AGRICULTURE IN A CHANGING CLIMATE

THE NEW INTERNATIONAL RESEARCH FRONTIER

Record of a conference conducted by the ATSE Crawford Fund
Parliament House, Canberra — 3 September 2008

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THE NEW INTERNATIONAL RESEARCH FRONTIER

The ATSE Crawford Fund
Fourteenth Annual Development Conference
Parliament House, Canberra
3 September 2008

Editor A.G. Brown

The *ATSE* Crawford Fund

Mission

To increase Australians' engagement in international agricultural research, development and extension for the benefit of developing countries and Australia

Mandate

To make more widely known throughout Australia the benefits that accrue both internationally and to Australia from international agricultural research, and to encourage greater support for, and participation in, international agricultural research and development by Australian governmental and non-governmental organisations and, in particular, the industrial, farming and scientific communities in Australia.

The Fund

The Australian Academy of Technological Sciences and Engineering established The Crawford Fund in June 1987. It was named in honour of the late Sir John Crawford, AC, CBE, and commemorates his outstanding services to international agricultural research. The Fund depends on grants and donations from governments, private companies, corporations, charitable trusts and individual Australians. It also welcomes partnerships with agencies and organisations in Australia and overseas. In all its activities the Fund seeks to support international R&D activities in which Australian companies and agencies are participants, including research centres sponsored by, or associated with, the Consultative Group on International Agricultural Research (CGIAR), and the Australian Centre for International Agricultural Research (ACIAR).

The office of the Fund was transferred from Parkville in Melbourne to Deakin in Canberra at the beginning of 2009.

More detail is available at http://www.crawfordfund.org

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Foreword

THE HON. NEIL ANDREW

This conference was the fourteenth in an annual series established by the Crawford Fund to raise awareness of the benefits that accrue both internationally and to Australia from international agricultural research — research that has as its primary goal the reduction of poverty, improvement of food security, and conservation of natural resources for agriculture in developing countries.

The theme of the conference was the impact of climate change on agriculture (including crops, livestock, fisheries and forestry), and vice-versa, in the Asia-Pacific region and Australia, and the need for a new international agricultural research agenda. The conference was extraordinarily timely. Apart from the global financial crisis late in the year and ongoing concerns about global oil supplies and the cost of transport fuel, few issues in 2008 captured the attention of Australian community more than the prospect of undesirable climate change caused by an increase in atmospheric levels of so-called 'greenhouse gases'. Indeed, climate change had been a factor in the election of a new Australian Government in late 2007. The Australian public was acutely aware of the ongoing drought in most of eastern Australia and the consequent severe water shortages, particularly in the Murray–Darling Basin but also in several state capital cities, and they saw these as possible early warnings of climate change. Most people were also well aware of the dramatic spike in global food prices, partly because they could see the effects in their weekly grocery bills, partly because they knew the Australian drought was a contributing factor, and partly because of frequent news stories concerning unrest in several developing countries due to reduced food supplies and high food prices. In summary, climate change was high on the Australian radar screen in 2008.

We took as our starting point a view that, on the balance of probabilities, global warming caused by a build-up of greenhouse gases (carbon dioxide, methane, nitrous oxide, etc.) is now a reality and that this has grave implications for food security. Agriculture, forestry and fisheries are themselves a major source of greenhouse gases, producing about 30% of the annual global total. Deforestation produces very large amounts of carbon dioxide. Agriculture is the principal source of methane and nitrous oxide emissions. Methane is generated chiefly by domesticated ruminants and rice paddy fields, whereas large amounts of nitrous oxide are produced by soils. Also, while it may save water, any proposed shift from conventionally-irrigated rice monocultures to rice–maize rotations and reduced-irrigation rice will have profound effects on soil organic matter and will potentially release large volumes of CO_2. Collectively, the Asia–Pacific region that is the

THE HON NEIL ANDREW was brought up in the SA Riverland, where his family and later Neil had interests in horticulture. He was an active participant in the SA Agricultural Bureau movement, and was Chairman 1980–1982. In 1975, he was awarded a Nuffield Agricultural Scholarship to make an overseas study tour. In 1983, he was elected to the Australian Parliament as the member for Wakefield in the House of Representatives. With changes in the boundaries of his electorate, he later moved to Gawler. He held various positions including that of Government Whip from 1997, and from November 1998 became Speaker of the House of Representatives. Neil retired from that position and from his seat in November 2004. He now lives in Adelaide and became Chairman of the Crawford Fund on the retirement of The Hon. Tim Fischer in June 2005.

focus of Australia's aid program may contribute almost half of the global agricultural emissions.

Conversely, climate change may also have a major impact on agricultural production. Reduced yields of rice and maize at low latitudes are likely to occur and there may be shifts in global cultivation of maize and wheat towards higher latitudes. The centres of genetic diversity of major crop plants will be under even more threat than at present. Extreme events (droughts, cyclones, floods) are likely to become more common. Lowland areas in tropical Asia may be permanently flooded, while in temperate Asia water shortages may become more severe. Livestock production will be affected directly through the effects of higher temperatures on reproduction and health, and indirectly via effects on the distribution of pests and diseases and via the quality of forage available to grazing animals. Fisheries, already under pressure from over-fishing and pollution, will be affected by changes in ocean currents and water temperature. These will affect fish distribution and migration, growth rates, population dynamics and genetic diversity.

These prospective impacts will dramatically change the agenda for international agricultural research during the next decade. Examining these impacts and positioning the research effort was at the heart of our conference.

The conference was opened by The Hon. Tony Burke, Minister for Agriculture, Fisheries and Forestry. It attracted a large audience — about 300 people — and once again we had to close registrations well in advance of the day. The overviews provided by our two keynote speakers, Ms Kathy Sierra and Professor Ross Garnaut, indicated that although the likely impacts of climate change may vary greatly over time and between regions, adaptation to climate change will require the global transformation of food production systems, and this transformation will require a significantly increased and re-focussed international agricultural research effort. Our other speakers covered the impact of climate change on particular industries (crop, livestock and fish production, and forestry), crop diversity, the distribution of weeds and agricultural pests and diseases, and on smallholder production systems in Africa. Peter Core, ACIAR's Chief Executive Officer, then provided a personal view of the way forward in research, and Denis Blight subsequently compiled a synthesis of the salient points of the conference. The conference was authoritative, absorbing, provocative and sometimes disturbing.

The Crawford Fund wishes to acknowledge the following supporters for their important in-kind and financial support for the conference:

- ACIAR — Australian Centre for International Agricultural Research
- AusAID – the Australian Agency for International Development
- Australian Government Department of Agriculture, Fisheries and Forestry
- Australian Government Department of Climate Change
- CAB International
- Center for International Forestry Research (CIFOR)
- International Maize and Wheat Improvement Centre (CIMMYT)
- Consultative Group on International Agricultural Research (CGIAR)
- CSIRO Climate Adaptation National Research Flagship
- Grains Research and Development Corporation (GRDC)
- Industrial Research Limited (New Zealand)
- South Australian Research and Development Institute (SARDI);
- Rural Industries Research and Development Corporation (RIRDC)
- The World Bank.

I hope you find the proceedings of the conference interesting and informative.

The Hon. Neil Andrew AO
Chairman
ATSE Crawford Fund Board of Governors

Agriculture in a Changing Climate

THE HON. TONY BURKE MP
MINISTER FOR AGRICULTURE, FISHERIES AND FORESTRY

International agricultural research

The Crawford Fund has been working on significant issues such as those that are the theme of this conference since 1987, and in DOIng so commemorating the important work of the late Sir John Crawford and his outstanding services to international agricultural research.

The Fund depends on grants and donations — from government agencies, private companies, corporations and charitable trusts. It could not function, however, without the financial support and the time given by individual Australians. On this occasion, I want to particularly thank Bob Clements, the former Executive Director of the Fund, for his energetic leadership of the Fund and the organisation of this conference.

International agricultural research is at the centre of the way we now have to deal with the world food crisis. This crisis is fundamentally different to anything we have seen before. The world food shortage has causes that are different to those that much of the public commentary suggests. The world food shortage has different solutions to the famines of the past.

TONY BURKE was appointed as the Rudd Government's first Agriculture, Fisheries and Forestry Minister in November 2007, following the Labor election win. Since his appointment, he has made it a priority to get out of the office to meet Australia's primary producers and industry representatives in the field. That includes seeing at first hand the impact of climate change and drought on our rural industries and communities. Tony is focused on the job ahead, particularly in ensuring a strong and vibrant future for Australia's primary producers. He was elected to the Australian Parliament in 2004 as the Member for Watson and has served as the Shadow Minister for Small Business and Shadow Minister for Immigration, Integration and Citizenship.

The global food supply

Many times over the past century the global community has had to deal with famine — in Kampuchea, Bangladesh, Ethiopia, Somalia. We saw the population of Mogadishu halve. But these food shortages were always relatively localised.

There was never actually not enough food globally. We were always dealing with problems of particular governments. Problems with lack of governance. Problems in those countries where there was in fact enough food but it simply wasn't being adequately distributed.

The situation is now different.

In past food shortages, the only people who felt the effects were the people in the nation of the famine and the people in wealthier nations who were making individual sacrifices to try to be part of the solution. Now everybody is affected in some way. In the poorest of nations there is just not enough food. In nations that are starting to become a bit wealthier, industries that were working suddenly can't deal with increased input costs.

There have been food riots in many countries over recent months. We see issues like the Government of Haiti falling, specifically over food prices; nations like Thailand earlier in the year having to put out an official call asking people to stop hoarding rice because the interest you could gain from storing rice under your bed was actually the best investment throughout Thailand.

These problems extend to wealthier countries throughout the world where people ask: 'How come the cost of food at the supermarket keeps going up?'

This is an edited version of the Minister's speech

Major influences on food availability

The public commentary on the world food shortage has focused disproportionately on biofuels as a cause. There is no doubt that the transfer of land from the production of food to the production of fuel has meant that a critical point has been reached sooner than would otherwise have been the case — but we have to acknowledge we were getting there anyway.

The fundamental problems are long-term structural ones, and that's why the responses and the solutions have to be different to those of the past. These long-term problems have occurred for a number of reasons, but two stand out: globalisation and climate change.

Globalisation means that when fuel prices and input costs go up, they go up around the globe. Fuel prices affect chemical prices and fertiliser prices. In wealthier nations, the cost of production goes up and that increase is passed through to the consumer. In poorer nations the question starts to be asked: 'To what extent can we continue to afford to produce?' These input costs are having a very real impact and are part of the long-term structural problem.

Food production is intimately linked to climate and climate change. We cannot underestimate the significance of the fact that long-term harvest averages around the world are not what they once were. It's not simply a case of cyclical drought in some countries. The droughts are getting longer, they are getting deeper and the interval between one drought and the next is not nearly as long as it used to be. That, by definition, creates long-term problems for food supply.

Many poorer nations have industrialised much of their economy, but almost without exception have neglected their agriculture sectors. As people have moved to the cities and become wealthier, they seek both more food and more protein in their diets, but supply is not keeping pace. The demand for meat results in transfer of land to livestock, and the land that's available for the cropping of staple food is increasingly growing food for the stock rather than food for people.

These factors indicate that problems were inevitable. Biofuel policies in North America and Europe have exacerbated difficulties, but it would be a mistake to think that a reversal of those policies will resolve the challenges of the global food shortage. It won't.

Responses

The challenges that the world now faces demand that we do exactly the sort of work that the Crawford Fund is doing, plus a whole lot more. The problem is different to that of the past, and we have that problem at a time when global population is continuing to increase significantly.

The solution therefore isn't simply to wind back the clock on biofuels policies, or to provide aid dollars or to support capacity-building in poorer nations. These actions will help alleviate parts of the current crisis, but they won't change the fact that we do have a global food problem.

The provision of aid dollars targeting the areas facing famine is critical — but as a result of rising food and fuel prices our aid agencies are now buying less food with a given amount of money. This was not a problem in the past, because if food was purchased beyond the region of famine the prices were 'normal'. With a global problem, all prices are elevated and therefore the aid effort itself has been blunted.

Monetary assistance

Australia has contributed $30 million to the emergency appeal of the World Food Program to assist in food aid operations, in addition to the $77 million that we gave in 2007–2008. This contribution helped the World Food Program reach its target of $US755 million over two months, a result that indicates that the world is awake to the crisis that we have.

At the same time the World Bank's global food price crisis response program, which is worth $US1.2 billion, is helping stimulate an immediate boost to food supplies, particularly in developing countries. In July of this year the Government announced that it would provide $50 million to the World Bank Trust Fund to stimulate agricultural production in developing countries adversely affected by rising food prices.

Trade

A contribution to alleviating the global food shortage would be to ensure freer movement of food around the world, for example through Free Trade Agreements. The collapse of the Doha FTA negotiations in July is a matter of regret, but Australia is pursuing bilateral agreements. Free trade agreements must cater for genuine social, economic, equity and biosecurity concerns, but they do help to alleviate restrictions on food movement.

The recent positive results of the ASEAN/Australia/New Zealand FTA negotiations are extraordinarily important. This regional agreement, coming as it did so soon after Doha, demonstrates that we are determined to ensure that trade becomes part of the solution of the serious humanitarian problem we face. My recent travels indicate that the significance of the movement of food in the world food shortage is well understood in Papua New Guinea and Indonesia.

Record prices encourage countries to let down their tariff barriers. There is no easier time for nations to do this than when their farmers are receiving high commodity prices — the political difficulties that countries around the world have faced in the past are somewhat alleviated now.

Producing and trading more food

A part of the answer to the world food shortage is to simply produce more food — but there has never been a tougher time to produce more food. Climate change has made sure of that. Input prices have made sure of that. The National Farmers Federation CEO, Ben Fargher, uses the line that we need to get 'more crop per drop', and that research and development is more important than it has ever been.

As a food-exporting nation we can potentially contribute to the response to the challenges now facing the globe. While we need to exploit every opportunity offered by research and development and to open our minds to any avenue whereby we might improve productivity, it will always be important to make sure that we have robust regulation to ensure health standards.

There will be a growing acceptance of genetically modified crops as one piece of the jigsaw in dealing with the challenges of food production in an age of climate change.

The development of biofuels will continue, because these are not the source of the structural issues we face and because there will be economic attractions in biofuels as the oil price continues to rise. We have a responsibility to try to drive research and development in biofuels away from staple food crops as feedstocks and towards either second-generation processes or to crops that are not staple foods[1]. We can make sure that R&D for biofuels complements core work on agricultural production of food, for both Australia and globally.

Discussions of technical market access have to continue. It is important that Australia adopts quarantine procedures that are *seen* to be science-based. That is something I am quite determined will be part of the Government's response to the Beale report on quarantine and biosecurity when I receive it later this month.

Conclusion

All of these issues come together in one simple concept: around the world it is becoming harder for families to feed themselves. That's the core of everything that we are dealing with; the challenges of climate change and globalisation come together in the world food shortage.

All of the work that we are involved in — whether it be the scientific end of straight production, or at the trade end in trying to remove barriers, or at the issues of driving investment — will affect people sitting around tables: in wealthy nations looking at the food bill, or in a poor nation suffering the lack of food.

The work of this conference is an important element of the discussion of the underlying complex issues, far more complex than most people understand.

We want to be part of the solution. We are determined to be.

The work will not wait a moment longer, and I am happy to declare the conference open.

[1] See Brown, A.G. (ed.) 2008. *Biofuels, Energy and Agriculture: Powering Towards or Away From Food Security?*. Record of a conference conducted by the ATSE Crawford Fund, Parliament House, Canberra, 15 August 2007. The ATSE Crawford Fund, Parkville, Vic. vi + 54 pp.

Climate Change, Sustainable Agriculture and the Research Road Ahead

KATHERINE SIERRA

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I feel genuinely honored to contribute to the annual conference of the Crawford Fund. Few organisations have done so much to promote international agricultural research. And few have pursued that aim so persistently.

As this conference makes clear, the Fund continues to show visionary leadership in shaping the research agenda and in mustering support for it — not just in Australia, but also by activities in other parts of the world.

As a Vice President of the World Bank, therefore, and as Chair of the Consultative Group on International Agricultural Research, I especially appreciate having this opportunity to discuss the intersection of climate change and sustainable agriculture, and the implications for the research road ahead, particularly with respect to the CGIAR.

Renewing the research agenda

When the organisers of this conference invited me to attend, they asked me to talk about the need for a *new* agenda of agricultural research. While some elements are new, many items that must appear on that agenda are hardly novel. Rather, they are central components in a longstanding program of research for sustainable agriculture which must be re-emphasised.

Therefore, what is most needed now is a **re-newed** agenda for agriculture research — one that will place sustainable agriculture and the reality of climate change at the forefront of our development thinking.

No one showed a better grasp of the central importance of agricultural research than the Crawford Fund's founding director, Professor Derek Tribe. His 1994 book *Feeding and Greening the World* charted a clear path forward. Yet, just as the journey was getting under way, stagnating support for agricultural research for development drastically slowed its progress.

The results have been made dramatically evident in the past few months as the international community deals with a global food prices crisis. While there were, and remain, multiple factors that led to the crisis, a fundamental element was the lack of capacity to supply more food when the world demanded it.

If there is a silver lining to this food crisis, it is that there is now a heightened awareness among many decision-makers that it was an error to have neglected investing in agriculture research for so long. There is also a greater realisation that agriculture's many value chains for food, feed, fibre and industrial uses all depend on research-based innovation. This was certainly one of the main messages of the World Bank's *World Development Report 2008: Agriculture for Development*, which detailed how much this lack of investment and lack of interest in agricultural research has cost us.

KATHERINE SIERRA, Vice President for Sustainable Development at the World Bank, has overall responsibility for strategies and work in agriculture and rural development, energy, the environment and natural resource management, social development, transport, urban policies and water. She also chairs several international consultative groups, including the Consultative Group on International Agricultural Research (CGIAR). Ms Sierra, an urban planning specialist, joined the World Bank in 1978 and has worked principally in Latin America and East Asia, holding increasingly senior positions in operational units. She served as Vice President, Human Resources (2000–2004) and Vice President, Infrastructure (2004–2006) before assuming her current position.

Climate change and agriculture — making the link

Before describing key features of the renewed agenda in agricultural research, I'd like to emphasise the complex link between agriculture and climate change. You may know that the World Bank Group is just now finalising a Strategic Framework on Climate Change and Development. This over-arching approach will guide our actions on climate change and development for the foreseeable future.

One key area we've focused on is agriculture since it plays such a large role in economic growth and poverty reduction in so many developing countries. The multiple interconnections between food security, energy, security and climate change have become increasingly evident.

Developing countries are likely to suffer the earliest — and the most — from climate change. Fundamentally, for those of us in the international community, the challenge is to help poorer countries grow their economies and improve living standards despite the higher costs of development inflicted by what some are calling 'climate chaos'.

The impact on agriculture

Despite the imprecision inherent in predicting the future, especially regarding global warming, we know that climate change will significantly affect agriculture and forestry systems.

Extreme weather, major changes in precipitation patterns, droughts and flooding will increase in coming decades and will have a major negative impact on land-production systems in some regions. Rising temperatures will create heat stress in some species of livestock and less stable crop yields, and lead to more frequent outbreaks of pests and disease. This will further complicate our efforts to control diseases, including those which are passed directly from livestock to humans and those which move from wildlife to livestock to humans.

Pasture production and grazing lands will also be affected, and the competition between crops for food versus animal feed, already being felt, could be exacerbated.

But the impact of climate change is not always certain — and not always negative. There is some evidence that higher atmospheric concentrations of carbon dioxide could actually increase plant growth and improve water use efficiency, particularly in wheat, rice, soybeans and potato. These results have not yet been verified in the field, where limiting factors such as pests, soil and water quality, and crop–weed competition exist.

We should also acknowledge that agriculture not only copes with the impact of climate change — it is, and will remain, a contributor to it. Agriculture is a major user of land and water resources, and a significant source of greenhouse gases — an estimated 10–12% of all GHG emissions resulting from human activity.

Expansion of the agricultural frontier through land clearing and slash and burn contributes even more, with the total impact of land use and forestry changes contributing almost one-third of GHG emissions in all developing countries.

This indicates that while adaptation to the impacts of climate change is a priority for agriculture, mitigation is also important. We must accelerate our search for new knowledge and technologies in both areas. We must exploit the significant synergies between adaptation and mitigation in agriculture to counter increased risks of climate change impacts.

Finally, the social dimensions of the relationship between climate change and agriculture cannot be ignored either. Farmers, fishers, foresters and herders in the 21st century will need to overcome significant challenges. These will arise largely from the need to increase the global food and timber supply for a world growing to 10 billion people or more, while adjusting and contributing to responses to climate change.

Success in meeting these challenges will require a steady stream of technical and institutional innovations, as well as adaptation and mitigation strategies that are consistent with efforts to safeguard food security and maintain ecosystem services.

CGIAR achievements

Before defining our road ahead, I'd like to mention one or two achievements in agricultural research. They are an indication of the foundation on which renewed research on agriculture and climate change will be built.

Improved seeds for major cereal crops were central to the success of last century's Green Revolution, and they will play a role just as important in this century's revolution in sustainable agriculture. The good news is the advanced guard of a new generation of climate-ready crop varieties is already reaching farmers' fields. Among them is a flood-tolerant variety of rice called 'Swarna-Sub1', developed by CGIAR scientists and their partners. In Bangladesh, it is rapidly displacing a popular but flood-susceptible version of the same variety, which is grown on six million hectares. The new variety enables farmers to obtain yields two to three times those of the susceptible version under prolonged submergence of rice crops.

In another example, more than 50 drought-tolerant maize varieties are already spreading rapidly in eastern and southern Africa. Developed by the CGIAR in collaboration with national partners using farmer-participatory methods, the new varieties are being grown on about one million hectares.

Our future agenda for agricultural research must draw on our experience and take into account the complex and unpredictable nature of climate change, and the agriculture – climate change nexus.

The road ahead for agricultural research and climate change

Looking ahead, there is a huge potential for developing more of these resilient crop varieties, and in a number of areas. There is a huge potential to push the frontiers of agricultural research to respond to climate change: the challenges that threaten and the opportunities that beckon.

Let me outline six areas where our work is leading us:

First, more research is needed to enhance the hardy varieties already available. Tolerance to stresses such as drought, heat and high salinity must be combined with other valuable traits, such as better nutritional quality.

Second, we must increase the flow of hardier varieties for a wider range of staple crops. Rice, wheat and maize are critically important. But the poor also depend on many other cereals, as well as roots, tubers and grain legumes.

Third, to make plant breeding more effective, we must make a more determined push to apply powerful new tools from molecular biology. Molecular genetic maps, for example, together with crop performance data from diverse sites, are critical for identifying areas of crop genomes that are linked to stress tolerance.

This use of new tools for crop improvement must go hand-in-hand with more vigorous evaluation of plant genetic resources. The traditional varieties and wild relatives being conserved are a rich source of genes needed to enhance stress resistance. To date, however, only about 10% of the 600 000 plant samples held in CGIAR gene banks have been characterised.

Fourth, we must focus on under-utilised crops. To adapt effectively to climate change, rural people will need to draw on an even wider range of biological diversity. That is why stronger efforts must be made to explore the commercial and food security potential of under-utilised plants, such as tropical fruits, medicinal herbs and certain agro-forestry species. These plants can play an important role locally in the diets and livelihoods of the poor.

Fifth, the development of hardier crop varieties must form part of an integrated approach, based on prudent management of crops, bio-diversity, soil and water. This will offer farmers their best hope for delivering larger harvests, despite the stresses brought on by climate change.

Developing and promoting integrated approaches for crop and natural resource management is complex, knowledge-intensive work. Taking full advantage of the income-enhancing potential for farmers and workers all along each value chain adds to the complexity — but the returns are substantial.

A notable case is the spread of minimum tillage in South Asia's rice and wheat systems. About a half million farmers now use this resource-conserving technology on more than 3.2 million ha. The resulting economic and environmental benefits are estimated at more than $100 million US annually.

The benefits have come from higher crop yields, lower production costs and large savings in water and energy. In addition, the practice of leaving crop residues in the soil has led to lower greenhouse gas emissions. The success of minimum tillage in South Asia is due in large part to the inclusive style of technological innovation used by CGIAR scientists and their national partners.

Simplified versions of that technology — referred to more broadly as 'conservation agriculture' — are being developed for smallholders in Africa's dry lands. One option centers on the use of so-called 'planting basins.' These are shallow depressions that farmers form in the soil during the off-season. The basins help concentrate moisture and nutrients around the base of the plant. That, in turn, leads to better establishment of improved varieties of diverse crops — such as sorghum, millet and cowpea. Farmers may then further improve soil fertility through cereal-legume rotations, partial ground cover with crop residues, and fertiliser micro-dosing.

An estimated 50 000 farmers have tested the planting basin method so far, mainly in Zambia and Zimbabwe. Although it raises labor requirements this has not constrained adoption, and the method has doubled or even tripled returns on labor. Fertiliser micro-dosing alone has been shown to increase profits from millet production in West Africa by a factor of four.

Sixth, another major challenge for research will be to provide the means to quickly diagnose local conditions and shape new crop and resource management practices accordingly. So accurate and timely diagnosis is important.

In our rush to act on climate change, we run the risk of grasping for simple recipes for success. This thinking would be counterproductive. The impacts of climate change in agriculture will vary greatly over time and across locations. Strategies for adapting to climate change must be carefully targeted.

CGIAR scientists have made great strides in devising tools that make better targeting possible. The new tools consist of geographic information systems linked with computer models that simulate changes in crops, weather and other conditions.

In one pioneering application, CGIAR scientists predicted the impact of climate change on maize production in all of Latin America and sub-Saharan Africa. Another recent study used computer models to predict how climate change will affect 23 staple and cash crops worldwide. Our scientists project that by mid-century the area of land suitable for the cultivation of more than half of those crops will have shrunk, in some cases dramatically.

CGIAR Challenge Program

While these results are impressive, there remain large gaps in our understanding of precisely how and where climate change will impact agriculture, as well as gaps in our ability to finance the necessary research.

One additional creative attempt to fill these gaps which holds great promise is the new 'CGIAR Challenge Program' on climate change, agriculture and food security. The program is being constructed jointly with the Earth System Science Partnership.

The Challenge Program is structured around several major research themes:

- **Assessing agriculture's vulnerability** and using sophisticated research tools to better target interventions;
- **Developing macro policies** to stimulate investment in climate change adaptation and mitigation;
- **Continuing and expanding the dialogue** between researchers and stakeholders on policy and intervention options;
- Thinking through current and future **adaptation pathways** for coping with climate change. One key question for research concerns the institutional arrangements that are needed to deliver information to support risk management, and the options immediately available to support diversifying agriculture;
- **Stimulating research on technologies, practices and policies** that might reconcile conflicting aims. How do we, for example, mitigate the impact of agriculture on climate change, help agriculture adapt to climate change, and also raise rural incomes? Carbon markets could offer rural people new opportunities to achieve both aims by giving them stronger incentives to manage natural resources more sustainably.

Accelerating the agricultural research agenda, however, will take more than one Challenge Program. The six-point plan I listed will require nothing less than a complete revitalisation of agricultural research. All agricultural research actors across both public and private sectors will need to work more closely together if we are to achieve this revitalisation, and truly realise the promise that research holds.

Conclusion

Agriculture has once again come to the forefront of our development agendas at a time when the importance of addressing climate change could not be more pronounced. This is an opportunity to renew both the program of agriculture research and our call for increased action.

By itself, though, the call will remain just that: a plan, an intention. Real progress in dealing with the issues which lie at the intersection of climate change and agricultural policy will depend on decisions and actions taken by many people — including you, whether you are a member of the industrial, farming, scientific, government or civil society communities in Australia.

We can all appreciate that this ambitious and timely CGIAR research agenda will not be easy to implement, nor will it be successful at every step of the way. But we must undertake this journey … for ourselves, for our children, and for the poor of the world in developing countries — and **their** children — who are looking to us to act.

We owe them no less.

Innovative Solutions to New Invaders: Managing Agricultural Pests, Diseases and Weeds Under Climate Change

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Global agriculture is struggling to keep pace with increasing demands for food as human population increases and food preferences alter. Changes in temperature, greenhouse gas concentrations, precipitation patterns and radiation further challenge farmers. Insect and nematode pests, plant diseases and weeds are major constraints to crop production. Developing models to project the potential distribution and abundance of a pest species under various climate change scenarios is essential, and the Australian scientific community has been at the forefront with the development of CLIMEX and its application to modelling some of the world's worst weed species, such as the pan-tropical Asteraceae, *Chromolaena odorata.* CABI is developing tools to assist farmers in coping with these challenges. In West Africa, *C. odorata* promotes other crop pests, such as the polyphagous *Zonocerus variegatus* grasshopper. CABI has developed an efficacious mycopesticide, a formulation of *Metarhizium anisopliae* var. *acridum,* to prevent threats from increasing grasshopper and locust populations.

Climate change models project increased precipitation in parts of the humid tropics. In Central Africa, this will exacerbate yield losses, such as to fungal 'blackpod' disease on cocoa. Farmers currently use contact fungicides, but this strategy will become less efficacious with increasing rainfall. CABI and partners are identifying endophytes, such as *Trichoderma*, as biocontrol agents to deal with this threat.

TREVOR NICHOLLS joined CABI in 2005 and has restructured the organisation to deliver clearer strategic focus and customer orientation, resulting in three consecutive years of operating profits and the elimination of a £7 million debt burden. Prior to joining CABI, his career covered 25 years experience of building international businesses in the life science industry, with a focus on genomics, in major pharma, biotech and academic clients. He has broad experience of initiating change and restructuring organisations, ranging from start-ups to FTSE 100/Nasdaq-quoted companies. Trevor holds a BA and DPhil in biochemistry from the University of York and diploma qualifications in marketing (CIM) and company directorship (IoD).

Other pests will become more damaging as temperatures increase. Populations of banana root nematodes increase with increasing temperatures and cause greater root damage. Furthermore, some species will spread to higher altitudes at which they are currently absent. CABI's Global Plant Clinic advises farmers on how to minimise damage from such pests. These examples of CABI's work are described in more detail below.

Introduction

The 2007 report of the Intergovernmental Panel on Climate Change (IPCC) confirmed many of the trends they had predicted in 2001. Atmospheric concentrations of greenhouse gases (CO_2, N_2O, CH_4) are continuing to increase. By the end of the 21st century, global average air temperatures are projected to rise by 1.8–4.0°C (IPCC 2007). This alters the hydrological cycle as the water-holding capacity of air increases by about 4% per degree Celsius. Boko *et al.* (2007) project increased rainfall in West Africa, although the distribution will not be even. Dry areas will become drier and humid zones wetter, resulting in more abrupt ecoregional transitions and closer isopluvials. Similarly, since the 1950s, north-western

Australia has become wetter while southern and eastern areas have become drier (Smith 2004). However, there is disparity between different global models as projections depend on the extent to which feedback from vegetation changes is taken into account.

There is strong evidence that more extreme weather events will occur (IPCC 2007). According to an index based on the total dissipation of power over the lifetime of a cyclone, tropical cyclones have become more destructive in the last thirty years (Emanuel 2005; Man and Emanuel 2006). This has had notable economic impacts on tropical crops, including the devastation of the northern Queensland banana crop in 2006 by Cyclone Larry, and Hurricane Dean destroying bananas worth A$300 million in Martinique in August 2007. Such disturbances, in tandem with increases in international trade, create a plethora of opportunities for pest introduction and favour rapid colonisers (r-strategists).

Over 70% of the world's food comes from just nine crops (rice, wheat, maize, potato, barley, cassava, soybean, sugar cane and oats), each of which is cultivated far beyond its natural range. The IPCC (2007) summarised 69 studies on the effects of higher temperatures on three of these: rice, wheat and maize (Fig. 1). While mild warming is projected to result in initial increases in crop yields in the temperate regions, when temperature increases exceed 3°C, yields will decline. Most disturbingly, any increase in temperature is projected to cause yield decline in the tropics, even for maize and rice, whose centres of origin are in or close to the tropics as they are already near the upper limits for optimum growth. These models do not take into account any increase in crop losses due to increased pest damage, and the effects of climatic change upon crop-pest relationships is largely unknown.

We will discuss three examples of CABI's work spanning the research–development spectrum: developing innovative methods to replace older control strategies that are less effective under climate change; technologies to control pests that are likely to be favoured by climate change; and the use of some commercial biopesticides to tackle pests whose range is expanding.

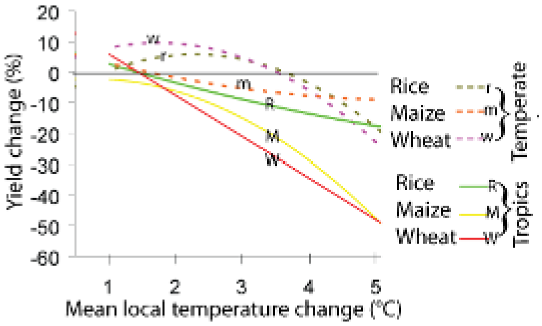

Figure 1. Effects of temperature change on yields of maize, rice and wheat grown in temperate and tropical conditions. Adapted by Norgrove from IPCC (2007), summarising 69 studies.

Novel biological control agents for cocoa blackpod disease

Theobroma cacao, the raw ingredient for chocolate, is an understorey tree, native to the forests of South America yet grown throughout the humid Tropics. World cacao production is about 3.5 million t y^{-1}, 90% of which is grown in Côte d'Ivoire, Ghana, Indonesia, Nigeria, Cameroon, Brazil, Ecuador and Malaysia, where millions of smallholder farmers depend on the revenue. Globally, some of the major constraints in cacao production are fungal diseases: blackpod caused by *Phytophthora*, predominantly *P. palmivora* and *P. megakarya*; frosty pod (*Moniliophthora roreri*); and witches' broom (*Moniliophthora perniciosa*). Witches' broom had devastating effects in Brazil in the 1990s. Globally, blackpod is the major biotic yield constraint, resulting in estimated losses of 450 000 t y^{-1} (Bowers *et al.* 2001).

While *P. palmivora* is cosmopolitan, *P. megakarya* is not known outside Africa. It was first identified in Nigeria in the 1970s (Brasier and Griffin 1979) and is now common in Cameroon and Gabon. *Phytophthora megakarya* has been isolated from fruit of a native *Irvingia* sp. tree in ancient primary forest near the Nigeria – Cameroon border (Holmes *et al.* 2003) so it may have shifted host and be a new-encounter pathogen. *Phytophthora megakarya* has invaded Ghana (Kebe *et al.* 2002) and is now spreading west into Côte d'Ivoire, threatening the region's largest cocoa producer. *Phytophthora megakarya* sporulates more abundantly than *P. palmivora*. The soil-borne phase of the *P. megakarya* disease cycle causes root infection, maintaining a reservoir of inoculum during the dry season, releasing zoospores into the soil surface water when rains start (Opuku *et al.* 2007). The soil is therefore the primary inoculum and disease tends to progress from pods at the bottom of the trunk and later into the canopy (Opuku *et al.* 2007).

Current control strategies include cultural methods, and fungicide use. Cultural methods aim to reduce inoculum and alter microclimatic conditions. Phytosanitary harvesting is the removal of mummified husks before the beginning of the rainy season and, thereafter, visibly diseased pods from the farm on a weekly basis. Other strategies are branch pruning, removing water shoots and eliminating shade trees. While phytosanitary harvesting and pruning can minimise yield losses from *P. palmivora*, these measures alone result in negligible yield in *P. megakarya*-infected areas (Opuku *et al.* 2000; Norgrove 2007a). Copper (I) oxide fungicides are applied using side-lever manual knapsack sprayers to treat trunks, pods and leaves up to 12 times per year. Alternative fungicides include contact cupric and copper hydroxide preparations, and the systemic potassium phosphonate, which is injected into the trunk and translocates in the xylem and phloem (Opuku *et al.* 2003). CABI and partners have been working together with cocoa farmers to promote more effective control methods, including rational fungicide use, improved sprayers and spraying techniques (Bateman 2004).

Yet projected higher temperatures, humidity or precipitation in some parts of the humid tropics, including the west African cocoa belt, will generally exacerbate yield losses as these factors promote fungal disease. For *P. megakarya* growth, temperatures above 26°C are reported to be sub-optimal (Brasier and Griffin 1979), so aggressiveness might reduce as climate change advances. However, higher precipitation will result in greater run-off of the fungicide, requiring either better formulations or more frequent spraying, further reducing profitability. So alternative control methods are necessary.

CABI, together with USDA and other partners, have been searching for endophytic *Trichoderma* fungi, plant symbionts that can protect their hosts from diseases through various mechanisms: competitive exclusion; antibiosis; induced resistance and mycoparasitism. *Trichoderma* spp. that exhibit these properties and colonise cocoa tissue are being collected, isolated and screened for potential as biocontrol agents (e.g. Bailey *et al.* 2008).

Dealing with greater pest pressure on *Musa* spp. through integrated pest management

Musa spp., comprising banana, plantain and highland banana, are grown by subsistence farmers across three continents within a diversity of cropping systems. *Musa* spp. are prone to pests and diseases, partially because genetic variability within the population is low. *Mycosphaerella fijiensis* (Morelet) fungus is the causal agent of black sigatoka, a major constraint to *Musa* production in lowland tropical humid areas. It originates from the Pacific, but is now prevalent throughout the tropics and can cause 40% yield loss due to incomplete finger-filling. Black sigatoka infection starts as dark streaks visible on the lower leaf surfaces, which form black lesions on both leaf surfaces and then become necrotic, destroying large areas of mature leaf tissue (Waller *et al.* 1993). It is spread by wind-dispersed ascospores (sexual) and conidia (asexual) and thus is beyond the control of plant quarantine measures. In upland areas, the less virulent yellow sigatoka (*M. musicola*) is more prevalent.

Musa spp. host a complex of root nematodes that destroy root tissue, increasing the risk of toppling, particularly after the bunch has emerged. *Radopholus similis* (Cobb) Thorne is the greatest cause of yield loss in *Musa* worldwide. The genus *Radopholus* is indigenous to Australasia (Sher 1968) yet is now cosmopolitan throughout the tropics. It is a pioneer root invader (Quénéhervé 1989) and can complete its life cycle without a soil phase. Infestation levels in the soil are lower than for other nematodes (Quénéhervé 1989) and populations within roots usually decline with time as *R. similis* is displaced by other nematode species (Bridge *et al.* 1995).

So what will be the impact of climate change on this suite of pests and consequently *Musa* yields? Black sigatoka may expand its range and spread to the highlands currently free of it and replace the less-virulent yellow sigatoka. *Radopholus similis* is sensitive to temperature and is currently absent at high altitudes and latitudes. In a global study, Fallas and Sarah (1995) compared growth of seven *R. similis* isolates from different parts of the humid tropics. They compared multiplication at 21°C, 24°C, 27°C, 30°C and 33°C, finding that the 30°C treatments had the greatest final population for all the isolates. In a similar study, Pinochet *et al.* (1995) compared in-vitro reproduction at 16°C, 21°C and 24°C. They found that reproduction was greatest at the highest temperature and at 75 days after commencement, the final population was nearly 16 times greater at 24°C than at 21°C. In a field study in Central Africa, there was a significant positive relationship between root damage by nematodes and soil temperature (Norgrove and Hauser, unpubl.). Combining these data, within its current range, increases in temperature up to 30°C will result in increased nematode populations, greater root damage and more crop losses (Fig. 2). Increases in temperature at higher altitudes will permit *Radopholus similis* to survive and reproduce in areas currently free of it.

CABI's Global Plant Clinic promotes integrated pest management to farmers, including methods to reduce damage from *Radopholus* and other nematodes. These include using clean planting material, such as suckers that have been immersed in hot water, tissue culture plantlets or carefully pared suckers. Some nematode species survive and reproduce in old corm material so this should be removed from the field at the end of the crop cycle. For species that have a soil phase and can survive without their host, it is advised to use crop rotation with non-susceptible crops or to leave land fallow for at least three years.

Interactions between changing climate, weed distribution, insect pests and crop diseases

Chromolaena odorata, or Siam weed, is native to South America, invasive throughout the tropics and a serious weed in cropped fields, timber plantations and pastures.

CLIMEX$_{TM}$ (Sutherst *et al.* 2007) uses IPCC models plus precipitation, vapour pressure and temperature data to project climate change surfaces for global weeds, including Siam weed. CLIMEX predicts that in Australia its potential range will extend south into coastal New South Wales by 2080, and in West Africa that the range will expand east to Central Africa and beyond (Kriticos *et al.* 2005). While there have been some biocontrol attempts in Papua New Guinea and in Ghana, this method is contentious in West Africa where many farmers perceive Siam weed positively as it outcompetes the more difficult-to-manage *Imperata cylindrica* (Norgrove 2007b).

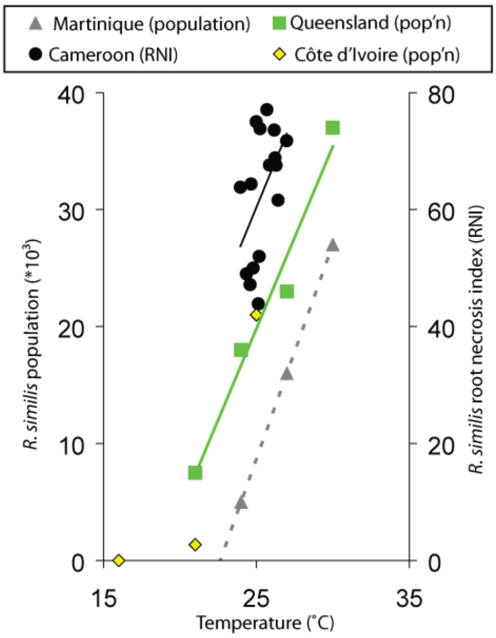

Figure 2. Temperature effects on *R. similis* populations and root necrosis indices in *Musa* spp. Data from a field study in Cameroon (Norgrove and Hauser, unpublished) and from controlled lab studies elsewhere (Fallas and Sarah 1995; Pinochet *et al.* 1995). Treatment means presented. All data significant at $P<0.05$.

So while Siam weed may have some redeeming qualities, it has other complex impacts. It is an attractant for the African grasshopper *Zonocerus variegatus*, which sequesters the pyrrolizidine alkaloids of *C. odorata*, protecting itself from antagonists and increasing its population (Fischer and Boppré 1997). *Zonocerus variegatus* is polyphagous, defoliating maize, cassava and other food crops (Le Gall *et al.* 2003), particularly during the dry season. Increases in *Z. variegatus* populations have been linked with the increasing cover of Siam weed in West Africa. As well as being a pest in its own right, it transmits cassava bacterial blight, one of the major cassava diseases in the region.

In the 1990s, CABI developed the 'LUBILOSA' project which culminated in the formulation of Green Muscle$_{TM}$, a biopesticide now being produced commercially in South Africa. Green Muscle is highly effective against grasshoppers and locusts, including *Z. variegatus*. It is transmitted between individuals aided by their gregarious behaviour. This is one 'off the shelf' technology that could be used to manage this increasing problem which is exacerbated by both land use and climate change.

Conclusion

In the light of climate change, there is much uncertainty about abiotic changes in the environment. The interactions between these, crops and their pests are hard to predict. However, minimising crop losses in this period of food insecurity is essential. To adapt to this uncertainty and to reduce risk, while smallholder farmers in the tropics should be encouraged to adopt innovations that minimise losses and increase yields, they should still maintain the richness and diversity of their traditional cropping systems. Farmers currently change the mix of their cropping systems on an annual basis. For example, if the rains are late, they reduce their investment in three-month crops such as groundnut and maize and increase investments in crops such as cassava, the tubers of which can be left in the ground for a variable time. Conversely, if rains are early they will shift focus to the cereal and leguminous crops, which have a higher protein content.

CABI will continue with fundamental research, developing technologies and advising vulnerable farmers in their IPM choices in the light of the new challenges posed by climate change in our member countries. We will drive the sustainable agriculture and climate change agenda through our innovative approach of knowledge, research, capacity building and action at a local level.

Acknowledgements

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Conserving Crop Biodiversity: Navigating Politics and Climate Change to Create a Global System

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A couple of months ago a journalist from a magazine asked me to name the five most important or influential books in my life. I had to start off with a little book called *Zeek the Rabbit* which hooked me on reading when I was about seven or eight years old, and that left me four more slots. One of those slots I gave to a remarkable book that I keep going back to over and over again. It's a haunting and informative book called *Feeding the Ten Billion* written by an Australian plant physiologist named Lloyd Evans. Lloyd looked at different moments in human history, going all the way back to when the population was five million and then 50 million, 100 million, a billion, 2 billion, and 3 billion. He asked what kind of food system was in place for each of those periods and how the way in which people procured or produced food had changed as the population grew, as the technology changed and as the environment changed. Today, as the population races along towards the nine billion expected in 2050, this is a question that should be examined. Just as important, perhaps, as asking how are we going to feed two and a half billion more people on planet earth, is asking how are we going to deal with an extra two degrees of temperature, or more.

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The challenges for agriculture — and us

Agriculture is facing an unprecedented combination of challenges. Water withdrawals from lakes and waters have doubled since 1960. The overdraft of aquifers is 25% in some places in China; 50% in some places in India. Each aquifer essentially has its own countdown to extinction, and global demand is increasing. Energy consumption now exceeds discoveries — which peaked in 1960 — by a factor of four. Half of the commercial nitrogen fertiliser that has ever been applied to our farms has been applied since 1985 — and nitrogen fertiliser is based on natural gas, which is linked to oil, so we have to question both availability and price. Then there is population growth, the development pressures spoken about by Minister Burke, low stockpiles, and the real killer, chronic under-investment in agriculture research. What a combination! And that's given us high prices that can only get higher unless we smarten up.

Climate change

Let me focus first on climate change. Twelve of the hottest years on record have all occurred since 1990. We have been working with climatologists at Stanford University and University of Washington, and the Bureau of Meteorology in Melbourne, to ask how climate change is going to affect — or should affect —how we manage our collection of crop diversity.

Examples

The graphs in Figure 1 display average temperatures for two countries, Nigeria and Thailand. The bell-shaped curves formed by the blue columns display the average summer temperatures over the last hundred years. The curves formed by the red columns give the projected temperatures for about 2080 onwards as derived from the mean of the different IPCC climate studies.

Note that there is virtually no overlap between current and future temperatures. In historical terms, this means that the hottest growing seasons of the past hundred years or so would in the future become the coldest growing seasons. The conditions that have caused problems lately during hot growing seasons will in the future seem like good years.

Taking a long-term view, present-day agricultural systems and crops have been adapted to specific regions with particular climates since Neolithic times. Many crop varieties, handed down from generation to generation, have been adapted to climates that are about to become extinct themselves. These particular country examples are not exceptional; the shift in climates will likely be significant in most parts of the planet. Of course climate change will be gradual, but the effects are already becoming visible.

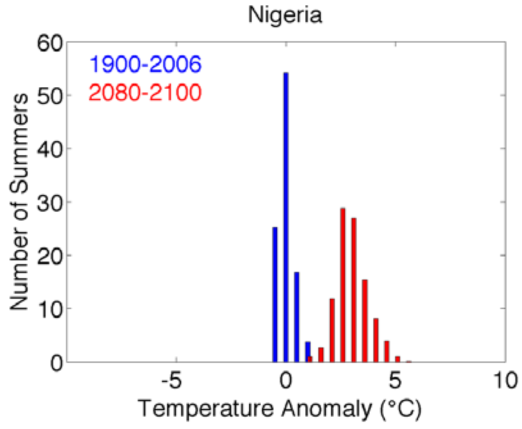
If we have the same varieties of corn in the fields in South Africa in 2030 — which is about two crop breeding cycles away — as we do today, the projection is that we will have about a 30% decrease in corn production.

Economists, seeing that we have had a certain increase in production every year in the past, will project that there ought to be a 30% increase in production by 2030.

Instead of the 30% increase, however, there may well be a 30% decrease because of climate change. People will starve to death in southern Africa unless we do something — and do something rather quickly. Two breeding cycles away is really not a terribly long time.

Human settlements of the past

Societies that decide that they can battle the climate and ignore climate change tend to suffer



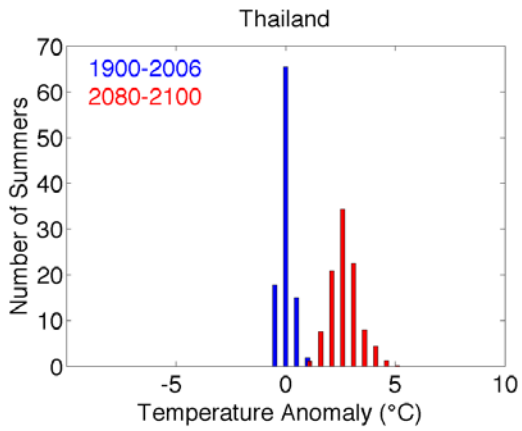


Figure 1. Distributions of (summer) growing season temperature against climate model predictions (Source: Naylor, R. and Battisti, D. 2008, pers. comm.)

the consequence. Figure 2 shows a church built by the Norsemen in Greenland. The last wedding ceremony was performed in this church in 1408. Some time in that century the Norsemen disappeared in Greenland. They disappeared because they didn't want or know how to adapt to climate change; the climate was getting colder and they wanted to continue to raise cattle which didn't do very well in those temperatures. The Inuit did adapt to the change, and are still in Greenland. The Norse now visit as tourists.

Options for feeding the world

Lloyd Evans writes that there are about six ways of increasing production, and that historically the most significant way has been to cut down trees to expand cropland. Globally this is becoming less and less of an option.

But something remarkable has happened since the mid-1980s. For the first time in all the history of agriculture dating back to the Neolithic we have started to produce more food principally by intensifying production through genetics and through inputs rather than through expansion of cropland. The question is whether we can continue to run faster and faster, to keep up or perhaps get ahead. The answer, or at least the key to answering that question, lies in crop diversity.

Figure 2. A church abandoned in Greenland some 600 years ago due to climate change

Genetic diversity is the key

Figure 3 shows just a couple of kinds of beans — they are pretty, but more importantly they have unseen diversity. There are about thirty thousand different varieties of beans, perhaps two hundred thousand varieties of wheat, and even more varieties of rice. These varieties are more than just beautiful, and more than just an historical library of the past of agriculture. They are the result of adaptation — not just to climate change but also to past diseases, droughts and the myriad environmental conditions on the planet.

Figure 3. Great diversity is evident in this sample of beans

There is no more important natural resource on earth for humans than crop diversity. There is also no resource upon which nations and people are more interdependent. This interdependence is worldwide — data indicate that Italy where I now live and Ghana are equally dependent on crops that originated outside those countries. The dependence is at the varietal level and at the pedigree level of our modern crop varieties. Luckily, along with being the most important resource, crop diversity is among the easiest and cheapest to conserve. It's a matter of freezing seeds. Despite the simplicity, though, we have no efficient coordinated global system for conserving this most valuable natural resource.

When a cyclone put about a meter of water and mud into the Philippines National Gene Bank in September 2006, destroying a number of distinct unique crop varieties, a number of varieties became extinct because of the absence of an effective global storage system.

The resources that became extinct that day in the Philippines may be exactly the resources needed in the future to breed a climate-ready crop in Australia, in Ghana or elsewhere. Now more than ever before we are our brother's keeper. What happens in other countries has to be of concern to us, if nothing else out of self-preservation.

The cost of conserving this diversity is so small and the benefits so incredibly large that not conserving it is really just beyond imagination. So what do we do? We cannot simply talk about the need to adapt to the challenges that lie before us. Short-term thinking has lead to long-term problems that are not going to be corrected by more short-term thinking or short-term approaches.

Investment in conserving, managing and developing crop diversity is going to be an early indication of how serious countries are in meeting the pledges made in the recent food summit to strengthen food security. Crop diversity is going to be the canary in the coal mine because it is the biological pre-requisite for adaptation and improvement.

My dream is that all crop diversity is stored safely and securely in two gene banks as well as at the Svalbard Global Seed Vault, and be freely available without political, legal or practical constraints. I cannot imagine any effective and sustainable solution to climate change or to water problems or energy problems without crop diversity. I invite you to consider that.

The Global Crop Diversity Trust

This is why the Global Crop Diversity Trust was created a few years ago. We are structured as an endowment fund and our mandate is to help create a global system that will conserve unique diversity in a cost-effective manner, not for 49 out of 50 years but for 50 out of 50 years.

The Svalbard Global Seed Vault

Of course every great dream or scheme or plan needs a fallback plan, a plan B, an insurance policy. That is what we have tried to provide in Svalbard, Norway, in a group of islands located far off the northern mainland coast of Norway. To go there you fly to a town called Tromsø in northern Norway and then on another plane fly an hour and a half further north to a location at about 78° north. This is a remarkably beautiful place, unique in the world. There are big glaciers. Of course there's climate change, so there are fissures in the glaciers, which may reach 100 m tall or more. There is also a small Norwegian village called Longyearbyen of about fifteen hundred people that provides excellent infrastructure. It is near this village that we find the Svalbard Global Seed Vault. The Vault was constructed and paid for by the Government of Norway. The entrance is via a tunnel that goes about 130 m inside a hill, where there are three vaults for storing seed. Together they have the capacity to store 4.5 million samples.

We have gone to Svalbard because it is remote. An insurance policy for seeds must survive storms, equipment failures, fires, wars and all the kind of things that sometimes destroy the collections and buildings that we call seed banks.

The location is in fact remote but accessible: remote to give safety, accessible to enable seeds to be moved in and out. And it is cold — naturally cold to avoid dependence on mechanical freezing equipment.

Each of the vault rooms is capable of storing one and a half million seed samples, with about 500 seeds per sample. One and half million is the number of total varieties worldwide we think actually exist. This is a building for the future; it has three times as much space as we think we'll need , and so we don't plan on the facility being full any time soon. We have about 350 000 different varieties of seeds stored there now.

A broader system

The Svalbard Global Seed Vault forms only part of a rational global system for conserving and using crop diversity. Had it been built ten years ago it would probably have been used ten times already to restore seeds to seed banks because the conditions in normal seed banks are so deplorable in so many countries.

We really have to prepare for the storm that is coming. With support from Australian Grains Research and Development Corporation (GRDC) the Trust has mobilised scientists and specialists worldwide to develop crop strategies that identify the most genetically important collections in the world. We know now what remaining diversity needs to be collected. We know how to conserve it, and we have begun to make long-term conservation grants that secure the most important collections — fifteen crops at the moment. We have a competitive grants program for screening the collections for useful traits, and we have another program for rescuing collections that are in bad shape — principally in developing countries. We think that between 100 000 and 150 000 distinct crop varieties will be rescued in the next couple of years.

We need to develop new information systems. We've given a couple of grants to create an amazon.com or a google.com for plant breeders, so that in the future if you are trying to breed climate-ready crops you can find the genetic resources you need by searching through all the collections around the world rather than just your home gene bank.

Conclusion

We face a major world problem if we don't conserve crop diversity. But we can conserve it — this is a problem we can solve. We don't need recourse to technology that has not yet been invented. The technology we need is something that you have got in your kitchen, it's called a freezer.

We need, however, to build the endowment fund and put together the institutional arrangements to make sure that this diversity is conserved for as long as we think we are going to need agriculture.

In the face of all the different challenges that we have with agriculture now we must choose our goals wisely and make those goals worthy of who we are and who we want to be.

I feel incredibly lucky to work in this field. I've had a charmed and very lucky life. Having worked on the Seed Vault and at the Trust with many wonderful people, I think of the lyrics from an old song:

> *… somewhere over the rainbow skies are blue, and the dreams that you dream really do come true.*

I know that dreams don't come true unless they are shared by a lot of people. So I want to end by saying that the Trust has had enormous critical visionary support from AusAid, from GRDC, from the Crawford Fund, from DAFF — I can't thank you enough.

Last but not least, I want to join the long queue of people recognising an individual here from whom we have had steady and substantial support — Bob Clements.

Thank you all very much.

Helping Small-Holder Farmers Deal with Climate Change

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Agriculture is a major activity and land use across the developing world; it is vulnerable to changes in climatic conditions. Climate change affects agricultural systems and production in various ways, for example by changing agro-ecological conditions. Changes in the pattern and amount of precipitation, as well as temperature, can directly affect the suitability of cultivable land for agricultural production, food supplies and food utilisation. Climate change can affect food security, depending on the region and the socio-economic status of the country involved. The poorest and food-insecure regions such as sub-Saharan Africa are expected to be most vulnerable to climate change. Overall, the adversities of climate change will disproportionately affect the small-holder poor who largely depend on agriculture and who have limited resources to cope with or adapt to climate change. More than 85% of the world's land-users are classified as small-holders, with farm sizes of less than 2 ha. The impacts of high temperature, variability in precipitation patterns, and events such as severe and frequent drought and floods will most likely enhance production risks for these farmers, further widening the gap between the rich and the poor. Adverse impacts of climate change on the poor may be reduced through appropriate policies such as investment in infrastructure, adoption of sustainable agricultural and natural resource management practices, and advanced technologies that can generate climate-resilient crop varieties and better-adapted livestock breeds. Examples of some of these advanced technologies are described in this account.

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The context

Agriculture is undoubtedly the single most important sector in the economies of most low-income countries, accounting for one-fourth to one-half of the gross domestic product (GDP) and the bulk of export earnings. About 75% of Africans depend solely on income from agriculture and agribusiness, which, in turn, provides 40% of the GDP of African nations (Machuka 2003). Production is subsistence in nature, with a high dependence on rain. Poverty is higher in most African countries than elsewhere in the developing world, and highest in rural areas. Crop yields are stagnant and production struggles to keep up with population growth by expanding land under agriculture, but the area of land suitable for agriculture is not unlimited. Therefore, accelerated growth in agriculture, with concomitant increases in incomes, is needed to sustain growth, to raise food-purchasing power and to reduce poverty. Poor people's links to the land are critical for sustainable development. The front line of any successful assault on poverty and environmental degradation must therefore have a focus on agriculture and rural development (Kelemu *et al.* 2003).

A major challenge for Africa is to feed its growing population. During the last two decades of the 20th century, the per-capita food production in Africa declined (Machuka 2003) because of dropping agricultural productivity and rapid population growth. Decline in agricultural productivity was associated with several biophysical and socio-economic factors, including an inability to replenish declining soil fertility; use of poor quality seeds and low-yielding crop varieties; recurrent drought; inability and lack of resources to control large yield losses to pests, diseases and weeds; limited access to and participation in local, regional and international markets; lack of, or ineffectual, implementation of supportive policies to boost agricultural production; poor infrastructure; and, particularly today, immense healthcare problems.

Africa's current population is projected to rise to 1700 million by 2050 (Pinstrup-Andersen and Pandya-Lorch 1999). Demand for imported food — mostly cereals and legumes — will increase from 50 to 70 million tons per year. If the current economic situation of Africa does not improve, food-deficit nations are unlikely to have the resources to purchase such a huge quantity of food on a commercial basis.

Agricultural productivity can be increased sustainably in numerous ways, such as using inorganic and organic fertilisers; improving disease, pest and weed control; practising soil and water conservation; and using improved crop varieties developed either conventionally or through biotechnology. Most remarkable is the unsatisfactory performance of agriculture in sub-Saharan Africa, especially when contrasted with parts of Asia and Latin America. There is a clear direct link between crop yields and poverty. For example, in the mid-1980s, cereal yields were comparably low and poverty was comparably high in sub-Saharan Africa and South Asia. Some fifteen years later, yields had increased by more than 50% and poverty had declined by 30% in South Asia. In sub-Saharan Africa, however, yields and poverty were static during the same period, making the issue of food security a major challenge for the continent (World Bank 2008).

Many of the countries in sub-Saharan Africa are too small to sustain effective agricultural research systems or to have a critical mass of agricultural research scientists. Because of small country size, agricultural research systems in sub-Saharan Africa are fragmented into nearly 400 distinct research agencies, almost four times the number in India and eight times that in the United States (Pardey *et al.* 2006). Funding per scientist is also low. With nearly 50% more scientists than India, and about a third more than the United States, all of sub-Saharan Africa spends only about half of what India spends and less than a quarter of what the United States spends (Pardey *et al.* 2006). It is important to note, though, that only a quarter of Africans classified as scientists have a PhD, compared with all or most scientists in India and the United States. All these factors hinder improvement in agricultural research and development. To prevent future human catastrophes, African countries will have to increase public spending in agriculture, develop and implement strategies for increasing agricultural productivity, and adopt technologies that can help cope with the negative effects of climate change, protect the natural resource base and tackle poverty as a whole.

Climate change and its unique challenge for African food security

Agriculture is vulnerable to the impacts of climate change that include increases in temperature, decreases in rainfall and increased frequency of extreme weather events, such as drought, fire and flooding over much of Africa and parts of Asia (Schmidhuber and Tubiello 2007). More climatic variability and extreme events will pose challenges for farmers, particularly small-holders with little or no capacity to cope with these changes. More than 85% of the world's land-users are classified as small-holders with farm sizes of less than 2 ha (FAO 2005). Improving the performance of agriculture as the basis for economic growth, and reducing poverty and food insecurity in agriculture-dependent developing countries requires a productivity and natural resources management focus on small-holder farming (World Bank 2008).

The climate in Africa is largely tropical in nature, which is classified into three major climatic zones: humid equatorial, dry and humid temperate. Within these zones, however, altitude and other localised variables generate distinct regional climates. Climate change, especially manifested by prolonged drought, is one of the most serious climatic hazards affecting the agricultural sector of the continent. As most of the agricultural activities in the majority of African countries are rain-fed, any adverse changes in the pattern and amount of precipitation would have a devastating effect on the sector in the region, and on the livelihood of most of the population. Variability is expected to increase, including frequent occurrences of extreme events particularly in marginal rainfall areas (Nkomo *et al.* 2006).

Drought is perhaps the most dramatic limiting factor to crop and animal production on a global scale, and the situation is expected to deteriorate in Africa. The current trends in land degradation, desertification and climatic variability have been predicted to intensify. The erratic rainfall across seasons, poor soil-water-holding capacity and poor management of water resources have led to drought occurring frequently. In the last two decades, droughts occurred in 1983–1984, 1991–1992, 1995–1996, 1999–2001 and 2004–2005 in parts of Africa with significant impact on human, animal, vegetation and other resources. The debate on climate change and its impacts on agriculture are, therefore, crucial to the very survival of the African continent and its people. The continent is particularly vulnerable to climate change because it consists of some of the world's poorest nations.

The impacts of climate change on agriculture also have the potential to exacerbate other natural resource management challenges in Africa. Examples of aggravated natural resource management challenges include increased soil erosion, increased incidence of wind and rain events; and increased incidence of certain weeds, pests and diseases. In addition, long-term changes in climate, water supply and soil structure and moisture could make it difficult to continue crop and animal production in certain severely affected regions.

As a continent, Africa has vast natural resources including wildlife, plant and animal genetic diversity. Over generations, Africa has contributed greatly to the world's agriculture as a centre of origin and diversity for some important crops and animals, and by supplying unique sources of resistance to diseases and pests of crops and other organisms of African origin (Kelemu *et al.* 2003). These plant and animal genetic resources are also vulnerable to adverse changes in climate, thus potentially depriving Africa and the rest of the world of this natural wealth.

Agriculture in the developed world is widely expected to be less vulnerable to climate change than agriculture in the developing countries, particularly those in the tropics. The poor developing countries are more vulnerable because of:

- their heavy dependence on agriculture and lack of economic diversification
- low income and high levels of poverty
- farming practices in marginal rainfall areas
- lack of advanced technologies to enhance production to keep up with population growth
- soil degradation
- generally poor infrastructure.

All of these factors collectively lead to low adaptive capacity. The effects of climate change will largely depend on the agricultural sector's ability to adapt through changes in advanced technologies and environmental conditions. Adjustment of agricultural management practices, and access to and adoption of various technologies, can help farmers adapt to climate variability.

Dealing with climate change: advanced technologies

There is no doubt about the impact of climate change on agriculture. Farmers know this better than anybody else. Adverse impacts of climate change on the poor may be reduced through appropriate policies such as investment in infrastructure and education, increased investment in agricultural research and development, implementation of sustainable agricultural and natural resource management practices, and advanced technologies that can generate climate-resilient crop varieties and better-adapted livestock breeds along with conditions for optimal production.

One such advanced technology that can help farmers deal with climate change is agricultural biotechnology. The potential role of agricultural biotechnology, particularly genetically modified crops and animals, in improving the livelihoods of the poor is being debated vigorously. Many biotechnology products are being developed in various countries for different uses. These products include modified plants for food and fiber, animal feed, medical care and bioremediation. I do not wish to imply that agricultural biotechnologies will, singlehandedly, solve Africa's agricultural production constraints and make Africans self-sufficient in food, or completely solve the impacts of climate change. While recognising the potential, genetically modified crop varieties — just like those developed through conventional breeding strategies — must be combined with other appropriate and optimal management practices for satisfactory production.

Data provided by the International Service for the Acquisition of Agri-biotech Applications (ISAAA) show that in 2007 (the twelfth year of commercialisation of genetically modified crops (GMC) or biotech crops), 23 countries adopted biotech crops, planting a total of 114 million ha of land (James 2007). Of these, twelve are developing countries, namely Argentina, Brazil, Chile, China, Colombia, Honduras, India, Mexico, Paraguay, Philippines, South Africa and Uruguay. According to this ISAAA report, during these first 12 years (1996–2007), biotech crops have provided substantial economic and environmental benefits to farmers in both developed and developing countries.

The accumulated area under biotech crops from 1996 to 2007 was 690 million ha, with the 67-fold increase between 1996 and 2007 making this the most rapidly adopted crop technology in recent history (James 2007). Furthermore, of the global total of 12 million farmers who adopted biotech crops in 2007, about 11 million were small-holders (most were growers of Bt cotton for insect resistance). South Africa is the only African country which commercialised biotech cotton, maize and soybeans, often grown by subsistence women farmers.

To make an impact in Africa, biotechnology research must be pro-resource-poor farmers and pro-women and children, target crops that African farmers traditionally know how to grow, and address agronomic traits of significant importance to their needs (Kelemu *et al.* 2003). Food shortages in Africa are often strongly associated with environmental calamities. The major abiotic stress factors affecting food production in sub-Saharan Africa are low soil fertility, drought, salinity, soil acidity and heat stress.

Scientists around the world are working on various strategies to develop drought-tolerant and other climate-resilient crops. Although challenging, drought resistance can be improved through conventional breeding, using existing genetic diversity. Modern tools, involving molecular markers, genetic engineering and comprehensive gene expression profiling, provide opportunities for directing the continued breeding of genotypes that provide stable grain yield under widely varied environmental conditions (Bruce *et al.* 2002).

Two examples of applications of crop improvement for dealing with production constraints and climate variability in Africa are described below:

- **Water-efficient maize for Africa (WEMA):** This is a five-year project, funded by the Bill and Melinda Gates Foundation and the Howard G. Buffett Foundation, to develop new African drought-tolerant maize varieties, incorporating the best technology available internationally and regionally (http://www.aatf-africa.org/projects.php). Maize is an important staple crop in Africa and it is severely affected by frequently occurring drought, putting at risk more than 300 million Africans who depend on this crop as their main food source. The African Agricultural Technology Foundation (AATF), located in Nairobi, Kenya, leads the WEMA project. The project involves conventional plant breeding, molecular markers and genetic engineering, and brings in public and private sectors as partners. Partner institutions include the International Maize and Wheat Improvement Centre (CIMMYT), the private agricultural company Monsanto, and the agricultural research systems in eastern and southern Africa. Partner African countries are Kenya, Mozambique, South Africa, Tanzania and Uganda, and the benefits and safety of the products of this project will be assessed according the regulatory policies and requirements of these countries.

  In this research partnership arrangement, AATF will provide leadership and experience in public–private partnership and project management as well as technology stewardship. CIMMYT, as a centre with a global mandate for maize improvement, will provide high-yielding maize varieties that are adapted to African conditions, and expertise in conventional breeding and testing for drought tolerance. Monsanto will provide proprietary germplasm, advanced breeding tools and expertise, and drought-tolerance transgenes developed in collaboration with BASF. The national agricultural research systems, farmers' groups, and seed companies participating in the project will contribute their expertise in field testing, seed multiplication and distribution. The project will involve local institutions, both public and private, and in the process expand their capacity and experience in crop breeding, biotechnology and biosafety. In the long term, the project is expected to make drought-tolerant maize varieties available royalty-free to small-holder farmers in Sub-Saharan Africa.

- **Cowpea productivity improvement — guarding against insect pests:** Cowpea (*Vigna unguiculata* L.Walp.) is a food grain legume in the dry savannas of Africa consumed by nearly 200 million Africans. The project is designed to tackle one of the major production constraints, a pod borer insect, *Maruca vitrata*, through genetic engineering, and to enable small-holder farmers in Sub-Saharan Africa to have access to farmer-preferred, elite cowpea varieties with resistance to insect pests. Partner institutions or initiatives in this project include AATF; the Network for the Genetic Improvement of Cowpea for Africa (NGICA); the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia; the International Institute of Tropical Agriculture (IITA), Nigeria; Monsanto Company, USA; The Kirkhouse Trust, United Kingdom; Institut de l'Environnement et de Recherches Agricoles (INERA), Burkina Faso; the Institute of Agricultural Research Zaria (IAR), Nigeria, and other national agricultural research systems in target countries of west Africa. The development and adoption of transgenic cowpea varieties that are resistant to the insect pest are expected to increase yields, and minimise pesticide use and its effects on human health and the environment.

Enhancing the capacity of Africa to develop its own solution

Technologies and gene constructs are often introduced to Africa from elsewhere through partnerships, as shown in the two major projects described above. In many instances, African scientists travel to institutions in the developed world to acquire skills in a number of biotechnology areas. To enhance Africa's capacity to develop its own solutions through science and technology, an initiative named Biosciences for east and central Africa (BecA) has been created (http://www.africabiosciences.org/network.php?network1=hub).

BecA aims to employ modern biotechnology to improve agriculture in eastern and central Africa. It also seeks to strengthen the capacity of scientists in that region to conduct bioscience research and to significantly contribute to improved products that can enhance livelihoods of farmers in the region (Kelemu 2008). BecA provides a focal point for the African scientific community to support the activities of national, regional and international agencies as they address agriculture-related problems of importance for alleviating poverty and promoting development.

BecA is co-financed by a substantial grant from the Government of Canada through the Canadian International Development Agency (CIDA), and by the International Livestock Research Institute (ILRI). BecA consists of a Hub with a state-of-the-art shared biosciences facility located on the campus of ILRI, Nairobi, Kenya, that provides a research platform, research-related services and capacity-building opportunities; a BecA Secretariat, also located at ILRI Nairobi, and a network of five regional nodes (University of Buea, Cameroon; Ethiopian Institute of Agricultural Research (EIAR), Ethiopia; Sokoine University of Agriculture (SUA), Tanzania; The Ugandan National Agricultural Research Organization (NARO), Uganda; and Kigali Institute of Science and Technology (KIST), Rwanda), and other laboratories distributed throughout eastern and central Africa for conducting research on priority issues affecting Africa's development. The BecA Network (BecANet) covers east and central African countries: Burundi, Cameroon, Central Africa Republic, Congo Brazzaville, Democratic Republic of Congo, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Kenya, Madagascar, Rwanda, Sao Tome and Principe, Somalia, Sudan, Tanzania and Uganda.

An overall program of construction is currently ongoing that includes upgrading the electrical infrastructure and water treatment systems for the ILRI–Nairobi campus, refurbishing existing laboratories and existing offices to required standards, procuring modern laboratory equipment and furniture, and constructing modern greenhouses and offices. These activities are being carefully phased by areas so that on-going and new research and training programs continue with minimal disruption to all site users and visitors. Construction and renovation are expected to be completed by March 2009. Once completed, the BecA Hub will have, among many other things, seven modern laboratories working on crop, livestock and microbial biotechnologies.

The need to ensure availability at the Hub of a critical mass of scientists and technical support staff covering the broad area of biosciences relevant for agriculture and its interfaces with human health and the environment was well recognised at inception of the BecA concept. Capacity in plant, microbial and animal biotechnology is developing at the Hub through various partnerships, ensuring that scientific advances and new technologies are readily available to the African scientific community. To provide expertise in crop sciences and related fields, ILRI has invited other CGIAR centres and non-CGIAR research organisations to locate some of their crop research projects relevant to the region at the BecA Hub. Building this human resource is crucial to the success, viability, sustainability and credibility of the entire BecA initiative. Expertise and knowledge of the livestock sciences is readily available to BecA participants — at the BecA hub, nodes and elsewhere in the BecA network countries — through ILRI and its partners in livestock research.

The challenges for this initiative include:

- to continually strengthen and expand core competencies and scientific capability, and pro-actively make these available to scientists at universities and research institutions across Africa
- to mobilise a critical mass of researchers and resources around key problems to deliver science-based solutions to some of the development issues facing African agriculture and its intersections with human health and the environment
- to make it a financially sustainable and affordable endeavor.

Conclusion

Comprehensive and progressive policies addressing a range of issues are needed to develop and implement effective ways of coping with climate change. Agricultural growth and poverty reduction depend on investments in rural infrastructure, markets and agricultural research and development. Studies show that those types of investments generally provide high returns. Average rates of return on investment in agricultural research and development, for example, have been documented in the range of 35% for sub-Saharan Africa to 50% in Asia in several studies. Results from China, India and Uganda also reveal that the highest returns in terms of both growth and poverty reduction are from investments in agricultural research, rural roads and education.

Current levels of agricultural spending in sub-Saharan Africa are inadequate for sustained growth. Increasing agricultural spending to 10% of national budgets brought success in Asia, and a similar increased spending in Africa may contribute to sustainable growth and poverty reduction. All in all, tackling poverty will help enhance the capacity of small-holders to cope with the effects of climate change.

There are many reasons to be optimistic about the future of Africa and its development: the average GDP growth in the last decade stands at 5.4% for sub-Saharan Africa; better economic policies are being developed and implemented in several African countries; Africa's diaspora is providing new skills and enthusiasm; conflicts are receding; internet use and access is increasing at a healthy rate; and infrastructure in general is improving. There are many local success stories and new opportunities on which to build. The conditions are conducive for further investments that will result in changes that are fast enough and adequate enough for a growing population in urgent need.

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Forests and Climate Change: Cause, Casualty and the Opportunity to Capture Co-Benefits

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The relationships between forests and climate change are complex and multidimensional. Deforestation and forest degradation are now recognised to be a globally significant source of greenhouse gas emissions, and it is asserted that reduction of forest-based emissions may be among the least expensive mitigation options. However, decades of unsuccessful efforts to reverse high rates of deforestation and degradation in the tropics have revealed the fundamental failures of markets, governance and policy that drive forest loss. New initiatives toward 'Reducing Emissions from Deforestation and Forest Degradation' (REDD) will face similar challenges, but could bring to bear new sources of finance and political will.

Forests are also vulnerable to the direct impacts of climate change. Warming temperatures, increased variability of rainfall patterns and increased frequency and severity of extreme weather events will all affect the ability of forests to continue providing goods and services to local communities and to society at large. Because healthy forests are more resilient to climate change, sustainable forest management must be given more emphasis in national adaptation strategies. Forest-related mitigation and adaptation strategies are also inter-linked: the permanence of carbon currently stored in forests is at risk from climate change, with some models predicting significant loss of forests due to climate change impacts.

Improved forest management in the interest of climate change mitigation and adaptation offers significant potential for co-benefits. The wealth of biodiversity harboured by tropical forests currently being eroded by deforestation and forest degradation can be conserved through management strategies that include biodiversity as well as carbon storage and adaptation objectives. While there will certainly be trade-offs between efficiency and equity, REDD initiatives provide a potential new source of income for rural communities. Finally, the newly-felt urgency of harnessing forests for climate change mitigation and adaptation could accelerate long-overdue reforms in the institutions and governance mechanisms necessary for sustainable forest management.

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An introduction to CIFOR

CIFOR is one of fifteen centres in the CGIAR system with a specific forestry research mandate. CIFOR is the only global-scale organisation with its international headquarters in Indonesia with staff and partners scattered all over the world conducting research programs. CIFOR is particularly pleased with our partnerships with Australia, a country that played an important role in the founding of CIFOR through inputs by ACIAR and CSIRO. We now have significant funding from ACIAR and AusAid, particularly for our climate change work, and lots of cooperation with the Australian scientific community.

Our global research agenda is focused on six areas, all of which are inter-related with issues of climate change. The two of primary focus in this presentation are the role of forests in climate change mitigation and their role in adaptation. The other four areas of CIFOR research are small scale and community forestry, conservation and development at landscape scale, impacts of globalised trade and investment on forest and forest communities, and sustainable management of production forests.

The role of forests in carbon emissions

Over the last two years, the global public has become increasingly aware of the threat of climate change in general, and the role of deforestation in exacerbating that threat in particular. Nevertheless, the linkages between forests and climate change — and the magnitude of the challenges in addressing them — remain underappreciated.

One key cause of climate change is the emissions from deforestation and forest degradation. An assessment of the *net* change in global forest area during 2000–2005 revealed that deforestation occurred at a rate of around 13 million ha per year, with the leading contributors being South America and Africa (FAO 2005). Interestingly, South-East Asia has the highest rate of deforestation but the net figures for that region are positive because of significant reforestation efforts in China.

One result is that deforestation and forest degradation are globally significant sources of total CO_2 emissions, forming about one-fifth of the total global emissions. According to the IPCC 2007, forestry is actually more important than the transport sector as a source of global emissions, with 1.7 billion tonnes of carbon released annually due to land use change (primarily tropical deforestation). Two forested nations — Indonesia and Brazil — currently account for some two-thirds of total annual emissions from land use change. As a result of those emissions, estimates now place those countries as the third and fourth largest overall GHG emitters, after the United States and China (PEACE 2007). Brazil's emissions are driven by high rates of deforestation in the Amazon. The draining, clearing and burning of peatland forests — much of which are concentrated in Indonesia — is particularly emissions-intensive.

The importance of peatlands

Peatland degradation creates around 11% of global greenhouse gas emissions and is disproportionately responsible (on a per-hectare basis) for emissions once those ecosystems are disturbed. As most peatlands are concentrated in South-East Asia that region is particularly responsible for those emissions (Fig. 1). Carbon stocks in peat are particularly large: peat may extend to depths of 6 m below the surface (Hooijer *et al.* 2006) in addition to above-ground vegetation, so emissions deriving from the burning and draining of peatlands for land conversion are disproportionately significant. Disturbed peatlands are the 'gift that keeps on giving' from the perspective of carbon emissions.

Causes of deforestation and degradation

Lots of research over the last decade has been directed toward understanding the causes of deforestation and forest degradation. Direct drivers of deforestation vary by country but include:

- conversion of forest for agricultural expansion, either commercial plantations or small-holder developments
- unsustainable wood extraction due to poor logging practices that leave behind wood waste that in turn leads to fires or conversion to small-holder agriculture
- infrastructure development, principally roads and mining, which may not themselves have a heavy footprint on the forest, but provide an entry and catalyst for other conversion or degradation processes.

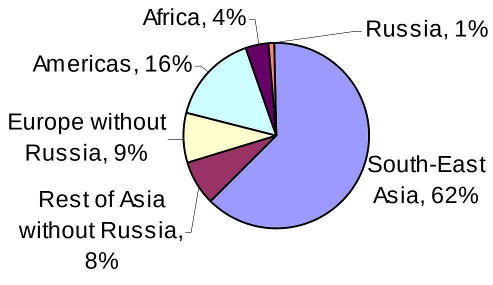

Figure 1. Decomposition of drained peatland to 800 million t of CO_2 per year. Source: Wetlands International and Delft Hydraulics

Oil palm plantations

An example of a direct cause of deforestation is oil palm plantation development. This is often an example of planned deforestation; part of national development plans, in the interest of economic growth and employment, to convert forested areas into productive agriculture. In Indonesia right now, the market for palm oil is driven by its use as a domestic cooking oil in developing countries as well its use as a 'climate friendly' transport fuel in industrialised countries (Naylor *et al.* 2007). However, the 'climate friendly' label is not deserved. Ironically, to the extent that agrofuels development comes at the expense of natural forests — as is occurring — the net impact on GHG emissions is a significant net *increase* (Searchinger *et al.* 2008). Research suggests that it would take more than 840 years to repay the 'carbon debt' from converting Indonesia's carbon-rich peatland forests to oil palm plantations and using the palm oil to substitute for fossil fuels (Fargione *et al.* 2008, p. 2).

Underlying causes

Underlying causes of deforestation and degradation revolve around:

- market failures that give biodiversity in forests no value by the market
- governments' failures that do not enforce laws and regulations
- misguided policies which provide perverse subsidies that are positive incentives to convert forest to low-value uses.

The pulp and paper industry

A second example in South-East Asia arises from the structural over-capacity in the pulp and paper sector. There is a mismatch between the amount of wood needed to keep the mills running to produce pulp and paper, and the sustainable and legal supply of wood coming from the plantations. As a result, lots of the wood necessary to feed current and planned expansion of capacity will have to come from the natural forest.

The pulp and paper sector illustrates all three underlying causes of deforestation:

- a market failure when investors fail to do their due diligence on the availability of legal and sustainable feedstock
- a governance failure stemming from the lack of law enforcement that allows mills to run on timber from illegal sources. However, the Indonesian government must be given due credit for recent efforts to step up enforcement
- finally, a policy failure, through a variety of subsides to the industry providing perverse incentives to convert forest to low-value uses; not least the bail-out companies were given in the aftermath of the 1998 financial crises.

The good news is that maintaining forest carbon has a low opportunity cost in many instances. A group of CGIAR centres and partners conducted research in advance of the Conference of the Parties to the UNFCCC in Bali last December to get a sense of what the opportunity cost incurred by forest users in keeping the trees in the ground would be. In many cases, forests are being converted for low-value uses such as cattle ranching, and the cost of compensating those users to leave the forest as it is would be less than $5 per ton for emissions averted. As global prices for emissions are on the order of $20 per ton, that seems like a good deal, with room left over to cover transaction costs. It is consistent with the Stern Review's assessment two years ago that mitigating forest-based emissions could be among the most cost-effective mitigation strategies in the global carbon emissions budget (Stern 2006). The Review asserted that controlling deforestation could provide one of the least expensive strategies for reducing emissions, and that such efforts must be a key element of any future climate protection regime. As a result, 'Reducing Emissions from Deforestation and Forest Degradation' (REDD) is now central to discussions of global and national mitigation strategies.

Policy options

The resulting policy implications based on this diagnosis of forests as a source of emissions are as follows:

- First, we must bring REDD into the global climate regime. This is already under way as a big part of the Bali road map agreed last December, which provides the necessary negotiating framework.
- Second, we need to give priority attention to countries with high deforestation rates and to peatlands. The Australian government is DOIng exactly this with a significant financial commitment to Indonesia and a specific focus on peatlands in Central Kalimantan.

- Finally, we need to address the underlying causes of deforestation, most of which lie outside the forestry sector narrowly defined. An economy-wide effort is needed to overcome the challenge.

Forests as a casualty of climate change

Forests are also a casualty of climate change. Forests are vulnerable to the extreme weather events that are likely to become more frequent with climate change. The mitigation potential of forests could itself be affected. A warmer, drier climate could trigger a positive feedback loop that results in the dieback of forests, and thus increased emissions and further warming (Bonan 2008). In other words, warmer, drier weather could lead to a vicious circle in which increased incidence of burning renders forests less able to recover and sequester carbon in forest vegetation, which in turn would accelerate climate change. Some models predict that a significant portion of the carbon-rich Amazon rainforest will be replaced by carbon-poor savannah ecosystems if global warming is allowed to proceed beyond a certain threshold, thus releasing significant amounts of carbon into the atmosphere (Mayle *et al.* 2007, p. 299; WHRC 2008).

Forests are also vulnerable to the increases in temperatures and rainfall variability likely to result from climate change. For example, longer and more severe droughts will lead to more frequent and severe forest fires, which are often catalysed by burning in adjacent agricultural lands. Damaged and fragmented forests are more vulnerable to these impacts because they are less resilient to these new pressures.

CIFOR scientists and our partners (Guariguata *et al.* 2008) suggest several steps to help forests adapt to climate change including increased use of reduced-impact logging to maintain ecosystem integrity, increased attention to fire prevention and management, and increased development of silvicultural options to facilitate genetic adaptation in plantations. A bigger policy implication, however, is the need to toughen up targets for reducing emissions overall. For this, of course, responsibility falls mostly with the industrialised economies and mostly in the fossil fuels sector. If some immediate changes are not made, we may lose many of the mitigation options that are currently available from forests.

Forests are also important to adaptation in other sectors. CIFOR is examining the different ecosystem goods and services, outlined by the Millennium Ecosystem Assessment, that are provided by forests to determine what sectors of the economies in different parts of the world are vulnerable to compromises in those services.

Maintenance of forest-based ecosystem services that support other economic sectors can strengthen societies' resilience to climate change. For example, forests play an important role in moderating the quantity and quality of water that flows out of watersheds. As rainfall patterns change, the hydrological services provided by forests will be increasingly important to maintaining municipal drinking water systems, agricultural water supplies and the production of hydroelectric power. This set of potential contributions to climate change adaptation has been ranked as especially important in Central America (TroFCCA 2008). In parts of South-East Asia, where droughts are anticipated to be more severe and episodes of heavy rainfall more likely, maintaining the role of intact natural forest vegetation in controlling forest fires and landslides is a priority (TroFCCA 2008).

In Indonesia, for example, a priority for adaptation is greater attention to keeping the forests healthy so they will be more resistant to forest fires as drought becomes more frequent and severe. The catastrophic forest fires experienced over the last decade have had a profound effect — not only on the forests, but on the health of the people inhaling the smoke and on economic activities where airports have shut down for days at a time while the haze cleared.

A second adaptation priority in Indonesia is landslides, a particular problem on Java. Trees serve as a natural adaptation option as they help bind and anchor the soil (at least from shallow landslides) — so maintaining natural vegetation is an important adaptation option.

Accordingly, the adaptation strategies of other economic sectors such as agriculture and hydropower (which are affected by forest hydrology) and air and land transportation (which are affected by haze from forest fires and landslides, respectively) need to be linked to sustainable forest management.

Co-benefits

There are several opportunities to capture additional co-benefits, such as managing forests better for climate change mitigation and adaptation, reflecting some potential win-wins. The first is that forests are a significant source of rural livelihood. Estimates show that 50–60 million people live on forest lands and derive income from forests. The World Bank estimates that 90% of the 1.2 billion people living in extreme poverty depend on forest resources for some part of their livelihood (World Bank 2004; UNDP *et al.* 2005). Forests are also particularly important as a safety net for vulnerable communities and individuals. Forests have proven to serve as important ‘safety nets’ for communities in times of economic stress. During the financial crisis in the late 1990s in Indonesia many households turned to the forest for supplementary cash and subsistence income (Sunderlin 2002).

In sub-Saharan Africa, households unable to afford high prices for modern energy sources revert to collecting fuelwood from the forest. Research in sub-Saharan Africa suggests that bushmeat from the forest provides an important source of protein to children orphaned by AIDS (Shackleton *et al.* 2006).

Forests are very significant for biodiversity conservation. The island of Borneo occupies less than 1% of the world’s land area, but harbors about 6% of the world’s flowering plant, bird and mammal species. Research suggests the livelihood and biodiversity aspects are quite interconnected. In East Kalimantan, Indonesia, research conducted with local communities identified more than 2100 forest species with 3642 different uses, including food, traditional medicine, hunting equipment, construction materials, and culturally-significant ornamentation. One hundred and nineteen of these species had no known substitute for the particular use (Sheil *et al.* 2001). If those species are lost, it will be of both economic and cultural significance.

Forests are also significant for dealing with broader government challenges in many countries. Tacconi (2007) (Fig. 2) discusses the interrelationship between problems such as illegal logging and the broader governance challenges that democracies, such as Indonesia, are trying to surmount. Challenges include issues of corruption, the need for increased transparency and inclusiveness in decision making, the need to clarify tenure and property rights, the challenges of decentralisation and the need to build capacities of all kinds on the part of local communities and governments.

REDD opportunities

We need to find a way for money to grow on trees left standing. Can we put ATM machines in the forest for people who currently have to cut down the trees to make some money? There are real opportunities to harness REDD finance for global financial transfers in order to achieve emissions reductions and simultaneously improve rural livelihoods, biodiversity conservation and governance:

- Firstly, we can make payments for environmental services that compensate communities for their forest stewardship.
- Secondly, the final D in REDD represents degradation; if we can improve logging practices, and provide additional income to compensate for additional carbon sequestered, we will also be able to save associated biodiversity and maybe tip the balance against current incentives to convert logged-over forests to other uses.

Figure 2. An analysis of illegal logging

- Thirdly, we can increase community-based fire management. There are some promising examples in Indonesia of work with local communities to bring them on the front lines of fire prevention, detection and suppression in a way that strengthens their sense of ownership over the forests and responsibility for that stewardship.

The bad news is that REDD readiness is going to require lots of work, including the technical capacity to establish baselines and monitor changes in forest carbon. Equally challenging, however, is the necessary strengthening of governance and institutional mechanisms that are now quite weak. On these efforts, I want to commend the Australian government for not only designing a program of experimentation with such projects, but also for funding parallel research on the part of my and other organisations to make sure that we build on our current knowledge and learn as we go along to get it right.

REDD controversy revolves around concerns regarding the seriousness of the international community about REDD and how to capture the benefits for the forested countries. A World Bank (2007) press release from the Bali meeting alludes to activists concern about how market mechanisms for forest carbon might negatively affect the poor or the rights of indigenous people. Clearly, there is a lot of political legitimacy still needing to be built at the global level, as well as practical problems needing to be resolved on the ground.

Conclusion

In summary, deforestation is a significant cause of emissions and reducing it has got to be part of the global mitigation strategy. Forests and their potential contributions to climate mitigation and adaptation are themselves at risk from the impacts of climate change. However, there are potential co-benefits that can be captured for poverty, biodiversity and governance.

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Climate Change: The Future of Cropping Systems

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Global consumption of grains is projected to double by 2050 due to projected growth in population and per capita consumption of grains directly and also in livestock production as incomes rise. Global food security depends on expanding current farming activities in a sustainable way to meet this demand. Climate variability already has a significant influence on global grain production and further impacts on production are anticipated as the climate changes. Grain yields are likely to decline in tropical and subtropical regions, as well as in regions with 'Mediterranean' climates. They could potentially increase in more temperate regions. Adapting to climate change may be effective in lessening the negative impacts of small changes in climate. Studies of global food security indicate, however, that the world's population will be exposed to a greater risk of hunger. In this paper we suggest that these studies may have significantly underestimated the risk to food security. Environmental limitations to grain production, increased variability in production and a range of policy constraints need to be addressed in a systematic and coherent way.

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Introduction

Global consumption of grains is projected to double by 2050 due to projected growth in population, per capita consumption and the use of grain to feed animals to meet a growing demand for protein. Consumption increases will vary regionally, with strong demand increases expected as incomes and populations grow in the world's poorer nations. Ultimately, the demand for food always equates to its supply; the challenge for food security is at what price to consumers? This challenge could be magnified as climate change reduces grain production in the tropics, subtropics and mid-latitudes — the regions where food security has historically been most problematic. In this paper we explore the interactions between climate change and grain production as they are expected to impact on the four dimensions of food security: availability, access, stability and utilisation.

Climate change and food security studies

Climate change scenarios for the tropics, sub-tropics and mid-latitudes indicate potential reductions in future global grains production. However, these potential reductions have not been fully incorporated in global-scale analyses of food security. These studies have included not only climate change but also demographic and economic changes and, in some cases, climate change adaptations. They conclude that, globally, impacts of climate and CO_2 increase are small compared with the positive effects of socio-economic development paths, with substantial regional variation (Easterling *et al.* 2007). For example, climate change alone is estimated to increase the number of undernourished people in

2080 by 5–10 million under the SRES B1 scenario, up to 120–170 million people under the A2 scenario (Fischer *et al.* 2005) or by ±30 million (Parry *et al.* 2005). In terms of regional disparity in food availability, Fischer *et al.* (2005) noted that for a high-emissions scenario (A1FI), 42 developing countries may benefit from substantial increases in cereal production (averaging 17%) by 2080. However, 52 countries with a population of up to 3 billion may lose on average 19% of their current yield potential over the same period.

In a review of global food security studies, Schmidhuber and Tubiello (2007) suggested that the robust economic growth projected for the 21st century will (in all but SRES A2 scenario) significantly reduce the number of people at risk of hunger in 2080. Their analysis suggested that this was because real incomes are likely to rise faster than real food prices, thereby increasing access to food. Average price variations expected from the effects of global change are much smaller than those from socioeconomic development paths. However, even if global food production does not decrease significantly under climate change, the additional transport necessary to compensate for regional disparities in production is likely to increase greenhouse gas emissions and handling costs. These constraints are yet to be fully considered in global analyses of food security. Interestingly, few analyses have flagged in advance the possibility of spikes in food prices like those of 2007–2008, nor the potential consequences of global financial crises like those experienced in Asia in 1998 and globally in 2008.

The positive outlook of most analyses of global food security relates to a projected increase in cropland at higher latitudes (developed countries 160 million ha), and a decline of cropland at lower latitudes (developing countries 110 million ha). The net effect of these changes could be to reduce prime cropping land by 135 million ha, but increase the availability of moderately suitable land by 20 million ha. A problem not usually considered in global food security analysis is that expansion of cropping into grassland or forest areas usually releases vast amounts of carbon dioxide. It is likely that both national and international policies will emerge that impose significant costs and constraints on emissions of greenhouse gases from land clearing and land-use change.

Climate change impacts underestimated?

Analyses of global food security may significantly understate the challenges arising from climate change. Specific concerns include:

- climate change is happening faster than expected, with the four key global indicators (greenhouse gas emissions, atmospheric carbon dioxide concentrations, global temperature and sea-level rise) all at or above the ‘worst case’ scenario developed by the IPCC about a decade ago (Rahmstorf *et al.* 2007; Canadell *et al.* 2008)
- effective adaptation technologies, management options and policies are not yet in place (Howden *et al.* 2007) because of the unexpectedly rapid climate change, even though some analyses suggest a very high return on investment if adaptations are implemented (e.g. Howden and Jones 2004)
- yield growth of the main food crops is declining due in part to a lack of investment in improving crop genetics and crop management, as well as increased bio-security risks
- the availability of irrigation water suitable for agriculture (surface and groundwater) is likely to decline in some regions due to lower rainfall and higher temperatures, depletion of glacial ice mass (although this may increase availability in the short-term), greater rainfall extremes reducing water quality and increased demand from the non-agricultural industry and urban sectors
- increased costs of fossil-fuel-based nitrogenous fertilisers, agri-chemicals and irrigation pumping
- reported increases in land degradation which systematically reduce the productive capacity of the land
- an increasing number of policy and market constraints to agricultural extensification and intensification including policies to reduce emissions of greenhouse gases, conserve biodiversity and maintain ecosystem services.

A crude way of understanding the urgency with which the implications of climate change for food security need to be addressed is to compare current trends in crop yields against projected demand. We state that it is a crude approach because it fails to consider the substitution possibilities created by new technologies and shifting demand preferences as the relative price of food commodities changes. Nevertheless it serves to focus on the challenges ahead. In terms of the demand side of this analysis, year-on-year yield growth of about 1.7% is needed to double food production by 2050. Existing trends in yield growth suggest that this may be difficult to achieve. For example, growth in wheat yields has been strongly downwards globally (Fig. 1) and is currently about 1.2% — well short of the 1.7% needed. In the case of Western Europe, the trend in annual growth in yields has already reached zero (i.e. yields have stabilised, albeit at a high level).

In contrast, the same analysis for Asia indicates that yield growth has declined from about 3% p.a. in 1970 to about 1.5% currently. If current trends continue, yield growth in Asia will be zero by about 2042. Whilst this is more encouraging than the Western Europe situation, the cumulative yield growth implied is about 34% — a long way short of the 100% needed to ensure food security with current patterns of supply and demand. The global picture for growth in wheat yields lies between the Western Europe and Asian trends, with zero growth projected by around 2030 on current trends. The cumulative increase in yield of 15% is even further short of the 100% needed to ensure global food security with current patterns of supply and demand. Importantly, this simple analysis does not include the prospective impacts of climate change as above and so the actual challenge may be even greater.

Climate change is also likely to affect the nutritional quality of food and food safety (Schmidhuber and Tubiello 2007). Experiments with crops grown under elevated CO_2 suggest possible reductions of grain and leaf protein by up to 10%, with health implications in regions where protein intake is low such as sub-Saharan Africa. Warmer conditions could potentially increase the incidence of salmonella and diarrhoeal diseases, and increase the frequency and distribution of the tropical reef-fish disease ciguatera. Water-borne diseases such as cholera may also become more prevalent if extreme rainfall events increase. However, there remain large gaps in the understanding of the implications of climate change for food safety.

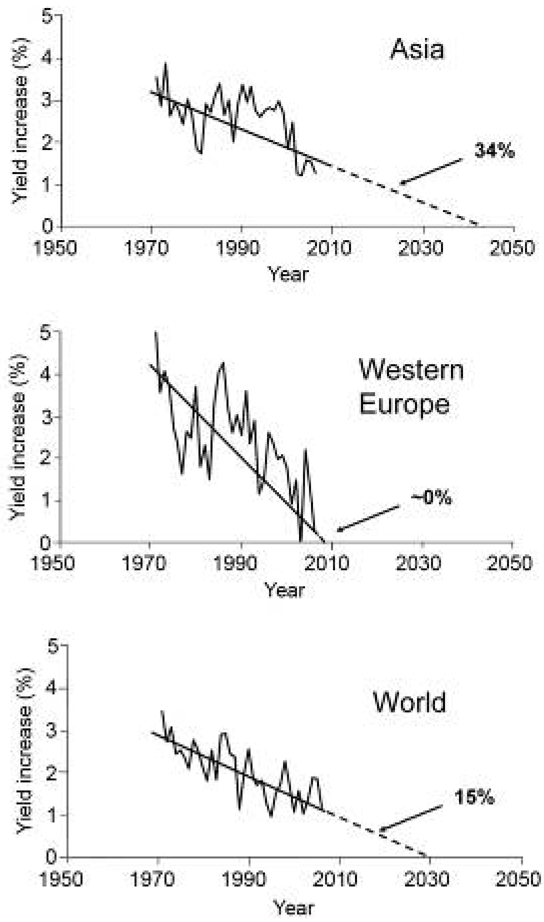

Figure 1. Trends in year-on-year growth for wheat from FAO yield data for Western Europe, Asia and globally. The straight line is a linear regression with the dashed part an extrapolation of this; the other line is a 5-year running average. The percentage figure is the cumulative increase in yield from now until the extrapolated regression hits the x-axis, representing future yield increases on the basis of current trends only.

Variability matters

The volatility in prices due to changes in climate variability that affect the ability particularly of poor people to access food have been much less studied. Two of the key summary points in the IPCC 4th Assessment Report were that:

- climate variability and climate extremes were likely to increase
- changes in climate variability are likely to have greater impacts on agricultural systems than changes in mean climate alone.

Historical and current experience informs us that variability is critical to food prices, availability and access. Changes in the volatility of food supplies due to climate change will affect food prices because climate variability has a large impact on grain production and exports. For example, global wheat exports are 50% higher in the El Niño years than in the La Niña years. Analyses of global food systems to date have tended to concentrate on food availability.

Past changes in food prices provide important insights into future volatility with, for example, the FAO food price index increasing by 37% in 2007. These price rises plus various climate-related disasters and several conflicts have resulted in 37 countries currently facing food crises. The FAO reports that the total cost of imported foodstuffs for low-income, food-deficit countries in 2007 was about 25% higher than in the previous year. This dramatic change in outlook was driven by the effects of climate variability (mostly droughts and floods) on several key commodities in a few key exporting nations. For some grains, the availability for human food is also being reduced by increasing demands for grains as animal feed and for biofuel production. This substitution in supply has resulted in record prices and contributed to unprecedented price volatility. Volatility is also occurring because liberalised agricultural commodity markets have resulted in food stocks being kept at historically low levels (lowest since 1983). Greater speculative investment in food markets has followed reductions in trading risks associated with greater market transparency. This has also contributed to recent increases in the volatility of agricultural commodities.

Pathways ahead

The volatility of production and prices should be a core part of future assessments of global food security alongside more traditional analyses of food availability. This raises the question as to whether new assessment methods are needed. For example, partial equilibrium economic models could be used instead of general equilibrium models to incorporate the impact of climate variability on food production. There is a clear need to increase investment into research of the biophysical, economic and institutional factors limiting growth in grain yields. More integrated systems research that includes genetics, management, policy and communication could open pathways to yield improvements that are closed to more traditional reductionist approaches. This could enable research to transcend the natural limits of single-factor research. These new integrated methods for assessing global food security need to be able to incorporate the new policies, constraints and opportunities associated with climate change, such as emissions restrictions and the emerging carbon economy. This may require more of a bottom-up approach including social, economic and cultural dimensions, and scaling these up to regional level. A stronger focus on managing climate variability is likely to deliver useful information and technologies at farm and community scales that can reduce supply and price fluctuations and be transferred between regions. Lastly, consideration needs to be given to collective action to build the livelihood options and risk management capacity of vulnerable groups to deal with climate change (Howden *et al.* 2007).

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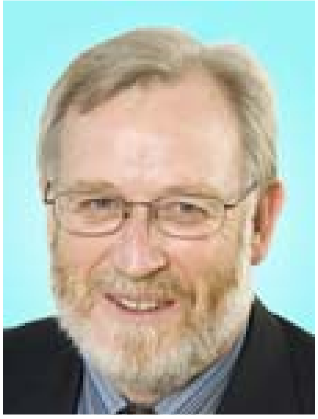

A Systems Approach to Climate Change Impacts on Livestock Production

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Livestock production is doubly impacted by climate change — it both contributes to the phenomenon and must adjust to its consequences. Whilst adaptation is being achieved, the true mitigation potential for livestock production is yet to be quantified. The situation is exacerbated by the fact that demand for animal products is escalating quickly, especially in developing and transitional economies. The sector is also subject of considerable biological variability, meaning that the industry does not fit easily into carbon trading schemes. Any response to climate change will need to consider changes in productivity to reduce emissions per animal; changes in consumption to restrict the total animal population; and policy or regulation changes as governments make difficult decisions on mitigation targets. There is a need to improve the reliability and applicability of regional impact models, to enable a system-wide assessment of climate change effects. Similarly significant gaps exist in our knowledge of the basic biology of animals, and especially the rumen. In the absence of new information for research, progress to reduce the current and projected impacts of livestock production will be slow.

Introduction

Climate change poses a challenge for livestock production that is not easily addressed, and an effective response is likely to involve changes in the consumption of animal products, in regulation and policy, and in productivity of production systems.

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Any examination of climate change and animal agriculture must consider three factors:

- First, the extensive land use and dependence on reliable weather by livestock production means that it is exposed to climate change impacts on a scale more significant than that for most industries.
- Second, it is a major source of greenhouse (GHG) emissions, and biological variability means that the sector is not conducive to mitigation actions, nor does it fit easily into carbon trading schemes.
- Third, global demand for animal production is resulting in rapid expansion of the animal population, particularly in transition and developing economies, thus adding further to total GHG emissions.

GHG emissions from animal agriculture have been long recognised to be a function of the efficiency of production (productivity) and of total numbers (see Bootsma 1994). Thus improved productivity is required to reduce emissions, and on a per-animal basis this has been achieved in many areas of the world. Efficiency gains, however, have been negated by increases in production so that the total contribution by livestock to climate change continues to grow. The mitigation potential for animal agriculture is yet to be determined (Plume *et al.* 2008) and there are significant gaps in knowledge of the processes surrounding the production of GHGs from animals (Kebreab *et al*. 2006).

'Livestock's long shadow' and global development

The 1999 publication of *Livestock to 2020 — The Next Food Revolution* by the International Food Policy Research Institute (Delgado *et al*. 1999) has had a major impact on the understanding of the critical role of animals in global development and poverty reduction, and provided clear evidence of the current and projected expansion of demand for animal products.

At the time that IFPRI released its study, there was already an emerging argument that the development of 'environmentally friendly' livestock production systems demanded that production increases should be met by improved productivity, and not by an increase in animal numbers nor expansion of land area under production (Leng 1993). Whilst this objective may be achievable in developed agricultural systems, it has clearly not impacted in the transition and developing economies.

A second important study, *Livestock's Long Shadow* from the FAO (Steinfeld *et al.* 2006), suggested that the global effects of the animal sector have remained unappreciated; a sentiment strongly shared by others (McMichael *et al.* 2007; Thorne 2007; Koneswaran and Nierenberg 2008).

The Steinfeld *et al.* (2006) study highlights a number of factors:

- Animal numbers are expected to double by 2050, with most increases occurring in the developed world.
- Animal agriculture contributes 18% of global business-induced GHG emissions.
- Livestock production accounts for 35–40% of global anthropregenic methane emissions, and 65% of global anthropregenic nitrous oxide emissions. (Methane and nitrous oxide have respectively 23 and 296 times the global warning potency of carbon dioxide.)
- While methane and nitrous oxide are the key GHG emissions from livestock production, the sector also impacts:
    - indirectly (primarily the result of fertiliser production for feed crops, on-farm energy, and transport and processing)
    - directly (primarily through deforestation and desertification) on CO_2 production, and contributes about 9% of total global CO_2 emissions.
- Livestock production contributes about 80% of the contribution of agriculture to GHG emissions.

Viewed alone, the climate change impacts of livestock production are alarming. Measures to reduce GHG emission that significantly curtail livestock production seem a simple and logical solution. When, however, they are viewed against the impact of animal agriculture on the breaking of the poverty cycle of poorer communities, and on global development in general, it is not so evident that a clear decision path exists. Nor is there clear pathway when re-investment costs are considered.

Climate change impacts on livestock production

Climate change effects on livestock production fall into two categories: those relating to increases in climate variability and frequency of extremes, and those relating to longer-term shifts in the eco-physical characteristics of regions.

The former result in greater frequency, duration and severity of flooding, and of drought. These add to the complexity of day-to-day livestock management and result in production losses, increased costs and longer-term degradation of pastoral lands. Significant social and economic disruption and costs are associated with these events, which are subject of major regional or country studies such as Fleischer and Sternberg (2006) and Stokes and Howden (2008). Widespread land degradation as a result of livestock production is reported in many areas of the world including northern China (Lin *et al.* 2007) and the Sudan (UNEP 2007).

Shifts in the eco-physical characteristics of regions are more benign but nonetheless significant. Changes in the patterns of rainfall and ranges of temperature affect feed availability, grazing ranges and feed quality, and weed, pest and disease incidence. As a result producers will need to adjust production systems and land use patterns. For example, it is forecast that New Zealand will become warmer, and that rainfall will become more variable (Table 1). As a result pasture productivity will increase, although in the

Table 1. Projected climate change impacts, New Zealand 1970–1999 to 2070–2099

Region	Change in temperature (°C)	Change in rainfall (%)
Northland, Auckland	+1.0° to +2.8°C	–10% to 0%
Western North Island from Waikato to Wellington	+0.8° to +2.7°C	0% to +20%
Eastern North Island from Bay of Plenty to Wairarapa	+0.9° to +2.7°C	–20% to 0%
Nelson, Marlborough, to coastal Canterbury and Otago	+0.8° to +2.5°C	–20% to +5%
West Coast and Canterbury foothills	+0.6° to +2.2°C	+5% to +25%
Southland and inland Otago	+0.6° to +2.2°C	0% to +30%

Source: Kenny (2001)

north production may decline as pasture quality declines due to encroachment of sub-tropical grass species such as paspalum and kikuyu. In the east of the North Island a greater incidence of drought is expected.

Other examples of impacts of climate change include changes in the ranges of diseases, such as the spread of bluetongue virus into the UK (Gale *et al.* 2008), or re-emergence of threats from previously endemic diseases such as Rift Valley disease (Fields 2008) and east coast fever (Olwoch *et al.* 2008) in sub-Saharian Africa. Globally there is a need to fully examine the potential impact of the extension to the ranges of mosquitoes, tsetse fly and ticks that are anticipated as a result of temperature increases. Both animal and human health will be increasingly vulnerable to insect-borne disease risks (Sutherst 2001, 2003).

Climate change, especially increases in temperature, has a direct impact by increasing heat stress in animals. This results in both a loss of production (largely through reduction of feed intake) and reduced reproductive efficiency (Baker *et al.* 1993; Smit *et al.* 1996).

Mitigating the impacts of climate change on livestock production

A range of technologies and management strategies at both the regional and on-farm scale exist to enable the impact of climate change to be mitigated. In China, for example, where widespread climate-induced instability in animal agriculture is reported since 1980 (Lin *et al.* 2007) a range of responses are being introduced including:

- better determination of grazing capacity of pastures in terms of climate change
- halting over-grazing and avoiding grassland degradation
- stopping and reversing the trend of desertification to enhance the resilience of livestock production to climate change.

Another example of regional responses is seen in a series of studies on livestock production in Africa (see Kurukulasuriya *et al.* 2006; Seo and Mendelsohn 2007) that have shown that small-holders have been able to change their species mix (principally moving from large ruminants to sheep and goats) in response to climate change. Larger enterprises with greater reliance on cattle have been unable to adjust and experience increased costs and loss of production as a result.

For regional responses to be fully effective there appears to be a need to reduce the present levels of uncertainty in impact assessment studies (Lin *et al.* 2007). The uncertainties of impact assessment come from four main sources:

- Understanding of climate change effects on various ecosystems and the interactions among them is limited.
- Not all factors are considered in the existing impact assessment models.
- The impacts of climate change on trade and socio-economic development is seldom included.
- Insufficient consideration is given to the effects of adaptation measures on reducing the vulnerability of livestock production to climate change.

There is little doubt that assessment of climate change impacts requires complex modelling on a regional basis. Despite problems, the reliability of models is improving, with impacts generally rising with more recent studies. Stern (2007), in particular, points to more serious concerns in the loss of agricultural productivity in both developed and developing regions of the world.

The response of the developing and developed economies is understandably different. Where economics allow, mechanical interventions such as use of artificial shade and evaporative cooling systems in animal enclosures (Frank *et al.* 2000) are available to ameliorate environmental impacts. In the developed economies, however, responses to climate change at the individual farm level appear not to have been well studied. A five-year study by Smit *et al.* (1996) in Canada suggests that:

- Farmers experience effects of climate change, but simply absorb them and make no strategic changes to their operations in response.
- Problematic climatic conditions are translated into economic stimuli, so that changes are attributed to economic rather than climatic forces.
- The effects of climate are swamped by those of variations in costs, prices, technologies and so on.

In addition to changes in production systems and production mixes, considerable opportunity exists to breed animal genotypes adapted to the changing conditions resulting from climate change. The CSIRO livestock improvement program based in Rockhampton, for example, has introduced tropically adapted cattle breeds into northern Australia and greatly improved reproductive efficiency and meat production (Frisch and O'Neill 1998; Prayaga 2004). Major livestock enterprises have used this genetic diversity to develop composite breeds of cattle adapted to our production systems and imparting greater disease resistance, heat tolerance, better capacity to graze and high reproduction rates (Bentley *et al.* 2008). Animals can also be selected on the basis of increased overall feed-use efficiency (Alford *et al.* 2006) to lower the GHG emissions.

Mitigation of livestock production impacts on climate change

The literature on GHG mitigation for livestock production is already large and escalates each year. Koneswaran and Nierenberg (2008) point out that thus far, most mitigation and prevention strategies have focussed on technical solutions such as investigating the reformulation of ruminant diets to reduce enteric fermentation and methane emissions. Whilst some progress has been made to reduce GHG per unit of production by about 20%, some studies, such as McMichael *et al.* (2007) advocate a need for aggressive reductions in meat consumption and restriction of animal numbers to address climate change. Plume *et al.* (2008) contended that the true mitigation potential remains undiscovered.

Improving productivity: growing production — the paradox

A common feature of many developed nations is that GHG emissions from agriculture have been falling (Leslie *et al.* 2008). Some developed countries, however, have not followed this trend. In New Zealand, GHG emissions from agriculture, in particular nitrous oxide and methane from pastoral agriculture have been rising at about 1% per year since 1990 (Ministry for the Environment 2007). Emissions growth has come first from increased individual animal production (meaning each animal consumes more forage and thus produces more methane and excretes more nitrogen). Second, this increased feed consumption has required growth in the use of inorganic nitrogen fertiliser from 52 000 t in 1990 to 345 000 t in 2005. But, while the total amount of GHG from NZ has increased, the amount emitted per unit of production has declined by about 17% (Table 2).

Genetic, nutritional and management strategies have improved animal productivity and lowered emissions in dairy and sheep production (Leslie *et al.* 2008) in NZ, as they promise to do in beef systems in Australia (Bentley *et al.* 2008).

The NZ changes reflect the global paradox livestock production faces. Given production growth projections and current technology, GHG emissions will continue to rise.

Table 2. Methane emissions per unit of production

Year	Dairy sector		Sheepmeat sector	
	Emissions (Mt y^{-1})	Emissions per unit production (kg CO_2 equ kg^{-1})	Emissions (Mt y^{-1})	Emissions per unit of production (kg CO_2 equ kg^{-1})
1990	4.99	8.32	11.2	2.1
2005	8.51	6.85	9.2	1.7
Change (%)	70.5	–17.7	–18.2	–17.5

Source: Leslie *et al.* (2008)

Whole-of-system approaches at the enterprise level

Attempts are now been made to go beyond simple genetic and nutritional approaches. One Australian pastoral company (NAPCO), for example, is seeking further emission reductions in general farming and grazing systems (Bentley *et al.* 2008). This includes ceasing broad-scale tree clearing, re-establishing native vegetation using permanent pastures and adopting zero-till farming practices. Fossil fuel use is also being reduced by adapting solar power for operations such as water pumping and lighting. The company is also investigating biogas generation from feedlot waste, and is using surplus liquid effluent strategically for irrigation. Solid effluent is been composted for off-farm sale as high-grade organic fertiliser in the horticultural and cropping industries.

Similar approaches (although not all on a whole-of-enterprise basis) are being explored for production of biogas from livestock enterprises in Asia (Liang *et al.* 2008; Su *et al.* 2008) and NZ (Lieffering *et al.* 2008); for treatment of effluent to reduce methane in European systems (Berg and Model 2008) and for reducing nitrous oxides in general (Eckhard 2006; De Klein and Eckhard 2008).

Mitigation of rumen GHG emissions

The literature is rich with studies aimed at rumen manipulation to reduce methane emissions. Approaches range from attempts to directly inhibit methanogens (McAllister and Newbold 2008) to vaccines (Wright *et al.* 2004) to transfer of methanogens between species (Klieve and Hegerty 1999). More recently genetic approaches (Alford *et al.* 2006) and genomics (Attwood and McSweeney 2008) have been commenced. Nutritional management studies continue (Beauchemin *et al.* 2008).

All approaches show merit, but it has been difficult to reliably capture benefits. In some cases inadequate performance of delivery mechanisms, such as controlled-release capsules, has prevented adequate analysis of results (Waghorn *et al.* 2008) Often different approaches do not have an additive impact, and in some cases different treatments can negate each other (McAllister and Newbold 2008).

Wright *et al.* (2006) report that a large proportion of methanogens cannot be cultured and studied in the laboratory, making it possible that non-culturable strains increase to replace those against which control measures are developed. The fact that diet and geography appear to influence the diversity of methanogen populations in the rumen (Wright *et al.* 2007) increases the challenge for rumen interventions.

Attwood and McSweeney (2008) sum up the present situation when they report that it is currently not possible to redirect rumen activity away from methane production into other end-products.

To date productivity interventions have contributed about 20% reduction in per-unit GHG emissions. This is a significant effect given that it has been achieved in the period from 1990. If demand for animal products was static, then meaningful reductions in climate change impacts would be evident. There is no evidence to suggest that this rate of improvement could not be sustained in the next 20 years. Alone, however, it is likely to be insufficient to compensate for the forecast growth in livestock production.

Species selection

Additional to attempts to reduce rumen emissions, to sequester carbon and to reduce CO_2 emissions, it has been suggested that decreasing the portion of rumen products in the total production population would be desirable. Species differences do exist (Table 3) and suggest that greater use of small ruminants, pigs and poultry may be desirable, especially in the development of animal industries in developing countries. There do not appear to be any detailed models, however, to reliably assess these approaches, and so such options should be included in improved regional models discussed earlier.

Non-traditional livestock species also need to be considered. A recent study (Wilson and Edwards 2008) has quantified the GHG savings Australia could make through substituting kangaroo production for cattle and sheep in the rangelands. Removing 7 million cattle and 36 million sheep by 2020 is projected to lower Australia's animal GMG emissions by 3%, and is a proposal that warrants further consideration. Such a change has other environmental benefits, and possibly health benefits, but also presents major social and cultural adjustments, and the study cited did not consider the financial investment required to achieve this shift. Trials of this potential are in their infancy.

Considered from a holistic viewpoint, there is an urgent need to improve our understanding of species (traditional and non-traditional) impacts in production systems and their potential to reduce climate change impacts.

Table 3. Species contribution to GHG emissions (million t of methane per year)

Species	Enteric	Manure
Dairy	15.69	3.08
Beef	50.16	4.41
Buffalo	9.23	0.34
Sheep and goats	9.44	0.34
Pigs	1.11	8.38
Poultry	-	0.97

Source: Steinfeld *et al.* (2006)

Table 4. Daily meat consumption, by region

Region	Daily consumption (g per person)
Africa	31
East and South Africa	112
West Asia (including Middle East)	54
Latin America	147
Developing countries (overall)	47
Developed countries (overall)	224
Total	101
Target under contract–converge model	90

Contract and converge: the challenge of consumption

McMichael *et al.* (2007) advocate a contraction and convergence strategy to reduce GHG emissions. On the assumption that available technologies would reduce non-carbon-dioxide emissions by less than 20%, their calculations indicate the need for a significant reduction in per-capita consumption of livestock product. Contraction of consumption in developed countries would define a lower, common ceiling to which developing countries would converge, or grow.

Assuming that there will be no advances in mitigation technologies and that the world population will grow by 40% by 2050, the contract–converge model has global meat consumption falling to 90 grams per person per day to stabilise emissions at current levels. The effect on daily meat consumptions by region may be appreciated by examining current consumption shown in Table 4.

The scenario also argues that significant health benefits will offset the discomfort of the adjustment in developed countries. The full workability of this approach is difficult to assess:

- First, it assumes no improvement in GHG mitigation technologies. Given that improvements of 17% or better were achieved in some regions from 1990 to 2005, this is a questionable assumption. This reflects some of the difficulties of over-simplification in assessment models.
- Second, there is sufficient variability and inconsistency in measurement of livestock GHG emissions (Kebreab *et al.* 2006; Laubach *et al.* 2008) that the accuracy of the baselines for such a model will be challenged.

- Third, the model looks at health (diet) benefits as well as climate change, but does not take into account the impacts of the livestock sector in breaking poverty cycles and contributing to economic growth in the transition and developing countries. There are wider trade-offs to be considered.
- Fourth, the study superficially covers the full social and cultural impacts, but does not consider the considerable re-investment and new investment needed for such a fundamental restructuring of animal agriculture.

Whilst the contract–converge scenario is feasible and attractive, it requires further validation and testing against a fuller range of assumptions. In its current form, it is unlikely to meet with widespread support because of the uncertainty of the actual mitigation potential.

Concluding remarks

There is little doubt that climate change is a serious issue for livestock production.

Climate change impacts on animal production are manifested mainly at a regional level, and could be more readily addressed were it not for the fact that livestock production also contributes significantly to the problem itself.

Similarly the critical roles that animals play in poverty reduction and development in transition and less developed economies cannot be ignored. The resultant increases in demand will result in continued growth of GHG emissions globally.

Given the present state of knowledge, it is not possible to envisage an industry program that would contain and reduce global emissions from animals without seriously compromising the aspirations of developing nations and the rural poor. Further improvements in productivity will be achieved, but recent evidence suggests these will not keep pace with growth in total production in the sector.

From a technical perspective two needs exist. The reliability and usefulness of regional impact models need urgent improvement so that there can be more confidence in baseline measurements and better appreciation of the true magnitude of targets to be achieved. A better understanding of productivity at the animal, or production unit, is needed, including a fuller exploration of rumen biology. The level of research being undertaken globally needs to be increased if these are to be achieved in a time frame conducive to more rapid mitigation. Without this information there will continue to be debate about the mitigation potential.

Similarly more information is needed about the impacts of animal products on health, the place of meat and milk in diets, and the changes in consumption needed to address these needs. As consumer knowledge increases it is likely that market forces will effect the necessary changes, but this is likely to be at a slower pace than required to address the climate change issues.

In the face of these issues, governments will need to make decisions on priority sectors to mitigate. Adjustments in livestock production to mitigate GHGs will likely involve a combination of consumption, productivity and regulatory measures. It is not inconceivable to consider a scenario in which the wider role of livestock in global development receives greater weighting than its impact on GHG emissions in setting mitigation targets. Other sectors, not so important to global food scarcity, would be called on to contribute more to climate change mitigation.

In the meantime the difficult task of reducing livestock's long shadow must proceed in the face of imperfect information, but in the knowledge that R&D will provide increasingly useful solutions that will eventually achieve the outcomes we desire. Progress can be made, albeit more slowly than many believe to be desirable.

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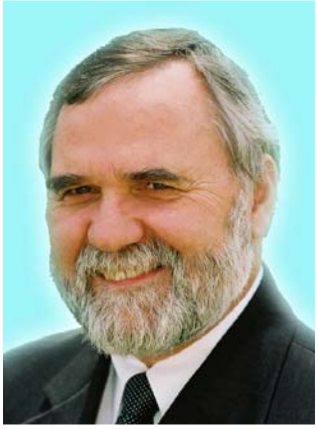

Impacts on Capture Fisheries and Aquaculture

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Over the last two hundred years the impact of industrial-scale fishing on fish stocks and their sustainability has been recognised and sought to be addressed or managed. This impact has resulted in some stocks collapsing, many being exploited at maximum or non–sustainable levels, with a subsequent increased focus on aquaculture as a source of fish protein to meet the demands of growing populations and economies.

It is now recognised that these enterprises are also subject to the additional influences of climate change. Due to the coastal and high seas nature of our fisheries, the complexity and diversity of riparian, coastal and oceanic systems, habitats and populations, the perceived impacts from climate change on fisheries and aquaculture are less defined than in other industrial and community areas.

Climate change induced impacts are anticipated to deliver both adverse and in some cases positive effects on fisheries and aquaculture. Potential adverse impacts include detrimental changes in oceanic physio-chemical characteristics (e.g. O_2, temperature, salinity, total inorganic carbon content and acidification) and key oceanic circulation systems, declines in production potential of traditional species, abundance changes and altered trophic/ecosystem relationships, disturbance of reproductive patterns and migratory routes, increased vulnerability to diseases and pests, increased extreme weather events (e.g. storm surges and cyclones) and the provision of a competitive advantage for lower-valued and invasive species. Adverse impacts also include decreased community (industrial and artisan) economic benefit, the additional cost of relocation and relocation of production system and coastal infrastructure, and the recognised vulnerability of coastal and low-lying island nations to rising sea levels.

Positive impacts include the potential for increased coastal nutrients and productivity from more intense upwelling systems, increased growth rates and extended growing seasons, increased competitiveness of high-valued less abundant and new profitable species, and climate change driven improvements in production systems, infrastructure and resource management strategies.

The critical challenge for the world's fisheries and aquaculture is to ensure they effectively contribute to the global response to address the causes of climate change, whilst embracing and adapting to opportunities that future change delivers.

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Introduction

'… all the great sea fisheries are inexhaustible: that is to say that nothing we do seriously affects the numbers of fish. Any attempts to regulate fisheries seems useless'

(T.H. Huxley at the International Fisheries Exhibition London, 1883)

'The supply of fish in the ocean may be considered to be practically inexhaustible'

(Introductory line of the chapter on seafood in Mrs Beeton's *Book of Household Management,* 1880)

I thank the Crawford Fund for this opportunity to present on the aquatic-industry-based sectors, complementary to the traditional land-based agricultural focus.

The foregoing quotations represent the status of the knowledge of fisheries at the time. We now know that globally fisheries have been challenged by a range of factors including recruitment and economic over-exploitation, natural variation in species stock dynamics, and habitat and ecosystem destruction by damaging fishing practices and or anthropogenic pollution. It is also now evident that the challenges from climate change need to be accommodated.

Fishing is a hunting/harvesting operation, aquaculture a farming/husbandry operation. Modern fisheries seek the sustainable exploitation of biologically renewable resources, delivering economic and social benefits to current and future generations. They embrace the interactions of complex biological, technological, economic, social and cultural, geo-political, regulatory and compliance factors.

The demand for fish products continues to increase as a consequence of increased population as well as to cater for the increasing recognition of their health benefits. Increased demand for fish products has also been driven by the global need for feedstock (fishmeal and fishoil) for aquaculture and other intensive animal industries emerging over the last forty years.

Current global capture fisheries production exceeds 90 million tonnes annually, with aquaculture production over 40 million tonnes (FAO 2004). Capture fisheries production grew at 1.2% annually after 1970 but it has stabilised over the last decade; aquaculture production has increased at an average rate since 1970 of 8.9% per annum (FAO ongoing). In 1970 aquaculture contributed 3.9% by weight; in 2002 it was 29% by weight. Estimates predict that by 2020 wild capture production will remain in the 90–100 million tonne range, with aquaculture possibly surpassing 70 million tonnes (FAO 2004). Seventy percent of the worlds aquaculture production is from China (FAO ongoing).

It is now recognised that the major stressors of large-scale marine stocks are over-fishing, habitat destruction and climate change (Handisyde *et al.* undated).

Climate change

When considering the impacts of climate change on fisheries and aquaculture it is convenient to group them in three categories:

- physio-chemical
- biological
- societial.

The impacts of climate change on fisheries and aquaculture are many and varied. The aquatic environment will respond to climate change in ways that are equally significant as the responses in terrestrial and atmospheric environments. The changes may be more gradual and less apparent than those taking place terrestrially, because of the ability of oceans to absorb and distribute heat (2WE Associates 2000).

Consideration of climate change impacts on fish stocks needs to recognise underlying short- and long-term fluctuations in populations. Examples of these are the persistent cyclic nature of stocks of Californian sardines and anchovy, where analysis of fish scales from offshore sediment cores covering 1700 years has identified cyclic time scales of abundance indices with periods of 54 to 57 and 223 to 273 years. These cycles have been correlated to air temperature as measured from fossil ice cores. Shorter-term fluctuations in the Peruvian anchovy stocks are closely correlated with strong El Nino events.

Physio-chemical impacts

Oceans, like terrestrial systems, are experiencing change in core parameters, albeit reflecting the nature of the medium. The Intergovernmental Panel on Climate Change (IPCC 2001) reports that over the period 1961 to 2003 global ocean temperatures increased 0.1°C in the region from the surface to 700 m depth. The global ocean heat content in the region from 0 to 3000 m increased over the same period, absorbing energy at a rate of 0.12 ± 0.04 Wm^2 globally averaged, with the top 700 m absorbing two-thirds of this input.

In the case of salinity, over the period 1955–1998 global freshening has been observed in sub-polar latitudes (Pacific), with salination occurring in the shallower parts of the tropical and sub-tropical oceans (Atlantic and Indian Oceans).

Acidification of the oceans is recognised to be a direct consequence of global warning. Uptake of anthropogenic carbon has resulted in the ocean becoming more acidic. The IPCC has estimated the total inorganic carbon content of the oceans has increased by 118±19 Gt C from the pre-industrial period (1750). The IPCC estimates the likely fraction of emitted CO_2 taken up by the oceans has decreased from 42±7% during the period 1750–1994 to 37±7% over the period 1980–2005 (it should be noted there is uncertainty around these data). The increase in total carbon results in a decrease in the depth at which calcium carbonate dissolves as well as a decrease in surface pH. The IPCC estimates an average decrease of 0.1 pH units since 1750, although for more recent times (over the last 20 years) an indicative rate of decrease of 0.02 pH units per decade has been suggested to be occurring.

Although much more investigation is required, the predicted impact of this acidification is a reduction in bio-calcification in marine organisms. The most obvious potential impact is a threat to coral reef communities and their structural integrity, as well as marine food chains based on carbonate plankton and organisms with aragonite calcareous skeletons and shells (e.g. crustaceans, molluscs).

The earliest impact of ocean acidification is expected to occur in deeper and polar waters. It is predicted that tropical areas will remain saturated but experience a significant drop in the aragonite availability to marginal levels in 2100.

Oceanic circulation and sea level rise

The best-known impact of climate change in the aquatic environment is the predicted rise in sea level. For aquaculture this means having to cope with changes in tidal amplitude and strength. It is well recognised that rising sea levels will particularly affect coastal areas and low-lying island nations. The main factors contributing to increasing sea level are:

- thermal expansion
- glacial contributions.

The contribution of thermal expansion to sea level rises (1961–2003) has been estimated to be 0.4±0.1 mm per annum.

The IPCC estimates that sea levels have risen over the period 1961–2002 at 1.8 mm per annum, although this is spatially non-uniform.

The major impacts of sea level rise will include:

- increased inundation of coastal wetlands and lowlands
- loss of estuarine, coastal species and communities
- increased intrusion of salt-water vegetation into freshwater ecosystems in coastal areas
- contamination of coastal quality water aquifers
- changes in the structure of coastal marine communities, including coral reefs
- loss of low-lying island states and coastal regions with consequential economic loss and social disruption.

With regard to mass transport distribution, there has not been any clear evidence for oceanic circulation changes, although changes in the contributing water body characteristics have been observed.

Ocean thermohaline circulation and continental shelf ‘flushing and cleaning’ mechanisms are crucial to coastal water quality and nutrient cycling and the global heat budget. Most climate change models indicate a weakening of the thermocline circulation (THC) in the northern hemisphere, although the extent with which this overall circulation is threatened is still uncertain.

There is an emerging literature that reinforces the concerns from the wholesale physical changes predicted. CSIRO has observed changes to ocean circulation in the western Pacific Ocean and Timor Sea, and an upward trend in water temperature has led to environmental modification in SE Australia as the East Australia Current pushes further south, carrying sub-tropical species into temperate waters (Hobday *et al.* 2006).

Extreme weather

Fishers and aquaculturalists derive their living from the sea; consequently they live and operate at the sea–land interface, and are therefore vulnerable to climate change induced impacts at this interface. Extreme weather events are intrinsically linked to the climate change regimes and influences. The warming and consequential increase in ocean heat content, thermal expansion and reduction in land-based ice are seen as contributory factors driving these phenomena. Extreme events include intensified precipitation and droughts; monsoonal, cyclonic and hurricane activity; storm surges and flooding; as well as temperature shocks. Extreme events can manifest themselves through both increased frequency and or severity. Extreme events occur on a global scale as seen from cyclonic events, or on a local scale as the Australian southern bluefin tuna farming industry experienced in 1996 when more than 95% of the standing production was wiped out by a localised high-intensity event.

One of the most intensively monitored phenomena has been the long-term observed changes in the El Nino Southern Oscillation (ENSO), with well-recognised effects on southern Australia in particular.

An area that has yet to receive significant attention with regard to climate change impacts is upwelling. Upwellings of deep ocean waters onto continental shelf margins are a major source of cold nutrient-rich waters that traditionally enhance regional productivity. Upwelling is induced by seasonal intensification of wind blowing parallel to the coastline (N–S alignment), usually resulting from intensified temperature differentials between the adjacent land mass and the ocean and consequent latitudinal shifts in inter-continental high-pressure systems. Under the influence of the Coriolis effect, surface water is transported offshore and is replaced by upwelled sub-surface water. The significance of upwelling events is reflected in the fact that upwelling areas account for 1% of the ocean surface but support 50% of the world's fisheries (Nellman *et al.* 2008).

Climate change has the potential to strengthen upwelling events, enhancing nutrient input to receiving regions. This is predicted to have both adverse and positive effects. Adverse effects include disruption of the bio-rhythms and processes of key species, whilst pluses are predicted to include increased regional productivity from the additional nutrient inputs.

Abundance and trophic/ecosystems relationships

Physico-chemical and circulation modification are manifested through physio-biological changes in the aquatic biota and ecosystems.

Aquatic systems are expected to be less tolerant than terrestrial systems, changing the adaptive capacity of species. This includes:

- increased competitive advantage for lower-valued and invasive species
- declining stocks and unstable fisheries
- species shift to those more tolerant of warmer and perhaps less oxygenated waters.

Changed physical environment , induced upwelling strengths, and shifts in oxygen and temperature can also result in more frequent algal blooms in coastal areas and increased incidence of fish kills resulting from toxic algae.

Phenology, migratory routes and reproduction

As with land-based plants and animals, there are expected to be climate-based changes in the phenology of seasonal and life-cycle movements in aquatic organisms. These can include changes in timing and location of annual peak abundance and movements for reproductive purposes.

Changes in those latitudes expected to experience elevated water and air temperatures are likely to be:

- longer growing seasons
- lower natural mortality (M) rates
- faster growth in higher latitudes,

with consequential beneficial impacts on growth rates and feed conversion ratios. These have particular interest to aquaculture and provide an opportunity to enhance this sector of the industry.

A literature search identified little solid empirical documentation for these phenomena. UK studies on the flounder (*Platichthys flesus*) and squid (*Loligo forbesii*) have documented shifts for these species in time of arrival on spawning grounds related to temperature, concluding that for these species migration phenology is 'driven by short term, climate induced change in the thermal resources of their habitats' related to the North Atlantic Oscillation (NOA) (Sims *et al.* 2004).

In Australia CSIRO (Thresher 2007) has reported that growth rates of coastal species such as juvenile morwong in the 1990s were 28.5% greater than recorded in the 1950s. Conversely he found that species at depth (1000 m), such as juvenile oreos, had growth rates 27.9% less than those extrapolated for the 1860s. Thresher has linked these observations to factors such as higher mortalities, reduced food availability and reductions in the size of sexual maturity. He observed that this also coincides with sea surface temperature rises in the south-west Pacific east of Tasmania of the order of 2°C, coinciding with the strengthening of the warmer southerly-moving East Australia Current.

Increased temperature of coastal waters provides the opportunity for increased production in aquaculture by expanding species ranges. This includes responses to reductions in sea ice resulting in an increased geographic range becoming available for aquaculture (IPCC 2001).

Diseases and pests/biotechnology

Changes in physical parameters impact on the adaptability and competitiveness of pests and diseases, resulting in an increased incidence of infections. A portent of the future could be the herpes virus that decimated southern Australia's southern bluefin tuna stocks in the 1990s, and the global spread of the toxic green alga *Caulerpa taxifolia* to locations including a number of sites in Australia.

With regard to aquaculture, there is a recognised increased occurrence and intensity of disease and vulnerability to pests due to factors such as stress induced by shifts in temperature and oxygen levels.

There is future potential for accelerated breeding programs, including the use of molecular bio-technologies, to deliver benefits (growth, abiotic and biotic resistance) while having to address wider community demands, and in some quarters opposition to the use of such technologies.

With an understanding of the physical and biological changes from climate change, the application of this knowledge is how society responds. Most the global consideration is focussed on the disruptive impacts from weakened biological systems, severe infrastructure and coastal degradation, economic loss, fragmentation of societal cohesion and lifestyle disruption to post extreme event health and nutrition challenges in artisanal communities.

Societal impacts

Opportunities for aquatic-resource-supported societies include the development of possible new profitable species and enterprises, biological enhancement of current stocks, drivers for industry and infrastructure planning and renewal, along with new management approaches and more efficient industries and communities driven through adaptive necessity. It is hoped that this would also result in greater recognition of the risks and opportunities, as well as support for greater knowledge of the systems and the uncertainty around the models to better enable science-based management.

Whilst research on climate-change-related aquatic systems (physical and biological) has contributed to the overall understanding of systems and their future landscapes, significantly less research has been directed at the impacts on fisheries and aquaculture.

The IPCC's general conclusion is also relevant to fisheries and aquaculture: that both mitigation (in the form of the industries' contributions to emission reductions) and adaptation must be embraced.

This will allow both industrial and artisanal industries and communities to address the impacts as well as to pursue the opportunities that climate change will inevitably present.

Summary

Responding to climate change in the aquatic environment requires both short- and long-term solutions. Near-term adaptation strategies include reinforcing coastline infrastructure, restoring wetlands to protect coasts and if necessary reconfiguring ports and coastal facilities to resist extreme weather events. In addition, jurisdictions need to plan for such events to enable adequate responses to protect and assist their citizens, whether it be to meet a consequential health risk in flooded areas (e.g. cholera), provide emergency shelter and sustenance, or rebuild destroyed infrastructure.

In the longer term, the critical challenge for the world's fisheries and aquaculture is to ensure they effectively contribute to the global response to address the causes of climate change, whilst embracing and adapting to opportunities that future change delivers. This involves adopting appropriate technologies and practices across the whole value and delivery chain to:

- reduce climate risks
- ensure continued investment in the large-scale research programs required to reduce uncertainty around future projections
- ensure that the outcomes of this investment are disseminated to assist governments and society to better interpret and understand the threat, balance the uncertainties and strategically plan to effectively adapt.

Climate change impacts in fisheries and aquaculture provide both risks and opportunities.

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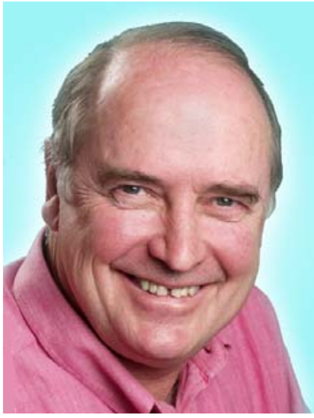

Climate Change and Agricultural Mutation

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I had my introduction to climate change issues through the international agricultural research system a few years ago.

Introducing IFPRI

The International Food Policy Research Institute (IFPRI), whose board I chair, started to undertake research — which has subsequently expanded — on the potential impact of climate change on global agriculture and particularly the agricultural food system. As we got into that work it became more and more arresting. It became clear that climate change itself was going to increase the old challenge of keeping abreast of the Malthusian spectre. It was also clear that the growing interest in bio-fuels, part of the mitigation solution of the climate change problem, was going to have very big effects on agriculture. These effects would exacerbate the food problem if supported by inappropriate policies.

The work that IFPRI has undertaken and published in recent years anticipated the large increases in food prices that we've had over the last year. It attributed some of this increase to the competition between bio-fuels and food for scarce land resources, and in part to the emerging effects of climate change on production systems.

PROFESSOR ROSS GARNAUT is a Distinguished Professor of the Australian National University as well as both a Professorial Fellow (Faculty of Economics and Commerce) and a Vice Chancellor's Fellow at the University of Melbourne. He is currently Chairman of a number of international companies and research organisations, including the International Food Policy Research Institute, and board member of several others. From 1985 to 1988, he was the Australian Ambassador to China. In April 2007, Professor Garnaut was commissioned by the Australian states and territories, and subsequently the Commonwealth Government, to review the impact of climate change on the Australian economy and potential medium- to long-term policies to ameliorate these.

It is clear to me now, if it wasn't clear at the beginning, that climate change is in every way a science issue. It was work in the physical and related sciences that anticipated the issue of anthropogenic climate change. It is going to be science that helps us if we do succeed in adapting to the very large challenges of climate change. It is going to be science that helps us to develop the new agricultural approaches and systems that can feed the world and keep us in a range of other resources as the biological base for agriculture changes. Agricultural and forestry innovation and the development of opportunities for bio-sequestration has transformative potential in relation to the Australian as well as the global mitigation task.

The big increase in international agricultural research resources in the 60s and 70s was spurred by the early recognition of the large challenge of feeding a growing global population from expanding but ultimately finite agricultural resources. It was that challenge in India that led to the work in which John Crawford was involved in the 60s with the planning commission and the agricultural department in India, and which gave rise to what later became known as the green revolution. That success helped to shape the world's response to great international concern about food prices and new realisation of the Malthusian challenge in the mid-70s, when world prices for a wide range of foodstuff went to unprecedented levels. That crisis led directly to the establishment of the International Food Policy Research Institute with John Crawford as its first chairman.

Kissinger played a major role in marshalling resources for that initiative, seeing it as a strategic issue for a great power. That was also a period when there was a big increase in the resources applied to the international agriculture research system and a strengthening of its institutional base. It is well recognised that that increase in resources and that strengthening of the institutional base was very productive.

We have become complacent over the last couple of decades. Public-sector resources going into agriculture and related research in general have declined — in real terms, declined alarmingly. The amount of resources going into the international agricultural research system from the public sectors of the world has been stagnant. A renewed realisation — within the last year — that we face a large global challenge of food supply is beginning to get people thinking again about how we need to arrest the decline in that effort, to strengthen it and to strengthen the institutional base for it.

In this account I will share with you thoughts on these and other issues of science and research that have come out of my work over the last year. These will be reflected in the final report of my review[4] when I give it to the Prime Minister and the Premiers on 30 September.

An Australian analysis

I have made heavy demands of the Australian science community in the course of my recent work. I needed a lot of very detailed analytic information about the anticipated impacts of climate change on various aspects of the Australian economy and Australian life. I learned that Australia has a great capacity in this area, but I also learned that it is nowhere near big enough to do the job that needs to be done.

Greater scientific capacity is needed

There are gaps in a number of areas. We need to do more and better at the higher-level climate science and modelling; this is really the foundation upon which a lot of the other work related to climate science has to be built.

We need that for two reasons. One is that if we are to interpret and properly understand the best work that's going on in the rest of the world, we need our own people working at the frontiers. There is some Australian work at the relevant frontiers, but we would have much to gain if we ourselves were making a larger contribution to the global effort. Secondly, there are some distinctive features of Australia's location and situation that require a southern hemisphere and Australian-based effort. Some of our climate challenges are different from those of the northern hemisphere.

We have a different local climate system. There are no other substantial developed countries with strong science capacity in the southern hemisphere. The application of the lessons of climate science to anticipate the demands of adaptation is going to require a strong local research effort.

The Garnaut Climate Change Review team also became aware of the excessively large gaps in communication between the policy communities and the science community. I found myself being greeted with some surprise when I started asking precise questions about probability distributions for various possible impacts. There was a lot of reluctance by people in the scientific community to chance their hands at estimates of parameters that were fundamental to building an overall view of climate change impacts in Australia. It is not part of the culture of our scientific community to answer question of a precise kind about probability distributions until there is a high degree of certainty about the answer. The big policy tasks that we are involved in, however, entail making policy under conditions of uncertainty.

The alternative to having the best-informed and analytically strongest people making these judgements is to rely on people like me who don't know very much at all about it — and having a best guess at the probability distributions of scientific outcomes. So there was a cultural gap that has affected how far we've been able to take the analysis of likely impacts of climate change in Australia.

For example, on a very concrete and practical question, the international community is involved in a discussion of the appropriate ambition for the global community and mitigation of climate change. There is discussion of whether we should be aiming towards a concentration of greenhouse gases in the atmosphere of 550 parts per million of carbon dioxide equivalent or 450 or 400 or, as

[4] Garnaut, R. (2008) *The Garnaut Climate Change Review: Final Report*. Cambridge University Press, Port Melbourne, Vic. xlv + 634 pp.

part of the science community is inclined to say, somewhat less than that. But we don't actually have the sharp, well-informed view of probability distributions of impacts to make fine judgements about what would suit Australia best. Filling that gap — not only the high science gap but the capacity for policy communities, social science communities and biological and physical science communities to understand the questions each is asking — is going to be important to our making a success of the future related to climate change.

A new focal institution?

One of the ideas that I have been discussing with the learned academies of Australia and other parts of the Australian science community is the need for a specialist institute for climate change policy research that will help strengthen some of the capacities that my own work has found to be weak. Part of what Australian needs to think about as it addresses the issue of climate change is how it contributes more and better to the international research effort in scientific areas that are closely related to our old interest in agriculture and forestry but which have new dimensions.

In my final report I will be saying something about relating the role of Australian participation in international agriculture research to cooperation between Australians scientists and developing country scientists in areas related to climate change.

I will also discuss the further development of the CGIAR system to assist the international community in meeting some of these challenges.

Challenges for agriculture and forestry

We are already experiencing some impact of changes in climate on global markets. The limited amount of warming that is already apparent has had an effect on runoff and evaporation, for example in Australia in the south-west of the country and in the Murray Darling Basin. Climate change is part of the story of the challenges to agriculture in large parts of southern Australia over the last few years.

Australia is big enough in global food markets for those challenges in Australia to contribute to the problem of tightening global food markets over the last couple of years. We need investments in climate science and the capacity to interpret ensuing results in terms of impact on Australia and our developing country neighbours to understand better what is happening to us. We are going to find that the rapidly changing world will require a lot of innovation, and innovation always makes demands on science. We have seen that right from the beginnings of the history of Australian agriculture.

Agriculture had to follow a hard road in this country. When Europeans first settled this ancient continent and brought with them ideas and plants and animals from Europe, nothing fitted very well. The success of subsequent Australian agriculture was very much a story of the success of innovation with a large science component. Australian agriculture has been successful over a long period because we have always been at the forefront of global work in agricultural, biological and related sciences.

In the period ahead, time and time we will face again the type of challenge that early Australian agriculture faced in adapting to a new environment. The future of Australian agriculture will depend on the success of that adaptation.

It is not going to be all negative. One of the interesting stories that I was able to study along the way to the draft report[5], which we released on 4 July,' was the complex interaction of the increased concentration of carbon dioxide in the air and Australian wheat production. There will be some regions with access to enough water to productively use the increased carbon dioxide in the atmosphere to increase yields — at least for a while. Eventually, however, temperatures will increase too much to take advantage of the carbon dioxide fertilisation effect. We had a careful study of that done for the review. Unfortunately most of the effects of climate change on production will be strongly negative.

The contribution of climate change to higher world food prices is going to make agriculture more profitable and attractive for those who are still able to remain productive: those in favoured locations who are able to keep abreast of change. I have no doubt that despite the challenges on the supply side, many Australian farmers will be taking advantage of those higher prices and in so DOIng making our own modest contribution to

[5] Garnaut, R. (2008) *Garnaut Climate Change Review: Draft Report: June 2008.* Garnaut Climate Change Review, [Canberra], x + 537 pp.

easing the pressure on world food markets. The biggest of the new opportunities are probably going to be related to bio-sequestration.

Of the OECD countries, we are probably the country with the largest area of woodland and forest per capita. Different management of these vast areas will provide a very large potential for bio-sequestration of many kinds. Up till now the biggest focus has been on plantation forests, for which there is great potential. These are in some respects problematic, and there's a lot of work to be done in reconciling the negatives with the positives, but certainly there is a great positive there. But that is only part of the potential for bio-sequestration in Australia.

Changes in land use could transform the mitigation effort

We consider opportunities for agriculture and forestry in chapter 22 of our final report. Better management of these opportunities could be generally transformative in the Australian mitigation effort — and potentially in the global mitigation effort. The opportunities are varied: different types of management of the northern Australian savannas has large potential. Climate models, crude though they tend to be in their estimates of future rainfall over the Australian continent, hold out reasonable prospects of higher rainfall through parts of northern Australia. That's not at all inconsistent with continued drying of southern Australia. There will clearly be opportunities for intensification of the growth of biomass in northern Australia.

We have in Australia huge areas of marginal pastoral country that are badly denuded from the original natural state. It has been denuded by relatively unproductive sheep and cattle grazing and by feral animals of various kinds. The sheep and cattle grazing was once more economically valuable than it is now.

Careful management and protection of growing forests — both areas that have been logged and natural forests — have much larger potential for bio-sequestration than is usually understood. There has been active discussion right across Australia over the last few years of bio-sequestration in the form of soil carbon.

Realising opportunities

To realise these opportunities, we will need lots of good work in the biological sciences. We will need lots of changes in institutional arrangements. We will need big changes in the established international approaches to accounting for carbon in trading regimes, because neither the Clean Development Mechanism (CDM) set up by the Kyoto protocol nor the European trading system credits many of these forms of carbon sequestration. If we are going to realise anything like the potential that these opportunities have, the incentive structure must be right.

Food or fuel?

Despite the problems to which I have referred, there is also potential to make use of the agriculture opportunities related to bio-fuels for mitigation. Bio-fuels have acquired a bad name over the last year or so, partly as a result of the work of IFPRI, because of their contribution to high food prices. That contribution is a result of poorly conceived policies.

When you specifically subsidise a particular form of mitigation or abatement of greenhouse gases independently of its cost, independently of the interaction between that and other areas of mitigation, large distortions are inevitable. The subsidies and the mandatory requirements to use a certain proportion of fuel from biological sources in parts of Europe and the United States led, over a short period, to shifting much land out of food production and into input for bio-fuels. This turned out to be very unproductive environmentally. Mandatory controls and crude subsidies encourage biofuel production even when the carbon and other greenhouse emissions saved from the use of bio-fuels are greater than the carbon emitted in the process of production.

That would not happen if incentives for biofuel production were integrated into general emissions trading schemes. It would not happen if carbon emissions in the inputs were taxed at the same rate as the emissions from fossil fuels that were replaced by the bio-fuels. It is a very simple error. The distortions in North America and Europe resulted from basic political economy forces that we all understand. The effects were powerful. We have to avoid that sort of outcome in future.

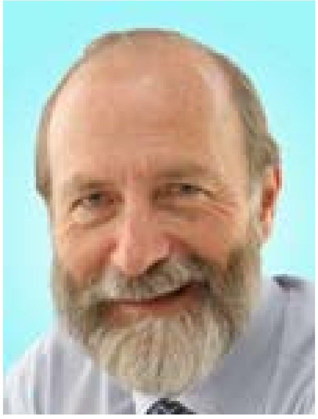
Bio-fuels do not have a good future on land which is currently highly productive for food. In the end, in the competition for land resources, food will beat energy. Enough people will be prepared to pay prices that are high enough to keep land in food production. Unfortunately poor people can be damaged along the way. In the end, the important source of bio-fuel is going to be biomass that does not compete with food production. Sometimes bio-fuels will use by-products from food production. They will also use land which is not productive for valuable food.

Conclusion

How well we manage a huge transformation, a mutation, in Australian agriculture and forestry in response to new incentive structures and new challenges associated with climate change is going to have a big effect on our rural communities and on our agricultural industries. It is also going to have a big effect on how painful our overall mitigation task becomes.

If we manage the land use mutation well, we will make the mitigation task much more manageable for Australia. We will also set standards and develop approaches that will make mitigation much easier for others. This will be especially important in our neighbouring developing countries where we have long-standing cooperative links in the bio-sciences, in agriculture and in forestry.

If we do all of this well, it will add up to a productive mutation of the Australian agricultural economy.



International and National Agricultural Research Frontiers

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Let me begin by saying that Professor Ross Garnaut was right when, at the National Press Club on 4 July 2008, he said:

> Climate change is a diabolical policy problem. It is harder than any other issue of high importance that has come before our polity in living memory. Climate change presents a new kind of challenge. It is uncertain in its form and extent rather than drawn in clear lines. It is insidious rather than directly confrontational. It is long-term rather than immediate in both its impacts and its remedies. Any effective remedies lie beyond any act of national will, requiring international cooperation of unprecedented dimension and complexity.

It is true that there is substantial uncertainty about the nature of the relationships between higher atmospheric carbon concentrations (Fig. 1) and changes in global temperature and rainfall and its distribution. This uncertainty, in part, is causing debate about substantive issues of the appropriate global response and the burdens of how this response will be shared. Taken together — the uncertainties and burden sharing — it is clear that we are facing a diabolical political problem where time is running out for us to slow down and stabilise atmospheric carbon levels. But start we must.

PETER CORE is the Chief Executive Officer of the Australian Centre for International Agricultural Research, a position he has held since July 2002. He has a long history in agriculture, initially with the OECD Agricultural Directorate in Paris and then with the Department of Primary Industries and Energy, rising to the position of Deputy Secretary in 1988 before accepting the CEO position with the Department of Industrial Relations in 1993. He then headed the Department of Transport from January 1995 until March 1996. During that period, he was a director of Airservices Australia and the Federal Airports Corporation. From May 1996 to June 2002, Mr Core was Managing Director of the Rural Industries Research and Development Corporation. He holds a Master of Economics and Bachelor of Rural Science from the University of New England.

My job here is to focus on the agricultural research response. Another way of thinking about this question is to ask how you would tackle allocating 100 units of research funding to agricultural research that focussed on a changing climate. Such an allocation might leave some of us uneasy, but the reality is that research funding

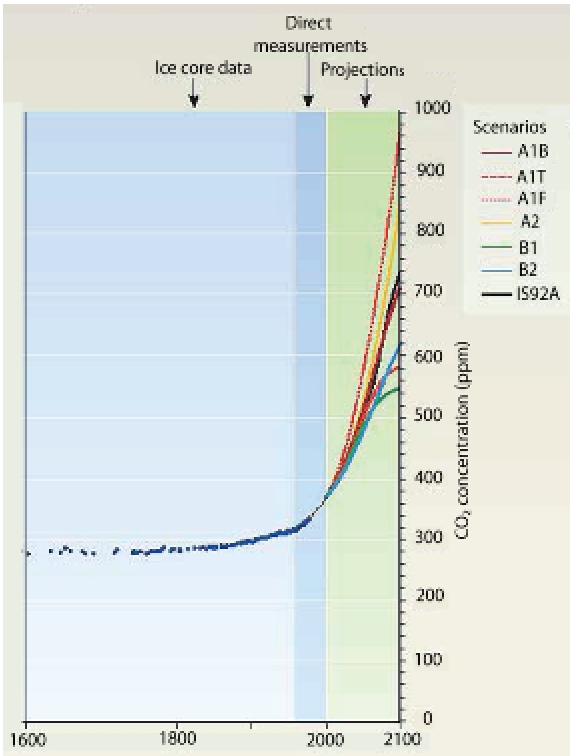

Figure 1. Past and future atmospheric CO_2 concentrations

is always limited and must always be prioritised. Serendipity has its place but, in my view, within relatively broad areas of priority research.

I will address the agricultural research response, but first let me share three key concerns with you that stretch well beyond agriculture.

The **first** is that I think it is unrealistic for the OECD — the rich countries — to expect that countries with GDP per capita of less than $2000 per annum will make the tough adjustments expected by countries with the standard of living of countries such as Australia. This problem has arisen from industrialisation fuelled by hydrocarbons, and it is the OECD countries that historically, and on a per-capita basis, have been the emitters.

My **second** concern is that the consequences for agriculture far outweigh its contribution to the problem. And, it follows from that, that the solutions to the problem rest much closer to those that are causing the problem.

That is not to say that agriculture does not have a role to play in mitigation. It does, but in my view any realistic response to climate change will rest with changing the energy mix away from hydrocarbons and reducing our own energy-intensive lifestyles.

My **third** concern is that I am fairly pessimistic about our collective willingness to reduce our energy consumption levels without significantly higher hydrocarbon prices. It is almost as if there is a 'disconnect' between the growing recognition of the problem and our own behaviour. It is as though this is one of those problems that someone else must do something about.

Broader research priorities — economy-wide

It follows from this that our primary research challenge as a people is to implement a much bigger effort in research, development and commercialisation of lower-emissions technologies. In reality, this investment is only just getting started in terms of the scale that is required. Global consortia will be required and, in my view, the outputs from these consortia need to have the status of international public goods — outputs that are not fettered by intellectual property rights.

We have heard much in Australia and elsewhere about emission trading schemes. These 'cap-and-trade' policies are an essential prerequisite to any climate policy response. Their purpose is to price carbon and provide the economic incentives for lower-emission technologies. A significant research agenda in terms of the public policies is required to underpin efficient energy markets. This research will be ongoing because the reality is that we are really talking about a relatively significant transformation across important components of the Australian economy.

Agriculture – climate – research

Earlier contributors have provided wonderful presentations on climate change as it relates to forests, crops, livestock, fisheries, pests and crop diversity. All these are key research issues and worthy of special focus.

But in my mind, being supportive of all does not necessarily help in resource allocation decisions. Remember my earlier question: how would you allocate 100 units of research funding to agricultural research that focussed on a changing climate?

Looking across the legitimate research priorities, my emphasis in approaching resource allocation would be as follows:

Climate-adaptive crops

Another way of expressing this area of work is stress-tolerant crop cultivars. In the future we will need crop varieties with greater tolerance to drought and heat. At the Consultative Group on International Agricultural Research (CGIAR) centres, scientists have worked and continue to work on developing hardier varieties. There are several important recent examples where the latest in molecular biology is being combined with farmer participation trials to give results that are truly relevant to local needs and preferences.

At the International Maize and Wheat Improvement Center (CIMMYT), scientists have been prioritising major stresses to **maize** — drought, low soil fertility, insect pests and soils — and replicating them on breeding stations. Previously, selections were done under well-fertilised, well-irrigated conditions. In Southern Africa alone, enough seed of new, stress-tolerant maize cultivars has been produced to sow two million hectares.

Similar gains are being obtained with **wheat** by CIMMYT scientists working with national partners. Experimental cultivars derived from crosses between wheat and goat grass, one of wheat's wild relatives, have produced up to 30% more grain than their wheat parents, in tests over two years under tough dryland conditions.

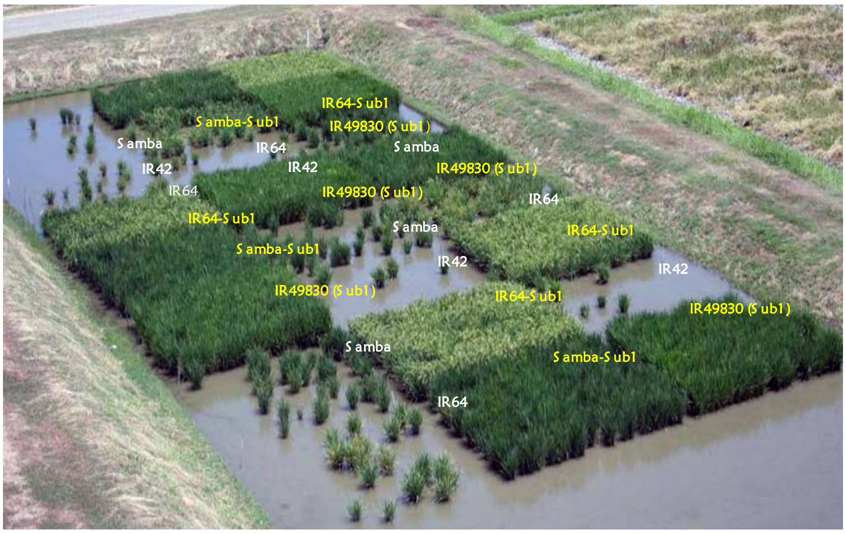

Figure 2. New Sub1 lines after 17 days submergence in the field at IRRI

One of the more exciting advances in crop improvement in recent times has been the development of **new rices** for Africa — the NERICA varieties. These varieties combine the high productivity of Asian rice with the ability of African rice to tolerate harsher growing conditions.

And here in Asia scientists at the International Rice Research Institute (IRRI) have found a genetic remedy for the risk of flooding in rice crops (Fig. 2). Rice is the only cereal crop that can withstand any degree of submergence, but most varieties die if fully submerged for more than three days. Now, IRRI researchers and collaborators have identified a rice gene which allows plants to survive completely submerged for up to two weeks. The 'waterproofing' trait has been transferred into a rice variety popular in Bangladesh and the improved version is giving high yields while protecting harvests against flooding.

I raise these as recent examples of the work being done on tolerance to drought, flooding and heat, and combining it with other valuable traits such as better nutritional quality. But the reality is that this work is being done on a shoestring. There has been a global complacency and there is an urgent need to double and redouble our efforts in developing climate-resilient crops.

But most importantly it does not stop with the breeders. All of their work needs to be done with national partners and ground truthed with site-specific trials. This is why the partnership between CGIAR centres and national agencies is so important. And moisture-conserving technologies such as reducing tillage and direct seeding of rice will be crucial in climate change adaptation.

Enhancing water productivity

Let me move to water. It is clear to all that climate change is putting pressure on water availability. This would be my second key research priority after seeking to develop stronger stress-tolerant crop cultivars. A lot of this work is site-specific and there are numerous examples of important work being done by CGIAR centres on dry irrigation and improved water-harvesting technologies. This work is vital but, in my view, even more important is the work on the public policy framework because a significant element of the water issue is a 'tragedy of the commons' — whether it be above ground or below. Both the International Food Policy Research Institute (IFPRI) and the International Water Management Institute (IWMI) are DOIng important work in this area, but much more needs to be done.

Let me divert for one second. When we talk about water, I suspect many of us here today think about how we should lower extraction rates and return more to the environment.

I am probably the odd one out, again, but I think better water storage is part of the solution in Africa. Take the case of Ethiopia, which is typical of many sub-Saharan African countries in terms of water resources and management. Its water storage capacity is less than 40 cubic meters per person, compared to almost 5000 cubic meters per person for Australia, an amount that may prove inadequate in the face of expected climate change impacts.

Africa will need new large- and medium-sized dams to deal with its critical lack of water storage capacity. But other, simpler solutions must be part of the equation as well, such as construction of small reservoirs, sustainable use of groundwater systems (inducing artificial groundwater recharge) and rainwater harvesting for small vegetable gardens.

My point is that as important global institutions move back into significant infrastructure investments, underpinning research will be vital to maximising the benefits of these investments to the community of farmers in low income countries.

Slowing deforestation

Deforestation through burning accounts for at least 20% of global carbon emissions. This is a key public policy issue and there are several research angles that need to be worked on. Monitoring clearly needs to be upgraded to foster transparency, but, much more than that, developing country partners need to be compensated for their carbon storage and this compensation needs to benefit those that are dependant on the forests. The Center for International Forestry Research (CIFOR), the CGIAR forestry centre, has a very important role to play in our region and, just recently, the Australian Government announced an International Forest Carbon Initiative. Activities under this initiative have provided $3 million to CIFOR to further the research on policy and technical issues associated with reducing emissions from deforestation. And ACIAR has its own $1.5 million project with the Australian National University, CIFOR and Indonesian partners on better governance arrangements to reduce emissions from deforestation.

There is a broader agenda

The impact of climate change on agriculture here in Australia and in the region is a diabolical problem. We have been too sanguine about our ability to feed the world. Over the past ten years we have stood by while productivity gains of our basic staples — rice, wheat, maize, cassava — have stagnated (Fig. 3). It is clear that the productivity gains of these key crops need to double — and get back to the results achieved in the 1980s and early 1990s, but we have to do it in an era of climate change.

We have diverted resources into areas with little scope for broad-based, high impact in the key producing areas. Policies that subsidise the conversion of grain into transport fuel are a real problem. Climate change is making our job that much harder. Nearly all the evidence points to this as the new reality. But I don't despair. Research partnerships are not an exclusive panacea but they are a very essential ingredient. We need to redouble our efforts and stay focussed over the longer term — something we are not good at here in Australia. In my view I would focus our joint efforts around:

- building stress-tolerant crop cultivars of the basic staples and conducting site-specific trials of these cultivars in the key production areas
- enhancing water productivity
- slowing the rate of deforestation.

And, if pushed, I would allocate my 100 units of the research funding with the following weights: 60 units to the breeders, 15 units to water productivity and 25 units to deforestation. And, for what it is worth, I want to reemphasise the crucial importance of research, development and commercialisation of lower-emission technologies. It is in this area that the key emitters should be focusing — for the longer term.

Conclusion

Yesterday I had an opportunity to listen to a presentation entitled 'High Food Prices' by a colleague of mine, Dr Andy Stoeckel. He confronted us with the dimension of the food security problem with a forecast 40% increase in population — an extra 2.4 billion people over the next 50 years and the associated productivity challenge (Figs 4 and 5). My reaction was that if we can manage to get productivity of the basic staples back up over 2% per annum on a consistent basis across the key regions of the world, we are going to be in a substantially better

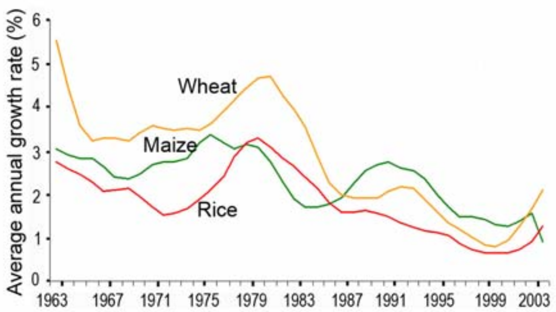

Figure 3. Growth rates of yields for major cereals are slowing for developing countries.
Source: *2008 World Bank, World Development Report: Agriculture for Development*. Washington, 2007

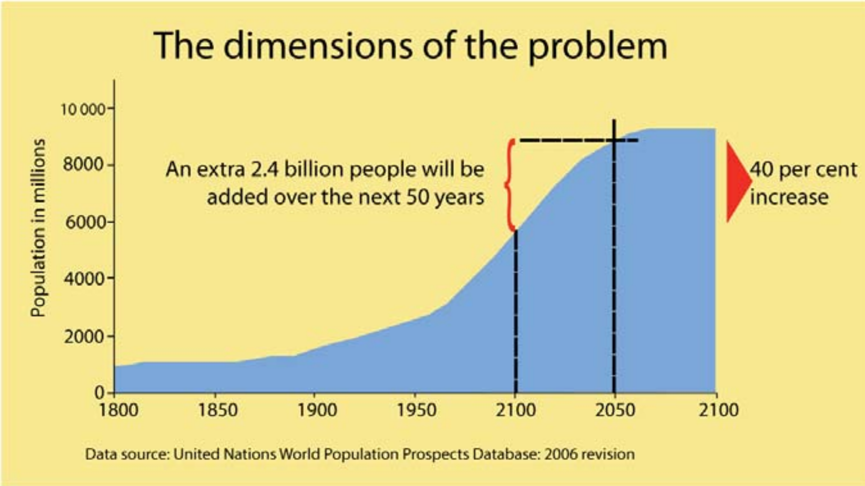

Figure 4. Population projections

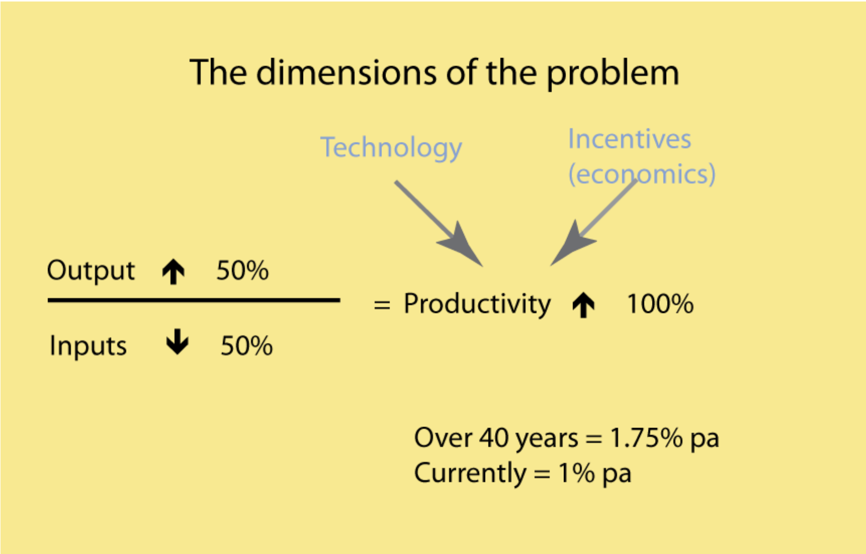

Figure 5. The productivity challenge

position than where we are now. It is going to be more difficult than in the past, but that is our challenge.

There are no guarantees, but I am sure that research investment will have high pay-offs. It has got a track record of high returns. We need to get on with the job.

Those responsible for these research investments need to be held accountable, but today's world is not 'business as usual'. It requires quantum changes and a new long-term focus.

Further reading

Stoeckel, A. (2008) *High Food Prices: Causes, Implications and Solutions*. Rural Industries Research and Development Corporation, Canberra, Australia, 24 pp. Available from: http://www.rirdc.gov.au/reports/GLC/08-100sum.html

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Von Braun, J. (2007) *The World Food Situation: New Driving Forces and Required Actions.* International Food Policy Research Institute, Washington, USA. Available from: http://www.ifpri.org/pubs/fpr/pr18.asp

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A Selective Synthesis

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In this summary overview of papers presented at the Crawford Fund's Parliamentary Conference, *Agriculture in a Changing Climate: the new frontier in international agricultural research*, I have been deliberately selective in synthesising elements of the presentations and for brevity I have omitted scientific references, which can be found in the foregoing contributions. Wherever possible, I have tried to draw out examples of Australian work and experience that may be relevant to the issues and to their policy and technology solutions. I have also tried to address or at least record questions and comments made by participants on the comment forms provided at the Conference and shown here in italics.

DR BLIGHT has a career including positions as a diplomat, public servant and chief executive. His association with international agricultural research began in earnest some 25 years ago when he was appointed Centre Secretary of the Australian Centre for International Agricultural Research, helping to establish ACIAR under the chairmanship of Sir John Crawford. He took up his current position as Executive Director of the Crawford Fund in February 2008, having retired as Director-General of CAB International, an intergovernmental body in research, training and publishing in the life sciences. Before that he spent 15 years with IDP Education Australia, the international development program of Australian universities and colleges, including the position as Chief Executive. Dr Blight is a consultant to CABI, chair of the Board of LIS Pty Ltd (see www.studylink.com), an advisor to the Graduate Insight Group (see www.i-graduate.org) and a member of the UK's Commonwealth Scholarships Commission.

The truth about climate change, and its impact on agriculture

The Conference more or less took as a fact an anthropogenic contribution to climate change and its impact, although qualifications on its extent and importance were registered. Ross Garnaut, whilst demonstrating little doubt about the reality of climate change said he faced:

> … a lot of reluctance of people in the scientific community to chance their hand at estimates of parameters that were really rather fundamental to building up an overall view of climate change impacts in Australia. Its not part of the culture of our scientific community to answer questions of a precise kind about probability distribution until there is a high degree of certainty about the answer.

Observing the phenomena from an immediate Australian perspective, Tony Bourke interpreted the advice that he had as suggesting:

> It's not simply a case of cyclical drought in some countries. The droughts are getting longer, they are getting deeper and the interval between one drought and the next is not nearly as long as it used to be.

Kathy Sierra probably expressed a consensus view when she said:

> Extreme weather, major changes in precipitation patterns, droughts and flooding will increase in coming decades and will have a major negative impact on land-production systems in some regions. Rising temperatures will create heat stress in some species of livestock and less stable crop yields, and lead to more frequent outbreaks of pests and disease. This will further complicate our efforts to control diseases, including those which are passed directly from livestock to humans and those which move from wildlife to livestock to humans.

> Pasture production and grazing lands will also be affected, and the competition between crops for food versus feed, already being felt, could be exacerbated.

The relationship between *climate change and pests and diseases* was further underlined in Trevor Nicholls' presentation. Using the case of Siam weed to illustrate the point, he cited predictions of $CLIMEX_{TM,}$ which uses IPCC models plus precipitation, vapour pressure and temperature data to project climate change surfaces for global weeds, including Siam weed:

> CLIMEX predicts that in Australia … [Siam weed's] potential range will extend south into coastal New South Wales by 2080, and in West Africa that the range will expand east to Central Africa and beyond. While there have been some bio-control attempts in Papua New Guinea and in Ghana, this method is contentious in West Africa where many farmers perceive Siam weed positively as it out-competes the more difficult-to-manage *Imperata cylindrica.*
>
> So while Siam weed may have some redeeming qualities, it has other complex impacts. It is an attractant for the African grasshopper *Zonocerus variegatus*, which sequesters the pyrrolizidine alkaloids of *C. odorata*, protecting itself from antagonists and increasing its population. *Zonocerus variegatus* is polyphagous, defoliating maize, cassava and other food crops, particularly during the dry season. Increases in *Z. variegatus* populations have been linked with the increasing cover of Siam weed in West Africa. As well as being a pest in its own right, it transmits cassava bacterial blight, one of the major cassava diseases in the region.

Frances Seymour warned that *forests* are also a casualty of climate change:

> Forests are vulnerable to the extreme weather events that are likely to become more frequent with climate change. The mitigation potential of forests could itself be affected. A warmer, drier climate could trigger a positive feedback loop that results in the dieback of forests, and thus increased emissions and further warming. In other words, warmer, drier weather could lead to a vicious circle in which increased incidence of burning renders forests less able to recover and sequester carbon in forest vegetation, which in turn would accelerate climate change.

There is little doubt in Shaun Coffey's view that climate change is a serious issue for *livestock production*:

> Climate change impacts on animal production are manifested mainly at a regional level, and could be more readily addressed were it not for the fact that livestock production also contributes significantly to the problem itself.
>
> Similarly the critical roles that animals play in poverty reduction and development in transition and less developed economies cannot be ignored. The resultant increases in demand will result in continued growth of GHG emissions globally.
>
> Given the present state of knowledge, it is not possible to envisage an industry program that would contain and reduce global emissions from animals without seriously compromising the aspirations of developing nations and the rural poor. Further improvements in productivity will be achieved, but recent evidence suggests these will not keep pace with growth in total production in the sector.

Rob Lewis drew attention to the climate change impacts on *aquaculture and fisheries*:

> Extreme weather events are intrinsically linked to the climate change regimes and influences. The warming and consequential increase in ocean heat content, thermal expansion and reduction in land-based ice are seen as contributory factors driving these phenomena. Extreme events include intensified precipitation and droughts; monsoonal, cyclonic and hurricane activity; storm surges and flooding; as well as temperature shocks. Extreme events can manifest themselves through both increased frequency and or severity. Extreme events occur on a global scale as seen from cyclonic events, or on a local scale as the Australian southern bluefin tuna farming industry experienced in 1996 when more than 95% of the standing production was wiped out by a localised high-intensity event.
>
> Climate change has the potential to strengthen upwelling events, enhancing nutrient input to receiving regions. This is predicted to have both adverse and positive effects. Adverse effects include disruption of the bio-rhythms and processes of key species, whilst pluses are predicted to include increased regional productivity from the additional nutrient inputs.

According to Mark Howden:

> … climate change is happening faster than expected, with the four key global indicators (greenhouse gas emissions, atmospheric carbon dioxide concentrations, global temperature and sea-level rise) all at or above the 'worst case' scenario developed by the IPCC about a decade ago.

Segenet Kelemu said the *African continent* is particularly vulnerable to climate change because it consists of some of the world's poorest nations.

> The climate in Africa is largely tropical in nature, which is classified into three major climatic zones: humid equatorial, dry and humid temperate. Within these zones, however, altitude and other localised variables generate distinct regional climates. Climate change, especially manifested by prolonged drought, is one of the most serious climatic hazards affecting the agricultural sector of the continent. As most of the agricultural activities in the majority of African countries are rain-fed, any adverse changes in the pattern and amount of precipitation would have a devastating effect on the sector in the region, and on the livelihood of most of the population. Variability is expected to increase, including frequent occurrences of extreme events particularly in marginal rainfall areas.
>
> Drought is perhaps the most dramatic limiting factor to crop and animal production on a global scale, and the situation is expected to deteriorate in Africa. The current trends in land degradation, desertification and climatic variability have been predicted to intensify. The erratic rainfall across seasons, poor soil-water-holding capacity and poor management of water resources have led to drought occurring frequently. In the last two decades, droughts occurred in 1983–1984, 1991–1992, 1995–1996, 1999–2001 and 2004–2005 in parts of Africa with significant impact on human, animal, vegetation and other resources. The debate on climate change and its impacts on agriculture are, therefore, crucial to the very survival of the African continent and its people.

But the impact of climate change is uncertain. As Kathy Sierra put it:

> … the impact of climate change is not always certain — and not always negative. There is some evidence that higher atmospheric concentrations of carbon dioxide could actually increase plant growth and improve water use efficiency, particularly in wheat, rice, soybeans and potato. These results have not yet been verified in the field, where limiting factors such as pests, soil and water quality, and crop–weed competition exist.

Similarly, Mark Howden placed the relative impact of climate change in the broader context of economic and social development when he referred to studies that showed:

> … globally, impacts of climate and CO_2 increase are small compared with the positive effects of socio-economic development paths, with substantial regional variation. For example, climate change alone is estimated to increase the number of undernourished people in 2080 by 5–10 million under [one] scenario, up to 120–170 million people under [another] scenario or by ±30 million. In terms of regional disparity in food availability, for a high-emissions scenario, 42 developing countries may benefit from substantial increases in cereal production (averaging 17%) by 2080 whereas 52 countries with a population of up to 3 billion may lose on average 19% of their current yield potential over the same period.
>
> In a review of global food security studies, [one report] suggested that the robust economic growth projected for the 21st century will (in all but [one] scenario) significantly reduce the number of people at risk of hunger in 2080 … because real incomes are likely to rise faster than real food prices, thereby increasing access to food. Average price variations expected from the effects of global change are much smaller than those from socioeconomic development paths.

Nevertheless, Howden worries that analyses of global food security may significantly understate the challenge arising from climate change and that effective adaptation technologies, management options and policies are not keeping pace with climate change. He also highlighted other factors: crop yield growth is declining; the availability of water for irrigation is under pressure from lower rainfalls and higher temperatures; increased fuel and fertiliser costs; land degradation; and policy and market constraints. This last point included policies to reduce emissions of greenhouse gases.

A related written comment by a participant warned that climate change adaptation measures could, unless we were careful, actually aggravate climate change.

The last word on the overall impact of climate change, however, might be left to the concluding speaker, Ross Garnaut. Talking of the Australian context and the review of climate change, which he led, Garnaut concluded:

> It's not going to be all negative and all challenges. … There will be some regions with access to enough water to productively use the increased carbon dioxide in the atmosphere to increase

> yields — at least for a while. Eventually, however, temperatures will increase too much.
>
> We had a careful study of that done for the review, but most of the effects on production will be of a negative kind.

The contribution of agriculture to climate change

Agriculture is, and will remain, a contributor to climate change. It is a major user of land and water resources, and a significant source of greenhouse gases — an estimated 10–12% of all GHG emissions resulting from human activity.

Expansion of the agricultural frontier through land clearing and slash-and-urn contributes even more, with the total impact of land use and forestry changes contributing almost one-third of GHG emissions in all developing countries.

As Francis Seymour pointed out:

> Deforestation and forest degradation are now recognised to be a globally significant source of greenhouse gas emissions, and it is asserted that reduction of forest-based emissions may be among the least expensive mitigation options. However, decades of unsuccessful efforts to reverse high rates of deforestation and degradation in the tropics have revealed the fundamental failures of markets, governance and policy that drive forest loss. New initiatives toward 'Reducing Emissions from Deforestation and Forest Degradation' (REDD) will face similar challenges, but could bring to bear new sources of finance and political will.

In commenting on what was described as an excellent presentation by Francis Seymour, one participant asked about the prospects for an inter-national system of environmental services payments to 'local people responsible for maintaining biodiverse forests?

The relationship between livestock and climate change is also complex as Shaun Coffey noted:

> A common feature of many developed nations is that GHG emissions from agriculture have been falling. Some developed countries, however, have not followed this trend. In New Zealand, GHG emissions from agriculture, in particular nitrous oxide and methane from pastoral or agricultural activities, have been rising at about 1% per year since 1990. Emissions growth has come first from increased individual animal production (meaning each animal consumes more forage and thus produces more methane and excretes more nitrogen). Second, this increased feed consumption has required growth in the use of inorganic nitrogen fertiliser from 52 000 t in 1990 to 345 000 t in 2005. But, while the total amount of GHG from NZ has increased, the amount emitted per unit of production has declined by about 17%.

A participant from the Crawford Fund's Victorian Committee asked whether the reduction in sheep numbers in Australia and reduced tillage in crop production was a major factor in greenhouse gas reductions, possibly the only sector in Australia to see such a fall.

Complexity is compounded by conundrum. According to Coffey:

> … the critical roles that animals play in poverty reduction and development in transition and less-developed economies cannot be ignored. The resultant increases in demand will result in continued growth of GHG emissions globally.

Might not the answer lie, asked one participant in a written comment, in a reconsideration post Kyoto of the treatment of emissions from ruminants that were in any case largely derived from cellulosic ingredients?

These complex interactions between agriculture and climate change, highlighted in the foregoing abstracts from Conference presentations, indicate that adaptation to the impacts of climate change and mitigation are both important. We must, it was argued in several papers, accelerate our search for new knowledge, policies and technologies in both areas. Indeed there is an opportunity to exploit the significant synergies between adaptation and mitigation in agriculture to counter increased risks of climate change impacts.

Whilst the emphasis was on technology, the social dimensions of the relationship between climate change and agriculture were not ignored. Farmers, fishers, foresters and herders in the 21st century will need to overcome significant challenges. These will arise largely from the need to increase the global food and timber supply for a world growing to 10 billion people or more, while adjusting and contributing to responses to climate change.

Agricultural research priorities

As Executive Director of the Fund, I was naturally pleased at the acknowledgement of the work of the Crawford Fund's founding director, Professor Derek Tribe. No one, it was said, showed a better grasp of the central importance of agricultural research than he. His 1994 book, *Feeding and Greening the World*, charted a clear path forward. Yet, just as the journey was getting under way, stagnating support for agricultural research for development drastically slowed its progress.

In making these points, Kathy Sierra added that the results of flattened growth in agricultural research funding and faltering investment in rural development have been made dramatically evident in the past few months as the international community deals with a global food prices crisis. While there were, and remain, multiple factors that led to the crisis — as reported for example in the 2008 Crawford Fund report, *A Food Secure World; how Australia can help*, a fundamental element was the lack of capacity to supply more food when the world demanded it.

Another Australian acknowledged during the conference was Lloyd Evans. His ‘haunting and informative book’, *Feeding the Ten Billion*, was an inspiration to Cary Fowler who cited Evans’s analysis of different moments in human history and the ways in which people procured or produced food changed as the population grew, and as the technology and environment changed. Lloyd Evans had pointed out that historically the most significant way has been to cut down trees to expand cropland. Globally, this is becoming less of an option and attention is drawn once again to enhancing crop and animal productivity.

Kathy Sierra was undoubtedly right, therefore, when she said that there is now a heightened awareness among many decision-makers that it was an error to have neglected, soon after the Tribe and Evans publications, investment in agriculture research for so long. There is also, as she said, a greater realisation that agriculture’s many value chains for food, feed, fibre and industrial uses all depend on research-based innovation. This was also certainly one of the main messages of the World Bank’s *World Development Report 2008: Agriculture for Development*, which detailed how much this lack of investment, and lack of interest, in agricultural research has cost.

One or two participants, in their written commentaries, described continuing population growth as ‘the root cause’ of food shortages and that that limits on growth, and how this might be achieved, were a priority for research and policy attention.

Kathy Sierra outlined the following priority areas, upon which I have expanded to take into account comments of others including in particular those by Peter Core:

- research to enhance the hardy varieties already available. Tolerance to stresses such as drought, heat and high salinity must be combined with other valuable traits, such as better nutritional quality. Peter Core expressed this area of work in another way as stress-tolerant crop cultivars, citing work by CIMMYT combining the latest in molecular biology with farmer participation trials prioritising major stresses to maize — drought, low soil fertility, insect pests and poor soils. He referred also to similar work on wheat and the development of new rices for Africa. He said that this work was being done on a ‘shoe string’ but deserved overwhelming priority
- an increased flow of hardier varieties for a wider range of staple crops. Rice, wheat and maize are critically important and should, according to Peter Core, be accorded priority. But the poor also depend on many other cereals, as well as roots, tubers and grain legumes. Shaun Coffey (and Derek Tribe) would no doubt remind us of the important role of livestock in poverty reduction.
- a more determined push to apply powerful new tools from molecular biology. Molecular genetic maps, for example, together with crop performance data from diverse sites, are critical for identifying areas of crop genomes that are linked to stress tolerance. This must go hand-in-hand with more vigorous evaluation of plant genetic resources. The traditional varieties and wild relatives being conserved are a rich source of genes needed to enhance stress resistance. To date, however, only about 10% of the 600 000 plant samples held in CGIAR gene banks have been characterised.
- In her presentation, Segenet Kelemu was more specific when she noted that the potential role of agricultural biotechnology, particularly genetically modified crops and animals, in improving the livelihoods of the poor was being debated vigorously. *(Indeed, as if to underline this point, one participant in a written comment asked whether we were caught up in this ‘high tech’ science without considering the totality of natural resource management.)* Many biotechnology products

are, she said, being developed in various countries for different uses. These products include modified plants for food and fiber, animal feed, medical care and bioremediation. She did not wish to imply that agricultural biotechnologies would, single-handedly, solve Africa's agricultural production constraints and make Africans self-sufficient in food, or completely solve the impacts of climate change. While recognising the potential, genetically modified crop varieties — just like those developed through conventional breeding strategies — must be combined with other appropriate and optimal management practices for satisfactory production. *[This issue was the main focus of the written questions and comments from participants. who queried what they described as an emphasis placed by some speakers on genetic manipulation as a silver bullet.]*

- a focus on under-utilised crops. To adapt effectively to climate change, rural people will need to draw on an even wider range of biological diversity. That is why stronger efforts must be made to explore the commercial and food security potential of under-utilised plants, such as tropical fruits, medicinal herbs, and certain agro-forestry species. These plants can play an important role locally in the diets and livelihoods of the poor.
- Peter Core singled out water where he emphasised work on the public policy framework characterising the issue as a 'tragedy of the commons.' He cited work by IFPRI and IWMI.

Perhaps an over-arching priority is for what Kathy Sierra described as an integrated approach, based on prudent management of crops, livestock, fisheries and forestry and their genetic resources, and including management of soil and water. This requires complex, knowledge-intensive research. We also need to take full advantage of income-generating opportunities for farmers and other workers right along the production and delivery chain to adapt technology to local conditions and to add value. The returns to such local adaptation are substantial, as illustrated (for example) by the spread of minimum tillage in South Asia's rice and wheat systems where it was necessary to design and build small, locally-adapted machines to replace the large machinery available from developed countries.

So accurate and timely diagnosis is important. Policy and technical issues in relation to slowing deforestration, covered in the presentation by Francis Seymour when she spoke of the fundamental failures of markets, governance and policy, deserved priority according to Peter Core. Trevor Nicholls added that developing models to project the potential distribution and abundance of a pest species under various climate change scenarios is essential, and the Australian scientific community has been at the forefront with the development of CLIMEX and its application to modelling some of the world's worst weed species, such as the pan-tropical Asteraceae, *Chromolaena odorata.*

Crop diversity, according to Cary Fowler, is going to be the canary in the coal mine because it is the biological pre-requisite for adaptation and improvement. Rescuing collections that are in bad shape — principally in developing countries — is a priority. Through the work of the global crop diversity trust between 100 000 and 150 000 distinct crop varieties will be rescued in the next couple of years.

Segenet Kelemu agreed, noting that plant and animal genetic resources are also vulnerable to adverse changes in climate, thus potentially depriving Africa and the rest of the world of this natural wealth. *One participant in written comments, whilst acknowledging the importance of seed (gene) banks, asked why less support was given in the formal presentations for domestic animals, which were also a priority, especially for Africa.*

Touching on the need for better information systems, one participant in a written comment noted that information collected on individual seeds if made available could enable the seeds to be grown successfully by a wider range of users.

Another participant, in a written comment, lamented the absence of a national seed bank in Australia, and the declining funding for the 200 000 seed accessions in five agricultural seed-banks collected over 60 years from 130 countries. The participant noted that Australian pasture seed collections were a particularly valuable and unique resource at risk.

According to Howden, the 'volatility of production and prices should be a core part of future assessments of global food security alongside more traditional analyses of food availability.' It also 'raises the question as to whether new assessment methods are needed. For example, partial equilibrium economic models could be used instead of general equilibrium models to incorporate the impact of climate variability on food production.' There is, in Howden's view:

> … a clear need to increase investment into research of the biophysical, economic and institutional factors limiting growth in grain yields. More integrated, systems research that includes genetics, management, policy and communication could open pathways to yield improvements that are closed to more traditional reductionist approaches. This could enable research to transcend the natural limits of single-factor research. These new integrated methods for assessing global food security need to be able to incorporate the new policies, constraints and opportunities associated with climate change, such as emissions restrictions and the emerging carbon economy. This may require more of a bottom-up approach including social, economic and cultural dimensions, and scaling these up to regional level. A stronger focus on managing climate variability is likely to deliver useful information and technologies at farm and community scales that can reduce supply and price fluctuations and be transferred between regions. Lastly, consideration needs to be given to collective action to build the livelihood options and risk management capacity of vulnerable groups to deal with climate change.

Three final written comments may be worth recording because they foreshadow possible future Crawford Fund Conference topics. The first related to application and communication of research outcomes. The second concerned questions of gender that had been 'completely neglected' in most presentations. And the third focused on the inter-relationships between publicly funded research organisations and the transfer of their intellectual property outputs to private multinational corporations.

Other Crawford Fund Publications since 2001

Brown, A.G. (ed.) 2001. *Prosper or Perish: Asian Poverty and the Australian Economy*. Record of a conference conducted by the Crawford Fund for International Agricultural Research, Parliament House, Canberra, 28 June 2001. iii + 58 pp. ISBN 1 875618 67 8

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Nairn, M.E., Henzell, E.F. and Williams, M.J. 2004. *Building on Success*. Report and recommendations of an independent review of the ATSE Crawford Fund, March 2004. ATSE, Parkville, Vic. 98 pp.

The ATSE Crawford Fund 2005. *Healing Wounds: An Australian Perspective.* Research that rebuilds agriculture after conflicts and natural disasters. The Fund, Parkville, Vic. 14 pp.

The ATSE Crawford Fund 2005. *Report 1 January 2004 to 30 June 2005.* The Fund, Parkville, Vic. 25 pp.

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Anon. 2007. *The ATSE Crawford Fund Report 1 July 2006–30 June 2007*. The Fund, Parkville, Vic. 28 pp. http://www.crawfordfund.org/publications/pdf/annualreport2007.pdf

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Persley, G.J. and Blight, D.G. (eds) 2008. *A Food Secure World: How Australia can Help.* Report of the Crawford Fund World Food Crisis Task Force, Australian Academy of Technological Sciences and Engineering (ATSE), Melbourne, 60 pp. ISBN 978-1-921388-00-2.

The Crawford Fund newsletter, *Highlights*, is available from the Fund's website (http://www.crawfordfund.org/index.htm) or in printed form. In 2008, two issues were published.

The publications below discuss the global setting for international agricultural research. The website of the Cooperative Group for International Agricultural Research (CGIAR) (http://www.cgiar.org/) provides other information.

Alston, J.M., Pardey, P.G. and Taylor, M.J. (eds) 2001). *Agricultural Science Policy: Changing Global Agendas*. John Hopkins University Press, Baltimore, 285 pp. ISBN 0 8018 6603 0

Pardey, P.G., Alston, J.M. and Piggott, R.R. (eds) 2006. *Agricultural R&D in the Developing World: Too Little, Too Late?* International Food Policy Research Institute, Washington DC. Available for download from http://www.ifpri.org/pubs/books/oc51.asp

World Bank 2007. *World Development Report 2008: Agriculture for Development*. World Bank, Washington, D.C. xviii + 365 pp. http://econ.worldbank.org ISBN: 9780821368077