Climate change and consequences for agriculture

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Background

The studies on anthropogenic climate change performed in the last decade over Europe indicate consistent increases in projected temperature and different patterns of precipitation with widespread increases in northern Europe and rather small decreases over southern Europe (Alcamo et al., 2007). These changes in climate patterns are expected to greatly affect all components of the European agricultural ecosystems (e.g. crop suitability, yield an production, livestock, etc.).

Climate change is expected to affect agriculture very differently in different parts of the world (Parry et al., 2004). The resulting effects depend on current climatic and soil conditions, the direction of change and the availability of resources and infrastructure to cope with change. There is a large variation across the European continent in climatic conditions, soils, land use, infrastructure, political and economic conditions (Bouma et al., 1998). These differences are expected also to greatly influence the responsiveness to climatic change (Olesen and Bindi, 2002).

The economic consequences may be considerable on a global scale, and it has recently been estimated that the costs of climate change greatly exceed the costs associated with reducing greenhouse gas emissions (Stern, 2006). However, the emissions and the related consequences occur on very different timescales, making economic evaluations difficult not only due to uncertainties in predictions of climate changes and impacts, but also due to uncertainties in the costs of technologies to mitigate change. Taking proper action on mitigating and adapting to climate change also requires long lead times, which have impacts on the way related policies are devised and implemented.

Agricultural systems are not only sensitive to climate change; they are also among the main contributors to global warming through emissions of several greenhouse gases (primarily CO_2, methane (CH_4) and nitrous oxide (N_2O)). Currently, agricultural activities are among the major contributors to total EU greenhouse gas emissions (GHG) (up to 9% in 2000) (EEA, 2002). Thus, mitigation strategies will also be required within the agricultural sector to comply with the reduction targets of the Kyoto Protocol.

Emissions scenarios and land use change

The evaluation of climate change is usually based on simulations with global climate models (GCM) for the IPCC emissions scenarios (SRES scenarios), which describe very different socio-economic futures (Houghton et al., 2001). The SRES scenarios are grouped into four different categories (A1: world markets, A2: provincial enterprise, B1: global sustainability, B2: local stewardship). The grouping relies upon two orthogonal axes, representing social values (ranging from consumerist to conservationist) and level of governance (ranging from local to global), respectively.

Temporally and spatially explicit future scenarios of European land use have been developed for the four core SRES scenarios (Schröter et al., 2005; Rounsevell et al., 2006). These scenarios are based on supply/demand models of market forces, rural development and environmental policies based on qualitative descriptions in the scenarios and the characteristics of the European landscapes.

The results show large declines in agricultural land area resulting from the assumptions about future crop yield with respect to changes in demand for agricultural commodities (Rounsevell et al., 2005). The scenarios showed decreases in European cropland for 2080 that ranged from 28% to 47% (Rounsevell et al., 2005). The reduction in European grassland for 2080 ranged from 6% to 58%. This decline in agricultural area will make land resources available for other uses such as biofuel production and nature reserves.

Scenarios of climate change

Most of the recent global climate model (GCM) experiment results are based on coupled ocean-atmosphere models (AO-GCM). The main modelling uncertainties stem from the contrasting behaviour of different climate models in their simulation of global and regional climate change. These uncertainties are largely a function of the relative coarse resolution of the models and the different schemes employed to represent important processes in the atmosphere, biosphere and ocean. There has recently been an increased effort in downscaling the coarse GCM results using regional climate models with spatial resolutions of 50 km or less (Christensen and Christensen, 2007). This has led to improved quality in projections of regional climate changes in Europe (Figs. 1 and 2).

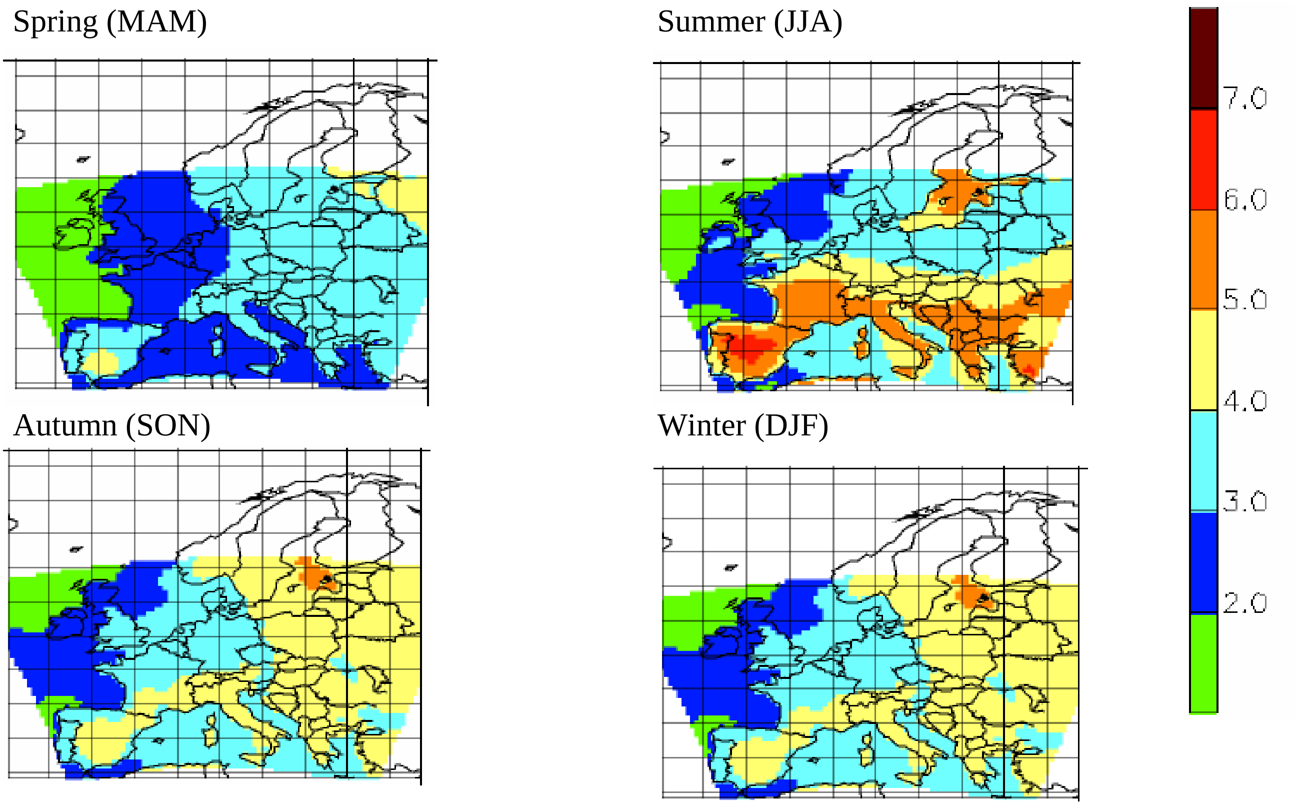

Fig. 1. Projected changes in mean temperature (°C) over Europe for each of the four seasons for 2071-2100 for the A2 emission scenario estimated by a range of RCMs driven by the HadAM3 GCM (Christensen and Christensen, 2007).

The results of GCM simulations based on the SRES scenarios indicate that annual temperatures over Europe warm at a rate of between 0.1°C decade^{-1} and 0.4°C decade^{-1}. The projected temperature increases are highest in Northern Europe during winter and highest in Southern Europe during summer. The general pattern of future changes in annual precipitation over Europe is for widespread increases in northern Europe (between +1 and +2 per cent decade^{-1}) and rather small decreases over southern Europe (maximum -1 per cent decade^{-1}).

There are marked seasonal and regional differences in the projected changes (Figs. 1 and 2). The warming is greatest over Eastern Europe during winter and over Western and Southern Europe in June-July-August (Giorgi et al., 2004). A very large increase in summer temperatures is projected in the southwestern parts of Europe (exceeds 6 °C in parts of France and the Iberian Peninsula) by the end of the 21st century under the A2 scenario (Fig. 1).

Generally for all scenarios, the mean annual precipitation increases in Northern Europe and decreases further south (Fig. 2). But the change in precipitation varies substantially from season to season and across regions. There is a projected increase in winter precipitation in Northern and Central Europe, whereas there is a substantial decrease in summer precipitation in Southern and Central Europe, and to a lesser extent in Northern Europe.

Recent results indicate that variability in temperature and rainfall may increase considerably over large parts of Central Europe (Christensen and Christensen, 2002; Schär et al., 2004). Indeed heat waves and droughts similar to the 2003 situation may become the norm in central and southern Europe by the end of the 21st century (Beniston and Diaz, 2004). This heat wave led to substantial and widespread reductions in farm income (Fink et al., 2004; Ciais et al., 2005).

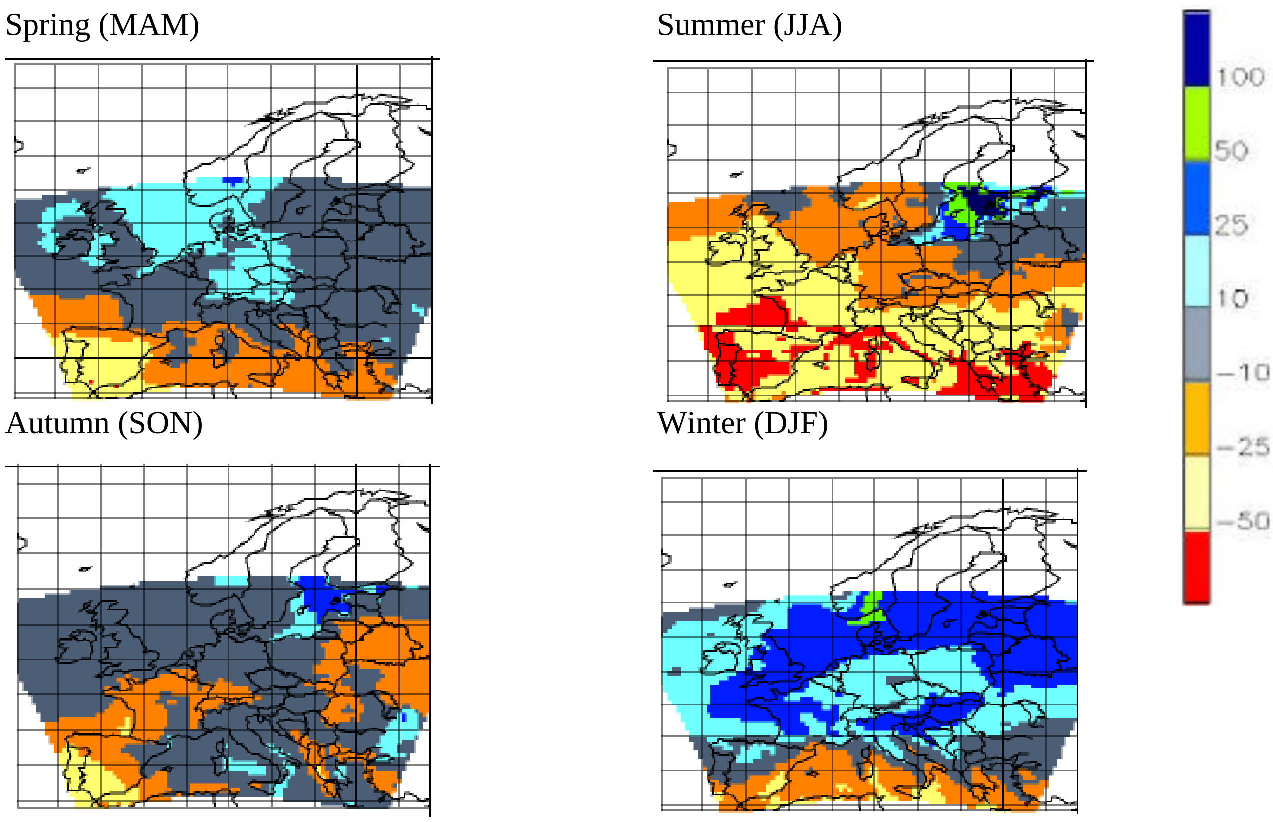

Fig. 2. Projected changes in mean rainfall (% change) over Europe for each of the four seasons for 2071-2100 for the A2 emission scenario estimated by a range of RCMs driven by the HadAM3 GCM (Christensen and Christensen, 2007).

Agricultural impacts of climate change

Biophysical processes of agroecosystems are strongly affected by environmental conditions. The projected increase in greenhouse gases will affect agroecosystems either directly (primarily by increasing photosynthesis at higher CO_2 (Drake et al., 1997)) or indirectly via effects on climate (e.g. temperature and rainfall affecting several aspects of ecosystem functioning (Olesen and Bindi, 2002)).

Crop suitability and crop production

Climate-related increases in crop yields are only expected in Northern Europe, while the largest reductions are expected around the Mediterranean and in the Southwest Balkans and in the South of European Russia (Olesen and Bindi, 2002; Maracchi et al., 2005; Alcamo et al., 2006). In Southern Europe, particularly large decreases in yield are expected for spring-sown crops (e.g. maize, sunflower and soybeans) (Audsley et al., 2006; Moriondo et al., 2007). Whilst, on autumn-sown crops (e.g. winter and spring wheat) the impact is more geographically variable, yield is expected to strongly decrease in the most Southern areas and increase in the northern or cooler areas (e.g. northern parts of Portugal and Spain) (Olesen et al., 2007; Moriondo et al., 2007; Santos et al., 2002). However, these results vary between SRES scenarios and climate models (Olesen et al., 2007).

Some crops that currently grow mostly in Southern Europe (e.g. maize, sunflower and soybeans) will become more suitable further north or in higher altitude areas in the south (Audsley et al., 2006). The projections for a range of SRES scenarios show a 30 to 50% increase in suitable area for grain maize production in Europe by the end of the 21st century, including Ireland, Scotland, Southern Sweden and Finland (Hildén et al., 2005; Olesen et al., 2007). Moreover, by 2050 energy crops show a northward expansion in potential cropping area, but a reduction in suitability in Southern Europe (Schröter et al., 2005).

The technological development (new varieties, better cropping practices etc.) is expected to far outweigh the effects of climate change (Ewert et al., 2005). When advances in technologies are considered in wheat simulations the resulting increases in crop productivity could range between 25% and 163% depending on the time slice and scenario.

Crop protection

Changes in climatic suitability will lead to invasion of weed, pest and diseases adapted to warmer climatic conditions (Baker et al., 2000). The speed at which such invasive species will occur depends on the change of climatic change, the dispersal rate of the species and on measures taken to combat non-indigenous species (Anderson et al., 2004). The dispersal rate of pests and diseases are most often so high that their geographical extent is determined by the range of climatic suitability (Baker et al., 2000). The Colorado beetle, the European cornborer, the Mediterranean fruit fly and karnal bunt are examples of pests and diseases, which are expected to have a considerable northward expansion in Europe under climatic warming.

Livestock

Climate and CO_2 effects influence livestock systems through both availability and price of feed and through direct effects on animal health, growth, and reproduction. Effects of climate change on grasslands will have direct effects on livestock living on these pastures. Results from a simulation study suggest that the impact on milk production for grass-based systems in Scotland would vary depending on the locality (Topp and Doyle, 1996).

For animals, higher temperatures results in greater water consumption and more frequent heat stress (Turnpenny et al., 2001), which causes declines in physical activities, including eating and grazing. Maintenance requirements are increased and voluntary feed intake is decreased at the expense of growth, milk production and reproduction (Mader et al., 2002). Livestock production may therefore be negatively affected in the warm months of the currently warm regions of Europe (Klinedienst et al., 1993; Mader and Davis, 2004). Warming during the cold period for cooler regions may on the other hand be beneficial due to reduced feed requirements, increased survival, and lower energy costs. Impacts will probably be minor for intensive livestock systems (e.g. confined dairy, poultry and pig systems) because climate is controlled to some degree. Increasing temperatures may also increase the risk of some livestock diseases.

Environmental impact

Environmental impacts of agriculture under a changing climate are becoming more and more important. In particular, the role of nitrate leaching on the quality of aquifers, rivers and estuaries is globally recognized (Galloway, 2004). A warming is expected to increase soil organic matter turnover provided sufficient water is available, and experiment have shown that increases in net N mineralisation rates may be considerably higher than the increases in soil respiration (Rustad et al., 2001).

Projections made at European level for winter wheat showed for the 2071-2100 time-slice that decreases in N-leaching predominate over large parts of Eastern Europe and some smaller areas in Spain, whereas increases occur in the UK and in smaller regions over many other parts of Europe (Olesen et al., 2007). This in combination with longer growing seasons for the aquatic ecosystems would likely lead to higher risk of algal blooms and increased growth of toxic cyanobacteria in lakes (Moss et al., 2003; Eisenreich, 2005).

The climate change scenarios could also lead to increases in GHG emissions from agriculture. Increasing temperatures will speed decomposition where soil moisture allows (Davidson and Janssens, 2006), so direct climate impacts on cropland and grassland soils will tend to decrease SOC stocks for Europe as a whole (Smith et al., 2006).

Extreme events and climatic variability

Crops often respond nonlinearly to changes in their growing conditions and have threshold responses, which greatly increases the importance of climatic variability and frequency of extreme events for yield, yield stability and quality (Porter and Semenov, 2005). Thus an increase in temperature variability will increase yield variability and also result in a reduction in mean yield (Trnka et al., 2004). Therefore the projected increases in temperature variability over Central and Southern Europe (Schär et al., 2004) may have severe impacts on the agricultural production in this region. Similarly, changes in rainfall variability (too little or too much) may have negative effects for crop yield and quality.

Adaptation to climate change

To avoid or at least reduce negative effects and exploit possible positive effects, several agronomic adaptation strategies for agriculture have been suggested. Studies on the adaptation of farming systems to climate change need to consider all the agronomic decisions made at the farm level (Kaiser et al., 1993). Economic considerations are very important in this context (Antle, 1996). Results of farm level analyses on the impact and adaptation to climate change have generally shown a large reduction in adverse impacts when adaptation is fully implemented (Mendelsohn and Dinar, 1999). This often implies changes in agricultural land use (Darwin, 2004; Rounsevell et al., 2006).

The agronomic strategies available include both short-term adjustments and long-term adaptations. (Easterling, 1996). Most of the short-term adjustments in involve relatively little cost to the farmers, since they are often just extensions of the existing schemes to deal with climatic variability. However, long-term adaptations and changes in farming systems, institutions, land use etc. may carry considerably higher costs. Some of these costs can be reduced, if timely action is taken (Stern, 2006). However, there is a need at regional, national and international levels to analyse the needs for such planned adaptation options, their costs and their time horizon.

Most adaptations to climate change are triggered by extreme or rare weather events, in particular when these events become recurrent. It is therefore important to be aware not only of changes in mean climatic conditions, but also of changes in climatic variability and extreme weather events.

Greenhouse gas emissions from agriculture

Agriculture contributed about 9% to EU15 GHG emissions in 2002, excluding changes in soil carbon stocks (EEA, 2005). A major part of these emissions originate from methane (CH_4) and nitrous oxide (N_2O) from livestock, manures and soils.

The intensive carbon and nitrogen cycling on livestock farms may cause these farms to be particularly large sources of both methane and nitrous oxide emissions (Oenema et al., 2005; Olesen et al., 2006). A large proportion of global (and European) methane and nitrous oxide emissions originate from livestock and the manure produced (Hogan et al., 1991; Lelieveld et al., 1998; Mosier et al., 1998). However, the emissions are greatly affected by both environmental conditions and management, and there most likely is a considerable scope for reducing emissions by improving management and through introduction of new technologies, in particular in feeding and handling of manures (Monteny et al., 2006).

For arable land the most important greenhouse gasses are N_2O and CO_2 (Six et al., 2004) and management practices highly affects the emissions (Robertson et al., 2000; Desjardins et al., 2005). The CO_2 fluxes are affected through the carbon inputs and through tillage, which affect the soil carbon turnover rate by affecting soil organic matter protection. The N_2O fluxes are primarily affected through nitrogen inputs, with excessive N inputs giving particularly large emissions (Chatskikh et al., 2005).

Strategies for reducing emissions from mineral soils have to focus on carbon sequestration, reducing fossil fuel consumption and at the same time reducing N_2O emissions (Freibauer et al., 2004). Carbon sequestration may be accomplished by increasing the carbon input to the soil or by decreasing the turnover rate of organic matter. Emissions of N_2O are primarily related to application of animal manure and mineral fertilizers, nitrate leaching and turnover of residues. Reduced tillage is considered to be one of the most effective management practices for carbon sequestration on arable land (Desjardins et al., 2005). In a comprehensive review, Alvarez (2005) estimated that direct drilling with residue retainment resulted in a long-term (20-30 years) carbon sequestration of 12 t C ha^{-1}.

Emissions of CO_2 are particularly large from cultivation of organic soils associated with the drainage of such soils (IPCC, 1997), and an effective abatement strategy could be to convert some of these drained peatlands back to wetlands would significantly reduce CO_2 emissions although methane emissions may increase (Merbach et al., 1996).

Mitigation measures in agriculture

The Kyoto Protocol under the UN Framework Convention on Climate Change commits industrialised signatory countries to reduce their emissions to below the level in 1990, and the EU15 countries have a common reduction target for 2008-2012 of 8%. From 1990 to 2003 EU25 GHG emissions decreased by 5.5%, but emissions in the transport sector grew 23% in EU15 (EEA, 2005). There is therefore a continued need to reduce emissions in other sectors, including agriculture.

The design of future agricultural production systems and agricultural policies need to consider the need for reductions in GHG emissions. The potential for changes in EU15 agricultural land use to reduce net emissions of CO_2 and N_2O have been estimated at about 8% of the total GHG emissions in these countries (Smith et al., 2000, 2001). However, realistically agricultural soils may be able to sequester less than a fifth of this potential by the Kyoto commitment period in 2008-2012 (Freibauer et al., 2004).

There a number of possibilities for reducing emissions of methane and nitrous oxide emissions through improving management practices and introducing new technologies (Schils et al., 2006; Weiske et al., 2006). Advantage should be taken of the fact that some of the measures simultaneously may reduce the net emission of several greenhouse gases. Such measures may be combined with land management measures to also sequester soil carbon. A number of options exist to reduce or even reverse the emissions of greenhouse gases from agriculture. These options can be grouped according to gases and modes of action:

- Reduction in direct energy use (fuel, electricity, heating) and indirect energy use (e.g. fertilisers).
- Substitution of fossil energy through biofuel production and anaerobic digestion of manure etc (Farrell et al., 2006).
- Increased carbon storage in soils through higher inputs (straw incorporation, manure, cover crops, grass in rotation) and reduced soil organic matter turnover (no-till) (Robertson et al., 2000; Alvarez, 2005; Smith et al., 2000, 2001).
- Reduced methane emissions through improved diets for ruminant animals and through improved handling and storage of manures (including anaerobic digestion) (Moss et al., 2000; Sommer et al. 2004; Monteny et al., 2006).
- Reduced nitrous oxide emissions through tighter nitrogen cycling and through technical measures to reduce emissions from manure stores and from manures and fertilisers applied to soil (Smith et al., 1997; Monteny et al., 2006).

In general, most of these management methods and technologies need to be further developed, if they are to be applied in a cost-effective manner. However, some of these methods provide additional social and environmental benefits, which need to the factored in (Freibauer et al., 2004).

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