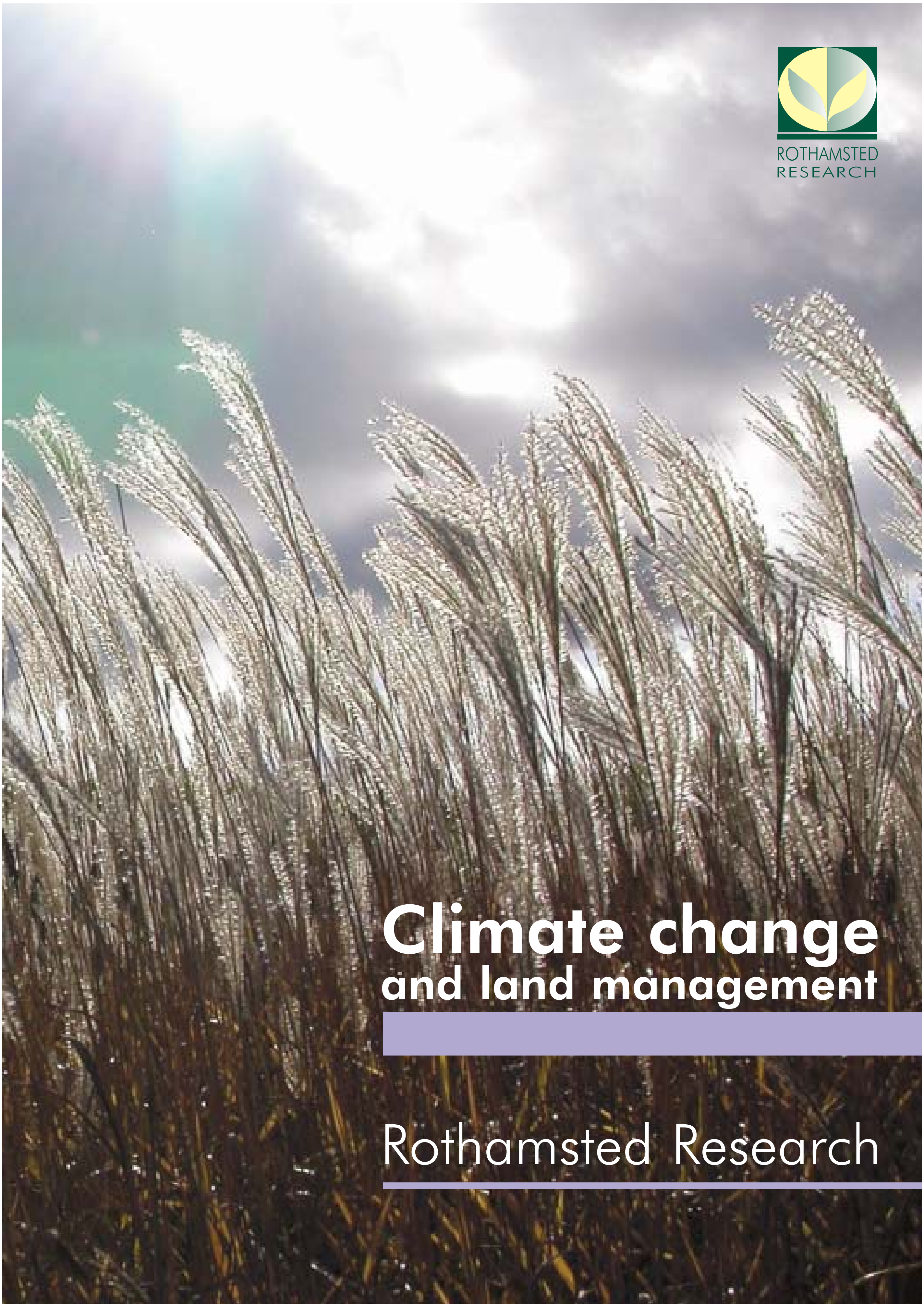
ROTHAMSTED RESEARCH



Climate change
and land management

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According to the Government Chief Scientist, Professor Sir David King and to the Department for Environment, Food and Rural Affairs (Defra), climate change is the biggest threat to our environment, with significant impacts across the globe. The UK is committed to the Kyoto protocol and to building an international consensus for cutting emissions and limiting the effects of climate change. Over the coming decades, land-based businesses will need to adapt to the effects of changing climatic conditions and at the same time modify practices to reduce their continuing impact on the environment. Predicting the impacts of climate change, developing strategies for adaptation to change and providing solutions for mitigating and minimising damaging emissions are important drivers for research at Rothamsted.

IMPACTS

Crop yields are affected by many factors associated with climate change, including:

1. Temperature
2. Rainfall
3. CO_2 concentration in the atmosphere
4. Extreme weather events
5. Climate variability

Models developed at Rothamsted in collaboration with others are producing predictions based on possible climate scenarios (see Box 1).

- Worldwide, the net effect of climate change will be to decrease stocks of organic carbon (C) in soils, thus releasing additional carbon dioxide (CO_2) into the atmosphere and acting as a positive feedback, further accelerating climate change. This is being quantified by linking the Rothamsted C (Roth C) model with models of climate change and vegetation growth developed at the Hadley Centre.

- Soil structure is affected by variation in temperature and rainfall. In particular, during hotter, dryer summers there is an increased tendency for subsoil to become "strong", making it more difficult for roots to penetrate. Some soils are likely to form impenetrable caps, increasing the risk of run-off and subsequent pollution events and flooding. Others may form cracks through which any rainfall will pass, reducing the trapping effect of the surface layers, further increasing risk of drought in the following year and also reducing the filtering effect of soil and increasing pollution risk.

- Higher temperatures and evapotranspiration combined with less summer rainfall make conditions for drought more likely. Work at Broom's Barn, in collaboration with the Climatic Research Unit at the University of East Anglia, has shown that sugar beet is very likely to experience summer drought, causing more and earlier leaf senescence. Beet drought losses are predicted to approximately double in areas with an existing problem and to become a serious new problem in north east France and Belgium.

In western and central Europe, simulated average drought losses rise from 7% (1961-1990) to 18% (2021-2050). The annual variability of yield (as measured by the coefficient of variation) will increase by half, from 10% to 15% compared to 1961-1990, again with potentially serious consequences for the European sugar industry. In contrast, winter wheat in the UK is predicted to avoid drought as it is likely to mature earlier due to higher temperatures in spring (see Box 1).

- OREGIN was the first of the Defra Genetic Improvement Networks to be established, in 2003. It has rapidly provided a focus for the research and stakeholder communities associated with the winter oilseed rape crop. Part of its remit has been to determine the effect of changing temperature on crop quality and sustainability, with particular reference to a fit-for-purpose oil profile. The project is also determining the effects of temperature on pathogens and pests to assess altered risk of attack and to develop strategic links with countries growing oil seed rape in climates closer to those that we might encounter in future (e.g. France and Australia, where severe phoma stem canker epidemics occur).

- Under average UK conditions over the past 30 years, aphids are able to produce 18 generations in a year. This is expected to increase to 23 generations with a 2°C rise in average temperature. However, as a result of interactions with natural enemies, this does not necessarily mean higher peak population levels. The study of the impact of climate change on these pest species has been aided considerably by the long-term datasets held by the Rothamsted Insect Survey (See Box 2).

- There is a contrast in the predicted impacts of environmental changes on pest organisms, and on organisms of conservation concern. The former are predicted to become more abundant and hence the need to devise sustainable control strategies will be greater. The latter are predicted to become rarer and hence the need to devise sustainable conservation strategies will be greater. This paradox can be resolved on the basis that those traits that tend to be associated with pest status, i.e. high mobility and a high intrinsic rate of increase, are also traits likely to lead to adaptability to change, whereas the opposite traits are likely to lead to rarity and a poorer adaptability to change.

IMPACTS

- As British winters become warmer and wetter, conditions will improve for certain pathogen species. Fusarium ear blight (*Fusarium graminearum*) and the closely related species, *Fusarium culmorum* are not yet major problems in the UK. However, fusarium ear blight favours climates warmer than ours and is predicted to become an increasing risk as the UK warms up. Climate change may also make conditions more favourable for growing maize and there is evidence that maize cropping boosts the populations of both *F. graminearum and F. culmorum*. Grain harvested from *Fusarium*-infected ears is frequently of poorer quality and contaminated with mycotoxins, including the highly toxic trichothecene mycotoxins, such as deoxynivalenol (DON). Mycotoxin contamination of grain presents a serious health risk to humans and animals, leading to the prospect of major problems for growers and the food industry alike.

Box 1 - Crop Modelling

Crop simulation models can be used to assess the likely impact of climate change on grain yield, yield variability, and geographic distribution of the crop. These crop models must accurately predict several key characteristics over a wide range of climatic conditions:

- timing of key phenological events such as flowering and physiological maturity, through correct descriptions of phenological responses to temperature, daylength and vernalisation;
- accumulation of yield, by accurately predicting the development and loss of leaf area and, therefore, a crop's ability to intercept radiation, accumulate biomass, and partition it to harvestable parts such as grain;
- crop water use, by correctly predicting evapotranspiration and the extraction of soil water;
- use of nitrogen (N), through descriptions of N mineralisation in the soil, uptake of mineral N by the crop, and partitioning of N in the crop biomass;
- influence of water and N deficits on crop growth and development.

Sirius is a wheat simulation model, developed in collaboration between Rothamsted Research and Crop and Food Research, New Zealand. Sirius calculates biomass from intercepted photosynthetically active radiation and grain growth from simple partitioning rules. Phenological development is calculated from the mainstem leaf appearance rate and final leaf number, with the latter determined by responses to daylength and vernalisation. Sirius has been used in several projects on climate change impact assessments funded by the European Union, Defra and the Biotechnology and Biological Sciences Research Council (BBSRC).

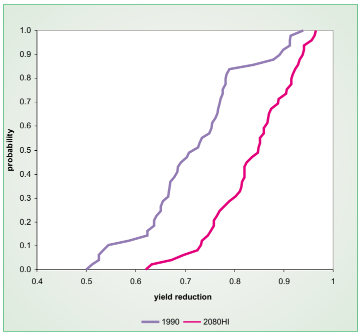


Figure 1. Cumulative probability function of wheat yield reduction related to water stress for the baseline (1990) and UK Climate Impact Programme (UKCIP) 2080HI high emission scenario at Sutton Bonington, for a shallow soil with 105mm available water capacity. Wheat avoided summer drought stress in this scenario by shortening the growing season due to the warmer temperature. The probability of 20% of yield loss due to water stress is lower for 2080HI (0.3) than for 1990 (0.85). Wheat yields were calculated using the Sirius crop simulation model. Climate change scenarios were produced using the LARS-WG stochastic weather generator and UKCIP predictions.

Box 2 - Impact on pests

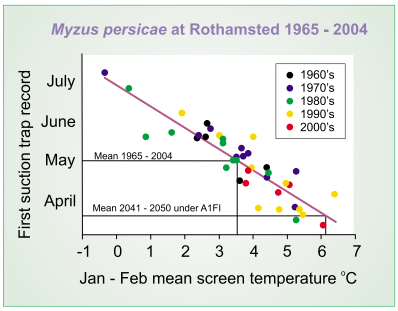


Figure 2. Suction trap records showing the effect of winter temperature on first flight for the aphid Myzus persicae. Mean 2041-2050 represents the predicted winter temperature under the Intergovernmental Panel on Climate Change (IPCC) Fossil Intensive Scenario (A1FI).

Rothamsted, together with the Scottish Agricultural Science Agency, organises a network of 16 suction traps for monitoring aphids throughout the UK, and co-ordinates a database for similar information from throughout Europe (approximately 70 traps in 18 Countries). Depending on the trap site, daily data are available for up to 40 years on the abundance of many aphid species. Analyses with climatic data have shown that the time of year when most species start to fly becomes earlier with increasing winter temperature. A rise of 2°C leads to an advance of about a month in the time of first flight, and hence in the time that aphids can potentially colonise spring sown crops. As the emergence date of most crops does not appear to be getting correspondingly earlier, the aphids are arriving at earlier crop growth stages, when crops tend to be more susceptible both to feeding damage and to the viruses which aphids transmit. However, such earlier arrival tends to result in many natural enemies breeding successfully early in the year and producing a strong second generation, which keeps peak aphid populations down, reducing feeding damage on more mature crops.

ADAPTATION

- An important adaptation to climate change is through crop breeding for improved response to the altered climate and increasing extremes that are predicted. In particular breeding for drought tolerance should enable growers to continue to produce crops in areas that are already at risk of drought stress such as the east of England (see Box 3).

- A European project coordinated by Rothamsted called STAMINA is using indicators such as crop establishment, workability of soils and harvestability of crops in hilly regions to devise a tool that will aid land use decisions and adaptation to climate change. Hilly regions are particularly susceptible to increased temperature and drought stress and this project builds on simulations that integrate the effects of climate and terrain on crop growth. Potential end-users provide feedback and socioeconomic evaluation, leading to the development of indicators and a decision support tool. These will aid decisions regarding suitability of areas for cropping, choice of crop, when to sow, desirable traits for breeders and/or choice of variety.

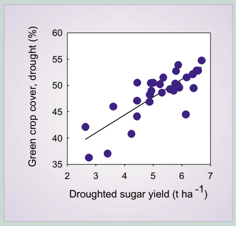
- Some pest aphids of potato, sugar beet and field vegetables already pose major problems because of insecticide resistance, and increased use of chemicals will undoubtedly exacerbate this. Furthermore, there is evidence that warmer winters improve the survival chances of the insecticide resistant aphids. Whilst cereal aphid species found in the UK currently do not show any resistance to insecticides, there is no a priori reason to assume that this will continue and it is vital to reduce this risk by optimising insecticide usage and considering alternative control strategies. Work at Rothamsted on forecasting and prediction of epidemics and the development of resistance will aid growers in adapting to these increased risks.

- Research at Rothamsted that is targeted at enabling growers to modify their practices and secure durable fusarium ear blight control in wheat includes:
  1) increasing our understanding of the epidemiology of the disease under UK conditions and whether the level of inoculum can be controlled by crop residue management and rotational approaches;
  2) the identification of promising biocontrol species that can restrict infection of wheat ears;
  3) defining the *Fusarium* genes required to cause disease and regulate mycotoxin production; and
  4) the characterisation of natural wheat resistance mechanisms that can lower mycotoxin levels without compromising grain quality.

- Risk assessment and forecasting are important tools enabling growers to adapt to new disease risks caused by changing climatic conditions. Light leaf spot (*Pyrenopeziza brassicae*) is a serious disease of oilseed rape that shows seasonal and regional variation associated with climate. "Light leaf spot" regions with similar patterns of disease incidence were defined by using principal co-ordinate analysis on survey data from winter oilseed rape crops in England and Wales (1987 to 1999). Empirical models were derived to predict, in autumn, the incidence of light leaf spot on crops the following spring at the regional and individual crop scales. The predictions have now been incorporated into a Web-based crop-specific interactive forecast for the disease (**www3.res.bbsrc.ac.uk/leafspot/**) to help growers make decisions that are more economical and environmentally friendly. In a related LINK project, a prototype web-based integrated pest and disease decision support system for winter oilseed rape (PASSWORD) is being developed. This combines the light leaf spot model with an existing Decision Support System for pests (DORIS, developed at the Central Science Laboratory (CSL)) to give growers and advisors up-to-date risk assessment information throughout the growing season. The light leaf spot forecast and a new empirical phoma stem canker forecast that Rothamsted is currently working on could both be used to model the effects of climate change on oil seed rape yield.

Box 3 - Breeding for drought

Drought affects food production worldwide, yet little is understood about how plants perceive and adapt to environmental stress. At Broom's Barn, the physiological responses of sugar beet to drought are being examined, and sources of germplasm with enhanced drought tolerance under field conditions are being identified. In these trials, experiments also focus on morpho-physiological traits associated with drought tolerance that could be used by breeders as indirect selection criteria. Emphasis is placed on traits that can be assessed rapidly and inexpensively on large numbers of entries in field trials. For example, in droughted plots the maintenance of green crop canopy, measured using a custom-designed spectral ratio meter, is highly associated with final yield (Figure 3). Another aspect of the work uses multi-environment trial (MET) data to identify varieties that show relatively good or poor drought tolerance. Breeders with an international seed company are actively involved, and are beginning to implement some of the research in their own breeding programmes. Advances in selection techniques and evaluation of MET data should also aid work with other crops.



MITIGATION

Research for mitigating climate change is aimed at countering or reducing greenhouse gas emissions and involves three key approaches:

1. Emit less greenhouse gas from all parts of the food chain.

- Analysis of agricultural operations has been carried out at Rothamsted, calculating the CO_2 emissions for each element and enabling decisions to be taken on management for increased carbon efficiency. CO_2 is evolved from the breakdown of organic matter in soil, from fuel used during operations such as cultivation, spraying and harvesting, in transport and manufacture of materials and products, and in food processing and packaging. One of the main conclusions is that nitrogen (N) fertiliser production is the dominant source of CO_2 emissions, so any saving in N inputs through improved N-use efficiency will make a contribution to climate change mitigation. An EU project coordinated by Rothamsted (SUSTAIN) is targeted at modifying wheat for improved N-use efficiency. A decision support system for assisting with advice on N fertiliser application (SUNDIAL) can be used to decrease wastage of fertiliser N through better accounting of N coming from soil and better timing of application in relation to crop requirements.

- Nitrous oxide (N_2O) is a powerful greenhouse gas, each molecule being about 300 times more potent than CO_2. Research is in progress to investigate management practices that minimise N_2O production. There is some evidence that although minimum tillage may decrease overall CO_2 emissions it may increase N_2O emission.

- Bacteria in wet soils can produce methane (CH_4), a greenhouse gas about 20 times more potent than CO_2. Under well drained conditions other bacteria in soil destroy methane in the atmosphere, produced from other sources, thus decreasing global warming. Research is in progress to identify the bacteria involved and devise management practices that make best use of this knowledge.

2. Lock up CO_2 - Carbon (C) sequestration in soil and vegetation.

- Research at Rothamsted has demonstrated that certain conversions of agricultural land will sequester C, e.g. creation of new forests or the expansion of field margins. Changes in agricultural operations such as tillage or the management of crop residues or manures may also help (see Box 4). However the impact of these changes on trace gases, especially N_2O and CH_4 must also be considered. By extrapolating data from long-term experiments, prediction of the potential for land use change options to mitigate the overall effect on all greenhouse gases can be estimated. This can be used to guide decisions on land-use change and agri-environment schemes being devised as part of Common Agricultural Policy (CAP) reform. The Rothamsted Carbon Model (Roth C) that simulates the dynamics of organic C in soil is currently being used as part of a Defra project coordinated by the Centre for Ecology and Hydrology (CEH) for reporting national C budgets for the United Nations Framework Convention on Climate Change (UNFCCC). In an international project funded by the United Nations Environment Programme (UNEP) the models are being used together with data from four regions of the world (Brazil, Kenya, Jordan, India) to study the potential for sequestration through land-use change and also the risk of further release of CO_2 from soils.

3. Replace fossil fuel with renewable bioenergy crops.

- The mitigation potential of the replacement of fossil fuels with biomass crops is significant. The Royal Commission on Environmental Pollution estimated that up to 15% of UK electricity could be generated in this way, though figures in the range of 3% to 10% may be more realistic. Crops, or their residues, can also be used to produce liquid transport fuels such as bioethanol or biodiesel. The aim with biomass crops is to produce the largest amounts of biomass possible with the minimum inputs. Rothamsted is working on a number of potential dedicated biomass crops including willow and perennial grasses.

MITIGATION

Willow.

Rothamsted hosts the national willow collection. The focus has been a breeding programme to maximise yield and incorporate pest and disease resistance, particularly willow rust. By studying the genetic diversity available in the willow collection using molecular markers, it is possible to select those traits of most value through a targeted breeding programme and through widening the genetic base of varieties available to growers. Cultivation practices including planting mixtures of varieties are also being investigated as an additional mechanism for reducing inputs and maximising production potential.

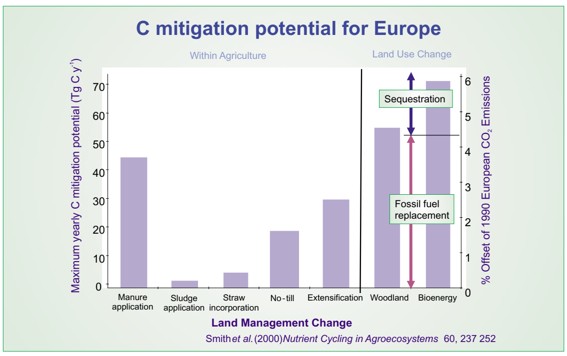
Perennial grasses, e.g. miscanthus, switchgrass and reed canary grass.

Yield potential and sustainability through optimising management practices in different parts of the UK and Europe have been measured over a number of years. This has lead to the selection of the most suitable species and varieties for particular climate and soil conditions and to the definition of appropriate agronomic practices (including establishment, harvest timing and fertiliser requirements) for the efficient cultivation of these new crops. The assessment of the impact of these crops on the environment, particularly biodiversity and local rural economies will enable decisions to be taken regarding their cultivation within the UK farming landscape. Work has been carried out in collaboration with CEH regarding the impact of these crops on water resources.

- Rothamsted contributes to a large programme on bioenergy crops in the SUPERGEN initiative funded by the Engineering and Physical Sciences Research Council (EPSRC). In this project the impact of growing conditions on the combustion properties of crops is being investigated. The aim is to achieve maximum energy yield and minimise difficulties for processing facilities such as build up of ash.

Box 4. Mitigation potential of land management practices for Europe

Some changes in the management of land can help in cutting overall emissions of greenhouse gases. This is mainly by causing some C, from CO_2 in the atmosphere, to be locked up ("sequestered") in soil or vegetation. Soils that have been in arable cropping for a long period usually have a low content of organic C, so they offer scope for additional sequestration. With soils already high in C, such as those under old grassland or woodland and peat soils there is little extra capacity for additional C storage. With these soils it is important to maintain them in their current state.



The diagram shows the estimated annual mitigation potentially achievable from a number of management change scenarios, if applied across the whole of Europe. Values are expressed in the right hand axis relative to European CO_2 emissions in 1990 because this is the baseline year for accounting under the Kyoto Protocol. The first group of scenarios involves changes to the management of existing agricultural land. The second group involves the conversion of set-aside land (about 10% of arable land in the EU) to other uses. If land is used for growing bioenergy crops, the main cause of mitigation is the replacement of CO_2 from burning fossil fuels. Accumulation of extra organic C in soil under these crops is thought to be an additional benefit. The values for C mitigation shown include an estimate of the impact of the management change on emissions of N_2O. Increases as well as decreases can occur, so in some cases the C benefit is less than would be the case if only C were considered. However, more research is required to obtain reliable data on changes in N_2O emissions.

Further reading

Delivering the Essentials of Life: Defra's five year strategy (http://www.defra.gov.uk/corporate/5year-strategy/index.htm)

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