestry combinations — as discussed by Pedro Sanchez — can be the most productive and stable land-use strategy for replenishing soil fertility. Also, as Pedro Sanchez, Eric Craswell and our keynote speaker emphasised, in vulnerable environments there can be great advantages in coordinating agroforestry approaches at the catchment or watershed level, preferably with community-based and partnership approaches.

While it is well to remember the tragedy of the commons in earlier times and the conservative inertia that overtook the common field system, there is real scope for more catchment or district cooperation between farmers, as many integrated pest management projects have shown, and many irrigation schemes cry out for.

So far I have been talking mostly of crop production, but the most rapid rises in demand are for animal products, milk, eggs and meat, which David Farrell sees as a recipe for disaster. About 20 years ago it was estimated that pasture and forage provided about three-quarters of the dietary energy for domesticated animals, but a recent estimate suggests that they now supply only about half, reflecting the rapid increase in poultry and pig numbers. Animal feed now accounts for 44% of cereal production, most of the soybeans and many other crop products and residues, with demand increasing rapidly.

From Farrell's figures one can estimate that the additional increase in feed grain production needed to meet growing demand — 80% of it for pigs and poultry — would be 22 million tonnes per year. This compares with an average yearly increase in cereal production over the last five years of 25 million tonnes per year. Thus, the rate of increase in grain production would have to be doubled to meet demand. This seems unlikely, but not wholly impossible given the requisite price incentives and the fact that much of the feed used does not enter trade and production statistics because of what Farrell calls the 'informal' feed industry.

Whereas not to be able to meet the food needs of developing countries would be disastrous, not to be able to meet their feed wants would be less so, albeit disappointing.

So far I have been suggesting that we can walk the tightrope between population and food supply over the next generation or two, but can we do so equitably and sustainably over the long term, given the inevitable costs to our resources of soil, water, nutrients, forests and genetic diversity? Of all these resources, access to water may well prove to be the defining issue for agriculture in the 21st century.

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Postel et al. (1996) estimate that humanity is already using 54% of the geographically and temporally accessible run-off water and that new dam construction might increase that by only 10% over the next 30 years. Moreover, while agriculture now uses about 70% of that water for irrigation to produce about 40% of the world's food, its share is likely to fall as industrial and urban requirements increase, because industrial and urban users can afford to pay so much more for it. On the other hand, agricultural research may well make it possible to use irrigation water much more effectively, as suggested by Dr Prathapar's data on the 14 canal commands of the Sindh, showing the three-fold range in the efficiency with which they use water to produce food. There is also the possibility that saline areas and estuaries could be used more productively, as both Prof. Swaminathan and Dr Barrett-Lennard urge.

Threats to our soil and forest resources have long been recognised — the Sumerians associated salting with excessive irrigation and the Greeks realised that silting was linked to excessive deforestation. Excessive is the operative word here and, unfortunately, comparable excesses are still to be found in modern agriculture and forestry. But they need not drive us into either confrontation or despair. Research continues to provide new insights into better management, as Jeffrey Sayer illustrated for the logging of rainforests.

Both agriculture and forestry have many possible futures, some still unforeseen. Both face many problems, some not yet diagnosed. The problems may be viewed as potential disasters or as opportunities, but either way, it is agricultural and forestry research, especially that focused on the problems of developing countries, that is the key to avoiding disasters and creating opportunities.

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However, to translate their findings most speedily and effectively into real progress for the poor and hungry, aid agencies must bear in mind the lessons for the future propounded by Prof. Swaminathan at the end of his inspiring lecture — namely the need for political will and commitment in the recipient nations, the need for partnership rather than patronage between donor and recipient, and the crucial role of home-grown scientific leadership.

As a despairing optimist I see no reason why we should fall off the tightrope, provided that we continue to view the problems that will inevitably arise along the way as challenges to our ingenuity, our understanding and our humanity.

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