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Adaptation of Crops and Cropping Systems to Climate Change
Book of abstracts
Arranged by NJF section II, Crop Science
Dalum Landbrugsskole
Odense, Denmark November 7-8, 2005

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Contents

Regional climate change scenarios for Europe

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Projections of future climate change from numerical models have existed for three decades, but these remain deficient both in regional detail and in the characterisation of their uncertainty. The assessment of potential regional impacts of climate change has, to date, generally relied on data from coarse resolution Atmosphere-Ocean General Circulation Models (AOGCMs), which do not resolve spatial scales of less than ~300km (Mearns *et al.*, 2001). Such AOGCMs do not provide information on the spatial structure of temperature and precipitation in areas of complex topography and land use distribution (*e.g.* the Alps, the Mediterranean, Scandinavia). Their depiction of regional and local atmospheric circulations (*e.g.* narrow jet cores, mesoscale convective systems, sea-breeze type circulations) and representation of processes at high frequency temporal scales (*e.g.* precipitation frequency and intensity, surface wind variability) are likewise insufficient to provide accurate information.

In order to address such inadequacies on a European scale, an interdisciplinary project entitled PRUDENCE (Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects) was undertaken during the period November 2001 – October 2004 by a team of 21 European research groups based in 9 countries with funding from the European Commission. Its primary objectives were to provide high-resolution climate change scenarios for Europe at the end of the 21st century using dynamical downscaling methods with climate models, and to apply and use these scenarios to a series of different impacts models.

While European collaboration on climate modelling and impacts analyses has been performed for more than a decade based on various EU research and development initiatives, rising to this challenge required a truly international and interdisciplinary effort. In order to provide practically useful measures of the uncertainty in climate projections, the uncertainty space of emission scenarios, model parameterisations, model resolution and natural variability needed to be probed *en masse*. This required co-ordinated involvement from as many climate-modelling groups as possible. PRUDENCE succeeded in designing, executing, analysing, and synthesising European high-resolution climate change simulations involving four high-resolution Atmospheric General Circulation Models (AGCMs) and eight Regional Climate Models (RCMs). All RCMs were run at horizontal spatial scales of ~50 km though a few were also run at ~20km and one even at ~10km. The "open doors" policy of the project in encouraging the participation of other research groups from Europe and beyond, added two more European RCMs to this list, funded from non-EC sources. Furthermore, all of the climate model results have now been made freely available to the general research community.[1]

The urgent need for improved numerical models and scenarios becomes particularly apparent when considering extreme weather events. The importance of extreme events for the European economy and environment has been demonstrated in dramatic fashion during the last few years with a number of serious events affecting the European continent, including major flooding events in central Europe (May 1999 and August 2002), the southern Alps (October,

[1] http://prudence.dmi.dk

2000), and the UK (October/November 2000), severe storms accompanied by avalanches in the Alps (February 1999), storm surges in the North Sea (December 1999) and major wind damage in central Europe (December 1999) and Scandinavia (January 2005); and the un-precedented summer heat wave affecting large areas of western and central Europe in 2003. Each of these events caused fatalities and tremendous capital damage.

It is anticipated that climate change will affect the frequency and magnitude of extreme events through an intensified hydrological cycle (Stocker *et al.*, 2001). Major limitations to model-based studies of these phenomena in the past have been the lack of appropriate spatial resolution (and a consequent smearing out of the character of sub-grid-scale events), the lack of sufficiently long integrations (which drastically reduces the statistical significance of projections), and the lack of co-ordination between different modelling groups (which led to unresolved differences between different studies). These three issues have all been thoroughly addressed in PRUDENCE, using state-of-the-art climate models at a variety of (high) resolutions, a co-ordinated project layout that also addresses critical aspects of uncertainty, and the application of impact models and impact assessment methodologies to provide a link to the needs of society and the economy. Furthermore, model-based results generated in PRUDENCE have already provided scientific background information in the aftermath of some of the above-mentioned extreme weather events (*e.g.* Christensen and Christensen, 2003; Schär *et al.*, 2004).

Christensen, J.H., O.B. Christensen, 2003: Severe summertime flooding in Europe. *Nature*, **421**, 805-806.

Mearns, L.O., M. Hulme, T.R. Carter, R. Leemans, M. Lal, P.H. Whetton, 2001: Climate scenario development. Chapter 13 in: Houghton, J. *et al.* (eds.). *Climate Change 2001: The Scientific Basis*. Intergovernmental Panel on Climate Change, Cambridge University Press, pp. 739-768.

Schär C, P.L., Vidale, D. Luthi, C. Frei, C. Häberli, M.A. Liniger, C. Appenzeller, 2004: The role of increasing temperature variability in European summer heatwaves. *Nature*, **427**, 332-336.

Stocker, T.F., G.K.C. Clarke, H. le Treut, R.S. Lindzen, V.P. Meleshko, R.K. Mugara, T.N. Palmer, R.T. Pierrehumbert, P.J. Sellers, K.E. Trenberth, J. Willebrand, 2001: Physical Climate Processes and Feedbacks. Chapter 7 in: Houghton, J. *et al*. (eds.). *Climate Change 2001: The Scientific Basis*. Intergovernmental Panel on Climate Change, Cambridge University Press, pp. 417-470.

Influence of elevated CO_2 and temperature on autumn growth and frost hardiness in winter wheat

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The CO_2 concentration is expected to increase from 370 to about 550µmol mol^{-1} accompanied by a temperature increase of 2-3°C within the next 50 years in Norway. A wetter and more variable weather during the winter including frequent fluctuations around zero degrees Celsius may cause severe injuries to crops like perennial grasses and winter wheat. A research programme financed by the Norwegian Research Council over five years was started during 2004 in order to evaluate potential future effects by such a climate change: “Climate change effects on winter survival of perennial forage crops and winter wheat and on plant diseases and weed growth and control at high latitudes”.

This paper presents some results on the effect of increasing the CO_2 to about 550µmol mol^{-1} and the temperature by 2.0-2.5°C on the growth of two cultivars of winter wheat during the autumn period (September-November) in 2004. The experiment was conducted in 16 “field chambers” (6 m^2 ground area) consisting of 2.0 m high transparent plastic foil walls without roof. Half of the chambers were supplied with CO_2 gas and half of the chambers with electrical heaters (4.2 kW). Fans blew the air from the outside air into the chambers through perforated tubes, and CO_2 and heat were added in order to obtain the desired “climate change”.

Increasing the temperature significantly increased the dry weight of winter wheat during the autumn. However, CO_2 enrichment had small effects. The frost tolerance and carbohydrate status (sugars and fructosans) of the plants were tested in November, December, January and March. While increased temperature decreased frost tolerance, small effects were found by CO_2 concentration.

The effect of CO_2 concentration on biomass will be discussed in relation to recent results on the effect of CO_2 on photosynthesis and photorespiration under different temperature and light conditions typical for Nordic conditions.

Controlled environmental experiments were carried out the spring 2005 in order to study the relationship between light/temperature and the development of frost hardiness. The relationship between carbohydrate status and frost hardiness will be discussed based on analysis of plant material with different frost tolerance.

Increased temperature and CO_2 in a grazed field – what did we learn?

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A semi-natural grassland, used for horse grazing was subjected to increased temperature and CO_2 concentration during the growing seasons of 1995-2000. Above-ground plant production and vegetation composition were monitored (Marissink, 2002) as well as root dynamics, root decomposability and soil carbon balances (Sindhöj, 2001).

In this paper we discuss the lessons learned and some of the problems and solutions relevant to field experiments with increased CO_2 and temperature, and how to extrapolate to Nordic and global future conditions.

Marissink, M. (2002). *Elevated Carbon Dioxide in a Semi-Natural Grassland: Plant Production and Vegetation Composition during six years*. PhD thesis, SLU.

Sindhöj, E. (2001). *Elevated Atmospheric CO_2 in a semi-Natural Grassland: Root Dynamics, Decomposition and soil C balances*. PhD thesis, SLU.

An Integrated Assessment approach to investigate options for mitigation and adaptation to climate change at the farm-scale

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Future climate conditions are just one of a range of drivers of change, such as the economic and policy environment, that will influence strategic planning and decision making at the farm-scale. New management practises will need to achieve a range of multiple-objectives, including greenhouse gas (GHG) emissions mitigation, sustainability and still ensure farm-scale financial viability. Therefore measures to change the land use composition and associated management that make up a farm enterprise will need to address issues beyond just those related to climate change impacts. In order to address this, a holistic Integrated Assessment (IA) approach is required, combining simulation modelling with deliberative processes involving decision makers and other stakeholders. This has the potential to generate credible and relevant assessments of climate change impacts on farming-systems and identify potential adaptation and amelioration strategies. The components that make up the Integrated Modelling Framework (IMF) (LADSS 2005), the primary tool used in the IA, and the overall IA approach (Rivington *et al.*, in press), are detailed. Previous studies have shown that the quality of input weather data can have a significant impact on the quality of land use model estimates (Rivington *et al*., 2003). Therefore, a first stage in the IA process is to assess and communicate the uncertainty that exists in future climate prediction data, and determine how such uncertainty is propagated through simulation modelling. Without this stage it is argued that interpretation of projected climate change impacts and identification of adaptation strategies becomes infeasible. This is illustrated by a case-study application of the IMF to a mixed cattle and sheep grass grazing and cereal for fodder farm in Scotland. Here, within the IMF, grass and cereals are modelled using the CropSyst cropping systems model (Stöckle *et al.*, 2003), connected to a bespoke livestock system model. An accounting framework permits appraisal of the labour and resources, financial and environmental costs and benefits of changes due to an altered climate. Fundamentally, however, it is shown that although this IA and IMF provides a valuable tool for developing adaptation and amelioration strategies, the substantial uncertainty in climate prediction data poses a serious restriction on our ability to make reliable climate change impact assessments.

LADSS, 2005. Land Allocation Decision Support System. http://www.macaulay.ac.uk/LADSS.shtml

Rivington, M., Matthews, K.B. and Buchan, K., 2003. Quantifying the uncertainty in spatially-explicit land-use model predictions arising from the use of substituted climate data. In: *Proc. of MODSIM 2003 Int. Congress on Modelling and Simulation: Integrative modelling of biophysical, social and economic systems for resource management solutions*. 14-17 July 2003, Townsville, Australia. Vol. **4**, 1528-1533.

Rivington, M., Matthews, K.B., Bellocchi, G., Buchan, K., Stöckle, C.O. and Donatelli, M. (in press). An Integrated Assessment approach to conduct analyses of climate change impacts on whole-farm systems. Environmental and Modelling Software.

Stöckle, C.O., M. Donatelli, and R. Nelson., 2003. CropSyst, a cropping systems simulation model. *European Journal of Agronomy* **18**, 289-307.

A methodology for assessing economic and environmental effects from climate change

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This presentation concerns a methodology for analyzing the effect of climate change on agriculture. Such a methodology must take into account that agricultural production and emissions are effects of a large set of interacting processes, cover many different substances, and may vary substantially due to shifts in natural and economic conditions. Thus, the methodology must both cover the specificities of the different processes/disciplines involved and foster integration across these in a consistent way. The methodology is implemented in a modeling structure called ECECMOD, and has been used for analyzing the effect of policies focused on reducing pollution from Norwegian agriculture under current climate conditions. The simulated practices and emissions were well in accordance with observations (Vatn et al., *in press*).

The current version of ECECMOD (2.0) covers the following environmental indicators: losses of nitrates, organically bound N, ammonia, soil, and phosphorous, as well as the amount of pesticides used. Changes in soil organic N and C can also be evaluated. Model farmers are assumed to maximize expected profits, and based on this, crop selection, tillage practices, fertilization rates, manure handling, springtime management and harvesting are simulated.

Weather is an important input to the modeling structure, and ECECMOD is therefore well suited for analyzing climate change. Downscaled simulations from global circulation models have been used as input to the modeling system (Bakken *et al*., 2004; Rørstad, 2004). The results from a preliminary simulation indicated that yields will increase, but due to unfavorable weather conditions at the time of harvest, income may not increase much. The results also showed that it is important to validate the climate scenarios.

Bakken, L.R, Bleken, M.A., Haugen, L.E., Lundekvam, H. and Rørstad, P.K. (2004). *Impacts of global change on agroecosystems, preliminary analyses for Southeast Norway: general summary*. EACC-report no 1/2004 Agricultural University of Norway. ISBN 82-483-0029-3, ISSN 1500-3469 (http://www.umb.no/eacc).

Rørstad, P.K. (2004). *Impacts of global change on agroecosystems, preliminary analyses for Southeast Norway: Economic optimal N-fertilization and gross margin.* EACC-report no 7/2004 Agricultural University of Norway. ISBN 82-483-0036-6, ISSN 1500-3469 (http://www.umb.no/eacc).

Vatn, A., Bakken, L., Bleken, M.A., Baadshaug, O.H., Fykse, H., Haugen, L.E., Lundekvam, H., Morken, J., Romstad, E., Rørstad, P.K., Skjelvåg, A.O. and Sogn, T. (in press). A Methodology for Integrated Economic and Environmental Analysis of Pollution from Agriculture. *Agricultural Systems*.

Adaptation in the wine industry: Lessons from the Okanagan Valley, B.C., Canada

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Adaptation is necessary for farmers to reduce the negative effects of climate change or to seize opportunities from it. In the climate change field adaptation has been considered through climate impact assessments, which focus on climatic stimuli, model agronomic impacts and assume adaptation options. A complementary approach, vulnerability assessments, seeks to understand how producers currently manage risk and what factors facilitate or constrain adaptation. This study of the wine sector in B.C., Canada employs a "vulnerability approach" which uses ethnographic methods to understand the risks to which producers are sensitive and their ability to adapt to these risks. The results of the study suggest that climatic stimuli are one source of risk among many, and that the presence of these other risks influences how producers adapt to or manage climatic risks at the farm level. To respond to seasonal weather conditions producers employ primarily tactical, farm management techniques, such as dropping crop to enhance the quality of the grape or making crop insurance claims. Longer-term, strategic adaptations, however, require the consideration of many other factors, particularly the market. While producers considered weather a significant risk for their operation, most were unconcerned with climate change. This suggests that any adaptations to future climate change will likely occur as adaptations to seasonal weather variability and will be influenced by various social, political, and economic variables.

Effects of observed climate fluctuation on wheat flowering as simulated by the European Crop Growth Monitoring System (CGMS)

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The combined effects of warming and precipitation change on crops yields are expected to vary by crop, location and magnitude of warming (Adams et al., 1998; van Diepen, 2003). The aim of this study was focused on the simulated phenological response of WOFOST model (Supit et al., 1994) from CGMS (Crop Growth Monitoring System) as influenced by climate changes from Europe.

The occurrence periods of beginning/ending of flowering and maturity were simulated basing on a 28 years archive (1975-2003) of interpolated meteorological observations at continental level and on their effects on crop growth as from the CGMS simulation model. The core of the CGMS model is WOFOST (World Food Studies) and is part of the Pan European Crop Growth Monitoring System run operationally in the AGRIFISH Unit in the IPSC of the JRC. Using as steering variable only the true observed climate and keeping unchanged the other input variables of the simulation (hypothesis of no changes in varieties, technology and other factors), all of the three phenological events considered in this experience showed significantly earlier occurrence in the 1988-2002 period than in the years before 1988 defining a border-line of climate effect on wheat (before and after the 1990's).

According with the simulation of the development stage in CGMS-WOFOST, an earlier occurrence of a given development stage is strictly related to the increase of the mean temperature inducing a quicker fulfillment of the thermal time requirements for that stage. The results were mapped using the European grid reference system of 50x50 km. The most evident reduction of the required time (in 10-day periods) for the beginning of flowering (from -0.7 and up to -1.4 days/year; which gives from 20 to 40 days of anticipation cumulated in the last 28 years) was observed along the Channel axis from Dorset to Norfolk and from Northern-France to Netherlands. The same reduction were noticed in other different areas; Centre England, Northern Spain, Centre France, South-Western Germany and Northern Italy. A similar situation was noticed for the other two phenological events; end of flowering and maturity. Changes in Central-Eastern Europe were less marked excepting an area concerning eastern Poland, and Belarus –Ukraine border.

Adams, R.M., Hurd, B., Lenhardt, S. and Leary N. (1998). The effects of global warming on agriculture. An interpretative review. *Journal of Climatic Change* **11**, 19-30;

Supit, I., Hoojier, A.A. and van Diepen, C.A. (eds.) (1994). System description of the WOFOST 6.0 crop simulation model implemented in CGMS. Volume 1: Theory and algorithms, JRC-EC, Luxembourg: Office for official Publications of the European Communities, 146 pp (EUR 15956).

Response and adaptation of agricultural crops to climate change

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Human activities are affecting the composition of the atmosphere, influencing global and regional temperatures and rainfall and through these a large range of physical and biological processes. These changes appear likely to continue over the forthcoming century. As climate and atmospheric CO_2 concentration are key factors in influencing plant production and other ecosystem processes such as decomposition, it is not surprising that changes in these will have consequences for the functioning of cropping systems. These consequences are likely to vary widely depending on the cropping system being investigated (i.e. cereals vs forage crops vs perennial horticulture), the region and the likely climate changes. For many cool-temperate systems, the prospect of global warming may bring new opportunities provided rainfall does not decline substantially. For warm-temperate and tropical regions, the impacts may be significant and negative with increasing water stress, increasing problems associated with high temperature conditions and a need for either substantial change in varieties and management activities or land-use change. In the last years, several studies have been carried out to review the impact of climate change on agriculture in Europe (Olesen and Bindi, 2002, 2004; Maracchi et al., 2005; Moriondo et al., 2005). Results suggest that substantial increases in temperature will influence Northern Europe during winter and Southern Europe during summer. Moreover, it expected that these changes will cause increasing water shortages in Southern Europe. Thus, in Northern Europe increases in productivity and expansion of suitable cropping areas are expected to dominate, whereas disadvantages from increases in water shortage and extreme weather events (heat, drought, storms) will dominate in Southern Europe. These effects may reinforce the current trends of intensification of agriculture in Northern and Western Europe and extensification in the Mediterranean and south-eastern parts of Europe. A large number of adaptation options have been suggested to minimise negative impacts of climate changes and to take advantage of positive changes. These can be categorised as operating within different time-scales (i.e. short-term or long-term) or different spatial scales (i.e. farm level to national policy level). In adopting these options, it is necessary to consider the multifunctional role of agriculture, and to strike a variable balance between economic, environmental and economic functions in different European regions.

Maracchi, G., Sirotenko, O. & Bindi M. (2005). Impacts of present and future climate variability on agriculture and forestry in the temperate regions: Europe. *Climatic change* (in press).
Moriondo, M., Bindi, M., Giannakopoulos, C. & Corte Real, J. (2005). Impact of changes in climate extremes on winter and summer agricultural crops at the Mediterranean scale. *Climate Research* (submitted).
Olesen, J.E. & Bindi, M. (2002). Consequences of climate change for European agricultural productivity, land use and policy. *European Journal of Agronomy* **16**, 239-262.
Olesen, J.E. & Bindi, M. (2004). Agricultural Impacts and Adaptations to Climate Change in Europe. *Farm Policy Journal* **1**, 36-46.

Effects of increased soil temperature and soil moisture on winter growth and nutrient uptake of two wheat cultivars

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Climate change scenarios envisage increased winter temperatures and precipitation in Denmark, where winter wheat is the most prominent autumn sown crop. An experiment was conducted to study the effects on survival and growth of winter wheat and possible differences between cultivars in the ability to cope with increased temperature and water logging of soils. Water stress of the root system potentially decrease the crop uptake of nutrients by confining the roots to upper soil layers and impede the aerobic metabolism necessary for active uptake of ions. Accordingly, the risk of nitrogen leaching may be increased but could perhaps be balanced by better growth at higher temperatures.

The experiments were established in 72 large plastic pots (height: 70 cm, diameter: 35 cm) that were filled with a loamy sand soil from a field belonging to Research Center Foulum. The lower 40 cm of the pots were packed with soil extracted from the B-horizon and the upper 30 cm from the Ap-horizon to a dry bulk density of 1.5 g cm^{-3}. The pots were equipped with 60 cm TDR-rods to measure water content, and drip tubes to apply dissolved tracer substances (RbCl and $SrCl_2$) at a depth of 50 cm. The pots were watered to field capacity (22% v/v) before seeding, where 37 plants per pot were spaced in a 5 cm grid. After seeding the 72 pots were submerged until 5 cm from the top in 9 water tanks where 1.3 m^3 of water in each could be maintained at different temperature levels at or above ambient. Two winter seasons from October to May 2002-2003 and 2003-2004 were studied. Water logging was imposed in February by supplying water through a tubing system. Treatments were distributed in a randomized split-plot design with 3 temperature levels as main-plot factor (0, +2.5 and +5 °C above field soil temperature at 10 cm depth) and 2 cultivars (Ritmo and Yacht), 2 soil water contents (FC and saturated during February) and 2 seeding times as sub-plot factors.

Increasing temperature above the reference level resulted in an earlier onset of growth in both springs: by mid-April the plant biomass was almost doubled in the T+5 °C treatments compared to the reference (T0). Soil water content and cultivar had little effect on growth, while early seeding resulted in a higher biomass during winter, a difference that however became negligible in May. Root length density in 10 cm soil layers was determined on 26th March and 8th May 2003. While temperature differences did not consistently change root growth in the layers, Ritmo had significantly higher overall root length than Yacht. There was no direct effect of soil water content, but this factor seemed to influence the root growth of cultivars differentially. Rb^+, added as RbCl tracer around February 1st at 50 cm depth, was determined in harvested plants by AAS. Consistent with growth, Rb-uptake was increased by higher temperature, early seeding, and was little affected by cultivar. However, unlike growth of both top and root, Rb-uptake was strongly reduced by water-saturated soil compared to soil at FC. This indicates that a metabolic bottleneck for nutrient uptake is rapidly established in waterlogged soils that make these vulnerable to nutrient leaching despite of deep root development. Since no interaction with temperature was found, higher temperature to some extent did offset the effect of waterlogging on nutrient uptake.

Response of a Danish and of a Swedish wheat cv. to increased temperature: growth and dry matter loss during the winter

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In Northern Europe an increase in temperature is expected mainly during the autumn and winter period. The use of dynamic models to predict the consequences of climate change on winter crops is limited by the fact that little is known about crop physiology at low temperatures and irradiance as experienced during the winter. The research projects EACC (Ecology and Economy of Agriculture in a Changing Climate) and WINSUR (Climate change effects on winter survival of crops) are collaborating to develop adequate crop growth models that can be used as exploratory tools to suggest good adaptation strategies to expected changes in climate. The present contribution is a part of this effort. It is concerned mainly with the basic physiological traits (dry matter allocation, development and loss of leaf area, loss of dry matter by respiration and death of tillers) of two contrasting wheat cultivars during the autumn and winter. Other aspects, such as winter diseases are considered by other sub-projects.

The scope of this study was to provide experimental data for the development of ad hoc crop growth model for wheat during the winter. Two contrasting wheat cultivars were used: Magnifik, the most winter hardy variety on the market, and Ritmo, a Danish cultivar that usually does not survive in Norway. Plants were grown in pots from September to April in 16 “field chambers” (6 m^2 ground area) with all combinations of two temperatures and two CO_2-concentrations, obtained by blowing air through perforated tubes. Control 'field chambers' without air blowing were also established.

The plants were harvested 12 times from October to April, and root, stubble and top dry matter was recorded in addition to number of green leaves, number of green tillers, and green leaf area. Top dry matter was divided in green (living) and dead parts.

The two varieties had clearly different growth and death patterns, and different responses to temperature increase. The winter hardy variety seemed to use several strategies (many tillers, higher specific leaf area, early allocation of assimilates to roots and apparent retranslocation from roots in late winter) to maintain a minimum green leaf area throughout the winter. Effects of CO_2, which were not detectable during the autumn growth, became significant during the winter in the treatment with higher temperatures.

The results indicate that, in Norway, good winter hardiness will be necessary also in a warmer winter climate.

Effect of climate change on autumn growth and winter survival of *Elymus repens*, *Cirsium arvense* and *Sonchus arvensis*

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The objective of this study was to examine the effects of increasing temperature (+2-2.5 °C) and CO_2 (370 ppm vs. 550 ppm) and 30% shading compared to outdoor conditions on autumn growth and winter survival of a northern (63°N) and a southern (59°N) ecotype of *Elymus repens* (L.) Gould, *Cirsium arvense* (L.) Scop. and *Sonchus arvensis* L. A change in the growth pattern of these perennial weeds may influence infestation of the following crops and the need for control measures.

Pieces of rhizomes (*E. repens*) and roots (*C. arvense*, *S. arvensis*) were planted in pots May 2004 and grown outdoors at 58°N until start of the experiment 2 September 2004. The plants were cut to 20 cm height 27 August 2004 to simulate crop harvesting. Every fortnight developmental stage, leaf area, dry weight of above-ground and below-ground plant parts, and root/rhizome length were assessed from 2 September to 1 November 2004. After survival during winter, leaf area, dry weight of new above ground shoots and below ground plant parts were assessed 12 April, 3 May and 30 May 2005.

After cutting, *E. repens* regrew in autumn with new shoots and more leaf area until end of October, while *S. arvensis* withered shortly after the start of the experiment. This is due to dormancy of *S. arvensis* in autumn (Fykse, 1974; Fogelfors *et al*., 2003). *C. arvense* held an intermediate position with small regrowth on the existing shoots, while the overall leaf area decreased. The southern ecotype of *S. arvensis* and *C.arvense* developed more roots than the northern ecotype with a corresponding lower shoot/root-ratio in autumn. The southern ecotype of *C. arvense* also produced more leaf area. The northern ecotype of *E. repens* developed more leaf area and shoot and root/rhizome dry weight. The leaf area and shoot dry weight averaged over all species, and the leaf area of *E. repens* and *C. arvense* increased with increasing temperature and shading in autumn. Elevated CO_2 increased the leaf area of *E. repens* in autumn. Since the roots/rhizomes were little affected by changes in autumn climate, it is expected that next year's infestation level is also not greatly influenced since it is the roots/rhizomes that survive winter and give rise to new shoots next year. The results of regrowth in spring will be clear in June 2005. However, there seem to be an effect of temperature on regrowth in spring for all species. Even though the above-ground shoots of *S. arvensis* withered down in autumn, the roots survived and will give rise to new shoots in spring.

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Will climate change give rise to increasing pest problems in agricultural crops?

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Global warming and consequently environmental changes will have significant effects on the insect world. Especially in temperate regions where pest problems are moderate more pest problems will probably occur. This will be valid for native species but also alien invasive species will give rise to pest problems.

Insect pests responses to climate change show individual species may respond differently to global warming. Warm winters may favour some species but be detrimental to others and this is probably related to how the insect spends the winter - active, dormant or diapause. Aphids, one of the most important pests in the temperate regions, will because of their short generation time and low developmental threshold temperatures, respond particularly strongly to environmental changes. Probably most aphids will fly earlier in the years ahead and in larger numbers during the critical periods when crops are especially susceptible to the damage aphids cause and to the viruses they transmit.

The Colorado potato beetle (*Leptinotarsa decemlineata*) gives some years rise to damage in the southern part of Denmark, but not most of the years. It is probable that an increase in the temperature very heavily will increase pest problem with this pest.

The northern frontier of the Western Corn Rootworm (*Diabrotica virgifera*) is situated about Mid Germany. It is a serious pest in regions where it lives and its prevalence will be drastically expanded if the northern temperate regions are exposed to global warming.

Climate change may favour some species with certain traits so scientists have attempted to identify broad generalities in the characteristics of certain invasive under certain conditions for prediction and future management.

Effect of climate change on resistance to pink snow mould (*Microdochium nivale*) in winter wheat

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The fungus *Microdochium nivale* causes pink snow mould damage on cereals and grasses in cold and temperate zones during winter. The level of snow mould resistance in plants is often enhanced after a period of cold hardening. Altered hardening conditions in the autumn due to climatic changes may influence the plants ability to resist fungal attacks under snow cover. We have studied whether increased temperature (+2-2,5 °C) and elevated CO_2 (550 ppmv) during the autumn influences the resistance to pink snow mould in winter wheat. Also, the effect of 30% shading compared to natural light conditions in the autumn was studied.

Two varieties of winter wheat (cv. 'Ritmo' and cv. 'Magnifik') were planted in pots and placed in open top chambers (field chambers) September 15th 2004. The plants were exposed to 4 different climatic conditions in the field chambers: 1) natural CO_2 and temperature conditions, 2) elevated CO_2 with natural temperature level, 3) increased temperature with natural CO_2 conditions, and 4) increased temperature and elevated CO_2 conditions. A total of 16 pots (8 pots of each cultivar) were placed in each chamber. Additionally, 16 pots were placed under 30% shade outside the chambers, and 16 pots were placed under natural light conditions in the field outside the chambers. Every condition had 4 replicates. Plants were inoculated with an aggressive isolate of *M. nivale* (isolate 3/98, 10 ml inoculum per pot) on December 1st. Control pots were sprayed with the fungicide "Amistar" (strobilurine) to ensure healthy control plants for each treatment. Each pot were covered with a layer of 2 cm moist paper and black plastic and incubated in rooms with 2 °C and darkness to simulate snow cover conditions. After incubation in 7 and 9 weeks, inoculated plants and control plants were cut down to an equal length of 6 cm and placed in a greenhouse chamber for re-growth (18 °C, 20 hours additional light). Plants were cut after 2 weeks re-growth and weighed (fresh and dry weight). The level of resistance is appointed as dry weight of inoculated plants in percentage of control plants within each treatment.

No effects of elevated CO_2 level on resistance to *M. nivale* in either of the two winter wheat varieties were found. Increased temperature however, did result in stronger tolerance to *M. nivale*. The effect was most obvious in cv. 'Magnifik' after 7 weeks incubation (40% regrowth of plants hardened under increased temperature compared to 15% regrowth when plants were hardened under natural temperature conditions. In cv. 'Ritmo', a similar effect was observed after 9 weeks incubation with 20% regrowth of plants cold hardened under increased temperature conditions compared to10% hardened under natural temperature conditions. A small (non-significant) increase in resistance to *M. nivale* was observed in 'Magnifik' plants hardened under field conditions compared to plants hardened under 30% shadow. Differences in resistance to *M. nivale* displayed in plants exposed to different climatic conditions prior to inoculation, may also be related to the plant size or carbohydrate level in plants at the time of inoculation.

Impacts of climate change and socio-economic development on European agricultural land use

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Agricultural land use in Europe has changed considerably in the past. A variety of drivers can be identified to have contributed to this change and include social (e.g. population growth and consumer preferences), economic (e.g. prices, import-export relationships, technology development), political (e.g. Common Agricultural Policy) and biophysical (e.g. climate) factors. There is increasing confidence about projected changes in climatic conditions for the 21st century. Possible impacts on agricultural land use have been described for Europe and elsewhere. However, climate change effects on land use have often been analysed independently from socio-economic and political conditions. In fact, the uncertainty and complexity of factors and relationships determining land use change are not well understood and predictions remain difficult. Alternatively, scenario analysis has become an attractive method for impact assessment studies to explore future changes. The Special Report on Emission Scenarios (SRES) of the Intergovernmental Panel on Climate Change (IPCC) provides a scenario framework that has been widely adopted for climate change impact research.

Recently, an attempt was made to develop quantitative, spatially explicit and alternative scenarios of future agricultural land use in Europe (Ewert et al., 2005; Rounsevell et al., 2005). A simple static approach was developed to quantify changes in land use depending on combined changes in crop productivity as affected by climatic conditions, CO_2 concentration and technology development, and demand for crop production and agricultural policies.

Results suggest that cropland and grassland areas may decline depending on the scenario by as much as 50% of current areas by the end of this century. Although changes in climatic conditions may be of importance for some regions, the dominant role of technology development for agricultural land use change became evident.

Drivers of technology development remain unclear but estimated impacts on land use provide possibilities for alternative land uses such as forests, recreational use or growth of bioenergy crops, of which the impacts on sustainability and rural development are not yet understood. Responses at the farm-level to climate and socio-economic changes deserve particular attention in this respect and are discussed together with some conceptual ideas to perform integrated analysis and assessment of land use change under future climates across spatial and temporal scales.

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Erosion in Southeast Norway in a new climate

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Erosion is episodic in nature and therefore weather data with high spatial and time resolution are needed. Weather data simulated with the GCM-model Max Planck ECHAM/OPYC3 GSDIO using scenario IS92a and downscaled by the model HIRHAM with empirical adjustments were used. Hydrological simulations were performed using the COUP model (Jansson, 2001) and the AVRJUST model (Lundekvam, 2002) and erosion was simulated by the ERONOR model (Lundekvam, 2002). The ERONOR model is empirical, based on Norwegian erosion experiments, with a resolution of one day and has performed better under Norwegian conditions than foreign erosion models so far tested.

Compared for the time period 1980-98, simulated air temperature was 0.7 °C lower than observed especially in summer, simulated precipitation was higher than observed especially in July and August, simulated days with zero precipitation were greatly reduced and days less than 12 mm/day were increased compared to observed. Thus the simulated weather showed rather serious deviations from observed. Simulated future climate (2030-48) showed an increase in average air temperature of 1.14 °C especially in January and February, but no significant change in precipitation compared to simulated present climate (1980-98. The hydrological models showed about 50% reduction in snow storage (similar results for COUP and AVRJUST) and an increase in surface runoff of 5 to 70% depending on model used and soil type. The increased surface runoff occurred mainly in January and February, but also in November and December. The reasons were milder winters with more rainfall on frozen soil, but also increased precipitation in autumn in future. The erosion model showed a doubling or more of soil loss for most tillage systems whatever hydrological data used. The increase was greatest in winter but an increase was also simulated in autumn. The main reason was more runoff in winter occurring by little or no snow cover often combined with rainfall. This is well in accordance with expectations, since we already have experienced several mild winters. The simulations showed a substantial reduction in soil erosion by no till in autumn compared with traditional autumn ploughing especially in the future climate. Extreme events were very important for the soil losses. At one site 50% of the soil losses occurred at 0.6-0.9% of total time. The deviations between simulated and observed present climates are great and a better downscaling method has been developed at http://www.met.no, but these simulated weather data has so far not been used in the erosion model. The results presented here (Lundekvam, 2004) are financed by the research program “Ecology and Economy in Agriculture under a changing climate” (EACC).

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Thermal stress and drought: major threats to crop production in the Alpine region during the second half of the 21st century?

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Recent simulations with regional climate models (Beniston, 2004; Schär et al., 2004) suggest that heat waves comparable to the one that struck many parts of Europe in 2003 could become rather common toward the end of the 21st century. In addition, a significant drop in the frequency of summer precipitation events is projected for the Alpine region by climate scenarios produced within the PRUDENCE project (Christensen et al. 2001; C. Frei, pers. comm.). These findings raise the question of whether heat stress and drought could represent, during the second half of the 21st century, major threats to agriculture not only in southern Europe but also in the Alpine region.

On this background, we investigated the impact of climate change on crop production in Switzerland using crop simulation models (Torriani et al., in prep.), stochastic soil moisture models (Calanca, 2004) and a variety of climate scenarios. Our results indicate that the radiation use efficiency of summer crops (currently grown cultivars) could indeed decrease by as much as a factor of two due to increasing water vapor pressure deficit. We also found a significant increase in the incidence of summer droughts, often largely exceeding the 2003 event in intensity. These negative impacts on the productivity of cropping systems will tend to outweigh the benefits of increasing atmospheric CO_2 concentrations (Fuhrer, 2003) unless adaptation measures such as the replacement of crops, the choice of more suitable cultivars, shifts in the period of growth or irrigation are implemented.

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Climate change and crop management: look towards the past and the future

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In a climatic framework supposed to be stationary, the evolution of the cereal yields in the 70-80 years was assumed to originate from a long-term trend, called "progress", and a variability due to the year to year climatic fluctuations. Yet accounting for the confirmed evolution of the climate over the past century and the perspectives of the future evolution it is worth investigating the relative weight of the technology, including the genetic improvements, and the climate change. This issue concerns both the past and the future and this presentation addresses those two components through case-studies on wheat and maize crops at two different scales, using crop modelling.

To perform the analysis on the past period, we used the ORCHIDEE-STICS model (Gervois et al., 2005) at the European scale, driven by a 100-year actual climatic data set (1901 to 2000). The assumptions of technological evolution concerned fertilisation (organic until 1950, then mineral with increasing amounts from 30 to 150 $kgNha^{-1}$), irrigation (allowed for maize crop from 1950) and genetics (lengthening of the grain filling durations and increase of the harvest indices). Three simulations were performed allowing separating the effects of 1) the increase in [CO2], 2) the global climatic evolution and 3) the technological modifications. The results clearly show the great impact of the techniques in agreement with data from the agricultural statistical service.

As far as future is concerned, the knowledge on the responses of the soil-crop system to climate, at short and long-time steps, informs us on the processes likely to be modified (Seguin et al., 2005). Yet this constitutes a complex set of responses with many contradictory trends, which justifies the use of crop models to operate a kind of hierarchy. In this objective we used STICS (Brisson et al., 2003) for a quadrennial rotation (maize-maize-maize-wheat) supplied by climatic data from the ARPEGE-Climat GCM. With the present time technology the results show opposite responses to climate change of the wheat (yield decrease) and maize (increase) crops mainly due to their differential phenology. The adaptation study exhibits a shift in sowing periods and a modification in fertilizer schemes accounting for both plant requirements and soil mineralization, which have impacts on nitrate leaching risks.

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Adaptation of horticulture and viticulture to climate change in France

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In the framework of the climate change impacts on agriculture, perennial productions like fruit trees and vineyards have been less studied up to now than annual crops. We intend to present here some recent results from studies in France on these crops. It is first necessary to take in account the direct effect of CO_2 increase on photosynthesis (by about30%), as well as the possible consequences of higher UV-B radiation. When looking at the whole cycle, the first direct consequence of climate change is through warming, resulting in an acceleration of the phenology. For fruit trees, the advance in flowering dates will be generalized and could reach more than one month, depending upon the scenarios and species. In spite of climatic warming, risks of spring frost will be increased in the south of France for peach and apricot, but not for apple. These predictions have been confirmed by observations during the last fifteen years, in relation with the attested warming (Domergue et al., 2004): an advance in flowering dates for all species and locations by some 8 to 15 days, which also create less favourable conditions for pollination. The lack of cold in milder winters also increases the frequency of bud necrosis and flowering abortion, as already noted for some sensitive apricot varieties. For grapevine, the same advance in phenology will occur for all significant stages, in spite of a delay by some 10 days in dormancy breaking: about 20 days for budbreak and flowering, and 30 to 40 days for veraison and harvest (Garcia de Cortazar et al., 2004). This finding is consistent with observed evolutions for all French vineyards in the last fifteen years, especially for harvest dates advanced by two to three weeks. The period between veraison and harvest will occur earlier in summer, which could be a problem for specific quality aspects, even if warmer temperatures will increase the sugar content and decrease the acidity. Management procedures will have to cope with photosynthesis increase and the foreseen enhanced drought in southern regions. Moreover, the extent to northern or higher altitude regions could be considered (1 °C corresponding to an approximate shift of 180 km and 150 m, respectively). For fruit trees, early flowering varieties will have to be avoided in traditional producing areas, as well as those sensitive to mild winters. For grapevines, the particularities of high quality production associated to ‘terroirs’ have to be considered (Seguin and Garcia de Cortazar, 2005). The change of cultivars could be a solution. But, for producers who decide to maintain their ‘terroirs’, they will try to keep those traditionally adjusted to local soil and climate. The challenge will be to adjust local microclimates, management practices and vine-making techniques in order to keep the specificities of traditional productions.

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Vulnerability and adaptation options of the potatoes (*Solanum tuberosum*) to climate change in high land and valleys regions in Bolivia

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Agriculture in Bolivian high land and valley is performed under permanent climatic constraints mainly due to drought, which likely will increase strongly under climate change. This study focus on the vulnerability and adaptation options for potatoes to climate change, because is a main energy source, especially for the western region with important socioeconomical effects by their extension and adaptation to diverse ecosystems with different soil and climate conditions. In general the crop is affected by climate change, in particular temperature, rainfall and CO_2. However, the responses may be modified by other factors, such as relative humidity and water and nutrient availability in the soil. The objective of this study was to identify vulnerability and adaptation options of potatoes in two different regions of Bolivia.

The model DSSAT v3 and the climate change scenarios IS92a and IS92c were chosen from a family of scenerios developed by the National Meteorological and Hydrological Service (SENAMHI) and National Climate Change Programme of Bolivia (PNCC-Bolivia) from General Circulation Model (CGM). For the variety *Sani Imilla* we had genotype parameters for two sub-regions Toralapa (Valley) and Choquenayra (high land) and other information including drainage, CO_2 atmospheric concentration. Under IS92a and IS92c a yield increase of 4.6 % in Toralapa for valley condition and 1.7 % for Choquenayra for high land condition was estimated for a ten years period. For a double CO_2 scenario there were additional increases in yield of 6.6 and 4.6%, respectively. But for this increase the crop required more nutrients and water. After 2030 there tended to be negative responses, because of increasing evapotranspiration. The most efficient adaptation measure was additional irrigation, which could increase by 50 to 180 mm. This addition irrigation will increase yields by up to 30 to 60%. Changes in planting date of up to 25 days did not have major effects on yields. With changes of more than 30 days in planting date, the crop would suffer for increasing water deficit and risk of freezing. The most important problem in high land regions in Bolivia is the reduction of rainfall between October and November, when the crop is the vegetative phase. Both reduction in the total precipitation and its temporal distribution is important for potato yield under these conditions.

Impact of climate change on rainfed wheat production in Iran

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The Mediterranean climate of Iran with long dry summers and winter rainfall is very sensitive to drought and vulnerable to potential future climate changes. It has been predicted that cereal production would decrease by up to 40% under rainfed agriculture by 2080 (Rosenzweig and Parry, 1994). Wheat is one of the main cereal crops of Iran, accounting for 35% of the food grain production of the country (12 Mt in 2004). Rainfed wheat accounts for about 60-65% of the cultivated wheat areas and contributes 30-35% of wheat production in the country. The demand for wheat is predicted to be over 20 Mt in 2025 (Sharifi, 2001). However, few studies have evaluated impacts of climate change with concurrent water limitations and rising air temperature across the country. The purpose of this study was to project the impact of climate change on rainfed wheat production in Iran by the years 2025 and 2050.

Weather data generated from mean monthly values from 1968 to 2000 for 12 major rainfed wheat production areas in northwest and western Iran were used with a General Circulation Model (GCM), United Kingdom Meteorological Office (UKMO), to predict the impact of climate change on rainfed wheat production at [CO_2] of 425 and 500 ppm and rising air temperature of 2.7 to 4.7 °C for 2025 and 2050, respectively.

The mean rise in air temperature during the growth period of rainfed wheat was predicted to be 3.5 and 4.3 °C for 2025 and 2050, respectively. Potential growth period was calculated on the bases of integration of predicted temperature rise and moisture availability (Nassiri and Koocheki, 2003). The crop simulation model, World Food Study (WOFOST, v 7.1, Supit *et al.*, 1994), projected a significant rainfed wheat yield reduction under the defined climatic scenarios. Average yield reduction was 18 and 24% for 2025 and 2050, respectively. The yield reduction was related to rainfall deficit and shortening of the wheat growth period. The rainfall deficit index could increase by 8.3 to 17.7%, and growth period could be decreased by 8 to 36 days.

Adaptation practices, like changing sowing date and genotype selection, are needed to modify the potential impact of future climate on rainfed wheat production in Iran.

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Assessing the adaptive capacity of European agriculture under different climate and management conditions

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Agriculture is vulnerable to changes in climate and climate variability. This vulnerability can be reduced through adaptation. Although it is generally assumed that farmers will adapt to these changes, such adaptive capacity has never been properly quantified. To increase understanding of this adaptive capacity, we analyzed the performance of farmers in the European Union. Extensive data on farm characteristics of individual farms from the Farm Accountancy Data Network (FADN) have been combined with climatic and socio-economic data to determine the influence of climate and management on crop yields, income and related variables that indicate adaptive capacity. We applied multilevel regression models that are explicitly designed for statistical analysis of hierarchically structured data and explicitly take the variability at different levels into account. Data of the year 2000 have been used for a cross-sectional analysis and additionally, data of 1990 and 1995 have been used to determine temporal changes.

The results suggest that input intensity, economic size and the percentage of arable land are generally good indicators that enhance the adaptive capacity of farmers. However, the influence of climate, socio-economic factors and farm characteristics on crop yields differs for different crops. High crop yields are not always related to high incomes. This implies that the adaptive capacity of the farms to respond to climate change also depends on the aspect considered. A farmer may be able to adapt to decreasing maize yields, but not to decreasing wheat yields. Even though a farmer isn't able to adapt to changing yields, he may still be able to adapt economically to decrease its vulnerability. Farm net value added per annual work unit is higher in regions with a more favourable climate, but farm net value added per hectare isn't. Farmer's income is not so much determined by crop productivity, but mainly by farm size and subsidies.

Although crop growth is highly influenced by climatic conditions, the actual influence of climate on farm performance was low. Regional differences in crop yields seem to be related to climatic conditions, but as socio-economic variables are highly correlated with climate variables, this influence can be confounded. Although wheat yields are generally lower in Mediterranean regions, yields of maize are of the highest in the European Union. Analysis of temporal changes indicates that the average farmer adapts its management such that vulnerability to climate variability is relatively low. Actual observed crop yields do not vary as much and often not in the same direction as water-limited and/or potential yields. This implies that the average farmer doesn't loose much in less favourable years, but also doesn't gain from improved conditions in better years. Individual farmers may still be vulnerable though, as there is a large deviation in crop yields and income within regions. In general, large intensive farms produce the highest crop yields and obtain the highest income. These farms will be the least vulnerable to climate change as they have the highest capacity to adapt to their (changing) environment.

Strategies to evaluate agro-climatic risk on the Canadian prairies

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The Canadian Prairies are situated at the northern fringe of agricultural production in North America. Farming in this region is sensitive to variations in the weather, including a frost-free period, accumulation of heat units for crop development, and available moisture. These factors can contribute directly to reductions in crop yield (Raddatz et al., 1994). The effects of both short- and long-term climatic trends are of great concern to agriculture as well as the inter-annual weather variability. The ability to evaluate agro-climatic risk is very important.

Records of observed weather parameters and their influence on crop production systems through agrometeorological modelling can be an effective way to determine risk. Over an extended period of time, long-term weather observation datasets and derived agro-meteorological responses can reveal subtle climatic shifts or trends. The most recent trends can provide insight into how the climate is currently evolving and perhaps what direction it might point within the near future. An updated agro-climatic database can be a useful roadmap to show the recent impacts of changes in the agriculturally important climate and may serve as a useful tool to assist with adaptation, enabling producers to take advantage of farming practices that minimize risk while optimizing production.

Long-term records of daily temperature and precipitation were used to model the development of various crops including spring wheat, canola, corn, forage, and potato. Modelling was based on specific soil characteristics using methods described by Raddatz (1989). This provided factors such as estimated seeding date, phenological development, growing season precipitation, crop water use, soil moisture content, plant moisture stress, and crop maturity. Results from multiple years of record were compiled to provide an assessment of the risk associated with the probability of various events. This information provides producers and policy makers with a quantification of the risk of production enabling them to adapt their crop or variety choice, timing of field operations, or farming methods to minimize the exposure to risk. These results may also evaluate the climatic suitability of new crops in various regions.

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Some key factors in economic adaptation of agricultural sector to climate change in Finland

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Estimated beneficial effects of the climate change in Finland include increased crop yields and reduced winter time energy consumption of farms. Longer growing period may also result in better and more homogenous crop quality of certain crops. The estimated reduced risk of frost as well as high and more homogenous quality of crops is expected to decrease economic risks, increase relative profitability of certain crops and diversify crop production Finland. Higher crop yield and quality would also benefit animal production.

However, it is not sure if any significant economic benefit can be obtained from the climate change since also increased costs of plant protection. Increasing crop and biomass yields make crop production more competitive only if these additional costs are covered. Furthermore, the competitiveness of Finnish agriculture in international markets may not increase if similar net improvements in profitability take place in major production areas in Europe and elsewhere.

The climate change will influence the relative profitability of different crops and animal products. For this reason the implications of climate change on agricultural production, farm income and competitive position on international markets were evaluated using a sector level economic model. The approach allows consistent treatment of different products and price changes as well as changes in production allocation in different areas in Finland. First simulations show that crop yields need to increase considerably, by at least 15-20%, on the average, before any significant economic benefit can be obtained. This result is nevertheless dependent on production and price development in Europe and elsewhere. The potential benefits of climate change also depend on the variety of crops cultivated in Finland in the future. If some special crops currently suffering from high production risks are no longer cultivated due to further de-coupling of agricultural support from production, for example, domestic production will be replaced by imports. Then it will be difficult to build up the entire value chain for these crops later even if climatic conditions become more favourable. Hence higher crop diversity is likely to improve chances of benefitting from the climate change in Finland.

Climate change impacts on agricultural land use - A Danish case study

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This paper addresses climate change impacts on agricultural land use in Denmark. The results are based on a regional case study applying an integrated modelling framework developed in the EU research project ACCELERATES. One of the aims of this project was to analyse the long-term (2020, 2050, 2080) climate impact on European agricultural land use by linking agriculture land use with environmental and socio-economic variables. The basic assumption of the model is that the pattern of the future land use depends on the decisions of profit maximizing landowners and land users (Annetts and Audsley, 2002). The land use decisions are modelled in a linear programming model including environmental and socio-economic constraints of a given location in Europe. The environmental constraints include water-, temperature-, and nitrogen-limited crop yields, sowing and maturity days and the number of workable hours. These constraints were modelled as a function of soil characteristic and derived grid climate/weather scenario variables. The socio-economic constraints, e.g. prices on agricultural inputs and outputs, technology, and environmental regulations, are defined in socio-economic scenarios.

The agricultural land use in Denmark in 2050 is modelled for five climate change scenarios. Keeping the socio-economic variables constant in order to demonstrate the effect of climate change alone the impact of the four HadCM3 scenarios (A1FI, A2, B1, B2) had more or less the same impact on land use. There is a small decrease in the area with winter wheat and a large decrease in the area with winter barley and permanent grass. Spring sown rapeseed will no longer be grown in Denmark. Instead, the area with spring barley, potatoes, sugar beet, and winter rapeseed increases. The model indicates that farmers will start growing grain maize by 2050 (1-4%). The changes in land use based on the PCM A2 scenario differ significantly from the HadCM3 scenarios. PCM climate causes a significant increase in the area with winter wheat and a decrease in the area with spring barley and sugar beet.

Obviously, the socio-economic context of the future crop production in Europe will change, e.g. crop prices will change due to changes in global demand and supply. Combining the climate changes with socio-economic scenarios indicates that land use may be more sensitive to the socio-economic changes, e.g. changes in crop productivity, than climate changes (see also Rounsevell et al., 2005).

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Rounsevell, M.D.A., Ewert, F., Reginster, I., Leemans, R., & Carter, T.R., (2005). Future scenarios of European agricultural land use. II: projecting changes in cropland and grassland. *Agriculture, Ecosystems and Environment* **107**, 117-135.

An integrated national research project on "Evolution of cropping systems as affected by climate change"

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The climate change induced by the global warming is expected to modify the agricultural activity and consequently the other social and economical sectors. An efficient management of the water resources is considered very important for Italy and in particular for southern areas to improve the economical and environmental sustainability of the agricultural activity. Climate warming could have a substantial impact on some agronomical practices, e.g. choice of the crops, sowing time and irrigation scheduling. For a particular zone, the impact of climatic change on agricultural activity will depend processes in the soil-plant-climate continuum

This three-year project is structured in four workpackages with specific objectives, high degree of interaction and information exchange.

1. *Identification of homogeneous areas*: the objective is to characterize areas in the southern part of Italy subjected to intensive agricultural activity. The characterization will be based on spatially distributed data concerning the soil, the climate and soil use. Several techniques of data spacialisation, clustering, geostatistical analysis. GIS will be utilized in order to achieve homogeneous areas.
2. *Climate change*: the aim of this workpackage will be the climatic downscaling or, in other words, the regionalization of climatic scenarios obtained by using the Global Climate Models. A dynamic approach (high resolution through global grids at multiscale) coupled with a statistical one (based on statistical correlations among variables at large scale and variables at local scale) will create climatic scenarios at temporal daily scale.
3. *Optimization of water resources*: the topics of this activity will involve the irrigation management of water resources that are expected to become more and more the main limiting factor for the agricultural activity. In particular, researches at field scale will be carried out for studies regarding the optimisation of several irrigation variables using water sources of different salinity and quality.
4. *Scenarios analysis*: using the information derived from workpackages 1 and 2, simulations will be effectuated at field and regional scale by using numerical models for simulating crops and cropping systems. In particular, calibrated and tested crop and hydrological models will be utilized in order to evaluate the effects that the future climatic scenarios will have on crop yields and to individuate the best agronomical strategy to optimize the use of water resources.

Finally, the aim of this project is to individuate integrated approaches for optimizing the use of water resources in areas of Southern Italy characterized by irrigated cropping systems that could be utilized by policy makers involved in land planning. The water use optimisation will involve several agronomical practices to ensure high productive levels by maximizing the water use efficiency in periods long enough to include the forecasted climatic scenarios.

Adaptation of the agricultural sector to climate change in Finland: first results from the FINADAPT project

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New cliamate change scenarios for Finland show annual increases by the 2080s of 2.4 to 7.4 °C (temperature) and 6 to 37 % (precipitation). Such climate changes are expected to have significant adverse effects on natural ecosystems, biodiversity, human health, and flood risk in Finland, while beneficial effects include increased crop yields and timber production and reduced winter energy demand. Regardless of any foreseeable reductions in emissions, some future climate change appears to be unavoidable, so society must be prepared to adapt to the inevitable consequences of climate change. Adaptation is thus a necessary complement to mitigation as a policy response to climate change. However, understanding of adaptive capacity is relatively poor so far across all sectors in Finland.

The FINADAPT consortium seeks to address both scientific and policy needs by conducting the first in-depth investigation of the adaptive capacity of the Finnish environment and society to the potential impacts of climate change. The consortium is being funded for the period 2004-2005 as part of the Finnish Environmental Cluster Research Programme, co-ordinated by the Ministry of the Environment (see: http://www.environment.fi/syke/finadapt).

The objectives of the study concerning the agricultural sector are to address: (i) the general need for adaptation to climate change in this sector; (ii) the potential and likely rate of autonomous adaptation; (iii) the need for planned adaptation; (iv) the effect of climate change adaptation measures in modifying the environmental impacts of agriculture; and (v) the influence of other events and the broader context, notably agricultural policy decisions that may affect the possibilities and need for adaptation. The study seeks to produce an initial overview of current knowledge and to identify specific areas where detailed adaptation studies are likely to be needed, i.e. the areas in which scientific support for planned adaptation is likely to be necessary.

Several both favourable (e.g. enhanced biomass production, successful overwintering of perennials) and disadvantageous (e.g. compaction of clay soils, increased risk of pests) changes in conditions affecting the agricultural sector are anticipated due to climate change in Finland. The analysis of the existing data from the past 30-40 years demonstrates changes in environmental conditions and consequently in agricultural practices: e.g. the period of night frost occurrence has become shorter and an earlier onset of spring has influenced sowing dates of certain crops in different regions of Finland.

This presentation will give an overview of the FINADAPT project as well as present some preliminary results concerning the agricultural sector.

Transient climate change scenarios for agricultural applications

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The Rossby Centre has recently completed a set of transient climate simulations for the full period of 1961-2100. The new version of our regional climate model, RCA3, has a new and more detailed submodel for soil/vegetation/atmosphere interaction used in the simulations. Two common greenhouse gas scenarios were applied, the high-emission SRES A2 and the more moderate SRES B2 scenario. The new scenarios allow us to study in more detail the whole century period up to 2100, and also analyse the trends in climate indicators of specific relevance for agricultural activities. For the two previously simulated periods 1961-1990 and 2071-2100 the new scenarios agree very well with previous results. While there is little difference between the A2 and B2 scenarios before about 2060, both suggest that already about 2020-2030 we may expect climate conditions outside the observed natural variability during 1880-2000. The general picture is that the warming trend is more pronounced during winter, where particularly cold extremes will become less severe (Kjellström et al., 2005). Conversely, during summer, high temperature extremes will increase more than the average warming. For precipitation there is large inter-annual and seasonal variations and an overall trend towards wetter winters, as well as drier conditions during July-August, except for in northern Scandinavia. Because of the warming trend the snow cover will decrease and the increased winter precipitation will generate more direct runoff. In general, the non-linear relationship between the change of projected averages and extremes, as well as the interaction between different climatic elements may change the climatic conditions for agriculture in a way that does not immediately follow from the warming trend (e.g. Jönsson et al., 2004). Here we will present some examples of simple climate indices that are relevant for agriculture. These include indices related to growing season, summer 'drougth' and water availability, and frost episodes.

Jönsson, A.M., Linderson, M.L., Stjernquist, I., Schlyter, P. and Bärring, L. (2004): Climate change and the effect of temperature backlashes causing frost damage in Picea abies. *Global and Planetary Change*, **44,** 195-207.

Kjellström, E., Bärring, L., Jacob, D., Jones, R., Lenderink, G. and Schär, C. (2005): Variability in daily maximum and minimum temperatures: Recent and future changes over Europe. *Climatic Change* (submitted).

Two methods predicting crop yield changes under climate change

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In the coming decades the climate of Sweden is predicted to become essentially warmer than today, and it is of interest to evaluate the possible effects on crop yields. Two different extrapolation methods were used to predict relative changes of crop yields. Sweden has a large difference in temperature climate between southern and northern agricultural regions. In the first method climate change over time in future is represented by the regional temperature climate differences of today. Present regional differences in crop yields then represent a scenario of future changes. The relative increase in crop yields per hectare, for a 2-3 ^{o}C temperature increase, ranged approximately between 15% in the south and 70% in the north, however, also strongly dependent on crop type (Sigvald et al., 2001). Estimation of the changes in the total regional production of seven different crops showed that a change of land use among these crops might increase production as much as the changes in yield per hectare. This extrapolation method represents a change of whole cropping systems in accordance to a change in annual temperatures similar to those of climate change scenarios. However, several factors not changed under climatic change were also included, whereas several factors were omitted that will change under climate change. To better consider only climate change related factors, a second method was used, in which the changes in carbon, nitrogen, water and heat flows in the plant-soil system were simulated based on daily weather at present climate, modified by monthly climate change scenarios (Downing et al., 2000), and including effects of increased atmospheric CO_2-levels on plant properties (Eckersten et al., 2001). The two methods were compared for winter wheat, and showed similar relative changes of the yield per hectare, although the methods in several cases represented different aspects of climate change. The results are discussed.

Eckersten, H., Blombäck, K., Kätterer, T., Nyman, P. (2001). Modelling C, N, water and heat dynamics in winter wheat under climate change in southern Sweden. *Agriculture Ecosystems and Environment* **86**, 221-235.

Downing, P.A. Harrison, Butterfield, R.E., Lonsdale, K.G. (Eds.) (2000). Climate Change, Climatic Variability and Agriculture in Europe: An Integrated Assessment. Research Report No. **21**, *Environmental Change Unit, University of Oxford*, Oxford, 445 pp.

Sigvald, R., Lindblad, M., Eckersten, H. (2001). Jorbrukets känslighet och sårbarhet för klimatförändringar - Underlag för Sveriges nationalrapport till Klimatkonventionen (Sensitivity of agriculture to climate change – material for the Swedish national report to the Climate convention). *Naturvårdsverket (Swedish Environmental Agency)*, report **5167**. 40 pp (in Swedish).

Agroclimatic indices of Iran under climate change

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While all climatic variables may affect plant growth, temperature, rainfall and length of growing period are considered as the main determining factors of crop production. On this basis several agroclimatic indices have been developed to relate climatic variables to crop requirements and to evaluate the impacts of climate change on crop production at regional level (Rosenzweig and Parry, 1994; Lin *et al*., 1997; Semenov and Porter, 1995). The semiarid Mediterranean environment of Iran is vulnerable, and climate change may exacerbate this vulnerability. However, these potential effects have not been studied in detail. The objective of this investigation is to predict variation in meteorological parameters due to climate change and to determine changes in agroclimatic indices of Iran that may affect agricultural production under future climate.

Changes in monthly maximum and minimum temperature and rainfall for a number of meteorological stations that represent general climatic conditions of the country were simulated by the UKMO General Circulation Model based on assumed scenarios for the years 2025 and 2050 (Koocheki et al., 2003). Agroclimatic indices such as seasonal temperature, rainfall and evapotranspiration, growing degree-days, seasonal water deficit, and temperature thresholds were calculated for present and defined future climates. Principal Component Analysis (PCA) was used to categorize these indices and cluster analysis was used to determine similarities between meteorological stations and to group them.

Results showed an increase in seasonal temperature and a decrease in rainfall for years 2025 and 2050. Rainfall reduction was more pronounced in arid, semi-arid regions and more in fall and winter than in spring and summer. Last and first freezing days were hastened and delayed by 4-8 and 5-9, and 7-12 and 8-15 days for the years 2025 and 2050, respectively. Change in freezing days resulted in an increase in the potential length of growth period by 5 to 23 days in 2025 and 16 to 42 in 2050. Results of PCA showed that two main components containing temperature and rainfall variables accounted for up to 90% of the variation in agroclimatic indices both for present and future climate. Cluster analysis showed that weather station can be grouped in 10 different clusters at present but by 2025 it will be reduced to 8 and in 2050 to 7 different clusters. In general, climate change may increase similarity of agroclimatic indices and reduce agroclimatic diversity of the country in the future.

Koocheki, A., Nassiri, M. and Jamali, G. (2003). Weather Condition of Iran Under Climate Change. Project Report, Iran Meteorological Organization, 110 pp.
Lin, E. D., Zhang, H. X. and Wang, J. H. (1997). Simulation of Global Climate Change Impact on China's Agriculture. China Agricultural Press, Beijing.
Rosenzweig, C. and Parry, M.L. (1994). Potential impacts of climate change on world food supply. *Nature* **367**, 133-138.
Semenov, M.A., and Porter, J.R. (1995). Climatic variability and the modelling of crop yields. *Agricultural and Forest Meteorology* **73**, 265-283.

National crop yield trends in Lithuania and variability due to climate conditions

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Lithuanian climate has been warming since the 18th century and, as projected by forecast climate models, by the middle of the 21st century it will have warmed up by 1.5-1.7°C (Bukantis, 2001). Effect of climate on agricultural crop yield is obvious, however, it is often difficult to separate weather from other factors. National crop yield trends and variability resulting from agronomical practices and climatic impacts in Lithuania were studied as part of the project "Impact of anthropogenic climatic and environmental changes on the vegetation of forests and agro-ecosystems (APLIKOM)" supported by the Lithuanian State Science and Studies Foundation.

Historical trends and departure from the linear trend was calculated for the main agricultural crops (winter wheat, spring barley, grass etc.) for 1881-2003. The largest increases in cereal yields were found during 1992-2003. Winter wheat grain yield increased by on average 0.123 t ha^{-1} and spring barley by 0.083 t ha^{-1} annually. The yield potential of crop varieties introduced recently in Lithuania as well as improved technologies and inputs available on the market may lead to an exponential type of growth during the nearest decades. However, on the national level logistic type of growth with potential for doubling yields over the period up to 2020-2030 seems more realistic, as it was suggested by Harris and Kennedy (1999).

Climate variability is a very important factor of cropping performance through its impact on yield variability. The departures from yield trend of cereals were higher during 1992-2003 compared with the 1881-1939 period, which corresponds to period (1885-1933) of monotonous climate. In contrast, the period from 1940 can be attributed to the so-called period of extreme climate. In relative figures, however, departures from trend were on the same level (aprox. 30 %) during the period 1881-2003.

In Lithuania summer air temperatures over the last decades (beginning with the seventh decade) have been quite contrasting: every second or third summer was either extremely cold or hot (Bukantis, 2001). Analysis of the data obtained from the State Variety Testing Stations revealed a substantial increase in the potential productivity of recently introduced cereal varieties. However, the capacity to tolerate extremes in weather conditions is still rather low and explains a substantial part of yields below the trend line.

Increases in temperatures may have especially significant effect on yield levels of grasses. A distinct and statistically significant increase in the mean air temperature during the vegetative growth period was noted at the experimental site of the Lithuanian Institute of Agriculture in Dotnuva, Kedainiai for the period 1984-2003. Statistically significant negative correlation ($P < 0.05$) was identified between sward yield (t ha^{-1}) and mean air temperature in April – August.

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Response of a Danish and of a Swedish wheat cv. to increased temperature: partitioning of assimilates during the winter

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In Northern Europe, an increase in temperature is expected mainly during the autumn and winter period. In Norway the winter survival of wheat is generally low, and an increase in temperature will probably have a great impact on it. A way to adapt to climate change could be by adopting more heat demanding cultivars, which also have a higher production potential. However, plants will have to survive under extremely low irradiation during November and December, and in a rather wet and variable weather, in order to reach the spring with sufficient vigour.

Little is known about the physiology of wheat plants during the Norwegian winter. An important aspect is the partitioning of new assimilates. We intend to examine this question by help of ad hoc growth modelling of the winter period and an experiment with two contrasting wheat cultivars: Ritmo, which is widely used in Denmark but normally not able to survive in Norway, and Magnifik, a Swedish variety which is presently the most winter hardy cv. used in Norway.

The experiment was conducted in 16 “field chambers” (6 m^2 ground area) consisting of 2.0 m high transparent plastic foil walls without roof. Fans blew the air from the outside air into the chambers through perforated tubes, and CO_2 and heat were added in order to obtain all combinations of two temperatures and two CO_2-concentrations. Control 'field chambers' without air blowing were also established. The plants were harvested 12 times from October to April. Before harvesting plants were moved to a heated chamber with artificial light and labelled with $^{13}CO_2$ for three hours. The pots were then returned to the 'field chambers', and harvested after 48 hours.

Preliminary analysis of the C^{13}/C^{12} ratio in top, stub and roots show a clear transport of new assimilates to roots in the middle of the winter (December) and also with temperatures slightly below zero. Differences between cultivars in their response to climate treatments will be discussed also in relation to how this information can be used in a dynamic plant model for the winter period.

Overwintering of winter wheat under marginal conditions

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Winter survival is crucial to succeed with production of winter wheat (*Triticum aestivum* L.). Risk calculations of winter wheat production in a changing climate or at new locations rely much on tools such as an overwintering model quantifying relationships between climatic factors and the plants' ability to survive during winter. Among such relationships is cold hardiness as affected by stage of phenological development.

As part of the research programme WINSUR on impacts of climate change, field trials were conducted at three sites, Stjørdal (63°29'N, 10°52'E, 26 m a.s.l.), Selbu (63°20'N, 11°01'E, 165 m a.s.l.) and Oppdal (62°34'N, 9°40'E, 590 m a.s.l.), with two cultivars of winter wheat, Bjørke and Portal, during two winters. Plants were raised in flats and hardened under natural conditions in Stjørdal, and in November distributed to the three field sites. Plant samplings from fields were conducted once a month from November through April for test of cold hardiness and studies of phenological development.

Weather conditions such as soil temperature and snow cover influenced gain and loss of cold hardiness during autumn and winter. Stage of phenological development was recorded by dissection of stem apices just after samplings and three weeks later, after growth at 18 °C under either short (7.5 h) or long (18 h) day. Long day was the first winter given at full light conditions (120 µmol $m^{-2} s^{-1}$), and the plants received 2.4 times more light energy than did plants at short day conditions. Then plants at long days passed the double ridge stage much faster than those at short daylength. Next winter, when both treatments got full light for 7.5 h only, and photoperiodic extension to 18 h was given by low light intensity (4 µmol $m^{-2} s^{-1}$), no significant difference in rate of development was found between the two photoperiodic treatments. For plants observed immediately after sampling from field, no visible change in stage of development of the main tiller apex was seen from November through March. However, the stem apex developed rapidly after snow thaw and when temperature started to rise in March/April. These results will, together with other ones from the field trials, be used in the further development of an overwintering model of winter wheat.

Photosynthetic pigments system: effect of stress and adaptation

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Abiotic and biotic stresses cause alterations in the physiological processes of plants and decrease their productivity. Plants can react to stress in two ways specifically. When due to special gene activation starts synthesis of stress proteins and special enzymes, and non-specifically, when course of usual physiological processes changes. Evidence of the non-specific stresses can be seen in the photosynthetic system (Alexieva et al., 2003). Climatic changes are linked to changes in surface ozone and UV-B radiation. They affect plants, including agricultural crops. (Reddy and Hodges, 2000). So it is important to determine how different plants react to changes of environmental factors. The objective was to investigate tolerance and adaptation of photosynthetic pigments system of horticultural plants to ozone and UV-B stress.

Three experiments were carried out in phytotron complex in Laboratory of Plant Physiology, LIH. In the first experiment effects of ozone concentrations of 120, 240 and 360 µg m^{-3} were studied. Plants were affected by 1, 3, 5, 7 and 9 kJ m^{-2} day^{-1} doses of UV-B in the second experiment. The third experiment was an investigation of adaptation to ozone and UV-B radiation, where during adaptation period plants were affected by 80 µg m^{-3} of ozone and 4 kJ m^{-2} day^{-1} of UV-B. The main effect was 280 µg m^{-3} of ozone and 8 kJ m^{-2} day^{-1} of UV-B. The subject of research was radish, tomato and pea in all experiments. In the experiments of ozone impact apple, apricot, peach, plum trees and strawberry were studied.

Chlorophyll content decreased in leaves of pea, pome fruits and strawberries and increased in tomato and radish when ozone concentration was increased. In leaves of apricot and apple rootstock 62-396 chlorophyll content significantly decreased only at higher ozone concentration. The chlorophyll a and b ratio in plant leaves decreased under these conditions. The pigment content in pea leaves significantly decreased even at the lowest dose of UV-B. UV-B radiation did not have negative impact on pigment content in radish leaves. In the third experiment no negative effect of ozone and UV-B could be seen, but the chlorophyll a and b ratio slightly decreased after an adaptation period. Only pea significantly reacted to UV-B effect. The pigment content in pea leaves decreased after repeated treatments of the same factor. Pigments content in radish leaves increased after main effect of UV-B radiation. The results show that tolerance and adaptation of photosynthetic pigments system of investigated plants depends on genotype and intensity of effect.

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Winter stresses to crops and native plants during climate change

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Perennial plants are subject to several kinds of stresses during winter caused by frost, frost heave, ice cover, flood, drought and low temperature microbes. Through natural selection indigenous plants have adapted to the natural winter stresses at their location. Therefore native plants are distributed on localities, where the stresses they are intolerant to are low. Frost is mainly damaging plants at low altitudes and latitudes where snow cover is limited, and low temperature microbes dominate at high altitudes and latitudes where long lasting snow cover protects the plants from frost. Ice cover is usually located in between these extremes, where snow frequently melts in winter thaws giving rise to ice cover on the ground.

Cultivated crops possess the natural hardiness belonging to the species but cultivars within species are often selected for increased hardiness. Generally the hardiness to different stresses are linked, plant species hardy to frost are also tolerant to ice or snow moulds and these plants are referred to as winter hardy. Grasses are winter hardy plant types while winter cereals are fairly unhardy with perennial legumes in an intermediate position. Within each species there can be substantial differences between cultivars in winter hardiness depending on the place of origin.

The expected climate change involves higher temperatures, especially during winter and in northern areas, increased precipitation and increased incidents of storms. Generally, this should increase plant growth and crop yield. However, these changes will also result in dramatic changes in the overwintering conditions for both wild plants and cultivated crops. Hardening conditions during fall and the number of days with protective snow cover during winter will be reduced, and plants will be subjected to increased exposure to killing frosts and ice encasement. In general this will mean that winter stresses will move to higher localities (altitude) and further north (latitude). Therefore plants not selected for specific winter stresses (frost, ice cover or snow moulds) might be damaged or killed during the expected climate change. Frost hardiness and ice encasement tolerance of cultivated crops and wild plants have been tested in laboratory experiments indicating that some wild plant species possess low ice encasement tolerance and some crops have low frost hardiness which could hit them in the future. Agriculture has to prepare for these changes.

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Modelling crop yield and nitrate leaching for winter wheat in Europe

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The climatic conditions not only influence crop production, but also the dependency on external inputs (e.g. fertiliser nitrogen (N)) and the effects of the cropping system on the environment (e.g. through nitrate leaching). Climate change is thus likely to influence crop production and nitrate leaching, partly through changes in the fertilisation regime and partly through effects on the nitrogen cycling in the cropping systems.

The Daisy model (Hansen et al., 1991) was run for 9 climate stations across Europe with varying soils, N fertiliser and climate changes in order to develop an empirical function for N leaching as affected by climate and climate change. Only a rainfed winter wheat monoculture without straw incorporation was considered. Based on the simulated N response, the optimal N rate was calculated for each climate-soil combination and this was used to estimate a multiple linear regression model of N leaching and yield at optimal N rate on soil and climate variables. The N leaching data was fitted to the expo-linear equation, and the parameters of this model were regressed on the soil and climate variables. The variables considered in the multiple linear regressions model were atmospheric CO_2 concentration, soil water capacity, and seasonal mean values of temperature and rainfall.

The regression equations were only calibrated for site conditions where the cultivation of winter wheat is viable. In parts of Europe, either severe winters and/or excessive rainfall may hinder the survival and effective establishment of winter wheat. Therefore, the regression indices for winter wheat yield and nitrate leaching were not applied in grid boxes across Europe, where two simple constraints for winter temperature and annual rainfall were exceeded.

The highest yields of rainfed winter wheat under the baseline climate (1961-1990) were estimated in central Europe with the largest estimates of more than 8 t ha^{-1} in France and parts of England. Smaller yields down to 4 t ha^{-1} were estimated for north-eastern and southern Europe. Estimates of the changes in productivity for 2071-2100 were very consistent among the nine regional climate model scenarios for the A2 SRES scenario with increases in most areas north of the Alps and decreases in southern Europe, especially over the Iberian Peninsula. The simulated changes in nitrate leaching were far more patchy compared to the estimated changes in wheat yield. 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.

Hansen, S., Jensen, H.E., Nielsen, N.E. and Svendsen, H. (1991). Simulation of nitrogen dynamics and biomass production in winter wheat using the Danish simulation model DAISY. *Fertilizer Research* **27**, 245-259.

Impacts of expected climate change on soil erosion processes

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The impact of the expected climate change on the frequency and extent of soil erosion processes is hardly assessable so far. This is mainly due to the fact that the available models of climate change produce at best mean daily precipitation data, whereas erosion is always the result of extreme but short-time events, lasting normally not longer than a few hours. The frequency and intensity of these extreme events are expected to increase in some regions, which could lead to increased erosion rates. Mathematical models are able to describe erosion rates under the conditions of these extreme events. However, so far prognostic meteorological data necessary for the application of these models are not available.

The use of a new method for the projection of meteorological time series and their extremes using global climate simulations permits for the first time an approximation of future soil loss. This research is based on simulated, high resolution data for extreme rainfall events in the period of 2031-2050, which reproduces the mean frequency, intensity and duration of future events with high precipitation intensities relevant to erosion within the investigated seasonal period from June to August. The simulations are performed for two example sites in Saxony, based on the EROSION 2D model, which is a process-based soil erosion model for simulating soil erosion and deposition by water on single slopes. Simulated precipitation for the 2031-2050 time period is used to model soil loss, and results are compared to soil loss based on 20 years of measured precipitation from 1981 to 2000.

The simulation results allow the impacts of climate change on erosion rates to be quantified by comparing current climate with predicted, future climate. However, expected changes in land use due to changed economic conditions are not taken into account so far.

Environmental effects of agricultural activities under climate change

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The agricultural production is affected both directly and indirectly by the global climate changes. The direct effect occurs through the effect of increased CO_2 and changes in climate on the development and growth of crops. The crop production is affected indirectly through effects of climate change on soil fertility, need for fertilisers, occurrence of weeds, pests and diseases, and the possibilities for carrying out field operations.

The increasing crop yields that results from increased CO_2 concentration and climate change will increase the optimal nitrogen fertiliser rates. This effect was estimated for continuous winter wheat cultivation using the DAISY model for two different greenhouse gas emissions scenarios (Olesen et al., 2004). There was in general an increase in optimal nitrogen fertiliser rates. In both scenarios there was an increase in nitrate leaching for a climate from Western Denmark, whereas there was a tendency for a reduction for loamy soils for a climate in Eastern Denmark. The environmental effects of climate change in Denmark may therefore vary regionally. The effects can mainly be attributed to changes in temperature and CO_2 concentration, because the effect of lower rainfall during the growing season is compensated by an increase in water use efficiency at higher CO_2 concentration. The model calculations showed a clear tendency towards higher increases in nitrogen leaching under climate change for the sandy soils compared with the loamy soils. This is an effect of an increase in soil organic matter turnover rates at higher temperatures and an increase in the duration of bare soil during autumn.

Loss of phosphorus from agricultural soils to the environment occurs as dissolved phosphorus or as phosphorus bound to soil particles. The phosphorus is in both cases transported with water to streams, lakes and estuaries, either by leaching, surface runoff or by erosion. The expected climate changes with more intense precipitation and higher rainfall outside the cropping season is expected to increase risk of phosphorus losses considerably, and this concerns all losses processes affected by water movement.

There are major uncertainties associated with the assessment of effects of climate change on agricultural land use, production and environmental impact. Major uncertainties are associated with the future agricultural and environmental policies and the agricultural structure, which probably have larger effects for agricultural land use and crop choice than climate change. The highest uncertainties are associated with the assessment of the effects of climate change on environmental impact of agricultural production, which for nitrate leaching is caused by opposing effects of temperature increase and higher CO_2. There is therefore in this area a need to improve the models to enable a more reliable assessment of climate change effects. This is also the case for processes affecting phosphorus losses from soils.

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Crop responses to climatic variability

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The yield and quality of food crops is central to the well being of humans and is directly affected by climate and weather. Initial studies of climate change on crops focussed on effects of increased CO_2 level and/or global mean temperature and/or rainfall on crop production. However, crops can respond non-linearly to changes in their growing conditions, exhibit threshold responses and they are subject to combinations of stress factors that affect their growth, development and yield. Thus, climate variability and changes in the frequency of extreme events are important for yield and its stability. In this context, threshold temperatures are found not to differ greatly for different crops and are important to define, so as to help climate modellers predict the occurrence of crop critical temperatures and their temporal resolution. Both simulation and experimental results have shown that altering the variability of temperature had the same order effect on the development and growth of wheat as changing its mean value. It is important to represent changes in both the mean and variability of climatic conditions in order to predict the impact of climatic change on crop development and yield.

Increasing temperature and precipitation variability increases the risks to yield, as shown via computer simulation and experimental studies. The issue of food quality has not been given sufficient emphasis when assessing the impact of climate change for food. Using experiments and simulation models of wheat, the concentration of grain protein are shown to respond to changes in the mean and variability of temperature and precipitation events.

Two other points are important for the future, in the context of climate change studies. Climate scientists should recognise the large body of information, often published in non-traditional references such as plant breeding trial reports that may be useful in defining what can be considered a ‘dangerous’ amount of climate change from the point of view of food production. The clear message from the crop community is that thresholds are well-defined, they can be effective over short time periods and can extensively damage yield productivity, mainly via restrictions on carbon and nitrogen sink formation and activity. There is a need to develop joint modelling and, especially, experimental studies of this topic. Crop modelling can predict the timing of stages when crops are sensitive to threshold temperatures; experimental studies can provide the quantitative responses that will permit the modelling effort to progress. In this endeavour, plant scientists could be guided by their zoological colleagues who have very carefully characterised the temperature limits of a range of physiological processes of cold-blooded (poikilothermic) animals. There is a need for equivalent information for the major food crops.

Global warming in Latvia and its influence on crop yields

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Global warming in Latvia emerges mostly at spring. Spring mean temperature has been increase by approximately 2 °C at past 50 years, while year mean temperature changes only for about 1 °C.

Yield of winter crops is affected mostly by winter mean temperature, for example, the correlation between yield of wheat and deflection of January mean temperature from optimal is 0.44 (Krogere and Pelece, 2004.), but optimal January mean temperature is about 5 °C higher than the mean for the past 50 years. Therefore global warming at January can increase yield of wheat, but the relationship is not strong enough to estimate possible increase of yield.

Yield of spring crops, for example oat, depends mostly on mean temperature of May and July (correlation coefficients between yield and temperature deviance from optimum are 0.39 and 0.54, respectively) (Krogere and Pelece, 2004.), but optimal temperature at May is approximately the same as the mean for the past 50 years, while at July it is about 0.5 °C higher. Therefore global warming can decrease yield of oat. Yield of spring barley was not found to be sensitive on monthly mean temperatures.

Krogere, R. and Pelece, I. (2004). Productivity of crop rotation in long-term field trial related to meteorological conditions. *Proceedings in Agronomy* **6**, *Jelgava.*

Impact of high temperatures during kernel filling on protein levels in malting barley

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The nitrogen content, measured as crude protein on dry matter (CP), is an important quality parameter in most cereals. For malting barley, CP is important for several reasons. Both excessive nitrogen and too little nitrogen in the kernels result in reduced malting quality. The malting industry accepts CP levels from 9.5 to 11.5%. An uneven CP level within a lot of malting barley is also a problem as it produces a malt of worse quality than if CP is even. Recent research suggests that many of the classical quality problems in the malting industry originate from uneven CP of the barley (Palmer, 2000).

A large number of studies during the last century have demonstrated the difficulties to reach pre-requested nitrogen levels in cereals. Originally, only very high temperatures during growth and kernel filling (30 ^{o}C and above) were supposed to be an explanatory factor for these difficulties (e.g. Savin and Nicolas, 1996). Recent work with winter wheat shows that even modest summer temperatures, between 20 and 25 ^{o}C, during anthesis and kernel filling have a profound effect on CP (Triboi and Triboi-Blondel, 2002). Knowledge on the relation between temperature and CP content might thus be assumed to be of importance for assesing CP contents of malting barley under climate change.

Within a Swedish malting barley project, sixteen fertiliser trials representing three seasons were monitored. The accumulated sum of daily mean air temperatures above 20 ^{o}C was used as an index for thermal stress time (TST20) The sum was calculated for a three week period biginning at growth stage 45 (scale according to Tottman and Broad, 1987) resulting in sixteen different heat sums. Most of the recorded CP variation between trials was explained by TST20 ($r^2_{adj} = 0.62$). It is concluded that the temperature condition during anthesis and kernel filling is an important determining factor for CP in malting barley. The implications from this in a climate change scenario will be discussed.

Palmer, G.H. (2000) Malt performance is more related to inhomogeneity of protein and β-glucan breakdown than to standard malt analyses. *Journal of the Institute of Brewing* **106**, 189-192.

Savin, R. and Nicolas, M.E. (1996). Effects of Short periods of Drought and High Temperature on Grain Growth an Starch Accumulation of Two Malting Barley Cultivars. *Australian Journal of Plant Physiology* **23**, 201-210.

Tottman, D.R. and Broad, H. (1987). The decimal code for the growth stages of cereals, with illustrations. *Annals of Applied Biology* **110**, 441-454.

Triboi, E. and Triboi-Blondel, A.-M. (2002). Productivity and grain or seed composition: a new approach to an old problem - invited paper. *European Journal of Agronomy* **16**, 163-186.

Impact of a high-temperature event on carbohydrate composition in barley seeds analysed by novel single seed MAS-NMR analysis

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Plant carbohydrates constitute a valuable energy source for both human and animal nutrition, and, as in the case of beta-glucans, have important effects on health. Climate change resulting in higher temperatures and more frequent episodes of extreme temperatures (Wollenweber et al., 2003) will effect plant growth and carbohydrate metabolism. Plants exposed to high temperature after anthesis show reductions of starch accumulation affecting both grain yield and quality.

As part of the ongoing Ph.D. project '*Elucidation of environmental constraints to carbohydrate-metabolism and quality parameters of barley grown for feed*' a high temperature-stress experiment was conducted at the Research Centre Flakkebjerg to clarify the variation in starch and beta-glucan during grain filling as even a few degrees difference from the optimum temperature around anthesis can decrease starch content and grain weight (Wallwork et al., 1998), reduce contents of starch (Savin and Nicolas, 1999) and beta-glucan (Savin et al., 1997), and, in some cases, increase amylose content (Savin and Nicolas, 1999).

During anthesis the plant material was exposed to two temperature regimes in a climate chamber (either 20 ^{o}C/16 ^{o}C (control) or 30 ^{o}C /17 ^{o}C) for two weeks. From anthesis to maturity eight harvests were performed to track changes in carbohydrates during grain filling. Three contrasting varieties with normal beta-glucan (BG) content (6-8 %), a mutant with high BG content (19 %) and a mutant with low BG content (2-3 %) were analysed.

Seeds from temperature stressed plants were analysed by Nuclear Magnetic Resonance (MAS-NMR), a novel technique for single seed analysis. This technique explores the intrinsic magnetic moment and nuclear spin of specific atoms in a sample located in a magnetic field. In order to obtain signal from solids, a special NMR technique is used in which the probe is spun at the 'magic angle', MAS of 54,7^{o}, leading to spectra with a wealth of detailed information of the chemical constitution of the seeds under high temperature episodes.

Savin, R. and Nicolas, M.E. (1999). Effects of timing of heat stress and drought on growth and quality of barley grains. *Australian Journal of Agricultural Research* **50**, 357-364.

Savin, R., Stone, P.J., Nicolas, M.E. and Wardlaw, I.F. (1997). Grain growth and malting quality of barley .1. Effects of heat stress and moderately high temperature. *Australian Journal of Agricultural Research* **48**, 615-624.

Wallwork, M.A.B., Logue, S.J., MacLeod, L.C. and Jenner, C.F. (1998). Effect of high temperature during grain filling on starch synthesis in the developing barley grain. *Australian Journal of Plant Physiology* **25**, 173-181.

Wollenweber, B., Porter, J.R. and Schellberg, J. (2003). Lack of interaction between extreme high-temperature events at vegetative and reproductive growth stages in wheat. *Journal of Agronomy & Crop Science* **189**, 142-150.

Interaction of more than one high-temperature episode in spring wheat?

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General circulation models have revealed that global warming may result in increases of both mean air temperature AND of the frequency of periods with extremely high temperatures. The frequency of occurrence of these extreme events is altered by relatively small climate changes and crop-specific high-temperature thresholds might be exceeded. Thus, with an increase in variability, episodic occurrences of high temperature could have an impact at vulnerable stages and be much more damaging to crop yields compared to more stable conditions. Physiological responses to temperature changes may occur over both short and long time-scales. Rapid changes in enzymatic reactions caused by differential thermosensitivity of various enzymes can deplete or result in accumulation of key metabolites. Long-term responses include alterations in the rate of CO_2 assimilation per unit leaf area and impaired cell anaplerotic carbon metabolism, sucrose synthesis, carbon and nitrogen partitioning within and between organs.

The developmental stage of the crop exposed to increased temperatures will determine the strength of possible damage experienced by the plant. Thus investigations of the responsiveness of crops to combinations of extreme temperature events have important implications for climate impact studies. *Double-ridge* (spikelet formation phase, whereby 2 bracts mark the end of the spikelet) and *anthesis* are extremely sensitive to heat stress. In the former, the development of spikelet primordia on the apex can be disrupted by high temperature. Extreme temperature events around anthesis interfere with the development of fertile grains, as meiosis and pollen growth are affected.

Results from experiments investigating the possible interaction of more than one high-temperature event in spring wheat are presented (Wollenweber et al., 2003). The effects of multiple high temperature events (HTEs) on crop growth could either be independent or be influenced by previous exposure. Our null hypothesis was that sequential HTEs are independent in their effects.

We found our null hypothesis clearly held. Total and grain yields were significantly reduced only by the later HTE. Its main effect was reduction of grain sink capacity; photosynthetic source processes were almost unaffected by either or both HTEs. The results are compared to those obtained from a modified version of the simulation model AFRCWHEAT2 (Porter, 1993) and discussed in relation to the implications of extreme high-temperature events at different phenological stages and to possible thermo-tolerance mechanisms of the whole plant.

Porter, JR. (1993). AFRCWHEAT2: a model of the growth and development of wheat incorporating responses to water and nitrogen. *European Journal of Agronomy* **2**, 69-82.
Wollenweber, B., Porter, J.R. and Schellberg, J. (2003). Lack of Interaction between Extreme High-Temperature Events at Vegetative and Reproductive Growth Stages in Wheat. *Journal of Agronomy and Crop Science* **189**, 142-150.

Adaptation measures of Finnish agriculture to climate change

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Under the current climatic conditions, the northern frontier of major cool climate field crops, fruit crops and ornamentals crosses Finland between 60 and 65 degrees latitude or the frontier lies just to the south of Finland. The current and projected trends of milder winters, earlier springs and slight changes in precipitation (Jylhä et al., 2004) suggest that new crop production opportunities will open within a few decades. To gain from the changes, breeding and testing programs for new crops and varieties are needed in the near future.

Potentially negative effects of climatic change are increases in pest and disease risks, nutrient leaching, erosion and soil compaction, and greenhouse gas emissions. Also overwintering problems may arise due to periods of abrupt warming during winters, lack of snow cover, or lack of ground frost. To minimize the negative effects, new cultivation techniques have to be taken into use. These include promoting direct drilling, constant green cover on the field surface, integrated and more frequent protection measures against pests and pathogens, and breeding of pathogen resistance to a wider variety of crops. Old traits such as growth cessation of overwintering crops during winter time, whether or not the temperatures rise, should also be maintained.

Agrifood Research Finland is to launch in 2006-2007 a new project aimed at stimulating measures to adapt to climate warming in the North.

The tasks we plan to carry out are: (1) modeling and testing of risk of cold and frost injury to perennial crops under conditions of warmer winters and earlier springs, (2) estimation of suitability of new winter type field crops, (3) study of yield formation of varieties originally adapted to more southern conditions under long day conditions, (4) formulating methods to estimate effects of drought and increased rain intensity on cereal yield, (5) estimation of pest risks and monitoring pest migrations, (6) modeling of nutrient losses from field crops, (7) estimation of future changes in soil structure and biodiversity, (8) estimation of the need for new cultivation methods, (9) long term limits of climatic competitivity of Finnish agriculture.

The program will consist of different projects carried out together with both national and international partners, and funded by several organizations.

Jylhä, K., Tuomenvirta, H. & Ruosteenoja, K. (2004). Climate change projections for Finland during the 21st century. *Boreal Environment Research* **9**, 127-152.

Adaptation to climate change - the case of silage maize

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Climate change will likely change the relative competitiveness of different crops due to their different responses to temperature and water availability. However, the competitiveness of a given crop species is not only determined by climatic factors, but also by genetic traits, management considerations and subsidies. Given these influencing factors, farmers make their decisions on which crops to grow. In a changing climate there will be a gradual change in the most suitable crops. However, current farm management may not always capture these changes sufficiently quickly, if there are inadequacies in the transfer of knowledge on climate change and in the sharing of cropping experiences.

The cultivation of maize has increased considerably in Denmark during the past two decades from 11,000 ha in 1980 to 118,000 ha in 2003 (Olesen and Bindi, 2004). The maize is harvested for silage and used as feed for dairy cows. During this period, maize has replaced fodder beets and cereals for whole-crop silage as winter feed for the cattle, and maize silage is now also used as an important feed supplement during the summer season. There are several reasons for this change, including the high quality of maize silage as a feed for cows, and a period from the mid 1990's where maize was subsidized and fodder beet was not. However, a main driver for the changes has been increasing yields and fewer years with yield failures. Among farmers and agricultural advisors this has mostly been attributed to new cultivars better adapted to the Danish climate.

The climatic suitability for silage maize in Denmark is usually described by corn heat units (CHU, Begna et al., 1999) accumulated from 15 April to 15 October, and this index has increased over the past ten years. There is a close relationship between the average dry matter yields obtained in variety trials in Denmark and the corn heat units. A multiple linear regression of maize yield on CHU and year showed that CHU explained 64% of the variation in yield and year only 1%. The climate therefore seems to be the main factor influencing maize yields, whereas improved technology (including varieties) only plays a small role. The increase in maize area in Denmark can therefore be explained by the warming that has occurred over the past two decades, and 67% of the variation in the area cultivated with maize can be explained by the average of the CHU over the past two years. Dairy farmers in Denmark have thus adapted quickly to the gradually warmer climate. This has not been a deliberate adaptation to climate change, and both farmers and advisors attribute the much of the change to other factors, such as improved varieties. Thus even undeliberate adaptation to climate change may be very effective. However, the lack of awareness of the role of climate change may mean that farmers would not be sufficiently prepared for the climatic variability that still exists, and which can result in yield failures in some years.

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