

Defra

Climate Change Impacts & Adaptations Research Programme (CC03)

Project Summaries Report

1987 - 2002

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Introduction

In addition to developments in social, technological and agricultural policy in the coming decades, UK agriculture will face the challenge of climate change. Agricultural businesses will need to adapt to the effects of changing climatic conditions to ensure economic viability, while at the same time continue to improve sustainable practices to reduce agriculture's impact on the environment.

The purpose of this report, compiled by the Institute of Water & Environment (Cranfield University), is to raise awareness of research, commissioned by Defra and previously MAFF, under the *Climate Change Impacts and Adaptations* research programme (CC03) which deals with the potential issues relating to agriculture. This report provides summaries of findings from this research in order to enable policy development and improve knowledge transfer in this area.

Background information on the causes and potential effects of climate change is presented below, including a brief synopsis of how observed and predicted changes to future climate may affect UK agriculture and the environment. These predicted changes, and the need to successfully adapt and exploit opportunities, are the main drivers behind the CC03 programme, the principal policy objective being to provide the scientific basis for the establishment of UK agriculture policy on climate change by:

- Assessing the possible scale and rate of impact of climate change on agriculture and water resources;
- Identifying options for response measures;
- Helping evaluate the economic and trade implications for the agriculture industry of changes in food production potential and food security issues;
- Communicating these findings to industry.

Research projects are presented in reverse chronological order, i.e. the most recently commissioned research is presented first. For each project, the report lists the project code and title, cost information, project duration, a summary of the research aims, and where available, a summary of the key findings. Most of the research funded under the CC03 programme has addressed climate change in the context of England and Wales. However, results and findings may be valid for the UK as a whole. It is envisaged that this report will be updated on an annual basis.

For further details on any of these research projects, including requests for final reports, please contact:

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Climate Change – Causes, effects and the CC03 programme

Background

The Earth would be about 30°C cooler if the planet was not surrounded by an atmosphere containing gases such as water vapour, **carbon dioxide (CO₂)** and **methane (CH₄)** that trap solar energy. If the atmospheric concentration of heat-trapping gases rises, less heat can escape back into space, and the natural **greenhouse gas (GHG)** effect is enhanced, warming the climate of the Earth.

Climate refers to the average weather experienced in a region over a long period, typically 30 years. The climate of the Earth is not static, and has changed many times in the past in response to a variety of natural causes. The term "climate change" usually refers to recent changes in climate that have been observed since the early 1900's.

Climate change is one of the most pressing and complex environmental issues that face us today. Recent reports from the **Intergovernmental Panel on Climate Change (IPCC)** suggest that the problem may be worse than previously feared.

Since Kyoto in 1997, the UK has been pressing ahead and introducing innovative policies which will have a significant impact on reducing greenhouse gas emissions. The UK Government also recognises the need to adapt to some degree of climate change, however successful it is at cutting emissions of greenhouse gases. The Government and devolved administrations are taking a lead in preparing to adapt to climate change, and these steps are outlined in the UK Climate Change Programme [<http://defraweb/environment/climatechange/cm4913/index.htm>]. Further information relating to action to tackle climate change can be found on the Defra website: [<http://defraweb/environment/climatechange/index.htm>].

Is the global climate changing?

Analysis of Antarctic ice cores indicates that the concentration of CO₂ in the atmosphere started to increase in about 1800, and that of CH₄ around 1700. Atmospheric levels of these and other gases such as nitrous oxide (N₂O) and fluorine-containing gases, have grown rapidly since the 1960s, arising mainly from human activities:

- CO₂ : from the burning of coal, oil and gas for heating and energy generation;
- CH₄ : released from organic waste buried in landfill sites, from ruminating animals such as cows, and from the incomplete combustion of fuels;
- N₂O : arises mainly from the use of nitrogen-based fertilisers, but also from crop residue incorporation, biological **nitrogen (N)** fixation and the cultivation of organic soils;
- fluorine-containing gases : used since the 1930s, mainly as refrigerants and insulators.

The Earth's climate has been relatively stable since the end of the last ice age (about 10,000 years ago), but it is now changing. Records show that global average surface air temperature (compiled from millions of individual thermometer measurements taken around the world dating back to 1860) has risen by about 0.6°C since the beginning of the 20th century, with about 0.4°C of this warming occurring since the 1970s (Figure 1). 1998 was the warmest year on record, and 2001 was the third warmest. The 1990s were the warmest decade in the last 100 years, and it is likely that the last 100 years represented the warmest century in the last millennium.

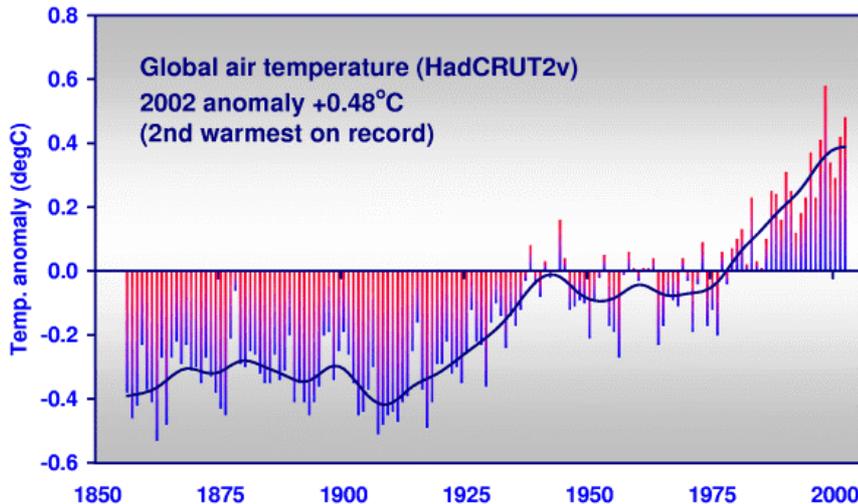


Figure 1: Observed increase in global-average surface air temperature anomalies (relative to 1961-1990 average). From Hulme, Turnpenny, Jenkins, (2002).

Analysis of UK climate data has revealed many changes that may be affecting agriculture and the environment, including:

- the thermal growing season for plants in central England has lengthened by about one month since 1900;
- heatwaves have become more frequent, while there are now fewer frosts and winter cold spells;
- winters over the last 200 years have become much wetter relative to summers throughout the UK;
- a larger proportion of winter precipitation in all regions now falls on heavy rainfall days than was the case 50 years ago;
- after adjusting for natural land movements, average sea level around the UK is now about 10cm higher than it was in 1900.

In its most recent report the IPCC stated: '*most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations.*'

Future UK Climate

The latest climate change scenarios, referred to as the UKCIP02 scenarios, were commissioned and funded by Defra for UKCIP, and developed by the Tyndall Centre for Climate Change Research at the University of East Anglia, and the Hadley Centre for Climate Prediction and Research at the Met Office. A summary of the key findings of the UKCIP02 scenarios are given below, all of which are relevant to agriculture and environment.

Temperature

- The UK climate will become warmer;
- High summer temperatures will become more frequent, whilst very cold winters will become increasingly rare.

Precipitation (rain and snow)

- Winters will become wetter and summers may become drier throughout the UK;
- Snowfall amounts will decrease throughout the UK.;
- Heavy winter precipitation will become more frequent.

Sea Level Changes

- Relative sea level will continue to rise around most of the UK's shoreline;
- Extreme sea levels will be experienced more frequently.

Scientific Objectives of the CC03 programme

In assessing the likely consequences of the observed and predicted changes in climate to agriculture in England and Wales, and assisting the industry to respond, the CC03 programme aims to:

1. To provide estimates at a national level of the likely scale, extent and rate of impact on soils, crops, water resources, farm animals, pests, weeds and diseases due to climate change.
2. To institute programmes to provide indications of the impact of climate change and to develop databases in which to record this information.
3. To initiate preparation of alternative agriculture options and other response measures, including alternative crops, cultivation methods and pest, weed and disease controls.

The CC03 programme aims to increase the understanding and awareness within agriculture of climate change impacts and adaptations and to ensure the industry is well placed to respond to the threats and opportunities that climate change poses. Promotion and dissemination of best practices to the agricultural community is an crucial component. Means for knowledge transfer include:

- Scientific papers, articles in farming press;
- Leaflets;
- Conferences;
- Demonstration farms; and
- Information transfer as a part of all Defra R&D projects.

Source

Hulme, M., Turnpenny, J., Jenkins, G., (2002). *Climate Change Scenarios for the United Kingdom: The UKCIP02 Briefing Report*. Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich, UK. 14pp

More information

Defra – Department for Environment, Food and Rural Affairs: www.defra.gov.uk

IPCC – Intergovernmental Panel on Climate Change: www.ipcc.ch

UK Climate Change Impacts Programme: www.ukcip.org.uk

The Hadley Centre (Met Office): www.metoffice.gov.uk/research/hadleycentre/index.html

Climate Research Unit, University of East Anglia: www.cru.uea.ac.uk

Environment Agency: www.environment-agency.gov.uk

Research commissioned in 2002

CC0378 Scoping Study Of Potential Impacts Of Climate Change On Nutrient Pollution (Of Water) From Agriculture

Duration:	01/04/02 - 30/09/03	Total Defra cost:	£66k
Contractors:	ADAS Consulting Ltd	Total project cost:	£66k

Description

This study brought together two strands of Defra-funded research relating to climate change and agricultural nutrient pollution. Approaches and modelling tools used to estimate diffuse pollution from agricultural land under current climate conditions were extended to explore the impact of future climate change on nutrient and sediment flux to water bodies.

Findings

Interim results have provided an initial indication of the responsiveness of elements associated with a changed climate. Nitrate losses are typically chronic during the drainage period; P losses are more acute, often associated with storm events with a low return period. Using the most suitable models, predictions were made of the relative importance of nitrogen and phosphorus loss in the future at the field and catchment-scale. Implications to the farming industry were placed in the context of Defra's policies on sustainability of rural environments.

Research commissioned in 2001

CC0374 Science Writer For RegIS Report

Duration:	01/06/01 - 30/09/01	Total Defra cost:	£3k
Contractors:	Mr Fred Pearce	Total project cost:	£3k

Description

The services of a commercial science writer, Mr Fred Pearce, were employed to assist in the dissemination of the outputs from MAFF research project CC0337 'RegIS'.

CC0373 Dissemination Of RegIS Report

Duration:	01/06/01 - 31/08/01	Total Defra cost:	£9k
Contractors:	Soil Survey and Land Research Centre	Total project cost:	£9k

Description

Funding was awarded to assist in the dissemination of outputs from the MAFF research project CC0337 'RegIS' via production of a leaflet, a summary report and presentations at a UKCIP technical workshop.

CC0365 Knowledge Transfer Initiative On Impacts And Adaptation To Climate Change In Agriculture

Duration:	01/04/01 - 31/03/02	Total Defra cost:	£39k
Contractors:	IGER	Total project cost:	£39k

Description

Greater discussion was sought by Defra about the current understanding of climate change within the agricultural industry and to raise awareness of potential problems so that the industry could plan for and respond to its effects. Liaison and dissemination were enacted via a forum with key representatives from the industry and a workshop on climate change research to increase understanding in the wider agricultural community.

Findings

The industry was confident that the major effects of climate change were manageable. However, information on climate change was not reaching the farmer or messages were vague. Information needed to be presented in a farmer-friendly format and more public debate was needed within a farming context. Information was lacking on planning to deal with extreme climatic events, on growing new crops, on the impacts of climate change and future management on biodiversity, its implications for ESA targets and the socio-economic effects of marginal agriculture under climate change. Awareness-raising was needed and should be peer-led, e.g. through on-farm meetings, Demonstration Farms, working day initiatives and on-farm advisors. Climate change impacts required evaluation within the context of different agricultural futures. More research was called for on mitigating agricultural contributions to climate change and its impacts (e.g. C-sequestration, better catchment management to reduce

run-off), for greenhouse gas audits of farming systems, soil conservation, new pest and disease risks, livestock breeding and forage suitability/adaptations. Planning for water conservation (especially with respect to crop irrigation) and change in the uplands were seen as key issues.

CC0372 The Wet Autumn Of 2000: Implications For Agriculture

Duration:	01/01/01 - 31/12/01	Total Defra cost:	£49k
Contractors:	ADAS Consulting Ltd	Total project cost:	£49k

Description

Climate change models predict wetter, milder autumns and winters for the UK. The wet autumn of 2000 affected most sectors of the farming industry in England and Wales. It provided an opportunity to study the real effects of extreme weather on farm crop and livestock production and profitability and implications for the environment. The report formed a companion to the report on the Hot Dry Summer of 1995 (CC0322, CC0325).

Findings

Financial effects were attributed to one of three causes: difficulties with harvesting (2000); increased establishment costs (2000); and reduced yield and/or output (harvest 2001). Potatoes and sugar beet were the worst affected root crops. Problems were offset in part by modern harvest machine technology. There were increased crop drying costs, increased feed and bedding costs, and reduced lamb production. Indirect effects included damage to soil structure, and increased soil erosion, phosphorus losses, nitrate leaching, nitrous oxide (N₂O) emissions and pesticide mobility. Many crops experienced sulphur deficiency in the following spring. It was difficult to quantify the overall impact because of favourable growing conditions in 2001 and a greater, compensatory area of spring crops was planted. Effects on livestock production were overwhelmed by the subsequent Foot and Mouth Disease crisis.

Research commissioned in 2000

CC0370 Maintaining UK Wheat Performance Through Improved Exploitation Of Drought-Resistance Traits

Duration:	01/11/00 - 31/01/02	Total MAFF cost:	£41k
Contractors:	ADAS Consulting Ltd, John Innes Centre, Nottingham University	Total project cost:	£41k

Description

This project built upon MAFF-funded project OC9602 in which the genetic control of drought-resistance traits was analysed using two double haploid (DH) populations derived from Rialto x Spark and Beaver x Soissons crosses. The main objective was to confirm, with field experiments, the drought resistance traits indicated in the earlier study.

Findings

An order of priority for drought resistance trait selection was found for breeders: flag leaf senescence or 'stay green' (most important), followed by stem reserves and flowering date. Stem carbohydrate reserves proved to be a poor indicator of drought resistance (contradicting results from project OC9602). Early flowering did not confer greater drought resistance and flowering date in general had neutral drought resistance. Genetic analysis of flag leaf persistence on the Beaver x Soissons population identified markers associated with flag leaf green area persistence on group 2 chromosomes. New major quantitative trait loci were found on chromosomes for soluble carbohydrates and grain yield using the Rialto x Sparks DH lines, providing novel sources of drought resistance for breeders to exploit.

CC0369 Reprint of ADAS Hot Summer of 1995 Booklet

Duration:	01/09/00 - 01/10/00	Total MAFF cost:	£2k
Contractors:	ADAS Consulting Ltd	Total project cost:	£2k

Description

This funding supported the re-printing and distribution of the ADAS publication '*A review of the direct effects of the hot, dry summer of 1995 on the main agricultural and horticultural enterprises in England and Wales*' (CC0325, CC0322).

CC0360 The Value Of Case-Studies In Determining The Impact Of Climate Change And Extreme Events On Agriculture In England and Wales

Duration:	01/07/00 - 22/03/02	Total MAFF cost:	£75k
Contractors:	ADAS Consulting Ltd	Total project cost:	£75k

Description

This project aimed to validate predictions of the impacts of future extreme events on the agricultural sector by comparison with past events. The effects of extreme events on selected

crops and livestock production were measured through the use of existing data and impact models, combined with expert evidence to highlight the most vulnerable agricultural sectors and commodities. Recommendations were made on crop/climate data requirements.

CC0357 Identifying And Costing Agricultural Adaptive Responses Under Climate Change Scenarios (ICARUS) (CTE9909)

Duration:	15/05/00 - 26/01/02	Total MAFF cost:	£50k
Contractors:	ADAS Consulting Ltd	Total project cost:	£50k

Description

This study investigated the economic impacts of climate change on agriculture in England and Wales, and potential adaptive strategies on key commodities (wheat, potatoes, cauliflowers, grass for dairy enterprises, greenhouse tomatoes and indoor and outdoor pig production) were gathered from research and expert consultation. The leading adaptive responses were further researched to determine their applicability, effect and the timescale of introduction.

Findings

Grower-based adaptations to counteract climate change impacts were dominant. Accurate climate change forecasting was seen as crucial to growers to secure the uptake of adaptations, requiring information transfer from the government. Many mitigating measures could be adopted in parallel with changes in other aspects of the industry. Investment in wheat breeding provided the highest net benefit. Shifts in future cropping areas would only be viable if the savings made through non-renewal of equipment in current production areas were balanced against potential moving costs. Changes in cropping distribution would also change transport costs for the processing industry. There were some unviable adaptations such as the storage and handling of pig slurry which will require government assistance. Both economic and policy conditions were therefore crucial to future adaptation.

CC0359 Influence Of Climate Change On The Sustainability Of Grassland Systems In England And Wales (CTE9907)

Duration:	01/04/00 - 31/03/03	Total MAFF cost:	£215k
Contractors:	IGER	Total project cost:	£215k

Description

This project studied the interactions between enhanced atmospheric CO₂ levels and temperature on herbage yields and forage quality for mixed species grassland swards covering lowland (dairy and beef) and upland (sheep) sites using experimentation in solar domes and refinement of a pre-existing model, LEGSIL. The possible consequences of climate change were assessed relative to the viability of livestock farming in the different grassland areas and the industries supplying inputs. Research findings were disseminated through a special Forum meeting, a technical report and a practical booklet for farmers.

Findings

The longer-term nature of climate change was seen as a background risk to which the industry could provide mitigation solutions through changes in land management, carbon sequestration and the cultivation of energy crops. Greenhouse gas audits were seen as a means of making

environmental impact assessments. Climate change could bring new opportunities including alternative crops and forages, extended ranges, a longer growing season and opportunities for carbon-trading. Flooding was seen as a serious threat to low-lying areas. Pests and diseases could change rapidly in response to climate change. There was a lack of information on how organic practices could be affected.

CC0358 Investigation Of Thresholds Of Impact Of Climate Change On Agriculture In England And Wales (CTE9908)

Duration:	01/04/00 - 31/03/01	Total MAFF cost:	£70k
Contractors:	University of East Anglia	Total project cost:	£70k

Description

This project integrated two approaches to modelling climate change effects on agriculture in England and Wales: top-down (likely effects of imposed climate change scenarios) and inverse (sensitivity analysis of various elements). Key thresholds of climate change impacts (environmental and economic) that affected the viability of major agricultural sectors were identified. Cereals, grasses and associated livestock systems, root crops, horticulture, pests and diseases, farm-level decisions, and economic margins and land-use allocations were considered. Points of critical sensitivity within or between vulnerable sectors, as well as key interactions with other sectors (e.g. water), were examined.

Findings

The project offered a new approach to assess the impacts of climate change on the economics of crop production and future crop viability in England and Wales. Relatively high global mean temperature changes of 3-5°C were required for crop yields to exceed critical thresholds. Emissions reductions of more than 20% by Annex 1 countries were required to delay most threshold exceedances by more than a decade. Response thresholds (i.e. those likely to significantly affect economic profitability) were estimated for four crops (winter wheat, sugar beet and barley) under four different economic futures (defined by IPCC's SRES scenarios), assuming a lower economic margin.

Research commissioned in 1999

CC0339 Effects Of Climate Change On Agricultural Land Use In England And Wales

Duration:	07/12/99 - 30/11/00	Total MAFF cost:	£71k
Contractors:	University of East Anglia	Total project cost:	£71k

Description

Likely land use responses to climate change are less well established than overall effects on agricultural potential. Previous work (MAFF project CC0320) developed a method for analysing national-scale land use changes resulting from climate change and related changes in global yields and demand. This funding supported methodological developments to CLUAM (Climate Land Use Allocation Model) and full descriptions of the CLUAM and Basic Linked System (BLS) models for non-expert audiences.

Findings

CLUAM captured most of the historical levels of change at the national and regional scale, although regional scale trends were less adequately modelled for areas where the land-cover type under scrutiny was less extensive. The representation of system inertia was only partially successful, as it was more useful at a regional, rather than national, level. CLUAM predicted that with future climate change the growing season would remain too short for sunflower production. Accumulated temperature however, would no longer be the most important variable for maize production in the future. Assumptions underpinning CLUAM were discussed and future policy considerations were outlined. A sensitivity analysis of the BLS model of world food trade was performed.

Research commissioned in 1998

CC0337 Regional Climate Change And Impact Response Studies In East Anglia And North-West England (RegIS)

Duration:	01/11/98 - 31/01/01	Total MAFF cost:	£150k
Contractors:	Soil Survey and Land Research Centre	Total project cost:	£299k

Description

RegIS developed a methodology for stakeholder-led, regional integrated assessment (IA) that explicitly evaluated local and regional scale impacts and adaptation options, and cross-sectoral interactions between the major sectors driving landscape change (agriculture, biodiversity, coastal zones and water resources). Socio-economic and climate change scenarios were linked to explore alternative futures in the two regions. RegIS was co-funded by the UK Water Industries Research under the United Kingdom Climate Impacts Programme.

Findings

RegIS showed that climate change, without adaptation, could lead to severe flood impacts in East Anglia, and significant agricultural abandonment. Despite yield changes, cropping is generally insensitive to climate, but very sensitive to socio-economic change. There is increased seasonality to river flows, compounded by increased urbanisation and irrigation demand. The East Anglian climate space of *Epipactis palustris* and *Valeriana dioica* contract, but *Plejebus argus* and *Silene otites* find climate space in the North West. Fundamental methodological issues for future IA studies were identified. The authors recommended that multi-sectoral, regional-scale scenario construction methodologies should be advanced. In addition, integrated approaches should be encouraged as a means of assisting the policy-formulating process.

CC0336 Assessing Drought Risks For UK Crops Under Climate Change

Duration:	01/10/1998 - 30/09/2002	Total MAFF cost:	£287k
Contractors:	IACR, Rothamsted	Total project cost:	£287k

Description

Climate change could affect crop production through increased drought (MAFF project CC0302). This project assessed how increased drought frequency, duration and severity could reduce crop yields in two key UK crops (winter wheat, sugar beet) on different soil types and in different regions of the UK. Changing agronomic practices, industry practices and crop (genotype) characteristics were evaluated to reduce risk and maintain crop productivity.

Findings

Drought stress was predicted to increase affecting yield for both crops, with those on shallow or sandy soils at greatest risk. Yield reductions were offset by improved radiation use efficiency due to rising CO₂ where crops were grown on suitable soils, securing production in established areas. These yield increases occurred regardless of improvements in varieties. Mean yields would rise for sugar beet and winter wheat (with further increases if new wheat varieties stayed green for longer). Earlier anthesis did not mitigate drought-related losses. Delayed sowing date

strongly affected achievable sugar yields. Delaying harvest of sugar beet would only compensate for some of the greater drought-related loss on sandy soils.

CC0338 Irrigation Monitoring With Synthetic Aperture Radar (SAR) Data

Duration:	01/07/1998 - 30/09/2000	Total MAFF cost:	£5k
Contractors:	University College London, Department of Geography	Total project cost:	£5k

Description

The potato (*Solanum tuberosum* L.) relies on temperature and soil water status to induce each developmental stage. Climate change could increase pressures on water resources in potato growing regions such as East Anglia. Crop moisture levels were modelled using cloud penetrating Synthetic Aperture Radar (SAR) data from the ERS-2 satellite. The model was calibrated and validated using *in-situ* measurements in the Fens. This project formed the basis for a NERC/CASE PhD studentship.

Findings

The CHIPS model (Controlled Hydrology and Irrigation Practice with SAR) was constructed and linked to a crop growth model to account for changing seasonal plant water demand and stress. A decrease in summer rainfall would cause a large soil moisture deficit to develop which would damage the crop if additional water was not provided. Further monitoring and modelling studies would enable targeting of water resources for agricultural irrigation by farmers, UK government and enforcement agencies as demand increases in the future.

CC0333 The Timescale Of Potential Farm Level Responses And Adaptations To Climate Change In England And Wales

Duration:	05/01/1998 - 05/01/2001	Total MAFF cost:	£178k
Contractors:	ADAS Consulting Ltd, Sutton Bonington, University of Nottingham	Total project cost:	£178k

Description

Farm enterprise profitability could be affected greatly by climate change. This project accounted for the economics of different farm enterprises, risk aversion and psychology involved in investment decisions. Climate change scenarios were translated through impacts on crop yields and farm activity models into measures of farm scale profitability for all the major arable and the most climatically-sensitive horticultural crops and livestock enterprises in England and Wales. The project indicated financial, technical and psychological obstacles to adaptations by farmers, their suppliers and customers.

Findings

The incentive to adapt was always positive (relative to not adapting). Changes brought about purely through changing economic conditions would probably outweigh the impact of forecasted climate change by 2050. Farm profitability generally increased. Effective use of limited amounts of labour and machinery would become increasingly important as climate seasonality increased and available autumn work days decreased. The grass growing season

would commence earlier increasing overall yields. Benefits would be offset by summer droughtiness and forage shortages so forage maize becomes important for dairy farms. Farm irrigation demand increases. Policy recommendations included: making information on climate change readily available to farmers and the industry; revision of policies to encourage diversification of income; introducing policies to aid adaptation to climate change on livestock farms; demonstration farms for new crops and techniques; better water resources planning; and information on 'best practice' techniques for soil conservation in a shortened cultivation window.

Research commissioned in 1997

OC9602 Maintaining Wheat Performance Through Improved Resistance To Drought

Duration:	01/09/1997 - 31/12/2000	Total Defra cost:	£294k
Contractors:	University of Nottingham ADAS Consulting Ltd John Innes Centre	Total project cost:	£294k

Description

In the drier areas of England up to 20% of wheat yield is lost due to drought conditions. Climate change may lead to more frequent droughts in the principal wheat-growing areas. The development and exploitation of drought resistant varieties could reduce yield impacts and encourage better water use efficiency. This project attempted to identify the genes responsible for conferring drought resistance traits. The effects of three major genetic introductions were studied (Rht2 semi-dwarf gene, the 1BL/1RS translocation and the Ppd-D1 gene).

Findings

The Ppd-D1 gene offered only marginal advantage for drought resistance but could provide a physiological mechanism for breeders to maintain current rates of yield improvement with the added benefit of water conservation. The Rht2 gene had neutral effects on drought resistance in the experiments but decreased the water use efficiency of the crop. The 1BL/1RS translocation may have inadvertently increased the wheat crop water demand under optimal growing conditions. The mapping populations (Rialto x Spark, Beaver x Soissons) showed no significant differences between irrigated and non-irrigated conditions. Molecular markers were located on key chromosomes explaining plant height, flag leaf green area persistence, flowering times and senescence. Knowledge transfer to plant breeders from this project could help them select drought resistance more effectively.

CC0329 To Investigate The Likely Impact On Vegetable Crop Development Of Changes In Temperature And CO₂ Associated With Global Warming

Duration:	01/04/1997 - 31/03/1998	Total MAFF cost:	£27k
Contractors:	HRI	Total project cost:	£27k

Description

This study aimed to improve the understanding of, and to model, yield responses of vegetable crops (represented by French beans) to enhanced atmospheric CO₂ and increases in temperature. Adaptive agronomic and economic strategies could be developed for UK crop production in response to climatically-driven environmental changes.

Findings

The effects on crop timing (earlier flowering and maturity) and yield in French bean plants were predominantly due to temperature. Elevated CO₂ concentrations had no effect on crop timing and only a small effect on the yield of mature beans. French bean production could expand in the UK with crops being grown further north. Temperature and moisture were identified as the major causal determinants of crop changes. The authors saw no further justification for 2xCO₂

manipulation experiments, and recommended new research to look at the combined effects of temperature and moisture stress on key plant processes .

CC0328 To Investigate The Likely Impact On Crop Development Of Changes In Temperature And Water Associated With Global Warming

Duration:	01/04/1997 - 31/03/1998	Total MAFF cost:	£77k
Contractors:	HRI	Total project cost:	£77k

Description

This study investigated the effects of soil moisture regimes ('wet' and 'dry') and temperature gradient on growth, development and agronomic characteristics of winter barley, edible brassicas, potatoes and peas in polyethylene tunnels.

Findings

Yields of potatoes, peas and barley were found to increase in the higher temperatures with a variable response to water availability. Pea crop yields increased in the 'wet' tunnel at higher temperatures. Barley flowering, ear development and grain ripening were advanced by higher temperatures in the 'dry' tunnel, but yields were higher in the 'wet' tunnel. Cauliflower curd initiation was delayed significantly at elevated temperatures, potato yields decreased when conditions were hot and dry, pea crop yield declined when temperatures exceeded 4°C above ambient and barley crops 'lodged' at the highest temperatures. A northerly migration of these crops was envisaged under climate change. Horticultural crops in the south demanded increased irrigation. The authors recommended a second, four-year rotation of these major crops. MAFF granted this project extension.

CC0340-CC0355 Climate Change Booklet

Duration:	01/02/1997 - 30/06/1998	Total MAFF cost:	£72k
Contractors:	University of Oxford, Environmental Change Unit	Total project cost:	£72k

Description

MAFF commissioned a booklet to summarise the key findings from its climate change impacts research programme. Contributions from many researchers were sought through projects CC0340-0355. The booklet describes the background to global climate change and its impacts on soils, crops, grassland and livestock, pests and diseases, farm management and water conservation. This was distributed to a wide readership to help raise awareness of climate change and its associated problems, particularly its effects on UK agriculture.

Research commissioned in 1996

CC0326 Effects Of Ultra Violet B Radiation On Crop Disease (*Septoria* Leaf Blotch)

Duration:	01/12/1996 - 30/11/1997	Total MAFF cost:	£50k
Contractors:	Lancaster University, Division of Biological Sciences	Total project cost:	£50k

Description

Previous research demonstrated that the effects of increased UV-B radiation on plants were small. The effects on pests and pathogens however, had not been researched in detail. Growth experiments explored the effects of UV-B increases (equivalent to moderate ozone depletion) on the incidence and severity of leaf blotch on winter wheat cv. Riband caused by the fungal pathogen *Septoria tritici* and the consequences for crop development and yield.

Findings

Increased UV-B resulted in slight changes in the structure of the crop canopy but there was no measurable change in agricultural yield. Increased UV-B significantly reduced the severity of leaf blotch infection on several occasions but these effects were inconsistent. When UV-B could be demonstrated to affect *S. tritici* infection, changes in the disease were too small and/or insignificant in duration to alter the physiology of the crop or to affect crop yield, and to not require changes to normal agronomic practices. Future research should be directed at other crop diseases under a wide variety of conditions.

CC0325 Publication Of The Review Of The Direct Effects Of The Dry Hot Summer Of 1995 On Decision Making Of The Individual Farmer

Duration:	01/09/1996 - 15/11/1996	Total MAFF cost:	£8k
Contractors:	ADAS Consulting Ltd	Total project cost:	£8k

Description

The final report of CC0322 (funded 1995) was edited into a suitable format for wider distribution entitled '*A review of the direct effects of the hot, dry summer of 1995 on the main agricultural and horticultural enterprises in England and Wales*' (ADAS). The aim of this publication was to stimulate debate on both the husbandry and structural changes that could be expected if these climate conditions were to occur more frequently in the future.

CC0324 Upgrading SPECTRE To Be Consistent With IPCC 1996

Duration:	01/07/1996 - 31/10/1996	Total MAFF cost:	£8k
Contractors:	University of East Anglia	Total project cost:	£14k

Description

SPECTRE (Spatial and Point Estimates of Climate change due to TRansient Emissions) is a user-friendly software package originally developed under contract to MAFF (projects OC9009, OC9303). This contract was issued to upgrade SPECTRE to ensure that its scenario

generation was in keeping with the latest climate science and climate change modelling results. SPECTRE 2 was automatically sent to all users of Version 1. All MAFF contractors were entitled to a free copy of the software and Manual.

Findings

Specific upgrades made to SPECTRE Version 2 were broadly consistent with the 1996 IPCC report. The User Manual was updated with the revised changes. Further upgrade priorities were suggested given further developments in climate change science during 1997 and 1998 and a move to a Windows compatible application was suggested.

CC0323 Insects and Climate Change (extension CC0304)

Duration:	01/04/1996 - 30/09/1996	Total MAFF cost:	£15k
Contractors:	IACR	Total project cost:	£15k

Description

Project CC0304 examined the effects of elevated CO₂ on interactions between aphids and their host plants, and suggested that interactions with aphids natural enemies may also be affected. This study examined the influence of elevated CO₂ on the effectiveness of parasite and fungal diseases affecting aphids. It formed the basis of a PhD studentship. Experiments were performed on the grain aphid *Sitobion avenae* on winter wheat and *Aulacorthum solani* on broad bean and tansy in 2x CO₂ concentrations. Further research was undertaken on the effects on aphid feeding and reproduction and their associated fungal parasitoids *Erynia neoaphidis* and *Aphidius ervi*.

Findings

Aphids feeding at elevated CO₂ concentrations all exhibited higher reproductive rates. Aphid growth rates were not affected by initial exposure to elevated CO₂ but after 4 months there were significant CO₂ effects on growth rates for aphids on wheat and tansy. Parasitoids developed more quickly and aphids were more susceptible to parasitism at elevated CO₂ concentrations. Introducing fungal pathogens at elevated CO₂ concentrations therefore offered more effective aphid control than at ambient CO₂.

Research commissioned in 1995

CC0322 Review Of The Direct Effects Of The Dry Hot Summer Of 1995 On Decision Making Of The Individual Farmer

Duration:	31/12/1995 - 31/03/1996	Total MAFF cost:	£18k
Contractors:	ADAS Consulting Ltd	Total project cost:	£18k

Description

Under future climate change scenarios, summers such as the unusually hot and dry summer of 1995 could be expected to occur more frequently in the UK. This project reviewed the effects of the 1995 summer on crop yields, livestock production and the costs of production to identify which sectors benefit under these conditions and those where profitability would be reduced.

Findings

The financial impact in England and Wales was an estimated net income reduction of £300 million. Only cereals, protected tomatoes and cucumbers benefited from the weather conditions. Other crops - potatoes and sugar beet - suffered more both in terms of yield and quality. Overall disease levels were lower but drought-enhanced diseases increased. Pesticides were less effective and insect populations flourished. Poor herbicide performance led to severe competition from weeds. All livestock sectors experienced increased costs and/or reduced returns. Forage supply and quality was compromised. Feed supplements were required to buffer reduced milk and meat yields. Dairy cow and pig fertility declined and egg production decreased. Ruminant parasite numbers were reduced but their seasonality changed unexpectedly. Farm-level responses included adjusting the numbers of stock and reducing heat in poultry production houses. More farmers could invest in technology (e.g. trickle irrigation) or change the seasonality of sowing to early maturing cultivars which would be less drought-susceptible. One perceived danger was that crop buyers could destabilise local markets by turning to other regions or to imports to guarantee continuity of supply.

Research commissioned in 1994

CC0320 Economic Implications Of Global Climate Change On Agriculture In England And Wales

Duration:	01/11/1994 - 31/10/1997	Total MAFF cost:	£162k
Contractors:	UCL, Department of Geography	Total project cost:	£162k

Description

The economic implications of potential long term changes in global climate on agricultural land use in England and Wales were modelled through effects on the world food system. The study linked a global model of the world food trade (Basic Linked System) to a UK model of agricultural land use allocation (Climate-Land Use Allocation Model) to provide combined projections of changes in agricultural land use in England and Wales as affected by world prices.

Findings

Agricultural land potential was more receptive to global developments than to possible changes in climate. Upland land use remained fairly constant but lowland agriculture changed considerably. Changing climate, yield and decreasing demand for livestock products saw shifts in the location and area of grass leys, cereals and other arable crops away from traditional 'heartland' areas. The area of lowland rough grazing did not alter but lowland permanent pasture was no longer used for production. A large area of land became suitable for maize production. Sunflowers were viable but only in restricted areas. Future agricultural policy reform may seek to maintain traditional land uses to meet environmental objectives.

CC0315 Impact Of Climate Change On Grassland & Livestock Systems

Duration:	01/07/1994 - 30/06/1997	Total MAFF cost:	£178k
Contractors:	ADAS Consulting Ltd BBSRC Silsoe Research Institute	Total project cost:	£178k

Description

Climate change is likely to affect the sustainability of different livestock enterprises with consequences for regional patterns of land use. A set of integrated models known as ECCLIPS (Effect of Climate Change on Livestock Production Systems) were developed for dairy cow, beef calf, sheep, growing pig and broiler chicken enterprises. The models were applied across a range of geographical and climatological scenarios to predict the performance of livestock enterprises in the future. Consequences for management (including building design), operations, the relative uses of grassland, other forage crops and concentrated ruminant feeds, and profitability were examined.

Findings

There was no evidence of changes in the relative suitability of areas for the livestock enterprises. Assuming no change in the relative prices of inputs and outputs, a small but positive increase in profitability was likely for all grass-based enterprises. Heat stress was likely to become a serious risk for housed intensive livestock, unless ventilation and cooling systems

are improved. Ruminants at grass or in naturally-ventilated buildings should be able to adapt. Modest increases in grass production could occur, permitting increased stocking rates. Further research was needed to model the effect of sward-animal interactions on grass production, and to improve the understanding of interactions between nutrition and metabolic heat production and dissipation.

CC0317 Responses Of Arable And Grassland Weeds To Climate Change

Duration:	01/05/1994 - 30/04/1997	Total MAFF cost:	£186k
Contractors:	Newcastle University, Sheffield University	Total project cost:	£186k

Description

This study refined the understanding of the consequences of climate change on weed populations of arable and grasslands in Britain. Climate manipulation experiments studied the fate of weeds beyond their present northern boundaries, to investigate the interaction between changed climatic conditions, soil fertility and intensity of exploitation. Models of weed dispersal, establishment and population dynamics were modified to predict changes in weed distribution, virulence, persistence and genetic constitution under a range of scenarios.

Findings

Arable weeds responded rapidly to climate change. New species would arrive and existing populations could undergo rapid adaptations in their genetic constitution. The balance of annual and perennial species was not expected to change greatly in most UK grasslands. The most responsive invasive species would be perennials that already had widespread distributions and ephemeral species with existing seed banks. Invasions by southern weed species would occur more slowly. Further effects could arise from elevated CO₂, enhanced UV-B radiation and increasing frequency of extreme drought. At elevated CO₂ levels there could be higher yields and changes in the competitive balance between the dominant perennials of the most productive grasslands. Increased drought frequency could gradually change the balance of species within grassland communities.

CC0316 Mapping The Geographic & Economic Responses Of Agricultural Systems In England & Wales To Climate Change

Duration:	01/04/1994 - 31/03/1997	Total MAFF cost:	£180k
Contractors:	IGER	Total project cost:	£180k

Description

Mechanistic models of crop growth were coupled with spatially differentiated meteorological data to map current and future limits of crops suitability under a range of climate change scenarios in England and Wales. The basic findings from MAFF project OC9011 were used with a wider range of crop growth models and climate change scenarios. Yield predictions were linked to IPCC 'business as usual' scenarios. A Micro Component analysis of changes in financial returns at the farm level and a Macro Component analysis of the effects of policy changes give an overall effect of climate change on cropping.

Findings

Yield increases due to increased temperatures could be offset by a shortened developmental cycle and the effects of summer drought. Grassland and forage maize production increased northward and westward. Spring barley and sugar beet had an increased suitability northward and westward but production was reduced in the East. Maincrop potato production remained static or showed small increases in yield. Early potatoes showed significant increases northward and eastward. Water availability and increased evapotranspiration would have the greatest adverse effects in the East and South East. Farmers could find new opportunities to move towards alternative production in those regions. A recommendation was made to integrate spatial agricultural production models with water-catchment management studies.

CC0312 Impacts Of Climate Change On Crop Pests And Diseases

Duration:	01/04/1994 - 31/03/1997	Total MAFF cost:	£159k
Contractors:	Central Science Laboratory	Total project cost:	£159k

Description

This project investigated the different research approaches adopted to assess the impacts of climate change on the incidence, severity and distribution of indigenous and alien pests and diseases of major UK agricultural crops. Pests and diseases studied included diamond backed moths, slugs, aphids, cabbage root fly, wireworms, nematodes, cutworms, *Fusarium* diseases, rusts, mildew and leaf spots. An assessment was made of the risk of new, alien pests and diseases becoming established. Pesticide use was assessed in relation to any foreseen changes in applications resulting from these adjustments to climate change.

Findings

The presence of pests was largely temperature-driven. Herbivorous and sucking pests had a wider spectrum of alternative hosts than diseases. Some cool-adapted alien pests could be ousted by warmer conditions (e.g. New Zealand flatworm) but by 2050 the Colorado beetle could cover 90 % of the UK's crop producing area. Disease epidemics were driven by the presence of a pathogen, a susceptible host and weather conditions. Entry control methods for alien pathogens were seen as satisfactory and should be upheld. Appropriate strategies required ongoing aetiological or epidemiological research in conjunction with improved methods to model climate-pest/disease interactions. The economic impact of changes in the importance of pests would depend heavily on technological changes in pest management practices. Pesticides would remain as the mainstay for control. Ultimately, the economics of crop production was predicted to override any climate change effects on pests and diseases.

CC0319 Evaluation Of The Effects Of MAFF Policies On Greenhouse Gas Emissions (Animals And Systems)

Duration:	01/02/94 - 31/03/95	Total MAFF cost:	£27k
Contractors:	BBSRC, Silsoe Research Institute	Total project cost:	£27k

Description

The balance between agricultural sources and sinks of greenhouse gases (GHGs) is strongly influenced by land use and management which, in turn, are controlled by agricultural policy.

This study evaluated the effects of present and future MAFF policies on emissions of greenhouse gases (GHG) from crop and livestock production systems. Policy effects were projected to the year 2000 based on a 1990 baseline.

Findings

The overall effect of MAFF policies on the three main GHGs (N₂O, CH₄, CO₂) was to reduce emissions by 7.5 %. The impacts of MAFF policies were therefore regarded as beneficial and convergent with obligations under international treaties. MAFF policies decreased N₂O emissions. Changes to dairy farming resulted in the largest emissions reductions, but this reduction will not occur if the land is converted to arable or beef production. The second largest policy impact on N₂O was through arable farming. MAFF policies resulted in an overall net reduction of CH₄ emissions but contributions from dairy cattle increased. Set-aside and the ban on straw burning had significant effects on carbon sequestration over the UK arable area. Land use conversions to grassland were more efficient at C sequestration but of limited areal extent. Further research was recommended to estimate N₂O release from fertilizers, the soil methane sink and the interaction between ammonium and methane oxidation in the soil.

CC0318 Evaluation Of The Effects Of MAFF Policies On Greenhouse Gas Emissions (Arable)

Duration:	01/02/94 - 31/03/95	Total MAFF cost:	£43k
Contractors:	Soil Survey and Land Research Centre	Total project cost:	£43k

Description

This desk study evaluated the effects of present and future MAFF policies (both production and environment related) on the net emission of greenhouse gases (GHGs) from UK crop and livestock production systems. MAFF policies on GHG emissions were likely to influence the type of agricultural systems, their management and potential farm profitability. The relative impact of each policy on net GHG emissions was reviewed and consequences for agricultural systems outlined.

Findings

Extensive literature review and interviews were conducted with appropriate UK experts. Mathematical modelling concentrated principally on predicting the influence of changes in cereal regimes on greenhouse gas emissions. A request was made in March 1994 to extend the project until June 1994 to broaden and deepen the study. The final project report was merged with findings from MAFF project CC0319 (above).

Research commissioned in 1993

OC9303 Preparation And Distribution Of 'SPECTRE' To Climate Change Scientists

Duration:	01/11/93 - 01/01/94	Total MAFF cost:	£12k
Contractors:	University of East Anglia, Climatic Research Unit	Total project cost:	£12k

Description

SPECTRE (Spatial and Point Estimates of Climate change due to TRansient Emissions) was developed under MAFF project OC9009. This funding was provided to ensure that the SPECTRE climate change model software existed in a form suitable for distribution to scientists engaged in UK climate change impacts research.

OC9219 On-Farm Water Conservation

Duration:	01/10/93 - 31/05/97	Total MAFF cost:	£179k
Contractors:	Silsoe College, Soil Survey and Land Research Centre	Total project cost:	£179k

Description

This study aimed to provide the information required for policy making to promote water conservation and water storage on-farm. Contemporary and future irrigation water requirements under a range of agricultural, technical, climatic and policy scenarios were provided. Future spatial irrigation demand was predicted to assess the overall water shortage problem, although the impact of climate change was not directly taken into account.

Findings

Water use for agricultural irrigation has increased, both in area irrigated and depths applied, and is predicted to grow. It has been directed increasingly towards more valuable crops. Improved irrigation methods and scheduling could increase water use efficiency but scheduling could increase abstraction. The benefits of water conservation vary by enterprise, so the uptake will always be site-specific. Further water conservation could be achieved by developing cultivars with improved drought and disease resistance and deeper rooting patterns. Irrigation using treated effluent was regarded as technically feasible with negligible risks to consumers. Water conservation measures could not compete where the cost of direct summer abstraction was low, but could be justified when water was scarce. A more flexible licensing system would help to promote effective use of water and water conservation.

OC9218 Responses Of Vegetable Crops To UV-B

Duration:	01/06/93 - 30/09/96	Total MAFF cost:	£261k
Contractors:	Lancaster University	Total project cost:	£261k

Description

The objective of this study was to quantify the impact of increasing surface UV-B, due to depletion of stratospheric ozone, on the productivity of UK vegetable crops (pea, onion, carrot

and brassicas) in controlled environments and in the field (so as to include the other abiotic and biotic stresses that could modify a plant's response to UV-B) and to identify cultivars or characteristics associated with UV-B tolerance.

Findings

These limited field trials suggested that peas or barley would probably not display significant UV-B effects on the yield or quality, although increases in plant-weighted dose significantly inhibited the growth, and significantly changed the morphology, of some varieties of pea and barley. Two pea cultivars displayed non-linear responses to the UV-B dose. Sub-tropical cultivars sometimes had greater morphological responses than temperate ones. The use of sub-tropical crop varieties to strengthen UV-B tolerance in future breeding programmes should be undertaken with caution. Future research was recommended on the interactions between UV-B and plant interactions with other abiotic (e.g. drought, CO₂) and biotic (e.g. pests, pathogens) factors of the crop environment.

Research commissioned in 1992

OC9010 Modelling The Effects Of Climate Change On Aphids And Their Enemies

Duration:	01/08/92 - 31/07/95	Total MAFF cost:	£106k
Contractors:	IACR	Total project cost:	£106k

Description

The objective was to predict the effects of climate change on the pest status of aphids and improve the understanding of the effectiveness of natural enemies in controlling aphid populations. This project built upon a previous simulation model describing the population dynamics of the pest grain aphid (*Sitobion avenae*). Predator (seven-spot ladybird beetle-*Coccinella septempunctata*) and prey were modelled together to provide realistic predictions of the overall impact of aphid outbreaks.

Findings

Control of the aphids depended on a complex relationship involving immigration times, immigration numbers early in the season and the ratios of these variables between predator and prey. Both the presence of the seven-spot ladybird and different climate change scenarios decreased aphid numbers in all summers, although aphids were likely to be more abundant in moderately hot summers than in relatively cold or relatively hot summers. The model required recalibration for use outside south-east England. The authors recommended the inclusion of other natural enemy species within a larger model to fully assess the effects of climate change on UK cereal production and pest control.

CC0311 Environmental Effects For Sunflower And Lupin

Duration:	01/04/92 - 31/03/93	Total MAFF cost:	£15k
Contractors:	Soil Survey and Land Research Centre	Total project cost:	£15k

Description

Climate change may provide more opportunities for the growth of non-traditional crops in England and Wales. Initial models were developed for assessing the suitability of land for growing newly developed varieties of lupins and sunflowers, based on the interaction of crop climate requirements with land qualities such as droughtiness, ease of workability at optimum sowing time and soil reaction or fertility. The land suitability thresholds were in turn used to map the distribution of each suitability class across England and Wales.

Findings

Over half the land in England and Wales was well or moderately suited to the production of the new genetic varieties of autumn determinate lupins. Around 15% of England and Wales was well or moderately suited to the Avante variety of early maturing sunflowers. The suitability of land in England and Wales for forage maize was also mapped. Further validation work required included pH limits, more precise use of workability data to identify sowing 'windows' and better definition of conditions conducive to freezing damage.

CC0309 T200 Data Input For LandIS

Duration:	01/04/92 - 31/03/93	Total MAFF cost:	£9k
Contractors:	Soil Survey and Land Research Centre	Total project cost:	£9k

Description

A database of daily air temperatures for the period 1961 to 1980 from 87 stations in England and Wales were extracted from the AFRC ARCMET database and stored on the VAX, peripheral to the operational LandIS system at the Soil Survey and Land Research Centre..

Findings

Missing values were estimated by substitution and correction (for altitude differences), for the appropriate period, from nearby stations. The daily temperature data were used to compute accumulated temperature above 5°C (AT5), 6°C (AT6) and 10°C (AT10) from each. Algorithms for estimating AT5, AT6 and AT10 from altitude, latitude and longitude were computed.

CC0308 Organic Matter Dynamics

Duration:	01/04/92 - 31/03/94	Total MAFF cost:	£34k
Contractors:	Soil Survey and Land Research Centre	Total Project cost:	£34k

Description

Losses of Soil Organic Matter (SOM) may be accelerated under future climate conditions. Numerous factors affect SOM including land-use type and management, hydrology and climate. The objective of this study was to assess the rate and direction of changes in SOM in non-humose (non-organic) medium and fine-textured topsoils by selecting and resampling sites in England with historical analytical data from the 1950s onwards.

Findings

Twenty-nine sites across climatic gradients, considered to be representative of typical long-term arable regimes, were resampled. Those sites with an original soil Organic Carbon (OC) concentration greater than 2.4 % declined on resampling; those with OC below 2.4 % showed an increase. These results suggested that topsoil OC concentrations had been moving towards an equilibrium level around this value. A sub-set of sites was recommended for future monitoring of soil changes.

Research commissioned in 1991

OC9011 Specification Of Climatic Sensitivity For UK Farming Systems

Duration:	01/12/91 - 30/11/93	Total MAFF cost:	£93k
Contractors:	IGER	Total project cost:	£93k

Description

This project identified the key climatic, soil and biotic limitations to the major agricultural systems of the UK- cereals, other arable, forage and animal production, horticultural and altered land use (i.e. the movement of land into and out of agriculture and interconversions between agricultural systems). Climatic thresholds (means, extreme events) above which there would be detectable economically significant perturbations in output were identified so that future climate modelling can provide agricultural policy makers with more detailed information.

Findings

Bibliographic analysis and expert consultation helped to determine more accurately (i) the timescale for the appearance of significant perturbations in the current patterns of UK agriculture; (ii) the nature of such perturbations and their economic consequences; and (iii) the potential benefits of agricultural mitigation strategies. When linked to an improved understanding of the transient responses of climatic forcing, it would be possible to identify when and where critical impacts could occur within the agricultural sector.

OC9008 The Effects Of Climatic Variation On The Geographical Distribution Of Vectors Of Animal Disease

Duration:	07/10/91 - 6/10/94	Total MAFF cost:	£243k
Contractors:	Institute for Animal Health	Total project cost:	£243k

Description

This project studied the effects of climatic variation and other environmental factors on the geographical distribution of vectors of endemic animal disease in the UK. Mathematical models were developed from field data to predict changes in presence and distribution of the vector fauna arising from climate change and any increased risk of invasion by exotic vectors and diseases. Long-term assessments were made for the likelihood of colonisation by imported vectors, the extent and speed of their distribution, and necessary changes in pest control strategies.

Findings

Any future vector 'problems' in the UK were not greater than those already experienced elsewhere in Europe. Only marginal changes in the activity and abundance of some potential arthropod vectors of animal disease were indicated. The import and establishment of novel vectors could not be substantiated. Under UK climate change scenarios, extended seasons of occurrence of cattle-visiting Muscid flies would result. Some species could become more abundant and achieve wider distributions, especially further north. Tick activity was not predicted to decline but reproduction rate could be increased so reducing generation times. Their effect on economic livestock production was considered unimportant. Good management practices were regarded as sufficient to control these disease vectors in the future.

OC9007 Effects Of Climate Change On Crop Diseases

Duration:	01/10/91 - 30/09/94	Total MAFF cost:	£98k
Contractors:	Harper Adams Agricultural College	Total project cost:	£98k

Description

The aim of this project was to develop a forecast system to predict the incidence and severity of Fusarium diseases of cereals under conditions of global warming. The effects of temperature and water on growth of the important Fusarium species causing foot-rot in UK cereals were determined. The relationship between national disease survey data for Fusarium foot rot and meteorological data was also investigated.

Findings

Fusarium culmorum was favoured by warmer, drier conditions; M. nivale was favoured by lower temperatures. A simple predictive model was developed for F. culmorum for the rate of foot-rot symptom development given temperature and soil moisture. A reasonably robust descriptive model was developed to predict foot-rot symptoms in each UK county based on a cumulative heat sum. Foreknowledge of the dominant foot-rot pathogen in each county and more information on the effects of temperature, soil moisture and certain fungicide treatments on competition between the two most important species (F. culmorum and M. nivale) were needed.

OC9009 Future Changes In Transient Climate And Climatic Extremes: Implications For Agriculture

Duration:	01/08/91 - 31/07/93	Total MAFF cost:	£51k
Contractors:	East Anglia University, Environmental Sciences Dept	Total project cost:	£51k

Description

The magnitude and spatial pattern of future climate change are needed to predict impacts on agricultural productivity in the UK. This project developed a model called SPECTRE (Spatial and Point Estimates of Climate change on TRansient Emissions). Spatial climate change scenarios were constructed and extreme (minimum and maximum) temperatures at point locations in the UK analysed. Climate change impacts on crop yields and production were summarised for two pilot sites in Scotland and South-East England.

Findings

The interactive PC-based DOS model known as SPECTRE allowed users to explore the potential effects on various aspects of UK climate of emissions scenario, climate models and/or site. For each emissions scenario, a range of possible future climates were presented. A supplementary contract with MAFF was negotiated in the autumn of 1993 to package and distribute SPECTRE to interested scientists (project OC9303). A further upgrade was requested in 1996 (CC0324).

CC0310 To Carry Out A Desk Study On The Impact Of Climate Change On Field Drainage

Duration:	01/04/91 - 31/03/92	Total MAFF cost:	£7k
Contractors:	ADAS Consulting Ltd	Total project cost:	£7k

Description

Artificial drainage is a prerequisite for the successful cultivation of many soils and for sustaining UK agricultural production. The objective of this study was to make assessments of the consequences of climate change for drainage requirements, surface run-off, flood events, and crop losses due to waterlogging in winter and summer conditions. Results from drainage models were used to identify the vulnerability of farming systems and management practices to changes in soil water regimes resulting from climatic change.

Findings

The need to adjust field drain spacing due to different cropping systems was much greater than adjustments required by changes in rainfall. As climate change offered opportunities for new crops, higher standards of drainage system performance were expected. Increased rainfall intensity could reduce the efficacy of mole drains. Wetter winters and drier summers could decrease the cultivation window. A reduction in available workdays would increase the power requirements for cultivation. It was recommended that drainage models should be integrated with grass utilisation models to indicate how climate change would affect the patterns and profitability of grassland enterprises.

CC0307 To Examine Effects Of Environmental Temperature On Top Fruit Quality And Cropping

Duration:	01/04/91 - 31/03/93	Total MAFF cost:	£205k
Contractors:	HRI	Total project cost:	£205k

Description

Environmental temperature affects fruit development. Fruit size of Cox's 'Orange Pippin' was continuously recorded non-destructively during the growing season. These data were used to quantify fruit growth and development in relation to their environment, particularly air temperature. Fruit growth dynamics were calculated to model growth as diametric and volumetric changes in size.

Findings

Fruit mineral nutrition was altered by elevated temperatures, particularly with respect to nitrogen concentration. Changes in leaf canopy development were also apparent although total leaf area remained constant. Extension leaf area declined and spur leaf area increased. Enhancing the dormant season temperature of Conference pears had a major influence on flower bud development. Temperatures greater than ambient delayed the flowering date.

CC0306 To Investigate The Likely Effects On Vegetable Crops Of Changes In Mean Temperature Associated With Global Warming

Duration: 01/04/91 - 31/03/97 **Total MAFF cost:** £194k
Contractors: HRI **Total project cost:** £194k

Description

This study investigated the effects of increased temperature on horticultural crop growth and development using a thermogradient tunnel. Project CC0303 was consolidated with CC0306 with effect from 1 April 1994.

Findings

The tunnel provided a means of studying the potential impact of temperature scenarios on crop growth. A second thermogradient tunnel was used with reduced moisture availability to study temperature-moisture interactions. The results of the thermotunnel experiments, and those from daylit cabinets (MAFF project CC0303), produced a categorization and strategic assessment of the effects of increased temperature on a range of vegetable species.

CC0304 To Assess The Likely Impact Of Climate Change On Aphid Pest Incidence

Duration: 01/04/91 - 31/03/96 **Total MAFF cost:** £195k
Contractors: IACR **Total project cost:** £195k

Description

This project assessed the impact of climate change on aphid pest population levels and consequent effects on agricultural production systems. Two species, the grain aphid (*Sitobion avenae*) and the potato aphid (*Aulacorthum solani*), were chosen for experiments on winter wheat and nitrogen fixing (bean) and non-nitrogen fixing (tansy) plants. Records from the Rothamsted Insect Survey (RIS) network were compared with meteorological data to reveal the climatic factors determining population distribution, abundance and flight timings.

Findings

Aphids would do better under conditions of elevated CO₂ and temperature. Milder winters resulted in earlier and larger flights that were continually parthenogenetic. Increased release of plant volatile chemicals in a CO₂-rich atmosphere attracted aphids to their hosts. Changes in volatiles released from the aphids and their host plants may influence the success of parasitic fungus locating their aphid hosts. More investigation was recommended on the tritrophic interactions between aphids, their host plants and their natural enemies.

CC0303 To investigate the likely impact on crop development of changes in temperature, CO₂ and water associated with global warming

Duration: 01/04/91 - 31/03/97 **Total MAFF cost:** £799k
Contractors: HRI **Total project cost:** £799k

Description

This project tested the impact of temperature, CO₂ concentration and moisture availability on field vegetable crop development and growth to improve the prediction of the consequences of

different climate change scenarios. Crops were selected representing major agricultural commodities (legumes, root crops and onions, brassicas and salads), or with contrasting climatic tolerances (peas- adapted to a cool climate; Phaseolus beans- requiring high temperatures; and alliums- marked temperature optima for growth). The work was extended for a second, four-year rotation (brassica, potatoes, pea, barley) to provide a replicate set of data to allow adequate statistical validation.

Findings

Changes in water and temperature were most significant to crop growth and yield. Secondary additional effects were brought about by CO₂ increases. Crops responded differently to temperature in the different soil moisture environments. Yields increased with enhanced CO₂ levels providing scope for improved efficiency of photosynthesis and water use in the future. Priorities for future work were to further research the combined effects of temperature and moisture stress on key plant processes. Screening of genotypes for tolerance of temperature and moisture stress was required. Localised sub-surface irrigation studies were recommended to identify whether root morphological patterns could be altered to improve water use efficiency. The major opportunity in vegetable crops was with Brassicas.

CC0302 To Develop The Arable Crop Model To Assess Likely Impact Of Climate Change

Duration:	01/04/91 - 31/03/97	Total MAFF cost:	£407k
Contractors:	IACR	Total project cost:	£407k

Description

This project continued development of arable crop models to assess the impacts of increased levels of atmospheric CO₂, higher temperatures and altered light regimes on the growth and yield of wheat and sugar beet. A new wheat model (the 'MAFF model') was developed and compared with other existing wheat models. An existing sugar beet model (INTERCOM) was tested with data from 3 years of experiments conducted at different CO₂ and temperature regimes. Emphasis throughout was placed on arriving at simple models that could predict yield accurately for current UK field crops.

Findings

The new wheat model improved the capacity to predict the yield of field crops. The sugar beet model performed reasonably well for all years and treatments. In controlled environment experiments, 2xCO₂ levels led to yield increases in both crops but temperature increases decreased yield. The crop models predicted only modest effects of projected increases in atmospheric CO₂ concentration and temperature over the next 30 years. Adaptive measures were therefore considered unnecessary. The models took no account of changes in drought incidence or other significant stresses. These would require inclusion before a complete assessment of the abiotic risk posed by climate change to UK crops could be made.

Research commissioned in 1990

OC8911 The Effect Of Future Climatic Change On Agricultural Potential

Duration:	01/11/90 - 31/03/93	Total MAFF cost:	£75k
Contractors:	Oxford University	Total project cost:	£75k

Description

Climate change could affect future regional agricultural potential by changing the number and periodicity of work day opportunities and the methods used for preparing the land. Work-day opportunities were modelled and agricultural potential for major crops (winter wheat, grain maize, grassland) were mapped under present-day and future climates. A probability assessment was made of the magnitude and rates of shifts in the geography of cropping based on projected environmental constraints.

Findings

Current agricultural systems could cope with temperature changes of up to +2°C, depending upon precipitation changes. Increasing temperatures and decreasing precipitation result in more autumn work-day opportunities. Spring work-days were more controlled by changes in rainfall than temperature. By 2050 principal winter wheat areas would suffer increasing drought stress and current marginal areas would become more suitable. The thermal limit for grain maize would move northwards. Drought stress would limit grain maize. Silage maize could become more viable. A warmer climate would be beneficial to trafficability and livestock movement on grassland. Increased precipitation would promote better yields, but increased temperature could limit suitability.

CC0301 To Investigate The Impacts Of Climate Change On Soils

Duration:	01/04/90 - 31/03/93	Total MAFF cost:	£109k
Contractors:	Soil Survey and Land Research Centre	Total Project cost:	£109k

Description

Global warming may alter the cycle of hydrological change in soils such that they may be unsuitable for tillage operations at important times in the agricultural year. The project reviewed the contemporary state of knowledge of soil workability and trafficability in the UK. Modifications were made to SSLRC's empirical models to map where present agricultural and/or cropping practices would need to be revised under a changed climate.

Findings

A climate comparable with the current dry quartile would benefit Autumn cultivation in the North-West but not in Eastern England. Increased summer moisture deficits would lead to very dry soils in early Autumn, hindering seedbed establishment. Increased Autumn rainfall could restrict opportunities to cultivate clay soils. Temperature increases of less than 2°C would benefit winter wheat yields if the climate was wetter. Areas suitable for maize would expand with temperature and precipitation increases but would remain restricted to southern England, Wales and lowland Yorkshire. Grassland would benefit from increased precipitation but its potential decreases above the 2°C temperature threshold.

Research commissioned in 1987

CC0305 To Develop Grasses Likely To Tolerate Climate Change

Duration:	01/04/87 - 31/03/94	Total MAFF cost:	£248k
Contractors:	IGER	Total project cost:	£248k

Description

Continued use of grassland to support livestock and maintain stable swards in a changing climate will depend upon the ability of grasses to adapt to climatic changes. This project aimed to produce a range of at least 30 potential varieties derived from hybridisation of ryegrass and fescue species. Genetic markers were used to identify and transfer useful adaptive traits, such as drought tolerance and disease resistance, between species.

Findings

The project demonstrated the value and potential of incorporating genes from fescue into ryegrass to cope with climatic stress. Fertile hybrids were produced from 2 ryegrass and 3 fescue species. Results of the research produced new information relating to genetic behaviour and relationships of traits associated with agronomic performance and climatic adaptation in grasses. Selections with greater amounts of genetic material from fescues had a greater ability to cope with drought stress and disease problems in warm climates.