THE ROYAL SOCIETY

Food crops in a changing climate: Report of a Royal Society Discussion Meeting held in April 2005

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Summary

Climate change is likely to impact on agriculture and food security across the globe. A large fraction of the world's food is grown as rain-fed annual crops in the tropics, where climate variability plays an important role in determining productivity. Through its wide range of participants, including leading climate change modellers, crop modellers, those performing experiments relevant to impacts of climate change on crops and key stakeholders, this meeting at the Royal Society provided a unique forum for discussion of the issues involved and the latest results.

There have been recent advances in our understanding of the physiology of crops and their sensitivity to weather, climate and the levels of particular gases in the atmosphere. These advances have indicated that the impact of these factors both on crop yields and on aspects of quality, such as protein content and toxin levels, will be more severe than previously thought. Experiments on crops under realistic field conditions have shown that the beneficial 'fertilisation' effect of increased levels of atmospheric carbon dioxide (CO_2) could be less than that previously estimated. Other studies have indicated that increased levels of near-surface ozone (caused by atmospheric pollutants) could reduce yields of some crops by up to 30% by 2050. However, none of these studies have been carried out in the tropics. More field-based studies, particularly in tropical regions, are needed to improve our understanding in this area.

There is increasing information on the importance of extremes of temperature and rainfall at key stages of crop development for crop yield. Research is needed to improve our understanding of how local weather patterns (which determine rainfall, high temperature events and the occurrence of high ozone conditions) will be affected by climate change and the associated impacts on different stages of the growing cycle of crops. Further development of crop cultivars that are more tolerant to extreme weather and growing conditions in terms of both yield and quality is needed. Improved understanding of the impacts of climate change on water availability is also required to inform the management of water for crops under climate change.
Agriculture will itself impact on the climate system and a greater understanding of these interactions is needed. Crops will use water more efficiently and lose less to the atmosphere under increased levels of atmospheric CO_2. If this occurs over a sufficiently large region it could lead to reduced rainfall in that region with obvious implications for water supply. It is important that agricultural adaptations to climate change do not make conditions worse; for example agriculture is a major source of two greenhouse gases (methane and nitrous oxide) and changes to land use or agricultural practice could affect their release.

Variability of climate, such as that associated with El Niño events, has large impacts on crop production. If skilful predictions of the probability of such events occurring can be made a season or more in advance, then agricultural and other societal responses can be made. Seasonal climate predictions and their applications in many areas, including crop forecasting, are starting to be made in some countries. It is clear that the development of strategies to adapt to variations in the current climate may build resilience to changes in future climate.

Complex models are required to perform simulations of climate variability and change, together with predictions of how crops will respond to different climate variables. Until recently, the simulations of climate have been undertaken at much larger spatial scales than crop process models. This has limited confidence in the accuracy and usefulness of predictions of the impact of various climate change scenarios on food crops. A key challenge for scientists is to

markedly increase the resolution of climate models and to develop and refine crop models working on the same scale. In addition, fully integrated climate-crop models (which can represent the important feedbacks between climate, crops, and the land and water use changes associated with agriculture) are in their infancy but must be developed. These advances are only possible if the relevant scientists are provided with a very substantial increase in computing power in the next few years to enable climate and crop models to be run at significantly higher resolutions. There are a number of physical and biological uncertainties associated with the prediction of the response of food systems to climate variability and change. It is important that these are quantified.

Africa will be the part of the world that is most vulnerable to climate variability and change, but knowledge of how to use climate information and the regional impacts of climate variability and change in Africa is rudimentary. Programmes are required that generate new knowledge and technologies relating to climate variability and facilitate their use especially by the most vulnerable. These should build on the Famine Early Warning Systems, which have demonstrated the benefits of the creative use of satellite monitoring, modelling and geospatial methods. The advanced warning given by such systems needs to be better capitalised upon, thus enabling disaster preparedness efforts and reducing the need for emergency relief.

Essential capacity building in climate and crop science could be achieved through institutional partnerships and studentship programmes between Africa and countries such as the UK. The climate and weather observation networks needed to monitor climate variability and change and to support weather forecasting are currently poor. Building on the Global Climate Observing System, the transfer of technology developed in countries such as the UK, combined with the knowledge and local expertise of African scientists, could address this. The development of well-founded climate impact models is a priority. These need to capture environmental and social vulnerabilities and provide information at the scale that international, national and local decision makers operate.

In order to develop appropriate adaptation strategies, predictions about changes in the quantity and quality of food crops need to be considered in the context of the entire food chain from production to distribution, access and utilisation. Collaboration between natural and social scientists and economists will be vital. There have been rapid changes in global food systems and, in parts of the world, adapting to climate change may focus more on changing infrastructures for food distribution rather than changing agricultural practices.

Globally, all societies will be vulnerable to changes in food production, quality and supply under climate change and these will have socio-economic impacts. World leaders, meeting at events such as the G8 Summit in Gleneagles, along with other governmental and non-governmental organisations, need to take action to understand, monitor and adapt to the impacts of climate change on food crops. This is particularly vital in the case of Africa where there is an urgent need to develop innovative solutions and adaptive strategies that deliver long-term, sustainable livelihoods in an era of climate change.

Preparation of this report

This report presents a summary of the key issues and challenges that emerged from the Discussion Meeting on food crops in a changing climate that was held at the Royal Society on 26 and 27 April 2005. It is not necessarily an expression of the views of the Royal Society. We are extremely grateful to: Professor Julia Slingo (NERC Centres for Atmospheric Science (NCAS) - Centre for Global Atmospheric Modelling); Dr Tim Wheeler (Department of Agriculture, University of Reading); Dr Andrew Challinor (NCAS - Centre for Global Atmospheric Modelling) and Professor Brian Hoskins FRS (Department of Meteorology, University of Reading) who organised the Discussion Meeting and prepared this report. The meeting programme can be found in Annex A. The proceedings of the meeting are scheduled to be published in late 2005 in *Philosophical Transactions of the Royal Society series B*, volume 360.

1 Introduction

Climate change is likely to impact agriculture and food security across the globe. A large fraction of the world's food is grown as rain-fed annual crops in the tropics, where climate variability plays an important role in determining productivity. Asia alone has more land under cultivation than all of the industrialised nations taken together. Although crops grown at mid-latitudes may be less sensitive to climate variability under current climates, crop production in some of these areas will become more risky under future climates as, for example, competition for water resources increases, and the frequency of extreme temperatures changes. Globally, all societies will be vulnerable to changes in food production, quality and supply under climate change along with their consequent socio-economic pressures.

This meeting provided a unique forum in which scientists working across the range of disciplines from climate and environment to crops and socio-economics were drawn together to assess the current state of knowledge on the relationships between food crops and climate, and on the vulnerability of global food production to climate change. It was evident that, as our understanding of the relationships between crops and climate has developed, the implications of climate change appear likely to be more serious than previously thought. The summary report will be sent to those preparing for the G8 Summit in Gleneagles in July 2005, which is focusing on climate change and Africa, and the UK's Presidency of the EU, which also has a focus on climate change. The detailed proceedings will contribute to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).

The engagement of stakeholders in the discussion was crucial. The meeting specifically addressed how to communicate risk and potential mechanisms for mitigating that risk to various sectors involved in food production, quality and supply, from the local farmer to regional economies to national and international agricultural planning and development organisations. It is clear that the dialogue with the range of stakeholders is essential in guiding the nature of the information provided from the scientists and in steering the research agenda in the future. Knowledge transfer mechanisms across disciplines and between the developed and developing world need to be strengthened.

2 Extent of current knowledge

Climate prediction involves the use of increasingly complex earth system models that represent the interactions between the atmosphere, ocean, biosphere and cryosphere, and addresses the concept of climate as a high-dimensional chaotic system in which the outcome of any prediction system should be viewed in the context of a forecast probability distribution. The simulations of past and present climate are able to reproduce much of the observed behaviour, though significant improvements in the models are still required. Predictions for months or seasons ahead are now starting to be used in a number of applications.

Climate models have the potential to provide information on changes in the statistics of weather which will be vital in estimating the impacts of climate change on food crops. As the resolution of climate models increases, the detail in the spatial and temporal distributions of key surface variables for crops (eg rainfall, temperature, soil moisture) will also increase. Pushing these models to higher and higher resolutions is a major driver for research and one that poses particular demands on both the climate and computational scientist. Access to significantly increased levels of computer power will be vital, such as that provided by the Earth Simulator and available to UK scientists through a major collaboration with Japan involving NERC's Centre for Global Atmospheric Modelling and the Hadley Centre.

In terms of crop science, there have been substantial advances in the understanding of the physiology of crops and their sensitivity to various aspects of weather and climate. The dependence of yields on the seasonal mean climate is well documented across a range of crops, and their response functions are now known to be far from linear eg there are optimal climates in terms of both their mean and their variability. Recently, the sensitivity of crops to drought and periods of heat stress at particular stages of development has emerged as increasingly important, suggesting that there are thresholds above which crops become highly vulnerable to climate and weather. More controversially, the response of crops to changes in atmospheric composition has produced conflicting evidence, with the benefits of CO_2 fertilisation being fewer than previously thought and potentially being counteracted by the damaging effects of increases in surface ozone. An advantage associated with the effects of CO_2 fertilisation is more efficient water use by the plant, particularly for C3 crop plants (such as rice, wheat and soyabean); this is an important aspect of the response of cropping systems to climate change since many regions will become increasingly water limited. Overall, C3 crops are much more sensitive to atmospheric CO_2 and surface ozone concentrations than C4 crops, such as maize, sugarcane and sorghum.

Crop prediction methodologies range from statistical methods, based on past associations between crop production and climate, to dynamic methods, which attempt to represent the physiology of the crop. The former methods have limitations for climate change studies because the statistical relationships that are valid today may not work in a changed climate and because these methods are less amenable as test-beds for adaptation strategies. The latter methods can be highly sophisticated and have the capability of capturing non-linear behaviour and the impacts of weather variations on crop performance, as well as enabling testing of adaptation strategies such as more tolerant varieties and changes in management. However, they tend to be tuned at the local or plot level, which has so far restricted their use in larger scale assessments. There is an increasing body of research exploring methods of bridging the scale gap between process based crop models and climate prediction systems. Currently, the direct use of climate model output within crop prediction systems is remarkably limited.

Assessments of the impacts of climate change on crops reflect the disparity of scale between crop and climate models. Climate models are typically run at horizontal scales in excess of 100km whereas crop models are usually developed at the scale of a kilometre or less, although the recent development of crop models designed to operate at scales of tens of kilometres was reported at the meeting. So far, the few studies that have attempted to provide a global assessment of food supply have necessarily used simple representations of the effects of climate on crops. They suggest that food crop production will increase slightly at high latitudes under moderate climate change, but then decrease towards the end of this century. In contrast, crop production is predicted to decline across the tropics even under moderate climate change. But there is little account of the effects of sub-seasonal variability in climate in these studies and the impacts of weather thresholds are entirely absent; both factors are likely to reduce crop yields further. In contrast, studies that use detailed, dynamic crop models over small regions may be compromised by the validity of the climate and weather inputs on those spatial scales. New research reported at the meeting described advances in integrating crop and climate modelling that has the potential to improve assessments of the impacts of climate change on crops by addressing in a more consistent manner the issues of the spatial and temporal scales on which the two systems interact. Furthermore, emerging evidence that major land use changes have already had detrimental effects on the local climate was reported, reinforcing the need for a fully integrated approach to crop-climate prediction.

Seasonal forecasting of crop yields is more mature than climate change prediction. In some regions (eg Queensland, Australia) the development of operational seasonal forecasting systems for agriculture provides important links with users. These have enabled the establishment of decision support systems which engage with farmers and agricultural advisory bodies, and encourage the analysis of risk associated with a range of crop management options. Seasonal forecasting is also playing an increasingly key role in Famine Early Warning Systems (FEWS), particularly for Africa. In parts of the world where climate variability is large and cropping systems are already vulnerable, there is evidence that the effective use of seasonal forecasts and the associated development of sustainable adaptive strategies may help build resilience to climate change.

3 Limitations and uncertainties in current knowledge: recommendations for future research priorities

3.1 Crops and atmospheric composition

New results from the meeting emphasised the uncertainties in our knowledge and understanding of the interface between atmospheric composition and crops. Until recently, research indicated that the positive impacts of CO_2 enrichment would most likely compensate for the negative impacts of rising mean temperatures (which shorten the growing season of most annual crops, and so reduce yields of current varieties). These conclusions were largely based on studies of crops grown in field chambers or in controlled environments that showed that the yield of C3 crops (such as rice, soy bean and wheat) increased by 24-43% with doubled CO_2. However, a new analysis based on a small number of studies of crops grown in near- field conditions suggest that the benefits of CO_2 enrichment may be fewer than this, in the range of 8-15%. Realising the benefits of CO_2 fertilisation depends on water and nitrogen availability and hence on the optimal management of the crop.

An important new result presented at the meeting described how the possible decline in air quality with increased levels of surface ozone could have serious, detrimental effects on crop growth. C3 crops are particularly sensitive; initial estimates suggest that the loss of yield is currently ~5%, rising to potentially ~30% in 2050, but further studies are needed to confirm these estimates. Countries such as China, where ozone levels are predicted to rise dramatically, may be seriously affected.

Overall, the impacts of changes in atmospheric composition may be more damaging than previously estimated, and more research is urgently needed so that these effects can be included in crop prediction models. In particular, there are, to date, no field experiments quantifying the impacts of increased CO_2 and ozone levels in the tropics, where most of the world's food is produced.

- **More studies of the effects of rising levels of CO_2 and ozone on crops under field conditions are needed; these should be carried out in countries where crop vulnerability is potentially high, and should cover a range of the major food crops.**

The adaptation of food systems to climate change will in turn also influence atmospheric composition through emissions of methane from, for example, rice paddies, and nitrous oxide from the use of synthetic fertilizers. Since these are important greenhouse gases it is disturbing that results presented at the meeting suggest that agriculture may contribute ~50% of future methane emissions and upwards of 60% of nitrous oxide emissions. As well as being a potent greenhouse gas, nitrous oxide is also involved in stratospheric ozone depletion.

- **The importance of developing adaptation options for agriculture that do not exacerbate climate and other environmental changes is crucial.**

3.2 Crops and water resources

It is generally accepted that the availability of water for agriculture will be a key issue for crop production in the coming decades. There is a focus worldwide on how to improve the efficiency of water use for crop production, which is expressed by the FAO as 'more crop per drop'. However, water availability for crops depends on processes across a range of spatial scales, requiring information from crop, climate and hydrological models. For example, for irrigated crop production, large-scale changes in rainfall will influence the water that is available from stream-flow or groundwater sources.

More evidence was presented at the meeting of the benefits of higher CO_2 levels on water usage by most crops. Under higher CO_2, stomata are smaller, transpiration is reduced and the plant loses less water. These changes in transpiration can alter the hydrological balance over land and affect the local climate, particularly where there may be large scale changes in land use associated with extensification of agriculture. Reduced transpiration over a sufficiently large region could lead to reduced precipitation there as well. The meeting highlighted the inseparable links between crops and water availability.

- **A more integrated approach to the impacts of climate change on food production, water availability and water quality is needed.**

Climate models still have substantial regional biases, particularly in their representation of the spatial and temporal scales of rainfall. New results presented at the meeting showed conclusive evidence that the *distribution* of rainfall through the growing seasonal was critical for many crops, particularly in the semi-arid Tropics. These variations in rainfall, generally associated with dominant weather patterns, are currently poorly simulated in climate prediction models.

- **There is therefore an urgent need within climate prediction and across many impact assessments to improve the accuracy of climate model simulations of the hydrological cycle. It is increasingly argued that this will not be achieved unless the climate models are run at much higher resolution, close to that used in numerical weather prediction, necessitating a substantial increase in computer power.**

3.3 Effects of extreme events on crops

Most previous climate studies of extreme events have focused merely on the occurrence and magnitude of individual extreme values: the number of days per year with maximum temperature exceeding a threshold, and the annual maximum one-day precipitation total, for example. More detailed information, however, is often critical for determining the impacts of extreme events. For example, preceding conditions affect the likelihood that heavy rainfall will cause a flood; clustering of intense weather systems magnifies potential damage; the spatial extent and temporal evolution of droughts is crucial for water-resource management; and the timing of heat- and water-stress during the life cycle of crops is a key determinant of yield. New results presented at the meeting suggest that extended dry spells may be more prevalent in West Africa under climate change.

- **Better understanding of how *local weather patterns* will change with global warming should be a major area of research. Different crops will have different weather sensitivities that will need to be taken into account when considering the changes. Drought resistant varieties of staple annual crops, such as wheat and maize, need to be developed further.**

Important climate thresholds for food crops include episodes of high temperatures that coincide with critical phases of the crop cycle as well as a change in the sub-seasonal distribution of rainfall. New results presented at the meeting emphasised that these high temperature episodes can lead to dramatic reductions in yield, in some cases in excess of 50%; for example, temperatures greater than 30°C lasting for more than eight hours lead to reduced grain-set in wheat. Experimental studies have led research in this field and these are beginning to be understood in terms of simple physiology. Quantitative methods to simulate and predict the impacts of high temperature episodes are being developed and combined with the probabilistic methods used in seasonal forecasts in order to enable the assessment of the impacts of climate extremes on crop yields.

Climate change scenarios suggest that critical temperature thresholds for food crops will be exceeded with increasing frequency in the future. For some crops, these critical temperatures, particularly at anthesis (flowering), are reasonably well known (eg temperatures greater than 35^{0}C for more than one hour leads to pollen sterility in rice), but for others they are not well characterised. Whilst some more heat tolerant varieties are becoming available, the lethal temperature limits for many species are effectively fixed; in general the reproductive limits for most crops are narrow, with temperatures in the mid-30s^{0}C representing the threshold for viability.

- **The meeting noted that defining critical temperature thresholds and their timing within the growing cycle across all major crops is crucial for providing more confident assessments of future global food production. High temperature events are likely to be one of the major impacts of climate change and hence probabilities of their occurrence must be included in future assessments.**

3.4 Influence of climate on crop quality

As well as yield, changes in crop quality can have a major impact on food systems and their vulnerability to climate variability and change. Results presented at the meeting showed that grain quality (eg protein content) is highly susceptible to current variations in climate and affects the type of foods that can be produced through, for example, glutenin levels and related dough strength. Other examples of the effects of climate on crop quality include pests and diseases, such as dangerous levels of mycotoxins in groundnuts. Relatively little is known about the potential impact of climate change on crop quality and much more experimental work and research on the three-dimensional structures of key grain proteins needs to be done.

- **Development of cultivars that are more resistant to extreme weather and growing conditions in terms of both yield and quality requires more research using an approach based on consideration of the complete biological system.**

3.5 Coupling crop, water and climate models

The interaction between climate, crops, and land and water use changes associated with agricultural practices has been largely neglected until recently. A large fraction of the land surface in the tropics is used for growing crops (eg 94% of land in South Asia is used for crop cultivation) and this may have implications for predictions of both the local climate and crop productivity. Some initial research has been conducted with a process-based crop model operating as an interactive part of the climate model's land surface scheme and has demonstrated the feasibility of this fully coupled methodology. This combined system allows the simulated weather to affect crop development on a sub-daily basis (important for assessing threshold behaviour as outlined in 3.3). Equally, it allows the developing crop in turn to influence the land-atmosphere system.

The coupled crop-climate modelling system will enable investigation of the impact of different scenarios of changes in agricultural land use on land-atmosphere interactions and on local climate . Furthermore it can be used to provide a consistent framework for assessing the effects of crops on the carbon and nitrogen cycles, the response of the latter being largely unknown. The impacts of changes in atmospheric composition noted in 3.1 can also be addressed more completely; the meeting noted that potential non-linearities in the feedbacks between atmospheric composition, climate and crops are currently unknown, but could potentially be very serious.

Early results have demonstrated changes in the water cycle, particularly the balance between fast and slow run-off, associated with land use change and crops. Combined with potential changes in evapotranspiration under climate change (see 3.2), it is likely that a prediction system which considers the coupling between crops, water resources and climate will in future be considered essential.

- **Fully integrated crop-climate modelling is currently in its infancy but offers huge potential. Its further development and extension to include the water cycle is a priority for research.**

3.6 Understanding socio-economic responses

The meeting emphasised the importance of considering the complete food chain from production to distribution, access and utilisation. This requires an appreciation of the intimate relationship between climate, socio-economic and environmental factors, and an understanding of major economic sectors and the embedding of agricultural systems within national economies.

Several examples were given of the complex web of policy and decision making along the value chain from farm to market to industry to consumer. There have been rapid changes worldwide in food systems associated with urbanisation and the dominance of supermarket chains. These may radically alter the relationship between food production and food security, with lifestyles and preferences driving consumption and demand with countries, such as India and China, already showing trends towards a western-style diet with increased consumption of meat. Adapting to climate change may be as much to do with improving infrastructures for food distribution as with changing agricultural practices.

The relentless pressures of increasing populations on land and water use are major factors in determining future scenarios for food security and are likely to be key factors in risks of famine. There is a gradual decline in 'carry over' food stocks with implications for food security. Understanding and assessing the vulnerability of populations requires engagement across a wide range of disciplines with the recognition that risk is multi-dimensional. Rapidly changing socio-economic factors can lead to increased sensitivity to climate shocks; for example, the high incidence of HIV and increasing levels of poverty in Africa increases the exposure of the population and its inability to cope with climatic stress.

- **Natural and social sciences need to work together if workable solutions to adapting to climate variability and change are to be found. At a meta level, the IPCC is a good attempt to achieve this, but it needs to occur at all levels.**

3.7 Quantification of uncertainty

The physical, biological and socio-economic processes described above determine the response of food systems to climate variability and change. Each of these processes has its own associated uncertainties. To date only a very limited range of these uncertainties has been sampled. Recently studies have begun to include more comprehensive estimates of physical and biological uncertainty.

- **It is vital that studies quantify the uncertainty due to physical, biological and socio-economic processes in order to provide firmly based and useful information on agricultural climate change impacts.**

4 Feeding Africa, now and in the future

Africa is the most vulnerable part of the developing world to climate variability and change. Its widely dispersed population is heavily dependent on rain-fed agriculture, with one third currently at risk from wide-spread hunger and malnutrition, a situation that is likely to worsen as climate change begins to have a negative impact. Africa is consistently predicted to be among the worst hit areas across a range of future climate change scenarios. New data presented at the meeting suggest that some seriously damaging trends in the weather are already occurring, such as the steep decline in rainfall in the first part of the growing season for Ethiopia in the past ten years.

Understanding the early impacts of climate change is essential; a focus on climate variability over the next few decades could bring with it tangible human benefits and ensure that advice is given with lead times that makes intervention possible. For example, Famine Early Warning Systems (FEWS) have inspired the creative use of satellite monitoring, modelling and geospatial methods. It is clear from the meeting that predictability on the seasonal timescale could be capitalised upon far more than it currently is, leading to the saving of not just lives, but livelihoods. There is a gap between development and relief activities that leaves each looking to the other for disaster preparedness. These benefits could be realised by mobilising the recommendations of the 2005 report of the Commission for Africa '*Our common interest*'.

Current knowledge of the regional impacts of climate change in Africa is at a rudimentary level and needs to be advanced substantially and quickly if further and more extreme environmental and consequent human disasters in Africa are to be averted. Weather events are critical to nearly all aspects of African society and the ability to forecast accurately on time scales of days, weeks and seasons is vital in enabling mitigation and adaptation to save lives and promote economic development. The advances made in weather and climate forecasting in the UK and other developed countries have not yet been transferred to Africa because of the lack of infrastructure and resources both in the UK but particularly in Africa. The UK possesses world-leading expertise in climate change science, in assessment of the socio-economic impacts of climate change and in weather and climate forecasting. This expertise needs to be mobilised and coordinated to focus on Africa in conjunction with African scientists and the development community. The use of local scientists to evaluate the current performance of climate simulations and of monthly and seasonal forecasts in their regions is important as this experience will help them to develop as critical users of climate information and results. The feedback to the UK experts will also be invaluable for future modelling.

- **A programme of research and technology development in climate prediction is urgently needed that will assess more completely the risks and impacts of climate change in Africa. This would inform adaptation studies that would promote Africa's sustainable development.**

The global weather and climate observational networks that underpin weather forecasting and monitoring climate change are severely deficient in Africa with little current prospect of improvement. African scientists have the knowledge and more importantly the local expertise to undertake this monitoring but lack the technology required. Accurate monitoring of both temperature and rainfall will be crucial. In some semi-arid regions crops are already near their thermal maximum and will soon become vulnerable to heat stress as outlined in 3.4. Changes in rainfall patterns and distribution through the seasonal cycle are likely to have devastating consequences. It is the responsibility of the developed world to assist the developing world by transfer of this technology.

- **Resources need to be found to support weather and climate related observational networks if an accurate and reliable picture of the current and future climate of Africa is to be built up in order to mitigate as many of the predicted problems as possible.**

Although great progress has been made in predicting whether annual crops are likely to fail, networks for making decisions about how to minimise the negative impacts of weather-induced food shortages are not using this valuable information to deliver timely humanitarian aid before a crisis has arisen. Since the 1980's the number of food emergencies has tripled as a result of this lack of preparedness.

It has to be recognised that poverty is the principal cause of increasing food insecurity in Africa, along with frequent and extreme weather and climate variability. Information presented at the meeting, showed that Africa is now in a critical situation with respect to drought because of population increase, disease (particularly malaria and HIV) and conflicts. Africa has very little resilience to cope with a widespread drought now, let alone in the next 50-100 years. Furthermore in many regions of Africa, such as sub-Saharan Africa, the options for employing traditional coping strategies are declining as a result of land degradation and increasing vulnerability to climate variability and change.

Many parts of Africa are marginal in terms of agriculture and it is in these regions that progress is slowest and poverty is most persistent. Escaping the poverty trap is a major challenge for development and cannot be achieved without coherent national and international policies and without proper recognition of the roles science, technology and innovation play in development. Currently, natural climate variability is one of many factors already pushing people below the poverty trap threshold. Farmers on the brink of poverty will not want to take a risk based on advice (such as to grow an alternative crop) and will make a decision that pushes him below the poverty level. They may decide to encroach on natural vegetation as has been the case in Burkino Faso, for example, and once that vegetation is destroyed it is very hard to recover the natural resources that local populations rely on for their livelihoods. The meeting was briefed on an innovative approach, Acute Hunger Insurance, aimed at avoiding responses by farmers that exacerbate the problems of climate variability and change, along with linking emergency aid with developmental support.

- **Development of innovative solutions and adaptive strategies that deliver long-term, sustainable livelihoods for rural Africa are essential. These should be delivered within a framework that promotes capacity building within Africa.**

World leaders and other decision makers meeting at events such as the G8 Summit in Gleneagles have the opportunity to address this through the following actions that build on the proposals of the Commission for Africa.

(i) A combination of (a) core activities dedicated to research to generate new knowledge and technologies, and (b) complementary activities to facilitate the use of that knowledge and technologies, especially by the most vulnerable. Basic climate and crop science needs to be strengthened and better institutional and observational structures need to be built in Africa.

(ii) A solid programme of model development to ensure that models capture environmental and social vulnerabilities, especially for sub-Saharan Africa. Regional models need to be cognisant of the scales at which decision makers (local and national) work.

(iii) Investment in people and capacity building in Africa by providing effective knowledge transfer mechanisms and opportunities for training of African scientists by the developed world. Possibilities include institutional partnerships and studentship programmes.

(iv) Acquisition and interpretation of climate observations. African observing systems varies from reasonable to non-existent and in some areas is deteriorating rapidly. A commitment has already been made to the Global Climate Observing System (GCOS), but data capture urgently needs strengthening.

(v) For Africa, where climate variability is large and cropping systems are already vulnerable, there is evidence that the effective use of seasonal forecasts and the development of sustainable adaptive strategies may build resilience to climate change. More emphasis should be placed on improving the use of seasonal forecasting, and more research on bridging the gap to climate change by focusing on the next 5-20 years should be encouraged.

(vi) All actions need to take a global perspective. Global population growth is leading to a gradual decline in food stocks; shifting climatic patterns may lead to questions of what will happen to current ‘bread baskets’ and what is being done to prepare new ‘bread baskets’.

Annex A Discussion Meeting on food crops in a changing climate (26 & 27 April 2005)

Only the speakers are listed

Session 1 The science of climate variability and change and of crop responses to climate

Chair Professor Brian Hoskins CBE FRS (*University of Reading, UK)*

Dr Tim Palmer FRS (*European Centre for Medium-Range Weather Forecasts, Reading, UK)*
Probabilistic prediction of climate: from basics to applications

Dr Chris Huntingford *(Centre for Ecology and Hydrology, Wallingford, UK)*
Aspects of climate change relevant to crops

Professor Stephen Long *(University of Illinois at Urbana-Champaign, USA)*
Response of crop photosynthesis to CO_2, ozone and temperature

Professor John R Porter *(Department of Agricultural Sciences, The Royal Veterinary and Agricultural University, Denmark)*
Crop responses to climate variability

Session 2 Integrating crop and climate modelling for current and future climates

Chair Professor Julia Slingo *(University of Reading, UK)*

Dr James Hansen *(The International Research Institute for Climate Prediction, USA)*
Integrating seasonal climate prediction and agricultural models for insights into agricultural practice

Dr Richard Betts *(Met Office, Hadley Centre for Climate Prediction and Research, Exeter, UK)*
On the need for an integrated approach to modelling future climate change and food production

Dr Günther Fischer *(International Institute for Applied Systems Analysis, Austria)*
Integrated assessment of global crop production

Dr Andrew Challinor and Dr Tim Wheeler *(University of Reading, UK)*
The development of a combined crop and climate forecasting system

Session 3 Food production under climate variability and change

Chair Professor Anand Patwardhan *(Indian Institute of Technology, India)*

Dr Roger Stone *(Queensland Department of Primary Industries and Fisheries, Australia)*
Operational seasonal forecasting of crop performance

Professor Martin Parry OBE *(Co-Chair, Working Group II, IPCC)*
Global food supply, risk of hunger and climate change

Professor Peter Gregory *(Chair of GECAFS, University of Reading and Scottish Crop Research Institute, UK)*
Climate change and food security

Professor Lin Erda *(Chinese Academy of Agricultural Sciences, China)*
Climate change impacts on food production with CO_2 fertilisation in China

Session 4 Climate change and Africa: priorities for G8

Chair Dr Tony Nyong *(University of Jos, Nigeria)*

Dr James Verdin *(US Geological Survey, USA)*
Climate science and famine early warning

Dr Michael Dingkuhn *(CIRAD, France)*
From GCM grid cell to agricultural plot: scale issues affecting modelling of climate impact

Dr Menghestab Haile *(UN World Food Programme, Italy)*
Weather patterns, food security and humanitarian responses in Sub-Saharan Africa

Dr Tom Downing *(Stockholm Environment Institute, Oxford)*
Multi-agent modelling of climate outlooks and food security on a community garden scheme in Limpopo, South Africa

Dr Ed Clay *(Overseas Development Institute)*
The policy environment: G8 and beyond

A selection of relevant Royal Society reports

Joint science academies' statement: global response to climate change (June 2005, 08/05)
Joint science academies' statement: science and technology for African development (June 2005, 09/05)
Response to Defra review of the UK Climate Change Programme (May 2005, 02/05)

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