A rough guide to climate change and agriculture

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Background and Acknowledgements

Over the last few years, our understanding and certainty about how the climate is changing and the possible impacts this could have has grown hugely. In response there are increasing efforts to 'mainstream' what we know about these impacts into development policy and planning processes. Given the fundamental links between agriculture and poverty reduction and agriculture's dependence on the climate, understanding in more detail about linkages between agricultural policies and climate change is important and urgent.

This paper is one of a series of five outputs produced under a small project for the Renewable Natural Resources and Agriculture Team of the UK Department for International Development (DFID). The objective of the project was to identify the implications of climate change for key areas of DFID's Agricultural Policy and the Renewable Natural Resources and Agriculture (RNRA) Team portfolio and to produce a series of practical outputs to assist the RNRA team in programme implementation and communication.

The five papers are as follows:

1. A rough guide to climate change and agriculture
2. Climate change: Implications for DFID's Agricultural policy
3. Climate change, agricultural growth and poverty reduction
4. Climate change and agriculture: Agricultural trade, markets and investment
5. Access to assets: Implications of climate change for land and water policies and management

The papers are written by a team of researchers from ODI's Rural Policy and Governance and International Economic Development Groups. The authors are grateful to DFID for their funding of this project. The arguments presented in the papers are those of the authors and do not necessarily reflect the policy position of DFID.

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1. Introduction

Agriculture has received a lot of attention from climate modellers because of the high dependence of agriculture on the climate. Human dependence on agriculture, particularly in developing countries, also means that agriculture has an important role in debates about adaptation to the impacts of climate change in developing countries. Currently agriculture accounts for 24% of world output, employs 22% of world population and uses 40% of land area (FAO 2003). Most studies of the impacts of climate change on agriculture indicate that there will be negative effects over the next century. Some estimate that 600 million additional people may be at risk of hunger if global temperature increases of over 3 degrees Celsius (Warren et al. 2006), particularly in developing countries where people are already at risk. But climate change is only one of a range of factors that may affect global food production in the future, so it is important to try and understand the scale of these impacts in relation to other changes such as improvements in technology and farming systems.

Given the complex relationships between crops, atmospheric composition and temperature, combined with the complexities of world agricultural policies and trade, making predictions about the future impacts of climate change on agriculture is fraught with difficulties.

This report reviews current knowledge about the relationships between agriculture and climate change and outlines the main areas of certainty. Coverage has been narrowed down to the following areas to simplify the analysis:

1. A focus on cereal crops for three reasons: (1) the main cereals (rice, wheat and maize) make up 85% of world cereal exports; (2) these crops are thought to be particularly sensitive to climate change (FAO 2003) and (3) have had most modeling work done on them. Potential climate change impacts on aquaculture are covered in a recent comprehensive DFID report (DFID 2006).
2. A focus on scenarios of future climate change developed and used by the Intergovernmental Panel on Climate Change, as these are the most widely cited in the scientific literature.
3. A focus on global climate change, rather than regional or local changes in climate, as these have more coverage in modeling studies.

The report also provides the basis for considering future agricultural policy in relation to climate change. Given the large uncertainties involved, an emphasis has been placed on providing four illustrative scenarios of possible futures and their potential impact on agriculture (section 4). These are used as the basis for considering policy responses which are considered in outputs two and three of this series for DFID.

2. How are the impacts of climate change on agriculture studied?

There are a number of tools used to understand potential effects of climate change on agriculture. These range from large-scale models representing the global climate, agriculture and food trade systems now and extrapolated into the future, to small, farm level or laboratory experiments used to study the responses of plant physiology to individual climatic drivers. The main methods currently in use are outlined below.

2.1. Global climate models

The most widely used approach is to use climate change models, which make projections about future climates based on current understanding of drivers of climate change and relate the outcomes of these models to potential impacts on crops. There are five main elements to these processes (see also **Error! Reference source not found.**):

1. **Scenarios of greenhouse gas and aerosol emissions:** Scenarios of future greenhouse gas emissions are developed based on sets of 'storyline' scenarios of possible future worlds. These define values for the main parameters affecting greenhouse gas emissions, including population growth, technology and economic state (global GDP and regional variation in GDP). The most common scenarios in use in the literature are the Special Report on Emissions Scenarios (SRES) developed by the Intergovernmental Panel on Climate Change (IPCC 2000).

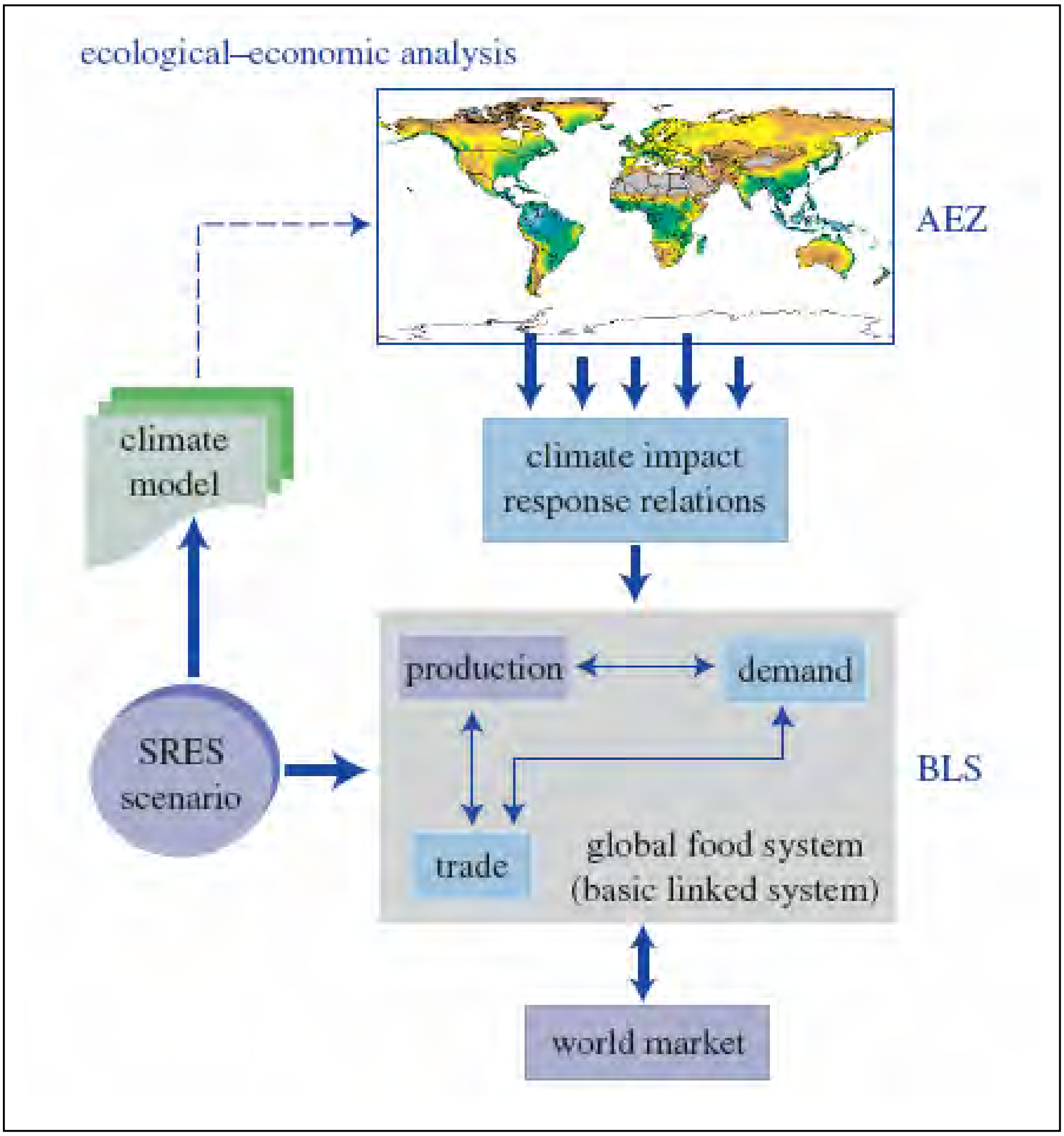
2. **Scenarios of greenhouse gas concentrations** in the atmosphere are then generated through models of processes that act to remove greenhouse gases from the atmosphere (e.g. uptake in the oceans and land, and chemical processes in the atmosphere).

3. **Scenarios of temperature changes** are derived by feeding these modeled concentrations into general circulation models (GCMs) which model changes in temperature (known as radiative forcing) and resulting changes in climate due to greenhouse gases.

4. **Impacts on agriculture** are assessed by feeding these projections into crop response models such as the 'Agro-ecological-zones' (AEZ) modeling framework (see for example Fischer 2002). These generally focus on the main cereal crops.

5. **Impacts on agricultural trade** are investigated by linking these models with agricultural trade models such as the 'Basic Linked System' developed by the UN Food and Agriculture organization (UN FAO) and the International Institute of Applied Systems Analysis (IIASA). The BLS is usually run using SRES scenarios 'without' and 'with' climate change factored in to separate out the impacts of climate change variables from others in the scenarios.

Figure 2.1: Schematic showing how climate change scenarios are linked to climate change impacts on agricultural production and trade.



It contains the main elements outlined in section 2.1. Source: Fischer 2005.

2.2. Controlled field experiments

Controlled field experiments are another tool used to model the impacts of climate change on crops. Crops are grown in controlled environments where variables such as concentrations of different gases in the atmosphere, available water and temperature can be varied. These models are crucial to our understanding of how climate change might impact on specific crops and as inputs into large-scale climate models. There are a number of uncertainties involved in combining crop-scale experiments with large-scale global climate models, outlined in the next section.

2.3. Integrated climate-crop models

Integrated climate-crop models are currently under development that attempt to address some of the problems outlined above. They focus on fact that food crops are likely to respond to climate change in complex ways and to various extra-sectoral drivers such as hydrological cycles. Examples include changes in land surface that may affect related parameters such as water runoff and feedbacks on climate change relating to changes in vegetation cover. There is also evidence that major changes in land use have had some effect on local climates, which are unaccounted for in most existing crop-climate models (Betts 2005).

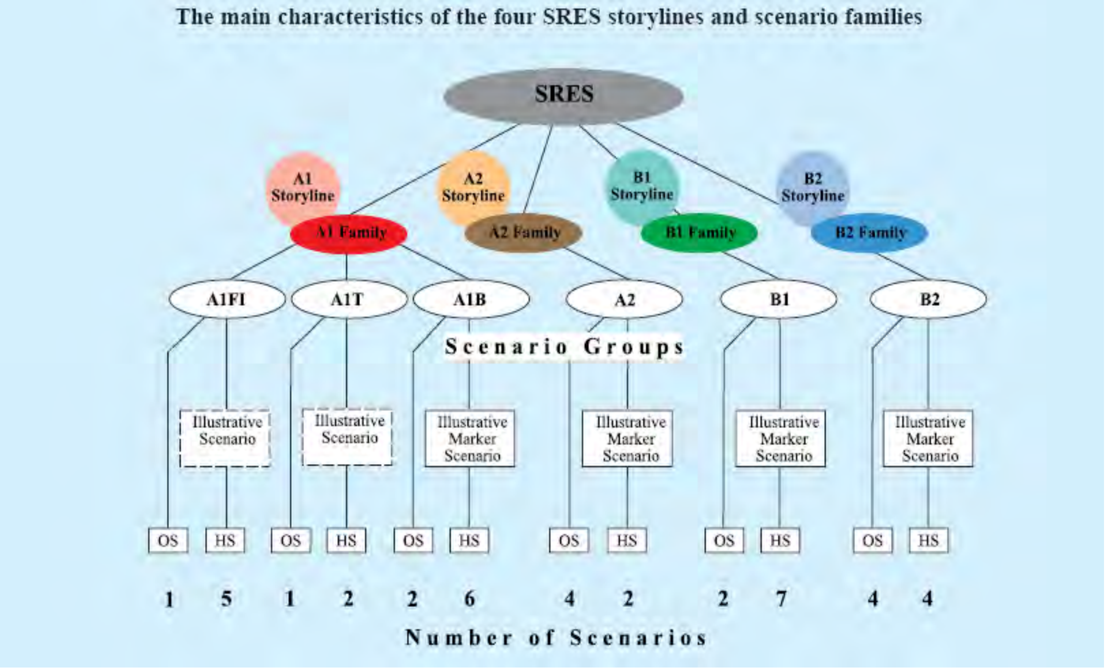
2.4. Statistical analyses of past climates

Statistical analyses of the impacts of past climates on crop production can be used to estimate how crops may respond in the future and to some extent to test the accuracy of climate models by running them using measurable drivers from the past. However, there is no guarantee that relationships that have existed in the past will exist in future climates, so the application of such techniques is limited.

3. Climate change scenarios and agricultural production

Modeling studies of the impacts of climate change on agriculture are often based on a set of scenarios developed by the Intergovernmental Panel on Climate Change (IPCC 2000). There are four scenario families defining four different storylines of different future worlds (**Error! Reference source not found.**). These differ in terms of projections in population growth, world GDP changes, differences in per capita income between developed and developing countries and energy intensity of the economy (related to level of emissions).

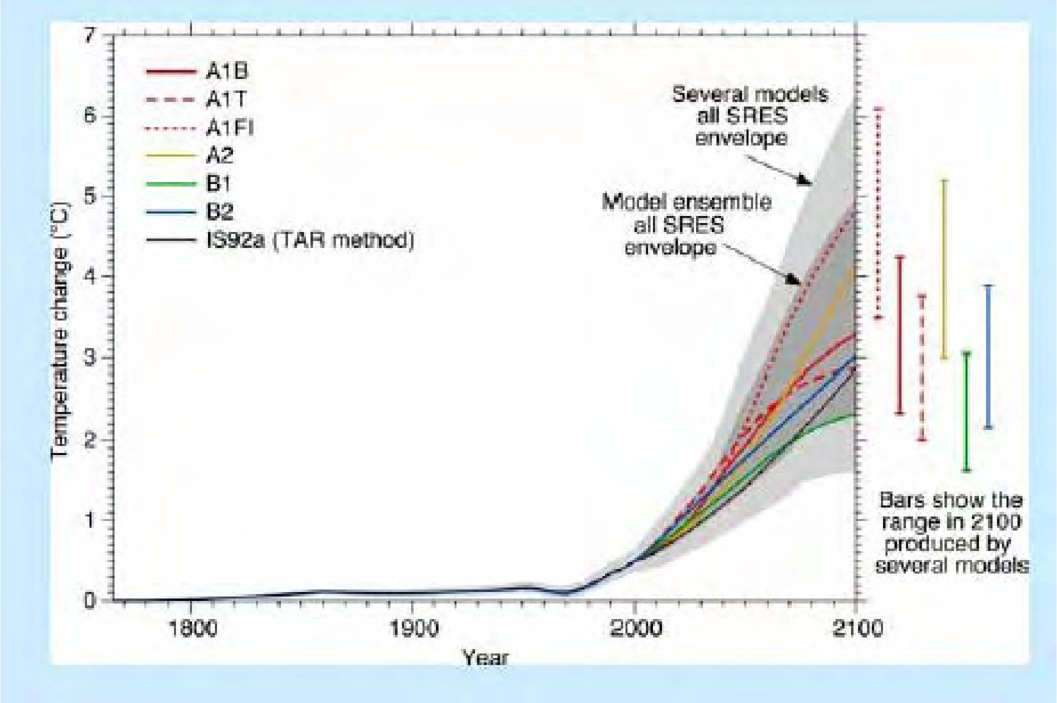
Figure 3.1: The SRES emissions scenarios developed by the IPCC.



Four qualitative storylines of future possible worlds define four equally valid scenario families. There are six scenario groups, A1F1 (fossil fuel intensive), A1B1 (balanced – i.e. not relying too much on one source of energy), A1T (Predominantly non-fossil fuel), A2, B1 and B2. Those marked HS are harmonized, meaning they share assumptions on global population, gross world product and final energy with others in the group. OS are scenarios that explore other driving forces. Illustrative marker scenarios are also produced which allow easier comparison between scenarios. The numbers indicate the number of models running the scenario. Source: IPCC 2000.

These scenarios form the primary drivers for emissions scenarios, which can be generated through modeling studies and used to make projections of temperature changes (Figure 3.2).

Figure 3.2: Temperature changes for the 21st Century, showing nine illustrative emission scenarios.



Blue shading represents uncertainty between the seven different climate models used. Coloured bars show the full range of uncertainty for different scenarios. Source: IPCC 2001

3.1. What do models attempt to project?

Combining the models and scenarios outlined above allows for projection of a number of different variables in relation to climate change over the next century. Most modeling studies focus on a set of different parameters relating to cereal crops, because of their importance in the world agricultural economy and their sensitivity to climate change. In general, model outputs include projections of:

- Changes in yields due to changes in seasonal climates
- Changes in production potential in relation to factors such as yields, available land suitable for agriculture and lengthened/shortened growing seasons
- Responses of crops to changes in atmospheric composition, such as concentrations of carbon dioxide
- Changes in the price of cereals resulting from climate change
- Changes in patterns of trade resulting from climate change
- Changes in the number of people at risk of hunger as a result of climate change, normally measured as the number of people whose incomes allow them to purchase cereals
- Water runoff and related water stress, normally measured in terms of the number of litres of water available per person per year

3.2. Model limitations and assumptions

There are currently large uncertainties in our understanding of how climate change impacts on agriculture. Given the complexities of the systems involved, models have to simplify certain parameters, some of which might have large implications for the outcomes. In general uncertainties become larger the further in the future projections are made.

3.2.1. Uncertainties in the drivers used for climate change and agriculture models

The inputs to models used for predicting the impacts of climate change on agriculture are themselves subject to large uncertainties and controversies. These include:

- Uncertainties over future emissions
- Uncertainty over how the climate system will respond (e.g. temperature changes)
- Natural variability and feedbacks being hard to model due to a lack of understanding of complex relationships
- Disagreements in assumptions, including: criticism of the economic growth rates assumed in the SRES scenarios for being too high (Schiermier 2006); the SRES storylines not accounting for all possible future worlds (e.g. 'disaster' worlds) (Arnell et al 2004); and population growth rates of the A2 scenario being too high compared to UN predictions (Fischer 2005).
- Crop yield change estimates (Parry 2004): 1) uncertainties arise in using yield functions from field experiments in larger modeling studies; 2) drought conditions are simulated in some models but not flooding; 3) farm-level adaptation is often simulated based on current available technologies, but these may be very different in the future.

3.2.2. Assumptions in the socio-economic processes included in the models

- Human adaptation to climate change (enabling farmers to cope with changes) is considered in different ways and to different extents within different modeling studies. Some studies assume no adaptation, others assume autonomous adaptation (i.e. at the farm level) and others assume economy wide adaptation (Stern 2006). Fischer (2002) for example makes optimistic assumptions about adaptation, assuming "an advanced level of inputs and management for currently cultivated areas" (Fischer 2002, cited in Warren 2006). This results in production increases in some developing countries.
- In food trade estimates more attention is paid to major cereal crops despite likely shifts in the balance between arable and livestock lands and sectors outside agriculture are very poorly modeled (Parry 2004).

3.2.3. Geographical scale issues

One of the biggest limitations of current modeling techniques is in bridging the scale gap between large-scale global climate models which generally have a resolution of over 100km, and the small-scale of most farming systems, which are generally below 10km.

Methods exist by which relevant outputs from large-scale models can be used as drivers for small-scale crop models, but these has been shown in come cases to give rise to systematic errors in estimated yields (Baron et al 2005). Generating information about climate change that is useful for the purposes of adaptation at a field scale has therefore so far proven problematic.

3.2.4. Temporal scale issues

Most large-scale modeling studies have low temporal resolutions, meaning that sub-seasonal variations in weather and climate are not covered in detail. Prediction of precipitation and extreme events is particularly problematic (Parry 2004).

3.2.5. Regional biases

Current climate modeling studies have significant regional biases, due to a lack of information on model inputs such as precipitation patterns (both temporal and spatial) in developing countries. Modelling rainfall patterns is difficult in itself because of the small scales and short timescales involved, so this lack of data adds to the problem.

3.2.6. Crop responses to atmospheric composition

Large uncertainties exist over the influence of atmospheric CO2 concentration on crops. This CO2 'fertilisation' effect occurs because of the dependence on CO2 for growth. Increased atmospheric concentrations can stimulate photosynthesis and improve the efficiency of water use by plants. The extent to which this happens depends on the type of plant (different plants use different photosynthetic processes) and factors such as water availability, nutrient availability and pests and diseases (Stern 2006). There are therefore complex relationships between atmospheric composition changes predicted by models and areas of increased water stress in particular (Slingo 2005).

There are large differences in the projection of climate models, depending on whether they take CO2 concentrations into account (Parry 2004). CO2 concentration is known to have more of an effect on C3 crops (e.g. rice, wheat and soybean) than C4 crops (e.g. maize, sugarcane and sorghum). In most modeling studies, CO2 impacts are based on controlled field experiments which indicate that a 20-30% rise in yield is found to occur for moderate CO2 increases. More recent evidence, however, indicates that the effect might be much less than originally estimated, resulting in an 8-15% increase for C3 plants and no significant change for C4 plants (Long et al 2006 cited in Stern 2006).

It is also possible that some of these effects could be counteracted by other atmospheric gases such as levels of surface ozone, which could be important in countries like China where ozone concentrations are expected to rise. Crop interaction with atmospheric processes is generally not covered in large-scale modeling studies. For example, large changes in land use have been shown to have an influence over local climates, and crops themselves can have an impact on atmospheric composition (Erda et al. 2005).

3.2.7. Extreme events

Many food crops are highly susceptible to episodes of high temperature at critical points in the growing cycle (Slingo 2005), which can result in large decreases in yield. Challinor et al (2006) for example, looked at the effects of extremes of temperature on yield for wheat, groundnut and soybean and found significant decreases in yield for crops in some areas, depending on the variety. Rozenweig et al (2002) predicted that current 3% yield losses in maize due to flooding could increase by up to 6% due to increased climate variability and flooding (Warren 2006).

Most large-scale climate studies model extreme events in terms of days per year that temperatures exceed a maximum threshold and the annual maximum one-day precipitation total (Slingo 2005). Their projections indicate that extreme events such as floods and droughts could increase in both severity and frequency as a result of climate change. There is, however, little information on factors such as the timing of drought periods in relation to crop life cycles and temporal clustering of intense weather systems. It follows that predicting the impacts of extreme events on crops through climate models is currently very difficult and poorly accounted for in most large-scale models.

4. Illustrative summary of scenarios up to 2080-2100 and possible impacts on agricultural production and trade

This section outlines four scenarios of possible alternative futures under climate change, as projected by a range of modeling studies. It should be noted that these are illustrative scenarios that only give an outline framework for considering possible policy responses to climate change. No single modeling study includes all of the outputs listed and there is large variation in the assumptions made and the processes used. Nevertheless the broad trends outlined are consistent with current studies, but might deviate significantly from any particular study.

4.1.1. A1F1 scenario

In the A1F1 scenario population growth increases towards 9 billion by 2050 and then declines to around 7 billion by 2100. Economic growth increases at about 3.5% per annum over this time with per capita income in developed countries reaching $76000 per capita and $42000 per capita in developing countries. The average income ratio reduces to about 1.6 implying a more equitable world. It is questionable whether such high growth rates can be sustained in reality. Mortality and fertility rates decline over this period.

In this scenario it is likely that the yields of crops will decrease, although this change may be small at a global average, especially until 2050, depending on the effects of CO2 'fertilisation'. Yields decrease especially in Africa, possibly by up to 20% by some estimates. The beneficial effects of CO2 in most areas of the continent may be less pronounced because of the large and damaging increases in temperature. Cereal production is also likely to decrease globally, and particularly in Africa. Cereal prices vary inversely with production changes and the largest price increases are seen out of any of the scenarios described here. Measures of the additional number of people at risk of hunger indicate that climate change has less impact than might be expected because of low population growth and high rates of economic growth in all areas when beneficial CO2 effects are included. Without these effects the number increases substantially towards the end of the century. The number of people suffering from water stress also shows little increase because of low population growth.

4.1.2. A2 scenario

The A2 scenario is characterised by very high population growth rising from around 8 billion in 2020 to around 15 billion in 2100. Economic growth increases at a much lower rate than A1F1 and around 2% per annum. Average per capita income in developed countries reaches around $37000 compared to $7300 in developing countries. Income differences between developed and developing countries decrease, but there are still large differences.

In this scenario global yields are likely to decrease towards 2050 as they do in A1F1 but decreases are less pronounced towards the 2080s. Cereal production decreases by up to 10% compared to the reference case without climate change. Cereal price increases are likely to be high. Cereal imports to developing countries show the greatest increase for any of the scenarios, to around 430 million tonnes with some model runs. Effects of climate change could increase this figure by up to 40%. High population growth, a greater concentration of people living in the developing world, greater economic disparities and greater regional differences in climate increase the number of people at risk of hunger dramatically with no positive CO2 effects.

4.1.3. B1 scenario

In the B1 scenario population growth follows a similar pattern to A1F1, but economic growth increases at a lower rate (around 2.75% per annum). Average per capita income increases to $55000 in developed countries and $29000 in developing countries implying around a 10% lower growth rate for developed countries and a 20% lower growth rate for developing countries compared to the A1F1 scenario. Income ratios between developed and developing countries are much less than today, implying an equitable world. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives (IPCC 2000)

In this scenario global cereal production is expected to decrease but much less markedly than in the A scenarios, mainly due to less extreme changes in temperature. As with other scenarios the results depend heavily on the effects of CO2 on crop yield. Cereal prices increase gradually, but remain low. This scenario results in the least dependence of developing countries on agricultural imports (about 170 million tonnes by 2080). The number of people at risk of hunger is much lower than in the A scenarios because of reduced inequality, low population and high rates of growth. The number of people suffering water stress varies in the same way as the A1F1 scenario.

4.1.4. B2 Scenario

Population growth in the B2 world increases gradually towards 10 billion by the end of the century. The rate of economic growth is similar to the A2 scenario but differences between developed and developing countries are less (although still more than A1F1 and B1). Technological change is less rapid and more diverse than the B1 and A1 storylines. Efforts to improve environmental protection and social equity focus on local and regional levels.

In this scenario, global decreases in yield are expected, although this again depends on the CO2 effect. The highest yield decreases are expected in Africa and South America although these are not as pronounced as the A2 scenario. If beneficial CO2 effects are assumed then yield increases might be expected, especially in high latitudes and Asia and reductions in yield will be much less severe in Africa compared with no CO2 effects. Global production is likely to decrease although much less than in the A scenarios, resulting in less extreme increases in prices. The number of people at risk of hunger is predicted to be low, mainly due to increased income in developing countries.

Table 4.1: Illustrative comparison of climate change scenarios and potential impacts based on current understanding from modeling studies.

IPCC SRES Scenario	A1F1	A2	B1	B2	General trends
Drivers (Stern 2006, based on SRES scenarios)					
Population by 2100	7 billion	15 billion	7 billion	10 billion	
World GDP growth	Very high 3.5% per annum	Medium 2% per annum	High 2.75% per annum	Medium 2% per annum	
Degree of convergence of GDP per capita in 2100 for rich vs. poor countries	High 1.6	Low 4.2	High 1.8	Medium 3.0	
Emissions	High	Medium high	Low	Medium low	
Expected level of climate change (Degree of warming) with indicative temperature increase in degrees Celsius for each year simulated by HadCM3 model	High 2020: 0.7 2050: 1.96 2080: 3.67	Medium high 2020: 0.59 2050: 1.59 2080: 2.9	Low 2020: 0.54 2050: 1.15 2080: 1.76	Medium low 2020: 0.61 2050: 1.31 2080: 2.08	
Outputs					
Cereal yield without beneficial CO2 effects. Parry 2004	Large yield decreases everywhere for all crops (10% reduction in cereals and 18% reduction in Maize) by 2050s. Larger reductions in cereals of up to 20% by 2080s	Largest contrast in yields between developed and developing countries. Very similar changes to A1F1 until the 2050s but much less of a yield decrease between 2050 and 2080 (no more than 10%)	Some negative impacts in the Baltic States as temperature increases are not accompanied by precipitation increases	Effects fall in between those of A2 and B1. Africa and South America suffer from reduced yields	Up until 2020 dominated by natural variability. CO2 effect has a large impact on yield.
Cereal yield with beneficial CO2 effects. Parry 2004	Yield increases in many areas except Africa where temperature impact overtakes beneficial CO2 impact.	Beneficial effects of CO2 everywhere but especially in high latitudes and in Asia.	Less contrast in crop yield changes because of lower CO2 change in the scenario	Reduction in yield is less pronounced in Africa and South America than in the without CO2 scenario. Increase in yields in high latitudes and in Asia	Up until 2020 dominated by natural variability. CO2 effect has a large impact on yield.
Production (millions of tonnes compared to reference case without climate change) without beneficial CO2 effects. Parry 2004	~10% decrease by 2080s due to greater temperature increases than the B scenarios	~10% decrease by 2080s due to greater temperature increases than the B scenarios	~5% decrease by 2080s	~5% decrease by 2080s	
Production (millions of tonnes compared to reference case without climate change) with	~2/3 reduction compared to value	~2/3 reduction compared to value	Smaller fertilisation effect results in less of a	Smaller fertilisation effect results in less of a	

beneficial CO2 effects. Parry 2004	without CO2 effects	without CO2 effects	reduction compared to A1 and A2	reduction compared to A1 and A2	
Cereal consumption and trade Fischer 2005; Parry 2004		Scenario that results in largest imports in developing countries (up to 430 million tonnes by 2080).	Scenario that results in smallest imports in developing countries (up to 170 million tonnes by 2080).		Consumers are assumed to be much richer in all SRES worlds, with less dependence on primary agriculture, so direct consumption of cereals declines. Developing countries increase imports in all scenarios. Climate change increases this import dependence by 10-40%
Additional number of people at risk of hunger due to climate change without beneficial CO2 effects. Parry 2004, in Warren 2006	2020: 63 2050: 100 2080: 263 Without beneficial CO2 effects large decreases in production increase the number of people at risk of hunger despite high economic growth	2020: 63 2050: 212 2080: 551 Highest increase in number of people at risk of hunger because of high population growth and low CO2 effect	2020: 44 2050: 34 2080: 34 Low because of increased income in developing world and lower temperature increases	2020: 54 2050: 66 2080: 151	All scenarios predict a baseline of number of people at risk of hunger similar or in most cases lower than today (800 million). Climate change could have a large impact on the number of people at risk of hunger.
Additional number of people at risk of hunger due to climate change with beneficial CO2 effects. Parry 2004, in Warren 2006	2020: 24 2050: 1 2080: 28	2020: 21 2050: 1 2080: -28 The lower degree of warming compared to scenario A1F1 means that CO2 effects are not out competed by temperature effect	2020: 22 2050: 3 2080:12 Little change compared to 'without CO2' because of low absolute CO2 levels	2020: 31 2050: 11 2080: -12	
Water stress (number of people when population has $<1000m^3$ per year, millions) Arnell 2004	2025: 2882 2055:3400 2085:2860	2025: 3320 2055: 5596 2085: 8065	2025:2882 2055: 3400 2085: 2860	2025: 2883 2055: 3988 2085: 4530	

Note: The outputs are comparable across scenarios as they are based on the same assumptions. Comparison between different outputs is not possible because of the different assumptions and models used. Sources: Cited in the table.

5. What else do we know?

There are many issues relating to the impacts of climate change on agriculture that are not covered in the scenarios outlined above, or the projections are hard to disaggregate in different scenarios. This section gives a brief overview of the potential impacts of climate change in other areas that have particular relevance to agriculture.

5.1. Impacts of climate change on livestock

Climate change can have both direct and indirect effects on livestock. Direct effects include factors such as air temperature and humidity, which can have an impact on biological processes such as reproduction and milk production. Indirect effects relate to factors such as availability and quality of food and occurrences of pests and diseases (IPCC 2001). Livestock can also be affected by more extreme events (e.g. more prolonged days of drought), where these exceed thresholds. Modelling studies have been conducted based on current understanding of these relationships and have found that climate change could have a large impact on livestock performance. For example, reduced production of milk by 5-14% amongst dairy cattle in the southern United States has been found in some scenarios (IPCC 2001).

A more recent study of the effects of climate change on livestock in Africa indicates differences in the responses of different types of livestock and different farm sizes to the impacts of temperature rise and precipitation increases/decreases (Seo 2006). It finds that commercial livestock owners (especially cattle owners) could be affected by warming because they are less able to adapt to other crop or animal alternatives. Small farmers on the other hand are less affected by climate change because they can switch more easily to more heat tolerant crops and livestock.

5.2. Relationships between climate change and soil degradation

Relationships between climate change and soil degradation are complex. According to IPCC (2001) land management practices will have most influence over soil organic matter content in the next few decades. However, semi-arid areas that already have poor soils are likely to feel the effects of climate change more severely, due to changes in vegetation cover, weather and climate patterns.

Climate change is likely to increase the frequency and distribution of stronger winds and increased rainfall, which are large determinants of erosion. Soil organic matter content and capacity to hold water is likely to decrease as a result. In semi-arid and arid areas, where nutrient content is already low and water stress already high, climate change could therefore act to decrease crop yields. This could exacerbate reductions in crop yield arising due to temperature increases.

5.3. Water availability

In a warmer world, the hydrological cycle is likely to become more intense, and there is already evidence of more 'very wet' and 'very dry' areas compared to past measurements (IPCC 2007b). Modelling changes in the hydrological cycle is challenging, particularly for events that happen on short temporal and spatial scales, such as thunderstorms and precipitation events, which can be very uncertain. Whilst precipitation changes are hard to model, in areas of the world that are dependent on snow pack for water, warmer temperatures cause earlier thawing and less precipitation falls as snow (Barnett 2005). This effect is the same even without changes in precipitation intensity (Barnett 2005). This implies more certainty in projections that such areas could suffer from water stress where storage capacity is not sufficient, than areas where water stress is related mainly to changes in precipitation.

In general, in semi arid areas annual mean soil moisture is expected to decrease and percentage changes of runoff in river basins is likely to increase in high latitudes and some of the wet tropics and decrease in mid latitudes and the dry tropics (IPCC 2007), although the extent and direction vary somewhat between models for given temperature changes. Climate change impacts on ground water are likely to vary significantly according to the site; shifts in recharge towards winter and lower summer recharge could occur in many aquifers, but recharge could increase in semi-arid and arid areas due to more frequent and heavier rainfall (IPCC 2007). However, globally the number of people experiencing extreme droughts at any one time could also increase by between 3 and 30% due to climate change for a 3-4°C warming (Stern 2006).

Water resources in coastal areas are likely to be affected by sea level rise, which will increase salinisation of soils and groundwater. For example, small island freshwater lenses are expected to decline in thickness with a 0.10m rise in sea level by 2040-2080. Most current climate models predict sea level changes of between 0.18m (B1 scenario) and 0.59m relative to the period 1980-1999, by the period 2090-2099 (IPCC 2007b).

5.4. Extreme events

The effects of extreme climatic events on agriculture can be large, but these impacts are currently poorly modelled in climate-crop models, as highlighted in section 3.2.7. General understanding about the frequency and severity of extreme events is more advanced, with the likelihood of phenomena such as the warmer days and nights and more frequent hot days being 'virtually certain' (99% probability of occurring) in the 21st century (Table 5.1).

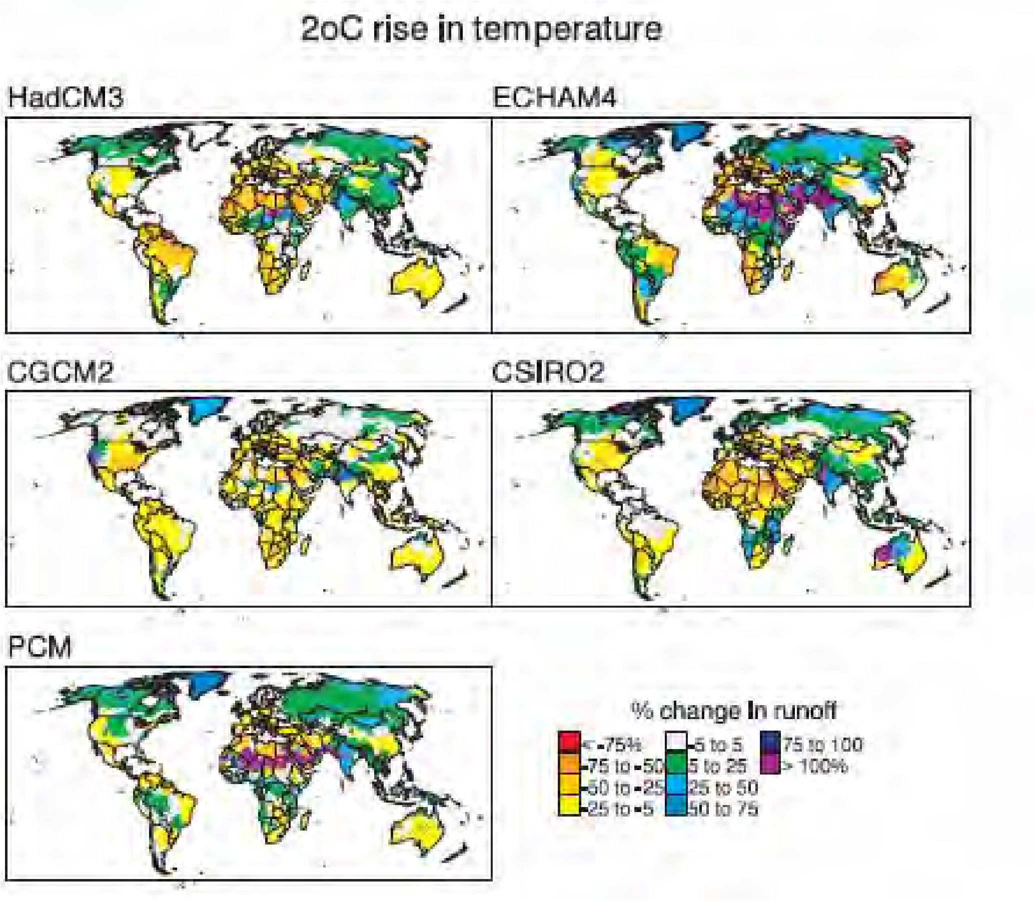
Table 5.1: The likelihood of various types of extreme event, according to probabilities defined in IPCC 2007 WG1 Report.

Phenomenon and direction of trend	Likelihood of future trends based on SRES projections for the 21st century

Warmer and fewer cold days and nights over most land areas	Virtually certain
Warmer and more frequent hot days and nights over most land areas	Virtually certain
Warm spells/heat waves. Frequency increases over most land areas	Very likely
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	Very Likely
Area affected by droughts increases	Likely
Intense tropical cyclone activity increases	Likely

Virtually certain › 99% probability of occurrence, *Extremely likely* › 95%, *Very likely* › 90%, *Likely* › 66%, *More likely than not* › 50%, *Unlikely* ‹ 33%, *Very unlikely* ‹ 10%, *Extremely unlikely* ‹ 5%. Source: Adapted from IPCC 2007b

Figure 5.1: Percentage change in runoff predicted by five different climate models for a 2 °C rise in temperature.



Source: Arnell 2006

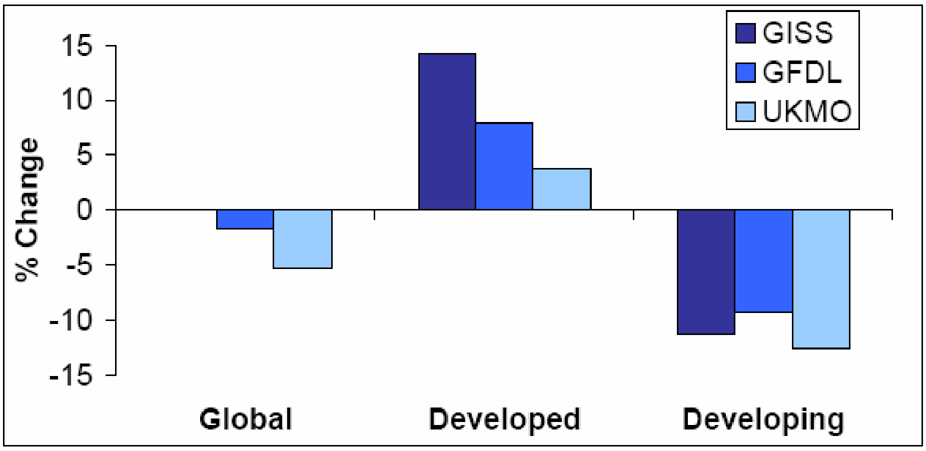
6. Ten things we know about climate change and agriculture

This report has outlined many of the complexities involved in understanding the impacts of climate change on agriculture in the future. There are many things that are uncertain, but there are also some things that are much more certain. These are summarized below:

1. **Scenarios project that global cereal production could continue to increase up to 4.3 G tonnes depending on the scenario and model used (Fischer 2005).** When climate change is factored in, global cereal production could be within 2% of reference scenarios. This implies that climate change is unlikely to result in large-scale collapse of food production at the global level under all but the most extreme scenarios. This aggregated trend masks potentially large regional variations.

2. **At a regional level most models project greater differences in cereal production between developed and developing countries by 2080 with increases expected in developed countries and decreases in developing countries** (**Error! Reference source not found.**) (Parry et al 2005, cited in Stern 2006). In general increases are expected in potential agricultural land in high latitudes, particularly North America (20-50%) and the Russian Federation (40-70%). Production in China is also expected to increase. In general, decreases are expected in low latitudes and developing countries, reflecting both declining potential land available for crop cultivation reported above and changes in productivity. Sub-regional variations are masked by these figures, with some short term increases possible in areas of overall decrease (e.g. Africa). For example, tropical highlands where current low temperatures prevent planting of certain crops, new land could become suitable for agriculture.

Figure 6.1: Change in cereal production in developed and developing countries for a doubling of carbon dioxide levels (approx. 3 °C in the models used) simulated with three different climate models.



Percentage changes are relative to what they would have been without climate change. Assumptions: mostly farm level adaptation; some economy wide adaptation; strong CO2 fertilisation effect. Source: Stern 2006

1. **Related to the projected regional differences in production, most scenarios project that tropical developing countries could increase cereal imports from developed countries and temperate areas.** Some models indicate that the influence of climate change on agricultural imports of developing countries could be between 10 and 40% (e.g. Fischer 2005).

2. **Comparisons between scenario studies suggest that the impacts of climate change on agriculture could diverge over time.** Few differences between current scenarios can be discerned over the next 20 years. This may be due more to the large uncertainties in projections making trends more discernable at the extremes. In addition, in the short term the frequency and severity of extreme events is also likely to increase, so more localized effects may be much more severe than indicated by the scenarios. As a very general rule these changes could occur in areas that are already most susceptible to these events. This may have implications for those policy responses aimed at supporting agricultural growth compared to those aimed at helping the poor to cope with extreme events.

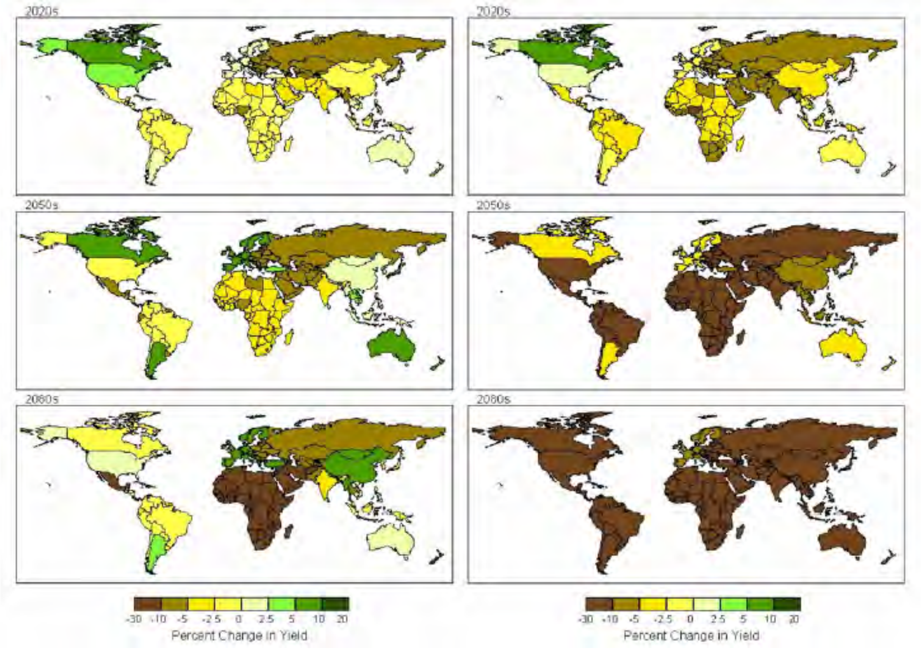
3. **CO2 'fertilisation' effects have a major impact on future yield projections** (**Error! Reference source not found.**). These are complicated to model, but most recent estimates suggest that the benefits of this effect are less than assumed in most climate models to date. The beneficial effects of CO2 for plants are different for different types of crop. Crops such as rice, wheat and soybean could increase yield by 8-15% for a doubling of CO2, whereas little change is expected in crops such as maize, sugarcane and sorghum (Long et al 2006 cited in Stern 2006). This implies that some crops could be more resilient in future climates, in terms of their response to CO2 levels. Complex interactions of other factors such as levels of water availability and responses to ozone at ground level complicate the relationship.

4. **Climate change could increase the number of people at risk of hunger by up to 600 million by 2080, and particularly in Africa** (Warren 2006). It should be noted that the number of people at risk of hunger bears a large relation to levels of economic growth in the modeling studies, so most future worlds show fewer people at risk of hunger compared to today despite climate change.

5. **Temperature increases could be beneficial for cereal crop yields in temperate regions for moderate warming (2-3°C).** In tropical regions temperature increases are likely to have negative effects because crops are already near to their threshold temperatures. Above 3 °C warming, negative impacts of temperature could occur in most areas (Stern 2006).

6. **Extreme events such as floods and droughts are likely to become much more severe and frequent over the next century under all scenarios and for most land areas.** The most recent IPCC projections for example indicate over a 90% probability that the frequency of warm spells and heat waves and heavy precipitation events could increase in most land areas. Whilst the exact changes in different scenarios and their relationship to impacts on crops are hard to predict, the general trend indicates that areas where agriculture is already at risk from such events, might be more severely impacted in future worlds with climate change.

Figure 6.2: Potential changes (%) in national cereal yields for the 2020s, 2050s and 2080s (compared with 1990) under the HadCM3 SRES A1FI with (left) and without beneficial CO2 (right) effects.



Note this figure is for only one scenario and one model. Source: Parry 2004.

7. **All climate change models project that the hydrological cycle could intensify with increased warming.** This is likely to lead to increased frequency and severity of droughts and heavy precipitation events. However, projections in precipitation can be very uncertain. There are much higher levels of certainty in projections of changes in seasonal levels of stream flow in areas dependent on snow pack melting for water resources. This implies that policy responses focusing on climate-related water resource issues in these areas (e.g. large scale water storage) might have more guaranteed success than responses in areas not dependent on snow melt.

8. **One of the most certain things about climate change and agriculture is that there are large uncertainties in current projections.** This report has highlighted the various uncertainties involved in projecting the possible impacts of climate change on agriculture. These result from uncertainties in the science of climate change itself, of crop responses to climate, complex socio-economic relationships and a lack of detail in current models. In policy terms, this raises the question of how our knowledge likely to improve over time. **Error! Reference source not found.** illustrates this with the example of how rainfall prediction in Africa is likely to improve in the next fifteen years. It indicates that projections will improve but that we will still be unlikely to know some information about climate change at scales that are crucial for agriculture. If this is the case, it raises an issue for policymakers in how to proceed and might imply a need for more ‘flexible’ policy approaches to cope with increased uncertainty about possible futures.

Table 6.1: The extent of knowledge about rainfall in Africa now and in the future.

What we know
1. Historical patterns of rainfall 2. Causes of rainfall variability 3. Rainfall prediction at seasonal timescales 4. Use of oceanic state to predict seasonal rainfall in many areas
What we do not know
1. Onset time of seasonal rainfall 2. Dry spells within seasons 3. Decadal and multi-decadal rainfall patterns 4. Climate information at scale of less than 100km 5. Sahelian climate
What we still will not know in fifteen years time
1. Large-scale climate models are unlikely to be able to produce information on the impacts of climate change at scales of less than 50km. 2. Little useful information on decadal and multi-decadal prediction of rainfall 3. Few insights into Sahelian rainfall patterns that are useful for agricultural adaptation

Source: Adapted from Washington 2007

This is one of the issues discussed in the next output in this series of studies for the DFID RNRA team, which considers DFID's agricultural policy in the context of what we currently know about climate change and agriculture.

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