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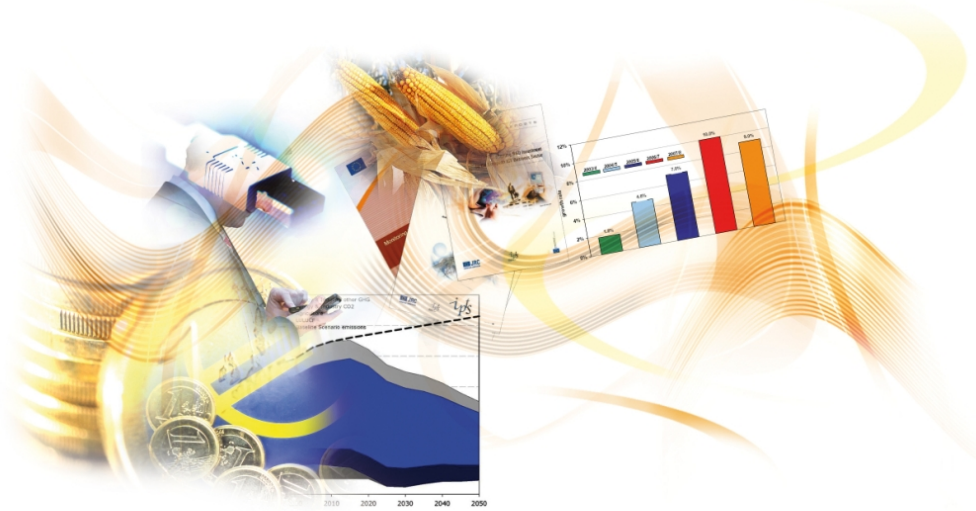

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Preface

The main objective of the PESETA (Projection of Economic impacts of climate change in Sectors of the European Union based on boTtom-up Analysis) project is to contribute to a better understanding of the possible physical and economic effects induced by climate change in Europe over the 21st century. PESETA studies the following impact categories: agriculture, river basin floods, coastal systems, tourism, and human health.

This research project has followed an innovative, integrated approach combining high resolution climate and sectoral impact models with comprehensive economic models, able to provide estimates of the impacts for alternative climate futures. The project estimates the impacts for large geographical regions of Europe.

The Joint Research Centre (JRC) has financed the project and has played a key role in the conception and execution of the project. Two JRC institutes, the Institute for Prospective Technological Studies (IPTS) and the Institute for Environment and Sustainability (IES), contributed to this study. The JRC-IPTS coordinated the project and the JRC-IES made the river floods impact assessment. The integration of the market impacts under a common economic framework was made at JRC-IPTS using the GEM-E3 model.

The final report of the PESETA project (please visit http://peseta.jrc.ec.europa.eu/) is accompanied by a series of technical publications. This report presents in detail the agriculture physical impact assessment, methodology and results.

Antonio Soria

Acting Head of Unit
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Summary

Objective

The objective of the study is to provide a European assessment of the potential effects of climate change on agricultural land productivity. The future scenarios incorporate socio economic projections derived from several SRES scenarios and climate projections obtained from global climate models and regional climate models.

Methods

The work links biophysical and statistical models in a rigorous and testable methodology, based on current understanding of processes of crop growth and development, to quantify crop responses to changing climate conditions.

Dynamic process-based crop growth models are specified and validated for sites in the major agro-climatic regions of Europe. The validated site crop models are useful for simulating the range of conditions under which crops are grown, and provide the means to estimate production functions when experimental field data are not available. Variables explaining a significant proportion of simulated yield variance are crop water (sum of precipitation and irrigation) and temperature over the growing season. Crop production functions are derived from the process based model results. The functional forms for each region represent the realistic water limited and potential conditions for the mix of crops, management alternatives, and potential endogenous adaptation to climate assumed in each area.

Nine agro-climatic regions are defined based on K-mean cluster analysis of temperature and precipitation data from 247 meteorological stations, district crop yield data, and irrigation data. The yield functions derived from the validated crop model are then used with the spatial agro-climatic database to conduct a European wide spatial analysis of crop production vulnerability to climate change. Three climate change scenarios are derived: from the Prudence HIRHAM RCM nested in the HadCM3 GCM under the A2 and B2 forcing and from the Rossby Centre RC4 nested in the ECHAM4 GCM under the A2 scenario.

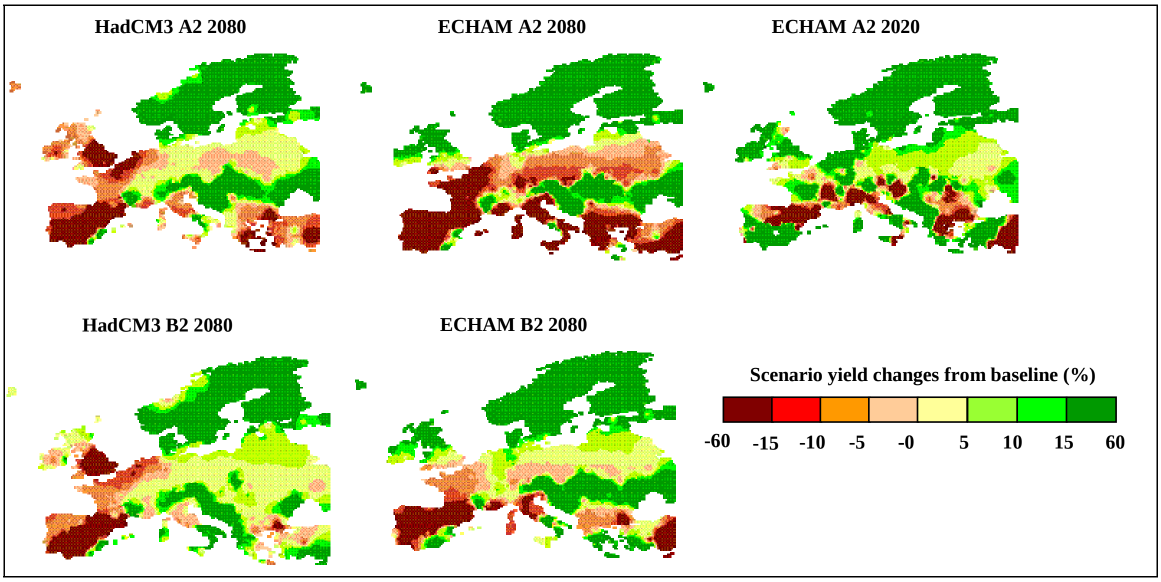
Adaptation is explicitly considered and incorporated into the results by assessing country or regional potential for reaching optimal crop yield. Optimal yield is the potential yield given non-limiting water applications, fertilizer inputs, and management constraints. Adapted yields are calculated in each country or region as a fraction of the potential yield. That fraction is determined by the ratio of current yields to current yield potential.

The crop production estimates incorporate some major improvements to previous European and global estimates since they are based in a consistent crop simulation methodology and climate change scenarios and changes in the agricultural zones at the Europe-wide scale. Furthermore, the estimations include weighting of model site results by contribution to district rainfed and irrigated production and explicit links to water demand and availability and explicit consideration of adaptation. Finally, the estimations include the updated valuation of the physiological CO_2 effects on crop yields.

Results

European crop yield changes were modeled under the HadCM3/HIRHAM A2 and B2 scenarios for the period 2071 - 2100 and for the ECHAM4/RCA3 A2 scenario for the period 2011 - 2040. The yield changes include the direct positive effects of CO_2 on the crops, the rainfed and irrigated simulations in each district. Although each scenario projects different results, all three scenarios are consistent in the spatial distribution of effects (Figure 1). Crop suitability and productivity increases in Northern Europe are caused by lengthened growing season, decreasing cold effects on growth, and extension of the frost-free period. Crop productivity decreases in Southern Europe are caused by shortening of the growing period, with subsequent negative effects on grain filling. It is very important to notice that the simulations considered no restrictions in water availability for irrigation due to changes in policy. In all cases, the simulations did not include restrictions in the application of nitrogen fertilizer. Therefore the results should be considered optimistic from the production point and pessimistic from the environmental point of view.

Figure 1. Crop yield changes under the HadCM3/HIRHAM A2 and B2 scenarios for the period 2071 - 2100 and for the ECHAM4/RCA3 A2 and B2 scenarios for the period 2071 - 2100 and ECHAM4/RCA3 A2 scenario for the period 2011 - 2040 compared to baseline



The results are then used to evaluate policy adaptation that takes into account natural resources management. The results are also used as input to derive monetary impacts of climate change in the entire European agricultural sector by using models that consider the production, consumption, and policy.

1. Introduction

1.1. Context and objectives

The aim of the PESETA (Projection of Economic impacts of climate change in Sectors of the European Union based on boTtom-up Analysis) project is "to make an assessment of the monetary estimates of impacts of climate change in Europe based on bottom-up sectoral physical assessments, given the state-of-the-art methods and knowledge of the physical impacts of climate change." The final report of the PESETA project is available at the Institute for Prospective Technological Studies (JRC-IPTS) website (please visit http://peseta.jrc.ec.europa.eu/) (Ciscar *et al*., 2009).

The aim of this report is to provide physical impact results, evaluate their confidence, and interpret them in relation to other empirical and modelling evidence. The quantitative results are based on numerical models and exposure-response functions formulated considering endogenous adaptation within the rules of the modelling framework. The results include production potential and potential water demand allowing the evaluation of possible policy adaptation options in the future for a range of climate scenarios in different agricultural regions. Water restrictions and socio-economic variables that modify the probabilities of change occurring may also be considered in a later stage of the study.

1.2. Challenges to agriculture in the European Union

Agriculture in the European Union faces some serious challenges in the coming decades: competition for water resources, rising costs due to environmental protection policies, competition for international markets, loss of comparative advantage in relation to international growers, changes in climate and related physical factors and uncertainties in the effectiveness of current European policies as adaptation strategies.

Demographic changes are altering vulnerability to water shortages and agricultural production in many areas, with potentially serious consequences at local and regional levels. Population and land-use dynamics and the overall policies for environmental protection, agriculture and water resource management determine, and limit, possible adaptation options to climate change. An improved understanding of the climate-agriculture-societal response interactions is highly relevant to European policy.

The vulnerability to global change of agriculture in the European Union has been previously analysed (EEA, 2008; Iglesias et al., 2007, Olensen and Bindi, 2002, among others).

1.3. Changes in climate and related factors

Table 1 summarises the climate change and related factors relevant to agricultural production at the global scale (Iglesias 2009a). The information provided in Table 1 refers to agriculture in all regions (globally) and pretends to give an idea that the changes in agricultural production are consequence of changes in some physical key factors that are expected to be modified with climate change. This includes changes in sea level, CO_2, etc. Soil erosion is a factor that is directly affected by climate conditions and has major consequences for agricultural productivity.

Table 1. Climate change and related factors relevant to agricultural production at the global scale

Climate and related physical factors	**Expected direction of change**	**Potential impacts on agricultural production**	**Confidence level of the potential impact**
Atmospheric CO_2	Increase	Increased biomass production and increased potential efficiency of physiological water use in crops and weeds Modified hydrologic balance of soils due to C/N ratio modification Changed weed ecology with potential for increased weed competition with crops	Medium
		Agro-ecosystems modification	High
		N cycle modification	High
		Lower yield increase than expected	Low
Atmospheric O_3	Increase	Crop yield decrease	Low
Sea level	Increase	Sea level intrusion in coastal agricultural areas and salinization of water supply	High
Extreme events	Poorly known, but significant increased temporal and spatial variability expected Increased frequency of floods and droughts	Crop failure Yield decrease Competition for water	High
Precipitation intensity	Intensified hydrological cycle, but with regional variations	Changed patterns of erosion and accretion Changed storm impacts Changed occurrence of storm flooding and storm damage Increased water logging Increased pest damage	High
Temperature	Increase	Modifications in crop suitability and productivity Changes in weeds, crop pests and diseases Changes in water requirements Changes in crop quality	High
	Differences in day-night temp	Modifications in crop productivity and quality	Medium
Heat stress	Increases in heat waves	Damage to grain formation, increase in some pests	High

Source: Iglesias (2009a)

Atmospheric CO_2 and O_3 concentrations

Greater concentrations of CO_2 in the atmosphere have the potential to increase biomass production and to increase the physiological efficiency of water use in crops and weeds. However, increases in CO_2 do not produce proportional increases in crop productivity-other factors play a significant role. While experiments with increased concentrations of CO_2 under controlled conditions have been shown to significantly increase yields of crops, these increases have occurred when other factors such as moisture supply, nutrients and pest and disease incidence have not been limiting. In practice insufficient supply of water or nutrients or greater pest/disease attack or competition from weeds are expected to frequently negate the fertilizing impact of increased CO_2 concentrations in the atmosphere. Since weed growth may also be enhanced by increased CO_2, changed weed ecology may emerge with potential for increased weed competition with crops.

Increased concentrations of in the O_3 troposphere will be expected to reduce crop yields.

Sea level

Forecast increases in sea levels of up to 5m will inundate coastal agricultural areas, unless measures are taken to protect low-lying agricultural land. Rising sea levels may also lead to salinization of the water supply. An indirect effect on agriculture may also be produced by rising sea levels making population centres uninhabitable. The displaced populations will need to be housed and at least some of the housing is likely to be built on agricultural land.

Extreme events

Drought conditions may also be brought on by lower amounts of precipitation falling as snow and earlier snowmelt. In arid regions, these effects may reduce subsequent river discharge and irrigation water supplies during the growing. Episodes of high relative humidity, frost, and hail can also affect yield and quality of fruits and vegetables (especially corn and other grains).

Interannual variability of precipitation is a major cause of variation in crop yields and yield quality. By reducing vegetative cover, droughts exacerbate wind and water erosion, thus affecting future crop productivity.

Crop yields are most likely to suffer if dry periods occur during critical developmental stages such as reproduction. In most grain crops, flowering, pollination, and grain-filling are especially sensitive to water stress. Management practices offer strategies for growing crops in water-scarce conditions. For example, the effects of drought can be escaped by early planting of cultivars with rapid rates of development; fallowing and weed control can help to conserve moisture in the soil.

Excessively wet years, on the other hand, may cause yield declines due to waterlogging and increased pest infestations. High soil moisture in humid areas can also hinder field operations. Intense bursts of rainfall may damage younger plants and promote lodging of standing crops with ripening grain, as well as soil erosion. The extent of crop damage depends on the duration of precipitation and flooding, crop developmental stage, and air and soil temperatures.

Precipitation intensity

Precipitation, being the primary source of soil moisture, is probably the most important factor determining the productivity of crops. While global climate models predict an overall increase in mean global precipitation, their results also show the potential for changed hydrological regimes (either drier or wetter) in most places. A change in climate can cause changes in total seasonal precipitation, its within-season pattern, and its between-season variability. For crop productivity, a change in the patterns of precipitation events may be even more important than an equal change in the annual total. The water regime of crops is also vulnerable to a rise in the daily rate and potential seasonal pattern of evapotranspiration, brought on by warmer temperature, dryer air, or windier conditions.

Temperature

When the optimal range of temperature values for a crop in a particular region is exceeded, crops tend to respond negatively, resulting in a drop in yield. The optimal temperature varies for different crops. Most agronomic crops are sensitive to episodes of high temperature. Air temperatures between 45 and 55ºC that occur for at least 30 minutes directly damage crop leaves in most environments; even lower temperatures (35 to 40ºC) can be damaging if they persist longer. Vulnerability of crops to damage by high temperatures varies with developmental stage. High temperatures during reproductive development are particularly injurious - for example, to corn at tasseling, to soybean at flowering, and to wheat at grain filling. Soybean is one crop that seems to have an ability to recover from heat stress, perhaps because of it is indeterminate (i.e., grows continuously).

Heat stress

Heat stress and drought stress often occur simultaneously, the one contributing to the other. They are often accompanied by high solar irradiance and high winds. When crops are subjected to drought stress, their stomata close. Such closure reduces transpiration and, consequently, raises plant temperatures.

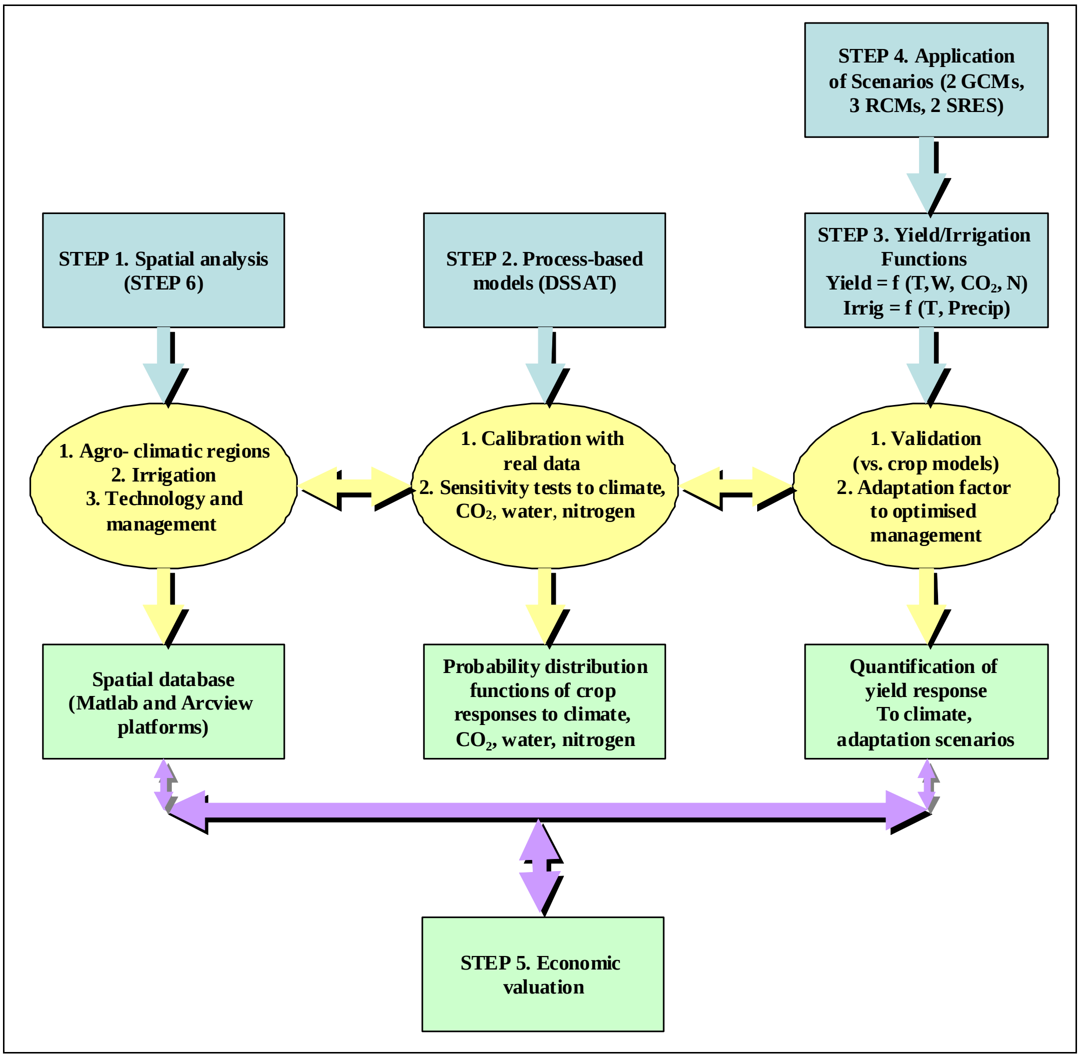
2. Methods and data

2.1. Approach

The response of agricultural systems to climate change are be driven by changes in crop yields as this strongly influences farmer decisions about profitability. Crop yields respond to climate change through the direct effects of weather, atmospheric CO_2 concentrations, and water availability.

We quantify the response of crops to climate change deriving crop production functions from process-based calibrated and validated models. First, we calibrate process-based crop models to determine and validate crop responses at the site level. Second we estimate crop production functions at the regional level taking into account water supply and demand, social vulnerability and adaptive capacity. Third, the crop production functions will be used as inputs for the monetary evaluation. The methodological steps are outlined in Figure 2. We consider that the drivers of agricultural change are both changes in climate and changes in socio-economic conditions. The methodology allows for evaluation of these changes together or separately.

Figure 2. Steps in the methodology



2.2. Deriving statistical production functions from process based crop models

In this study we use a combination of methods: we derive functions from crop model results to be able: (1) to expand the results over large areas (crop models have a limited application over wide areas due to limitations in the datasets; (2) to include conditions that are without the range of historical observations; and (3) to be able to simulate optimal management and therefore estimate possible adaptation. Table 2 summarises the characteristics of process-based crop models, empirical statistical functions, and production functions derived from model results.

The work links biophysical and statistical models in a rigorous and testable methodology, based on current understanding of processes of crop growth and development, water demand for irrigation, and adaptation strategies. The validated site crop models are be used for simulating the range of conditions under which crops are grown in Europe, and provide the means to estimate production functions when experimental field data are not available. The functional forms represent the realistic water limited conditions that characterise many European regions. The resulting functions are designed to be linked to a spatial climate database, representing both current and future climatic conditions. Adaptation is explicitly considered and incorporated into the results by assessing the country or regional potential for reaching optimal crop yield. Crop production functions are then used as inputs of an economic model to derive monetary impacts of climate change in the European agricultural sector.

Table 2. Summary of the characteristics of process-based crop models, empirical models and crop production functions

Type of methodological approach	Description and use	Strengths	Weaknesses
Process-based crop models	Calculate crop responses to factors that affect growth and yield (i.e., climate, soils, and management). Used by many agricultural scientists for research and development.	Process based, widely calibrated, and validated. Useful for testing a broad range of adaptations. Test mitigation and adaptation strategies simultaneously. Available for most major crops.	Require detailed weather and management data for best results.
Empirical statistical models	Based on the empirical relationship between observed climate and crop responses. Used in yield prediction for famine early warning and commodity markets.	Present day crop and climatic variations are well described.	Do not explain causal mechanisms. May not capture future climate crop relationships or CO_2 fertilization.
Production functions derived from crop models and validated with empirical data	Based on the statistical relationship between simulated crop responses to a range of climate and management options. Used in climate change impact analysis.	Allow to expand the results over large areas. Include conditions that are without the range of historical observations. Allow to simulate optimal management and therefore estimate possible adaptation.	Causal mechanisms are only partially explained. Spatial validation is limited due to limitations in the database.

The crop production estimates incorporate some major improvements to previous European and global estimates since it combines:

1. Consistent crop simulation methodology and climate change scenarios at the Europe-wide scale;

2. Weighting of model site results by contribution to district rainfed and irrigated production;
3. Revised estimation of physiological CO_2 effects on crop yields;
4. Shifts in agro-climatic zones;
5. Explicit links to water demand and availability;
6. Explicit consideration of adaptation;
7. Qualitative evaluation of the uncertainty derived from models and assumptions.

2.3. Simulations with process-based models

Process-based models use simplified functions to express the interactions between crop growth and the major environmental factors that affect crops (i.e., climate, soils, and management), and many have been used in climate impact assessments (Porter and Semenov, 2005; Meza and Silva, 2009; Iglesias et al., 2000; Parry et al., 2004). Most were developed as tools in agricultural management, particularly for providing information on the optimal amounts of input (such as fertilizers, pesticides, and irrigation) and their optimal timing. Dynamic crop models are now available for most of the major crops. In each case, the aim is to predict the response of a given crop to specific climate, soil, and management factors governing production.

Yield responses to climatic and management are be simulated at the selected sites using the DSSAT crop models (Rosenzweig and Iglesias, 1998). DSSAT includes mechanistic crop models that simulate daily phenological development and growth in response to environmental factors (soil and climate) and management (crop variety, planting conditions, nitrogen fertilisation, and irrigation). The models are designed to be applicable in diverse environments and to utilise a minimum data set of commonly available field and weather data as inputs. DSSAT models have been calibrated and validated over a wide range of agro-climatic regions (e.g., Rosenzweig and Iglesias, 1998). Crop yield simulations are used to derive statistical production functions that will be the outputs for the economic model.

Daily and monthly climate variables for the 1961 to 1990 time period (maximum and minimum temperature, precipitation and solar radiation) were obtained from NOAA. The quality control of the database has been performed by National Climate Data Center of the National Oceanographic and Atmospheric Administration of the USA. This freely available validated dataset is used by thousands of scientists every year; since it is freely available, it has been externally validated in numerous occasions. Soil characteristics needed for crop model simulations at each site (depth, texture, and water-holding capacity) and management data were obtained from agricultural research stations. Crop distribution and production data were obtained from EUROSTAT.

Two sets of simulations were done with the DSSAT models:

Potential and water-limited yield. The first set of simulations utilises automatic nitrogen and irrigation applications according to the specifications of automatic management in the crop model. The results of these simulations provide the yield potential with non-limiting nitrogen and water conditions at each site, given current climatic, soils and management conditions. The same set of simulations was repeated with water-limited conditions at each site to represent rainfed crop management practices.

Responses to temperature, precipitation, and CO_2. The second set of simulations investigates the sensitivity of yield response to changes in climatic and environmental data for water non-limited and water-limited conditions.

Four model outputs are analysed: dates of anthesis and maturity, grain yield, and irrigation water demand. The crops simulated are: winter wheat, spring wheat, rice, grassland, maize and soybeans.

2.4. Estimating production functions at the regional level

Complex multivariate models attempt to provide a statistical explanation of observed phenomena by accounting for the most important factors (e.g., predicting crop yields on the basis of temperature, rainfall, sowing date and fertiliser application). Statistical models may be developed from empirical data or from the combination of empirical data and simulated data that represents the causal mechanisms of the agricultural responses to climate. Multiple regression models can be developed to represent process-based yield responses to these environmental and management variables (Antle and Capalbo, 2001). Yield functions have been used to evaluate the sensitivity and adaptation to climate in China (Rosenzweig et al., 1999), Spain (Iglesias et al., 2000; Iglesias and Quiroga, 2007; Quiroga and Iglesias, 2009), and globally (Parry et al., 2004; Lobel et al., 2008; Iglesias et al., 2009a).

Crop production functions are derived for each region from the results of the crop models at the sites included in each region. Here we use a regression model utilizing simulated crop yield responses to climate. The multiple regression function tested does not impose non-zero elasticity of substitution among factors:

$$Y_i = \alpha_1 + \alpha_2 (CO_{2i}) + \alpha_3 (T_{1i}) + \alpha_4 (T_{2i}) + \alpha_5 (T_{3i}) + \alpha_6 (T_{4i}) + \alpha_7 (T_{ai}) + \alpha_8 (W_{1i}) + \alpha_9 (W_{2i}) + \alpha_{10} (W_{3i}) + \alpha_{11} (W_{4i}) + \alpha_{12} (W_{ai})$$

where Y_i is the crop yield (kg ha^{-1}), T_i is the temperature of the months 1 to 4 of the growing period (that change with location and crop, see Table 3) and a refers to the annual total average, W_i is total water amount (precipitation plus irrigation) received by the crop (mm), the subscript i refers to year, and α_{1-12} are parameters.

Table 3. ***Estimated months which climate explains a major proportion of crop yield variation in European agro-climatic regions***

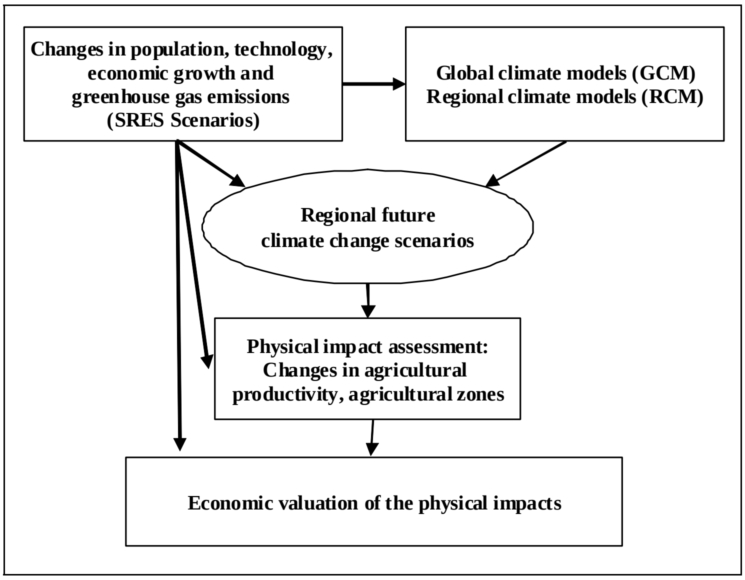
Agro-climatic zone	Validation site	Months which climate explains a major proportion of crop yield variation
Boreal	Oslo	June to September and annual average
Continental North	Muenchen	May to August and annual average
Continental South	Bucharesti	April to July and annual average
Atlantic North	Cork	May to August and annual average
Atlantic Central	Dijon	April to July and annual average
Atlantic South	Lisboa	March to June and annual average
Alpine	Insbruck	June to September and annual average
Mediterranean North	Pescara	March to June and annual average
Mediterranean South	Almeria	March to June and annual average

2.5. Climate change scenarios

2.5.1. Climate models and socio economic scenarios

Regional climate change models are used to downscale global climate models driven by socio-economic scenarios. Figure 3 shows the development of climate change scenarios that drive impacts in agriculture. It is important to notice that social conditions have a direct influence in the climate scenarios since they condition the amount of CO_2 and other greenhouse gases in the atmosphere. The socio-economic scenarios are, at the same time, main determinants of the possible adaptation options, since economic development is a driver of technological change, population defines demand and consumption, and land use change is influenced by policy.

Figure 3. Linkages between climate models and scenarios for the evaluation of physical impacts of climate change in agriculture and economic valuation of the physical impacts



Five climate scenarios were used in the study (Table 4 and 5), constructed as a combination of Global Climate Models (Had CM2 and ECHAM4) downscaled for Europe with the HIRHAM and RCA3 regional models and driven by the A2 and B2 socio-economic scenarios (Table 6). The source of climate scenario data was the Prudence project (Prudence, 2007).

Table 4. Summary of the seven climate scenarios used in the study

Institute	Driving GCM	RCM	A2	B2
DMI Prudence	HadAM3H/HadCM3	DMI/HIRHAM	(2071 - 2100)	(2071 - 2100)
SMHI Prudence	ECHAM4/OPYC3	SMHI/RCA	(2071 - 2100)	(2071 - 2100)
Rossby Centre	ECHAM4/OPYC3	SMHI/RCA3	(2011 - 2040)	

Table 5. Summary of the five climate scenarios used in the study

Scenario	Change in average annual temperature averaged in Europe (deg °C)	Average CO_2 ppmv
HadCM3 A2/DMI/HIRHAM period 2071 - 2100 (2071 - 2100)	3.1	709
HadCM3 B2/DMI/HIRHAM period 2071 - 2100 (2071 - 2100)	2.7	561
ECHAM4/OPYC3 A2/SMHI/RCA3 period 2071 - 2100 (2071 - 2100)	3.9	709
ECHAM4/OPYC3 B2/SMHI/RCA3 period 2071 - 2100 (2071 - 2100)	3.3	561
ECHAM4/OPYC3 A2/SMHI/RCA3 period 2011 - 2040 (2011 - 2040)	1.9	424

2.5.2. The socio-economic scenarios

Scenarios represent alternative futures; in case of climate change, socio-economic scenarios are defined by the IPCC Special Report on Emission Scenarios (IPCC SRES, 2001), representing the potential socio-economic futures that will determine the level of greenhouse gas emissions to the atmosphere. There is a large uncertainty surrounding future emissions and the potential development of their underlying driving forces, as reflected in a wide range of future emissions paths in the literature. This uncertainty is increased in going from emissions paths to climate change, from climate change to possible impacts and finally from these driving forces to formulating adaptation and mitigation measures and policies. The utility of applying different scenarios to the analysis of climate change lies in the possibility of describing the range of possible future emissions. Socio-economic scenarios are also key for understanding the potential adaptation capacity of agriculture to climate change.

Each of the SRES socio-economic scenarios takes a different direction of future developments. The basic emission scenarios (A1, A2, B1, B2) represent storylines about possible world developments in economic growth, population increase, global approaches to sustainability and other sociological, technological and economic factors that could influence GHG emission trends. In the scenario family A, economic development is the priority; while in the scenario family B environmental sustainability considerations are important.
The "1" and "2" scenario groups differ on the technological development path, faster and more diverse in "1" and slower and more regionally fragmented in "2". Each scenario is identified as having low (B1), medium-low (B2), medium-high (A1) and high emissions (A2).

The differences between the scenarios are greatly amplified thought time, in an increasingly irreversible way, describing different futures. The different SRES storylines try to cover a wide range of "future" characteristics, like technology, governance, and behavioural patterns. Since no single projection is a prediction, it is essential to incorporate more than one socio-economic scenario into an impact and adaptation assessment. Here we consider the SRES A2 and B2 since they are used by many other studies and they cover a wide range of possibilities, avoiding the extreme non-realistic assumptions of the A1 and B1 scenarios in terms of population growth and economic development.

The Heterogeneous World Scenarios (SRES A2)

The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological changes are more fragmented and slower than in other storylines. According to our interpretation of the A2 scenario, the implications are:

- Agriculture: Lower levels of wealth and regional disparities.
- Natural ecosystems: Stress and damage at the local and global levels.
- Coping capacity: Mixed but decreased in areas with lower economic growth.
- Vulnerability: Increased

The Local Sustainability Scenarios (SRES B2)

The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines (see Table 6 for details). While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels. According to our interpretation of the B2 scenario, the implications are:

- Agriculture: Lower levels of wealth and regional disparities.
- Natural ecosystems: Environmental protection is a priority, although strategies to address global problems are less successful than in other scenarios. Ecosystems will be under less stress than in the rapid growth scenarios.
- Coping capacity: Improved local
- Vulnerability: global environmental stress but local resiliency

Table 6. Overview of main primary driving forces in 1990, 2050, and 2100 for the A2 and B2 scenarios. (Adapted from the Special Report on Emission Scenarios)

Scenario group	A2	B2
Population (billion) (1990 = 5.3)		
2050	11.3	9.3
2100	15.1	10.4
World GDP (1012 1990US$/yr) (1990 = 21)		
2050	82	110
2100	243	235

2.5.3. Climate change scenarios developed for the study

Climate change scenarios at the site and spatial level were derived applying monthly changes in model output (scenario minus control runs) to the observed station data (at the site level and spatial level). Figure 4 to 7 shows changes in annual mean temperature and precipitation over Europe for the range of scenarios developed for the study.

Figure 4. Changes in annual mean temperature and precipitation by 2071 - 2100 relative to 1961 - 1990 from the HIRHAM RCM nested in the HadCM3 GCM under the A2 forcing

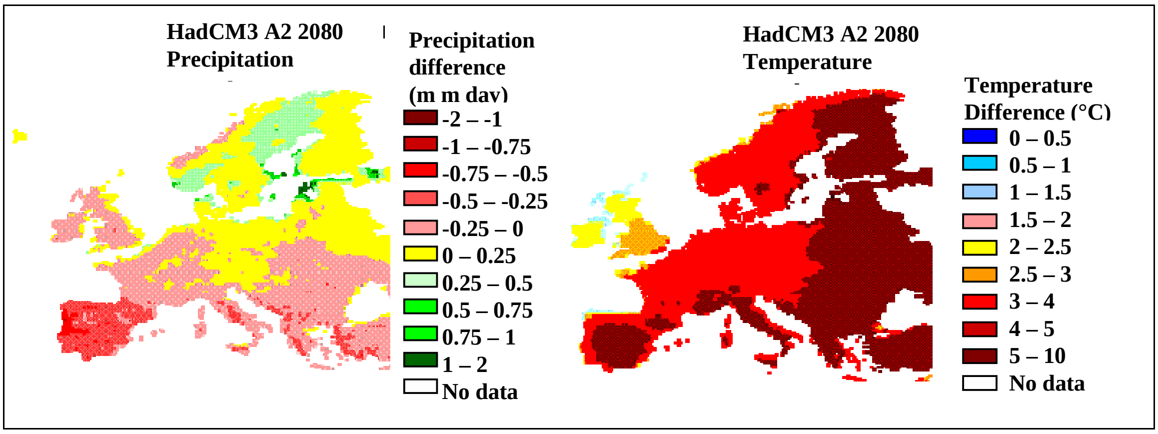


Figure 5. Changes in annual mean temperature and precipitation by 2071 - 2100 relative to 1961 - 1990 from the HIRHAM RCM nested in the HadCM3 GCM under the B2 forcing

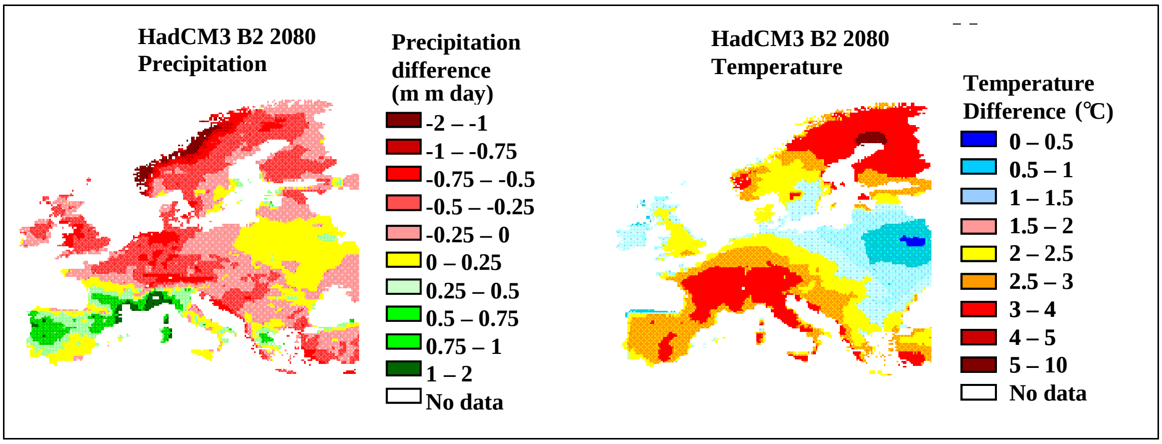


Figure 6. Changes in annual mean temperature and precipitation by 2071 - 2100 relative to 1961 - 1990 from the RCA0 RCM nested in the ECHAM GCM under the A2 forcing

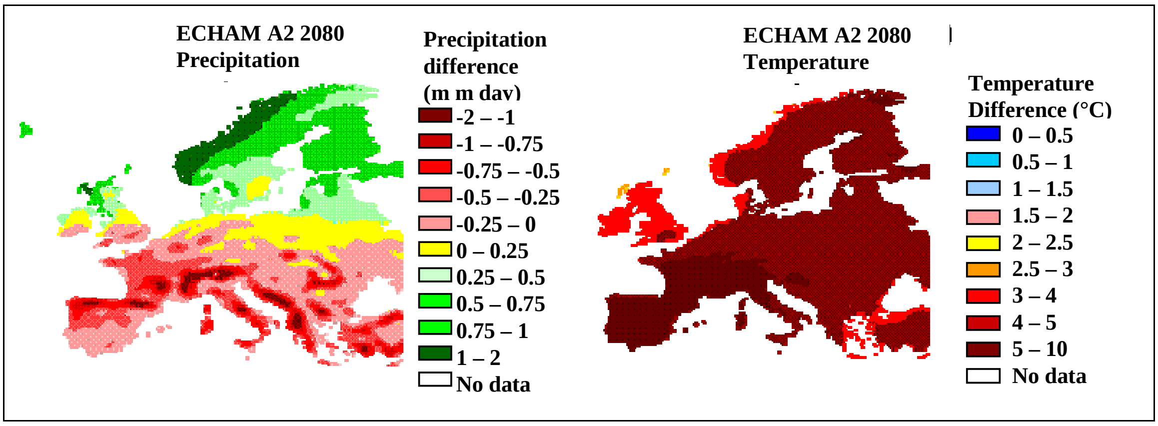
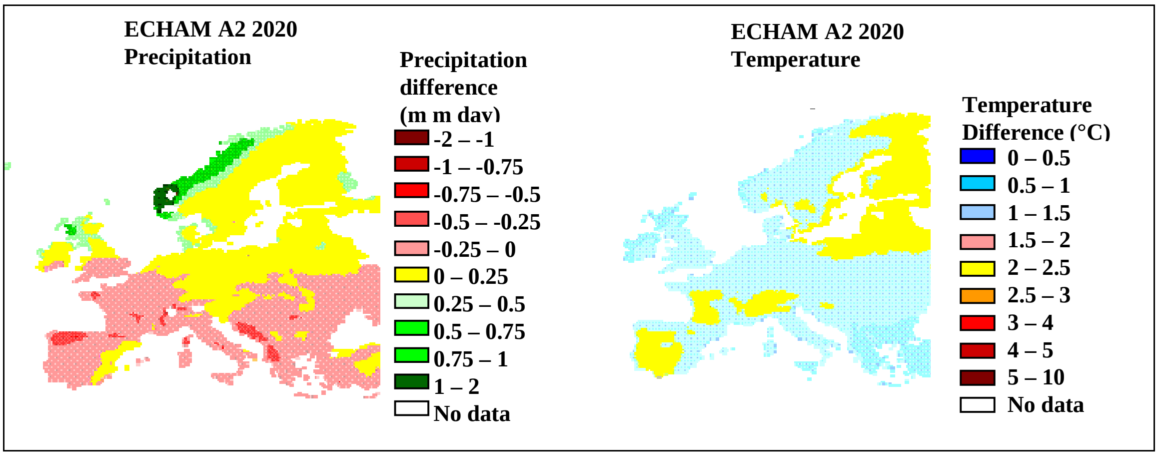


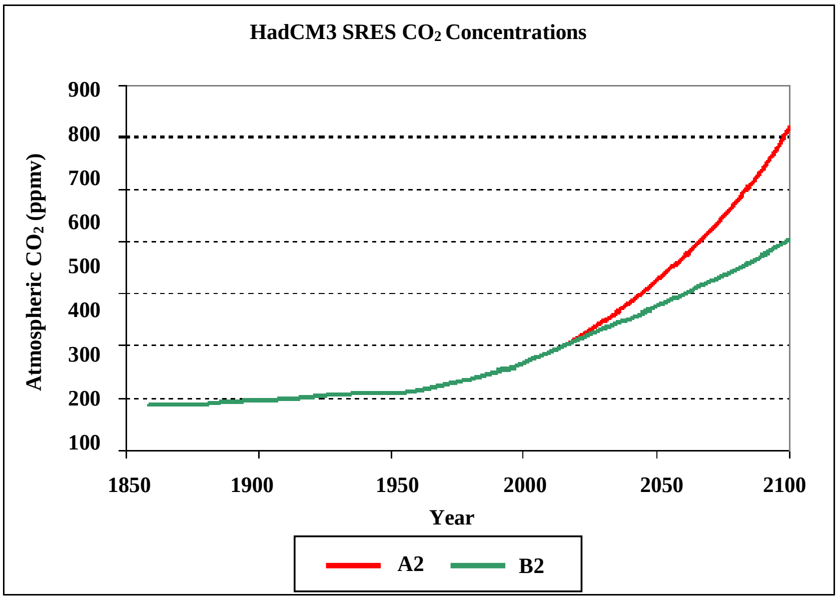
Figure 7. Changes in annual mean temperature and precipitation by 2011 - 2040 relative to 1961 - 1990 from the RCA0 RCM nested in the ECHAM GCM under the A2 forcing



2.5.4. CO_2 concentrations in the scenarios

CO_2 affects directly crop growth and water demand. The direct positive effects of CO_2 on crop production were simulated in the study. Figure 8 represents the CO_2 levels for the A2 and B2 scenarios included in the HadCM3 simulations.

Figure 8. ***CO_2 concentrations for the 1950 – 2100 period under the A2 and B2 forcings entered in the HadCM3 GCM. The average CO_2 concentration for the 2071 – 2100 period is 709 for the A2 and 561 for the B2 SRES***



2.6. Datasets

Annex 1 provides information on the climate, agricultural, land use, and water resource datasets used in the study.

2.7. Uncertainty

Annex 3 discuses the sources of uncertainty of the study.

3. Current and future agro-climatic regions

Nine agro-climatic regions are defined based on K-mean cluster analysis of temperature and precipitation data from 247 meteorological stations, district crop yield data, and irrigation data. The data used for the analysis are shown in Figure 9. Shifts in agro-climatic zones are considered for the application of the climate change scenarios, so the crop types simulated in the future are adequate. The future zones are derived in the same way as the zones in the current climate, but modifying the climate of the station by the changes of the climate scenarios. The results are consistent with previous analysis (Metzger et al., 2006; Rounsevell et al., 2006). Figure 10 compares zones under the current climate and in period 2071 - 2100.

Figure 9. ***Spatial crop data, climate, and irrigation define agro-climatic regions***

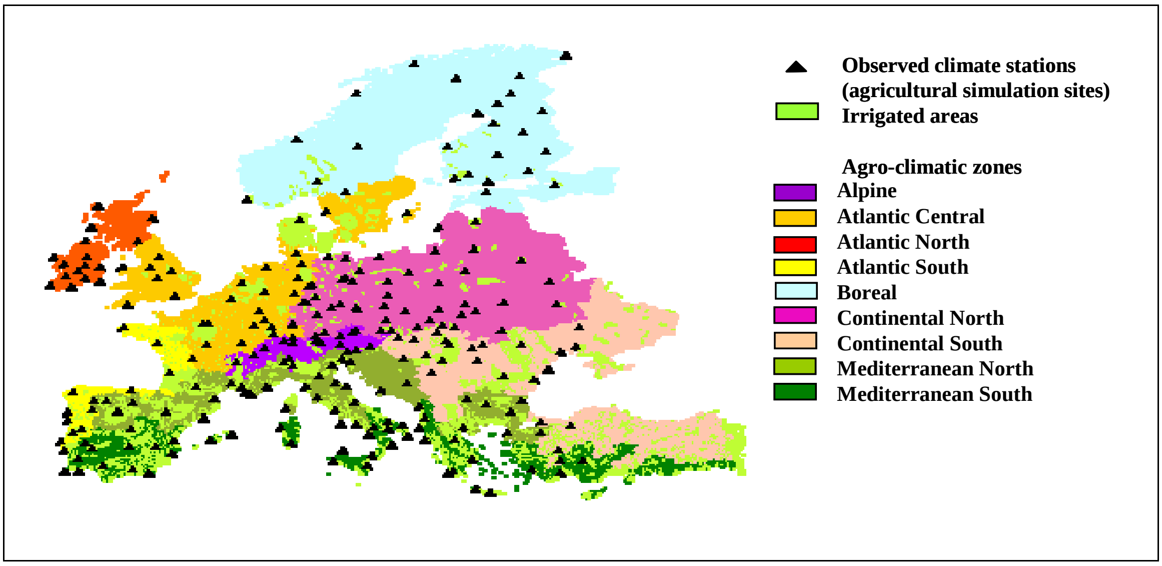
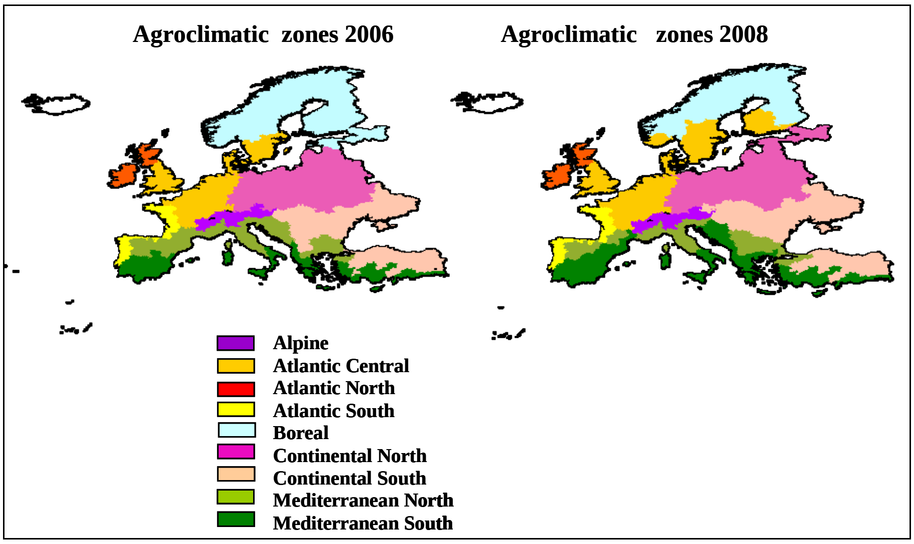


Figure 10. ***Shifts in agro-climatic areas***



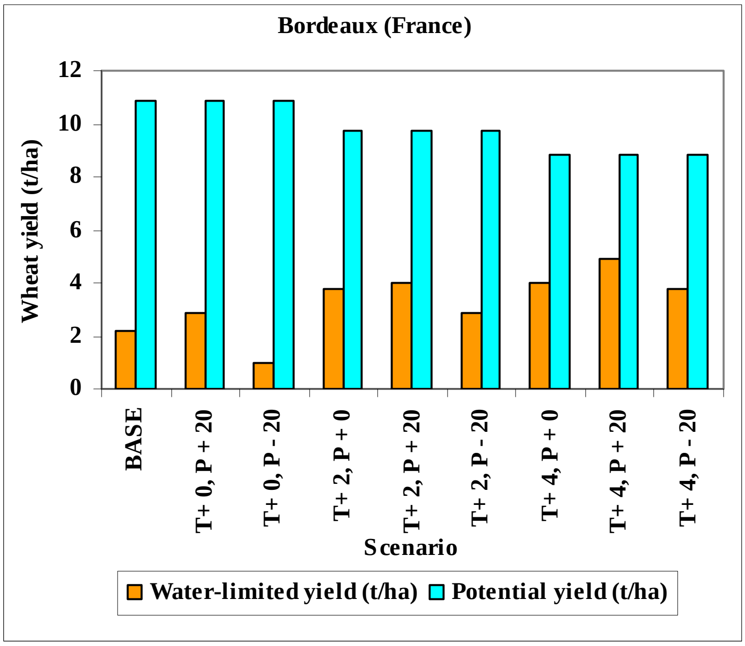
4. Crop responses at the site level

4.1. Simulations of crop yield including farmers private adaptation

Estimation of the potential and water limited yield at the site level for major commodity groups using process-based crop model. The simulations will include current conditions and future climate change scenarios for the 2070 - 2100 and 2011 - 2040 time horizon developed from a global climate model (or models) forced with carbon dioxide increases derived from the SRES scenarios. The simulations of future crop production will include changes in management that may represent possible adjustments to climate change.

Nine sites are selected to represent the major rainfed and irrigated agricultural regions. Conditions at the sites range from semi-arid to temperate sites and from traditional farming to highly technical systems. Some of the high latitude sites included in Northern Europe represent the current limit of agricultural production and are currently marginal areas that may become more productive under climate change conditions. Figure 11 summarises the sensitivity of potential and water limited production in Bordeaux, France, as an example.

Figure 11. Sensitivity of potential and water-limited maize yield in Bordeaux, France



At each site, crop yield and irrigation demand is simulated for each temperature and precipitation combination applying optimal management to account for farmers private adaptation (see Section 6.3). Figure 12 show as an example the evaluation of optimal planting date and Figure 13 the optimal application of nitrogen fertiliser and irrigation for potential production in Sevilla, Spain.

Figure 12 Sensitivity of potential wheat yield to sowing date in Sevilla, Spain

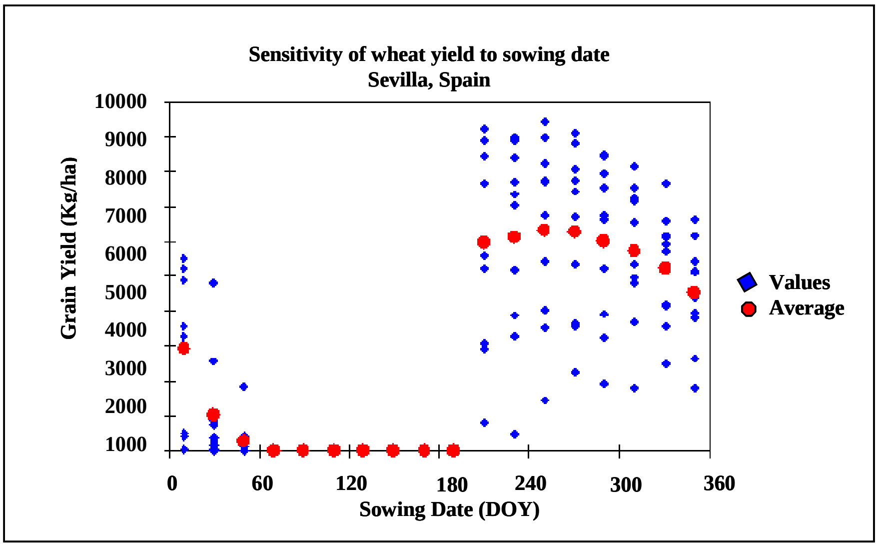
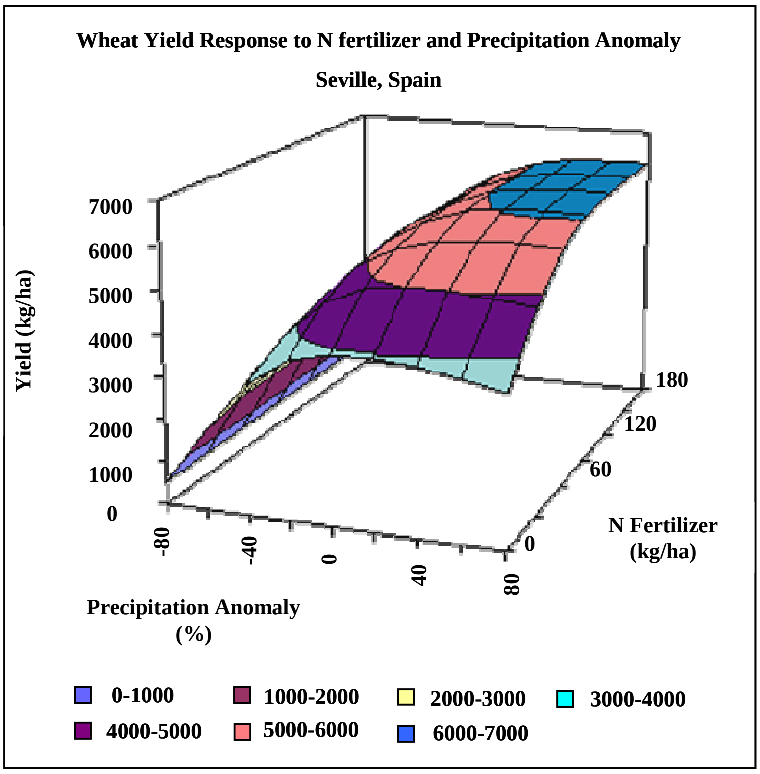


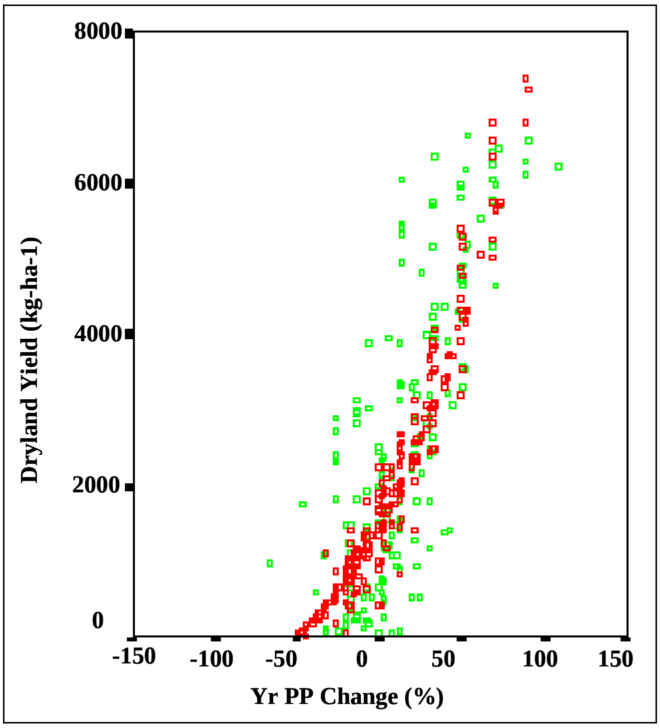
Figure 13. Wheat yield response to nitrogen fertilizer and precipitation in Sevilla, Spain



4.2. Validating the yield functions

Figure 14 shows as an example the validation of crop yield function in Almeria, Spain. The results show that the functions are adequate to quantify crop responses over the range of climates projected by the scenarios used in this study.

Figure 14. Predicted and actual wheat yield in Almeria, Spain

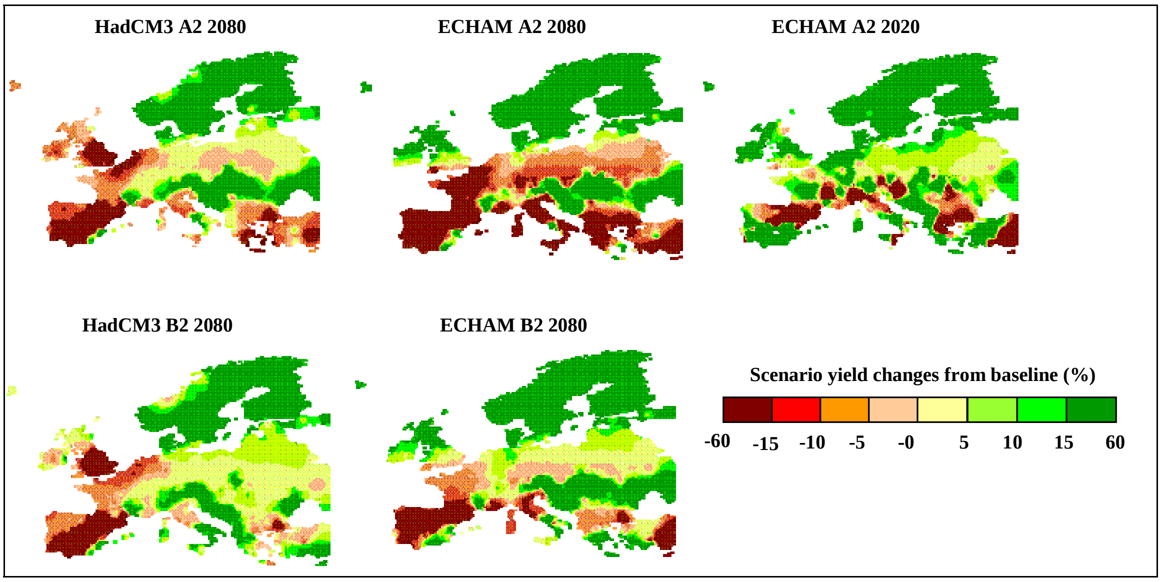


5. Spatial effects of climate change with farmers adaptation

Figure 15 shows modelled European crop yield changes for the HadCM3/HIRHAM A2 and B2 scenarios for the period 2071 - 2100 and for the ECHAM4/RCA3 A2 and B2 scenarios for the period 2011 - 2040. The yield changes include the direct positive effects of CO_2 on the crops, the rainfed and irrigated simulations in each district, changes in crop distribution in the scenario due to modified crop suitability under the warmer climate, and endogenous adaptation.

Although each scenario projects different results, all three scenarios are consistent in the spatial distribution of effects. Crop suitability and productivity increases in Northern Europe are caused by lengthened growing season, decreasing cold effects on growth, and extension of the frost-free period. Crop productivity decreases in Southern Europe are caused by shortening of the growing period, with subsequent negative effects on grain filling. It is very important to notice that the simulations considered no restrictions in water availability for irrigation due to changes in policy. In all cases, the simulations did not include restrictions in the application of nitrogen fertilizer. Therefore should be considered optimistic from the production point and pessimistic from the environmental point of view.

Figure 15. Crop yield changes under the HadCM3/HIRHAM A2 and B2 scenarios for the period 2071 - 2100 and for the ECHAM4/RCA3 A2 and B2 scenarios for the period 2011 - 2040 compared to baseline



The results were aggregated in nine agro-climatic zones to provide a summary of responses. Table 7 summarises the average regional changes in crop yield and coefficient of variation under the HadCM3/HIRHAM A2 and B2 scenarios for the period 2071 - 2100 and for the ECHAM4/RCA3 A2 and B2 scenarios for the period 2011 - 2040 compared to baseline. The results are in agreement with the biophysical processes simulated with the calibrated crop models, agree with the evidence of previous studies, and therefore have a high confidence level. Sources on uncertainty are discussed in Annex 3. It is very important to notice that the simulations considered no restrictions in water availability for irrigation due to changes in policy. In all cases, the simulations did not include restrictions in the application of nitrogen fertilizer. Therefore should be considered optimistic from the production point and pessimistic from the environmental point of view.

Table 7. Average regional changes in crop yield and coefficient of variation under the HadCM3/HIRHAM A2 and B2 scenarios for the period 2071 - 2100 and for the ECHAM4/RCA3 B2 scenarios for the period 2011 - 2040 compared to baseline

	HadCM3/ HIRHAM A2 period 2071 - 2100		**HadCM3/ HIRHAM B2 period 2071 - 2100**		**ECHAM4/RCA3 A2 period 2071 - 2100**		**ECHAM4/RCA3 B2 period 2071 - 2100**		**ECHAM4/RCA3 A2 period 2011 - 2040**	
Region	Yield Change %	SD %	Yield Change %	SD %	Yield Change %	SD %	Yield Change %	SD %	Yield Change %	SD %
Boreal	41	38	34	32	54	22	47	15	77	44
Continental North	1	2	4	2	-8	7	1	4	7	5
Continental South	26	17	11	19	33	30	24	6	17	29
Atlantic North	-5	6	3	6	22	17	16	10	24	15
Atlantic Central	5	24	6	27	19	38	17	23	32	30
Atlantic South	-10	5	-7	3	-26	10	-12	9	9	20
Alpine	21	14	23	17	20	24	20	20	-13	49
Mediterranean North	-8	4	0	3	-22	8	-11	7	-2	13
Mediterranean South	-12	41	1	43	-27	41	5	46	28	83

6. Discussion on adaptation

6.1. Complex choices of adaptation

Agriculture depends on climate, because heat, light, and water are the main drivers of crop growth. Nevertheless, agriculture in the European Union is a complex and highly evolved sector, dependent on social issues (i.e., policy, markets, labour) that competes for essential resources with other sectors of the economy and the environment. The key task facing those this climate adaptation assessment is to identify those regions likely to be vulnerable to climate change, so that impacts can be avoided (or at least reduced) through implementation of appropriate measures of adaptation that are in synergy with the overall environmental, agricultural and water policies of the European Union (COM, 2009).

6.2. The adaptation concept

Adaptation refers to all those responses to climate change that may be used to reduce vulnerability or to actions designed to take advantage of new opportunities that may arise as a result of climate change (Burton, 2005). Adaptive capacity is the ability of a system to adjust to climate change, including climate variability and extremes, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC, 2007).

According to time of implementation, agricultural adaptation can be reactive (after the change) or proactive (before the change) (Table 8). According to economic resources, adaptation can be private or public. Private adaptation is on the actor’s rational self interest and it is initiated and implemented by individuals, households or private companies. Public adaptation addresses collective needs and it is initiated and implemented by governments at all levels.

While most adaptation to climate change will ultimately be characterised by responses at the farm level, encouragement of response by policy affects the speed and extent of adoption. Most major adaptations may require 10 to 20 years to implement. Two broad types of adaptation are considered here: farm-based adaptation (private) and policy adaptation (public).

Table 8. Summary of the types of adaptation strategies and measures

Time of implementation	Adaptation	Example of adaptation strategy or measure
Proactive	Planned as result of a deliberate decision, based on an awareness that conditions may change and that action is required to achieve a desired state.	Tactical advise to investments or agricultural policy
Reactive	Autonomous (spontaneous) not a results of a conscious response to climatic stimuli but triggered by changes in the agricultural systems.	Changes in planting dates
	Planned as result of a deliberate decision, based on an awareness that conditions may changed and that action is required to achieve a desired state.	Increased irrigation area

Table 9 summarizes the agronomic and farming system impacts, adaptive capacity, and sector outcomes, aiming to guide European policy in evaluating the objectives and intended outcomes of relevant climate change assessments.

Table 9. Characterization of agronomic and farming sector impacts, adaptive capacity, and sector outcomes

Source: Iglesias (2009a).

Impact	Uncertainty level	Expected intensity of negative effects	Socioeconomic and other secondary impacts	Adaptive capacity
Changes in crop growth conditions	Medium	High for some crops and regions	Changes in optimal farming systems. Relocation of farm processing industry. Increased economic risk. Loss of rural income. Pollution by nutrient leaching. Biodiversity.	Moderate to high
Changes in optimal conditions for livestock	High	Medium	Changes in optimal farming systems. Loss of rural income.	High for intensive production systems
Changes in precipitation and availability of water	Medium to low	High for developing countries	Increased demand for irrigation. Decreased yield of crops. Increased risk of soil salinization. Increased water shortage. Loss of rural income.	Moderate
Changes in agricultural pests	High to very high	Medium	Pollution by increased use of pesticides. Decreased yield and quality of crops. Increased economic risk. Loss of rural income.	Moderate to high
Changes in soil fertility and erosion	Medium	High for developing countries	Pollution by nutrient leaching. Biodiversity. Decreased yield of crops. Land abandonment. Increased risk of desertification. Loss of rural income.	Moderate
Changes in optimal farming systems	High	High for areas where current optimal farming systems are extensive	Changes in crop and livestock production activities. Relocation of farm processing industry. Loss of rural income. Pollution by nutrient leaching. Biodiversity.	Moderate
Relocation of farm processing industry	High	High for some food industries requiring large infrastructure or local labour	Loss of rural income. Loss of cultural heritage.	Moderate
Increased (economic) risk	Medium	High for crops cultivated near their climatic limits	Loss of rural income.	Low
Loss of rural income and cultural heritage	High	Not characterised	Land abandonment. Increased risk of desertification. Welfare decrease in rural societies. Migration to urban areas. Biodiversity.	Moderate

6.3. Private farmers adaptation and indicators of adaptive capacity

Historically agriculture has shown a considerable ability to adapt to changing conditions, whether these have stemmed from alterations in resource availability, technology or economics. Many adaptations occur autonomously and without the need for conscious response by farmers and agricultural planners (Brooks et al., 2005).

As far as possible the response adjustments need to be identified along with their costs and benefits. There is much to be gained from evaluating the capability that exists in currently available technology and the potential capability that can developed in the future.

Farm based adaptation includes changes in crops or crop management. Table 10 outlines examples of farm based adaptation measures that can be implemented. The degree of implementation or success of the measures depends on the adaptive capacity of farmers as individual agents. The adaptive capacity can be evaluated by using indicators (Table 11). The indicators of those adaptive capacity indicators for European farmers are very robust, suggesting that their adaptive capacity is very high and therefore it can be safely assumed that private adaptation may be optimally implemented providing that there are not policy restrictions (i.e., environmental issues arising from options that result in environmental damage).

Policy based adaptation creates synergies with the farmers' responses particularly in countries where education of the rural population is limited (Urwin and Jordan, 2008). Agricultural research to test the robustness of alternative farming strategies and development of new crop varieties are also among the policy based measures with a potential for being effective in the future.

Table 10. Adaptation measures, actions to implement them, and potential results

Measure	Action	Potential result
Choice of crop	Drought of heat resistant	Reduction of risk of yield loss and reduction of irrigation requirements
	Pest resistant	Reduce crop loss when climate conditions are favourable for increased weeds and pests
	Quicker (or slower) maturing varieties	Ensure maturation in growing season shortened by reduced moisture or thermal resources; maximization of yields under longer growing seasons
	Altered mix of crops	Reduction of overall production variability
Tillage and time of operations	Change planting date	Match altered precipitation patterns
	Terracing, ridging	Increase moisture availability to plants
	Land levelling	Spread water and increase infiltration
	Reduced tillage	Reduction of soil organic matter losses, soil erosion, and nutrients
	Deep ploughing	Break up impervious layers or hardpan, to increase infiltration
	Change fallow and mulching practices	Retain moisture and organic matter
	Alter cultivations	Reduce weed infestation
	Switch seasons for cropping	Change from spring to winter crops to avoid increased summer drought
Crop husbandry	Alter row and plant spacing	Increase root extension to soil water
	Intercropping	Reduce yield variability, maximise use of moisture
Irrigation and water harvesting	Introduce new irrigation schemes to dryland areas	Avoid losses due to drought
	Improve irrigation efficiency	Avoid moisture stress
	Water harvesting	Increase moisture availability
Input of agro-chemicals	Vary amounts of fertilizer application	Increase nitrogen to improve yield if more water is available; or decrease to minimise input costs
	Alter time of application	Match applications to (e.g.) altered pattern of precipitation
	Vary amount of chemical control	Avoid pest, weed, and disease damage

Table 11. Categories and indicators of adaptive capacity

Coping capacity category	Indicators
Environmental	
Resource base	Water supply; soil quality and diversity; land size and distribution; land unmanaged; population density
Risk	Variability of the current climate and extreme events
Economic	
Resource base	Land tenure and size; financial capital; material equipment and machinery; animals; GDP per capita
Risk	Variability in production; variability in input and output prices
Financial resources	Access to formal and informal credit
Diversity	Diversity of the agricultural system (seeds available and used and number of crops planted); diversity of income sources (agriculture, livestock, off-farm and non-farm)
Variability in the rural economy	Migration; land sales, land rental
Agricultural innovation and information dissemination	Public expenditure in agricultural research and extension/population; technological gap for cereal production
Social	
Resource base	Population in the workforce; education; age; gender
Support programs	Technology transfer; technical assistance
Social programs	Emergency welfare programs; social services

6.4. Public (policy) adaptation

Public adaptation may be implemented at the local level or regional level. For example, at the local level adaptation initiatives may combine water reallocation initiatives, engineering and structural improvements to water supply infrastructure, agriculture policies and urban planning/management. At the national/regional level, priorities include placing greater emphasis on integrated, cross-sectoral water resources management, using river basins as resource management units, and encouraging sound and management practices. Given increasing demands, the prevalence and sensitivity of many simple water management systems to fluctuations in precipitation and runoff, and the considerable time and expense required to implement many adaptation measures, the agriculture and water resources sectors in many areas and countries will remain vulnerable to climate variability. Water management is partly determined by legislation and co-operation among government entities, within countries and internationally; altered water supply and demand would call for a reconsideration of existing legal and cooperative arrangements.

Adaptation is, in part, a political process, and information on options may reflect different views about the long-term future of resources, economies, and society. The capacity to adapt to environmental change is implicit in the concept of sustainable development and, implies an economic as well as a natural resource component. Perception of environmental and economic damage is also a driver of the economic component of adaptation.

The main effect of public policies on adaptation capacity may be limited by a range of conditions that will constrain the adaptive capacity of individual farmers. Some of the limits to public adaptation include:

- Resource limits (i.e., water and land)
- Social limits (i.e., acceptance of biotechnology, support of biofuels)
- Rural development limits (i.e., rural population stabilization may not be optimal land use planning)
- Cultural limits (i.e., acceptance of water price and tariffs)

In contrast with private adaptation, public adaptation is far more uncertain and difficult to project. In Europe, the trend in agricultural and water policy focuses on resource management, and in most cases environmental issues are gaining relevance in contrast with agricultural production and this trend will be intensified after 2012 when the CAP will be revised. Policy adaptation is more limited than private farmers' adaptation since the management of scarce resources - especially water-implies the establishment of priorities between production strategies, other users such energy, and the environment. In this context two scenarios may modify the results obtained of the physical impacts:

- Adaptation with emphasis on water resources protection and urban development. This may be taken as the case of no agricultural adaptation.
- Adaptation with emphasis with protection of agricultural production and rural development. This may be taken as the case of best scenario for agricultural adaptation.

The implications of these scenarios are not uniform across all regions in Europe (Table 12). In some regions, such as Boreal, Continental North or Atlantic North, agriculture in future scenarios does not depend on water policy and therefore water management policy will have no effect in crop yields, but restrictions in the use of fertilisers are expected to have an effect.

Table 12. Estimation of different levels of public adaptation in projected regional changes in crop yield under the HadCM3/HIRHAM B2 scenario for the period 2071 - 2100

	Yield Change %		
Region	Adaptation with emphasis on water resources protection and urban development	HadCM3/ HIRHAM B2 period 2071 - 2100	Adaptation with emphasis with protection of agricultural production and rural development
Boreal	25 to 30	34	35 to 40
Continental North	0 to 5	4	5 to 10
Continental South	-10 to 5	11	15 to 25
Atlantic North	0 to 5	3	5 to 10
Atlantic Central	-5 to 5	6	10 to 20
Atlantic South	-10 to -10	-7	-5 to 0
Alpine	10 to 20	23	25 to 40
Mediterranean North	-5 to 0	0	0 to 5
Mediterranean South	-50 to -25	1	0 to 20

The values in Table 12 have been estimated based on average values of yield changes obtained in the simulations considering the restrictions imposed by public policies on boundary conditions (water availability and fertiliser use). The greatest effects of adaptation are expected in Southern Europe, where water availability for irrigation is crucial to maintain agricultural activity.

7. References

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Annex 1. Datasets

Figures 16 to 21 show the spatial databases and examples of data used in the analysis.

Figure 16. Observed temperature and precipitation derived from station data (1960 - 2000)

Source NOAA.

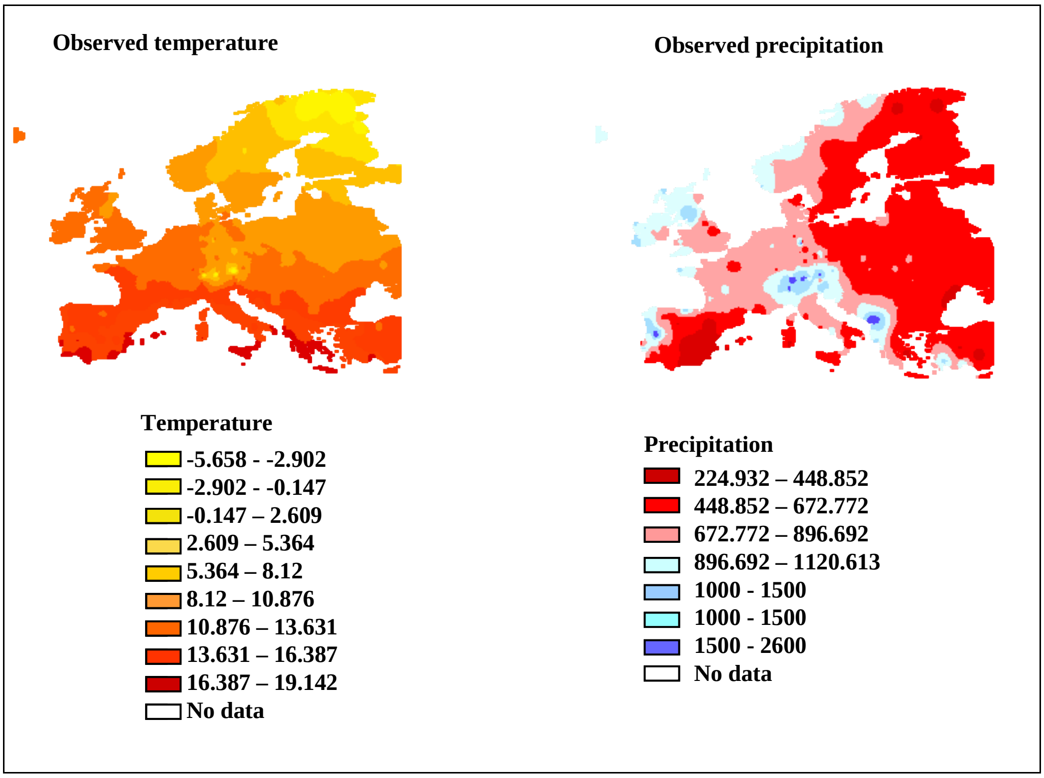
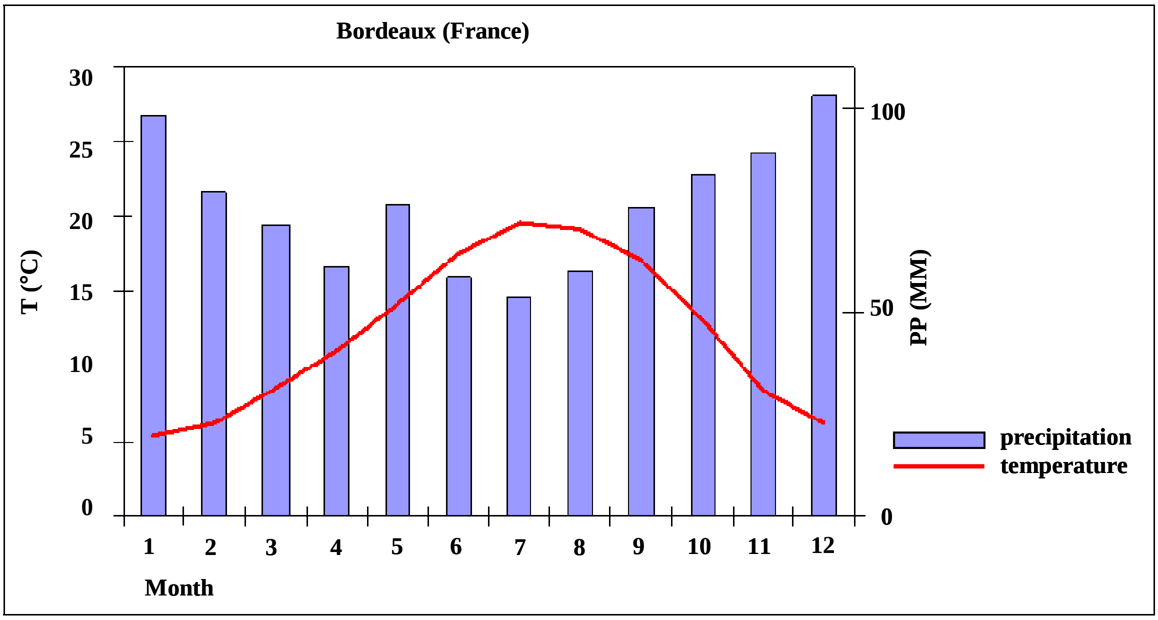


Figure 17. Observed temperature and precipitation at Bordeaux, France, averaged over the 1960 - 2000 period



Source NOAA.

Figure 18. Example of runoff dataset (month 180, control baseline Had CM3/HIRHAM)

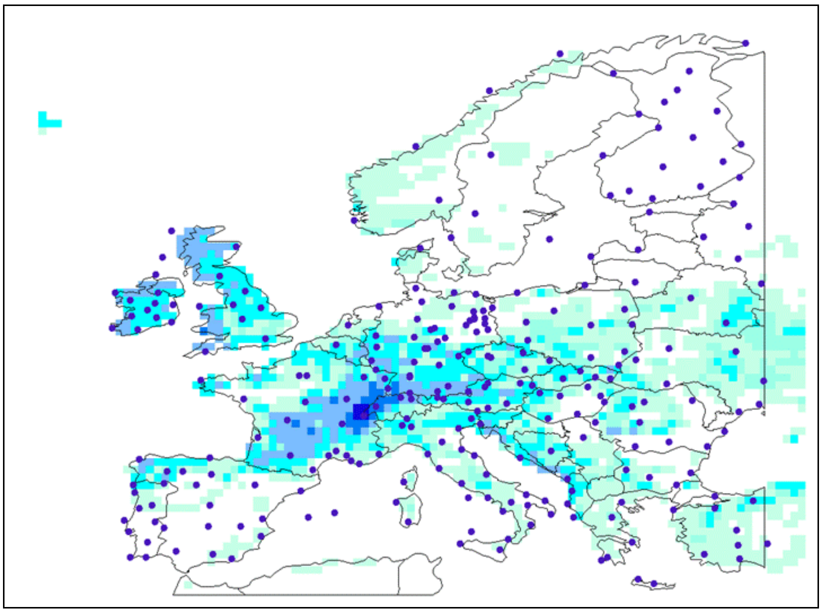


Figure 19. European basins

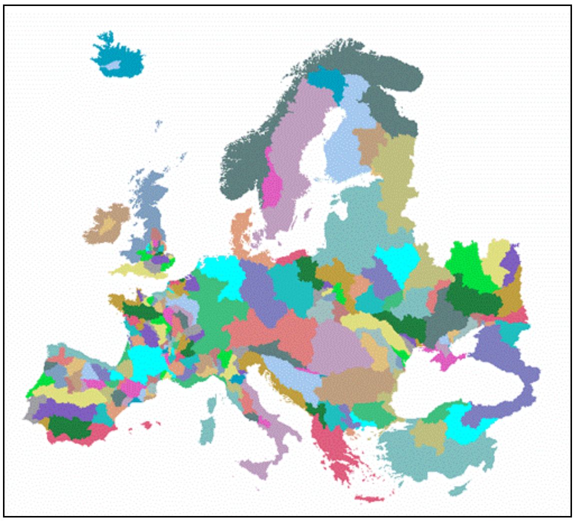


Figure 20. Percentage of irrigated area

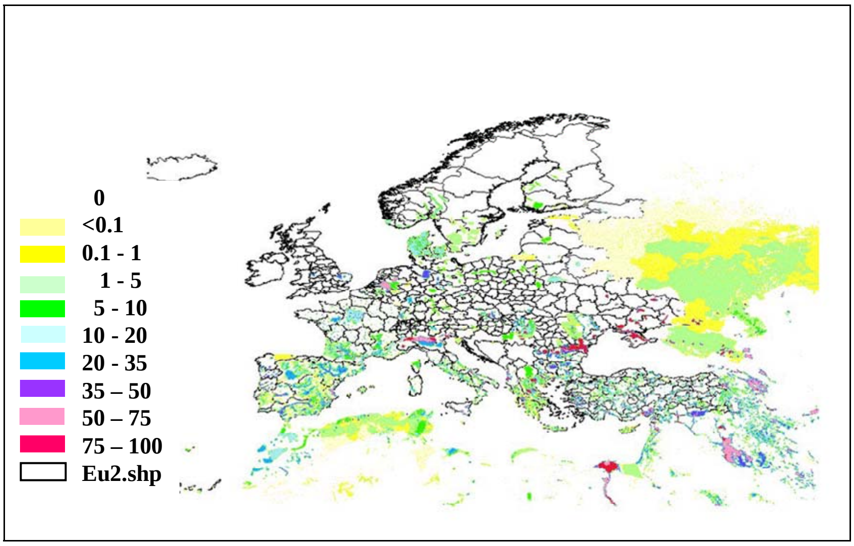
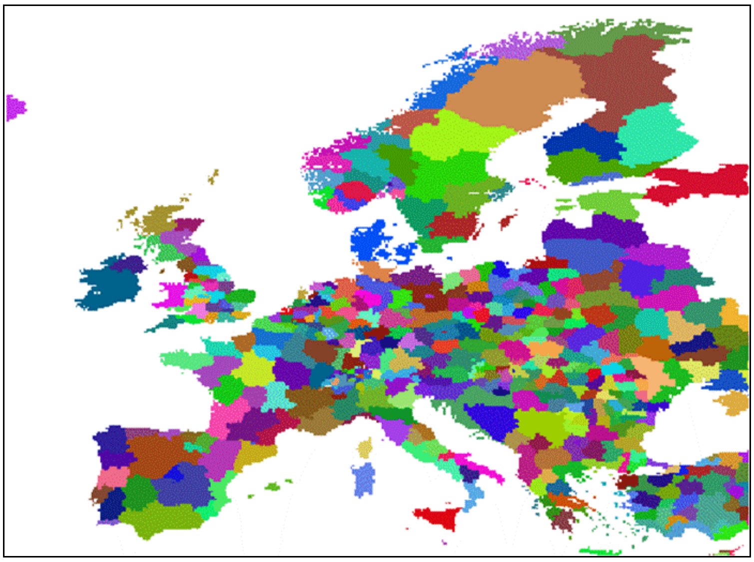


Figure 21. Nuts 2 regions with crop data used for the study



Annex 2. Uncertainty

Climate change scenarios

Climate change scenarios are derived from global climate models (GCMs) driven by changes in the atmospheric composition that in turn is derived from socio-economic scenarios (SRES). A main challenge is to interpret the results derived from climate scenarios that are used as inputs. In all regions, uncertainties with respect to the magnitude of the expected changes result in uncertainties of the agricultural evaluations. For example, in some regions projections of rainfall, a key variable for crop production, may be positive or negative depending on the climate scenario used. The uncertainty derived from the climate model related to the limitation of current models to represent all atmospheric processes and interactions of the climate system. The limitation of projecting the socio-economic development pathways is an additional source of uncertainty.

Climate variability

Regional climates naturally fluctuate about the long-term mean. For example, rainfall variability occurs with regard to the timing and quantity, affecting agriculture each year. It is clear that changes have occurred in the past and will continue to occur, and climate change modifies these variability patterns, for example resulting in more droughts and floods. Nevertheless, there are a lot of uncertainties, especially about rainfall scenarios for the future.

Water availability scenarios

Climate change, population dynamics, and economic development will likely affect the future availability of water resources for agriculture differently in different regions. The demand for and the supply of water for irrigation will be influenced not only by changing hydrological regimes (through changes in precipitation, potential and actual evaporation, and runoff at the watershed and river basin scales), but by concomitant increases in future competition for water with non-agricultural users due to population and economic growth.

Agricultural models

The agricultural models contain many simple, empirically-derived relationships that do not completely represent actual plant processes. When models are adequately tested against observed data (calibration and validation process), the results represent agricultural output under current climate conditions. Nevertheless, the simplifications of the crop models are a source of uncertainty of the results. For example, agricultural models in general assume that weeds, diseases, and insect pests are controlled; there are no problem soil conditions such as high salinity or acidity; and there are no catastrophic weather events such as heavy storms. The agricultural models simulate the current range of agricultural technologies available around the world; they do not include potential improvements in such technology, but may be used to test the effects of some potential improvements, such as improved varieties and irrigation schedules. Provided that the limitations are carefully evaluated, a range of agricultural models are used widely by scientists, technical extension services, commercial farmers, and resource managers to evaluate agricultural alternatives in a given location under different conditions (i.e., drought years, changes in policy for application of agro-chemicals, changes in water input, among others).

Livestock production is a significant component of the European agricultural system and is also potentially sensitive to climatic change. This study does not consider livestock production.

Effects of CO2 on crops

CO_2 is a component of plant photosynthesis and therefore influences biomass production. It also regulates the opening of plant stomata and therefore affects plant transpiration. As result, in theory, plants growing in increased CO_2 conditions will produce more biomass and will consume less water. Experiments in greenhouses confirm such plant behaviour, nevertheless due to the multiple interactions of physiological processes, result only in changes smaller than the theoretical ones. In field conditions, the changes are even smaller. Most of the crop models used for climate change evaluations include and option to simulate the effects of CO_2 increase on crop yield and water use (see Rosenzweig and Iglesias, 1998; Rosenzweig *et al*. 2004). It is difficult to validate the crop model results since there are only a very limited number of these experiments worldwide, raising uncertainty of the simulated results.

Issues of scale

Scaling up the process-based results to derive production functions at the regional level is, as in most scaling exercises, not an easy task. Ideally the degree of their representativeness would need to be established. This study relies on crop production data of EUROSTAT at the Nusts 2 level, on irrigation data of FAO, and on station climate data (247 sites) to define homogeneous agro-climatic regions to scale-up the process based results.

Socio-economic projections

The limitations for projecting socio-economic changes not only affect the SRES scenarios but also the potential adaptive capacity of the system. For example, uncertainty of the population (density, distribution, migration), gross domestic product, technology, determine and limit the potential adaptation strategies.

Thresholds, risks, and surprises

Risk can be evaluated when the probability of occurrence of an event is known, but in impact evaluation, the associated probabilities to a particular scenario are generally not known. Therefore, the inclusion of uncertainty (i.e., when the event is known but the probabilities that will occur are not known) into climate change impact methods is very important and recent studies are now beginning to include explicit methods to deal with it. Earlier studies have often used best estimate scenarios which represent the mid-point of predictions. The inclusion of a range of scenarios representing upper and lower bounds of the predicted effects is more realistic and allows for the propagation of uncertainty throughout a model system. Further, probability distributions of different events may be defined, with contrasts between low probability catastrophic events (surprises) and higher probability gradual changes in climate trends.

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Abstract

The objective of the study is to provide a European assessment of the potential effects of climate change on agricultural crop production and monetary estimates of these impacts for the European agricultural sector. The future scenarios incorporate socio economic projections derived from several SRES scenarios and climate projections obtained from global climate models and regional climate models.

The work links biophysical and statistical models in a rigorous and testable methodology, based on current understanding of processes of crop growth and development, to quantify crop responses to changing climate conditions. European crop yield changes were modeled under the HadCM3/HIRHAM A2 and B2 scenarios for the period 2071 - 2100 and for the ECHAM4/RCA3 A2 scenario for the period 2011 - 2040. The yield changes include the direct positive effects of CO2 on the crops, the rainfed and irrigated simulations in each district.

Although each scenario projects different results, all three scenarios are consistent in the spatial distribution of effects. Crop suitability and productivity increases in Northern Europe are caused by lengthened growing season, decreasing cold effects on growth, and extension of the frost-free period. Crop productivity decreases in Southern Europe are caused by shortening of the growing period, with subsequent negative effects on grain filling. It is very important to notice that the simulations considered no restrictions in water availability for irrigation due to changes in policy. In all cases, the simulations did not include restrictions in the application of nitrogen fertilizer. Therefore the results should be considered optimistic from the production point and pessimistic from the environmental point of view.

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